The acute effect of commonly used preparation strategies on short term high intensity motor capabilities

IAIN M. FLETCHER
Ph.D by Publications

2011
UNIVERSITY OF BEDFORDSHIRE
THE ACUTE EFFECT OF COMMONLY USED PREPARATION STRATEGIES ON SHORT TERM HIGH INTENSITY MOTOR CAPABILITIES

By

Iain M. Fletcher

A thesis submitted to the University of Bedfordshire, in partial fulfilment of the requirements for the degree of Doctor of Philosophy by Publications

July 2011
Dedication

To my wife Natalie and children Olivia and Eleanor and to my father Brian and in the memory of my mother Jane (1945-2005).
ABSTRACT

The overall aim of this thesis was to investigate modalities used as components of pre event/training preparation, to try to develop an optimal preparation strategy for sports performers. It concentrates on the stretch modalities commonly used by athletes as part of a warm-up designed to prepare them for subsequent performance. Past literature suggests that static stretching as part of a warm-up leads to a decrease in performance when compared to an active warm-up or a warm-up including dynamic stretches. Not surprisingly this has led to a movement away from static to dynamic stretches by many athletes. The presented publications were conducted to clarify a number of issues raised by past research studies. A lack of ecologically valid studies is apparent; the static stretch protocols used in most of the early research in this area has failed to explore what sports performers actually use as part of their training, while there was a lack of research examining the effect of dynamic stretches on performance. Of particular relevance is the lack of research looking at the mechanisms behind the changes in performance linked to warm-ups incorporating dynamic stretches. Therefore, this group of publications attempts to systematically examine the effects on performance of manipulating the stretch component of an active warm-up, while exploring the potential mechanisms linked to any changes in performance.

The general findings of this series of papers provides evidence that static stretches, as part of an active warm-up, are linked to a decrease in the acute performance of a range of physical capabilities; including sprint, agility, jump and maximal force output. The mechanisms behind these performance changes are multifaceted, with decreases in core temperature and heart rate, decreases in musculotendinous unit stiffness and a decrease in muscular activity, when compared to a general active warm-up established. In contrast when a dynamic stretch replaces the static stretch component and is incorporated within a warm-up, performance is enhanced when compared to an active warm-up. The mechanisms behind this seem to be less temperature related and more closely linked to the neuro-muscular system. Greater muscular activity is linked to dynamic stretches, causing an increase in peak force and rate of force development, compared to an active warm-up protocol. This effect seems to be enhanced the faster and more specific the dynamic stretches are to the chosen performance measure, while combining static stretches with dynamic stretches as part of a preparation strategy still leads to decreases in performance compared to an active warm-up combined with dynamic stretches.

In conclusion, to maximise acute maximal performance in sports specific motor skills, an active warm-up combined with specific dynamic stretches is recommended to sports performers and coaches.
LIST OF CONTENTS

Title Page..........................................................................................................................i
Dedication..........................................................................................................................ii
Abstract............................................................................................................................iii
List of contents...................................................................................................................iv
List of Tables.....................................................................................................................vi
List of Figures....................................................................................................................vii
List of Appendices.............................................................................................................viii
Acknowledgments..........................................................................................................ix
Authors Declaration........................................................................................................x
Operational Definitions.....................................................................................................xi

1.0 Chapter 1: Introduction..........................................................................................1

1.1 Structure of the report............................................................................................2
1.2 Study overview ........................................................................................................2
  1.2.1 General limitations of presented papers.........................................................4
1.3 Background and rational for the series of publications........................................5
1.4 Overall aim and related objectives.......................................................................9
  1.4.1 Objective 1..........................................................................................................9
  1.4.2 Objective 2.........................................................................................................10
  1.4.3 Objective 3.........................................................................................................10
  1.4.4 Objective 4.........................................................................................................10
  1.4.5 Objective 1.........................................................................................................10
    1.4.5.1 Contribution to the advancement of the field of study.........................12
  1.4.6 Objective 2.........................................................................................................13
    1.4.6.1 Contribution to the advancement of the field of study.........................15
  1.4.7 Objective 3.........................................................................................................15
    1.4.7.1 Contribution to the advancement of the field of study.........................19
  1.4.8 Objective 4.........................................................................................................20
    1.4.8.1 Contribution to the advancement of the field of study.........................21
1.5 Potential mechanisms associated with different preparation strategies ..........22
  1.5.1 An outline of force production and the neuromuscular system..................22
  1.5.2 Muscle efficiency and the stretch shortening cycle......................................23
  1.5.3 Evidence supporting different mechanisms associated with
changes in performance.................................................................25

1.6 Statistical methods employed..................................................32

2.0 Chapter 2: Paper I.................................................................34

3.0 Chapter 3: Paper II.................................................................35

4.0 Chapter 4: Paper III...............................................................36

5.0 Chapter 5: Paper IV...............................................................37

6.0 Chapter 6: Paper V.................................................................38

7.0 Chapter 7: Paper VI...............................................................39

8.0 Chapter 8: Thesis Impact and recommendations......................40

8.1 Thesis Impact...........................................................................41
8.2 Practical application...............................................................45

References.....................................................................................46
Appendices....................................................................................60
LIST OF TABLES

Table 1: Outline of Papers I-VI Main Findings.......................................................8
LIST OF FIGURES

Figure 1-7 Paper I passive static stretches .....................................................72
Figure 8-12 Paper I active dynamic stretches ...............................................74
Figure 13-19 Paper I active static stretches ...............................................75
Figure 20-21 Paper II stationary dynamic stretches .................................76
Figure 22-24 Paper II static passive stretches ...........................................78
Figure 25 Paper III static passive stretches .............................................79
Figure 26 Paper IV static stretches ............................................................79
Figure 27-28 Paper IV dynamic stretches ...................................................80
Figure 29 Paper V stationary dynamic stretches .........................................81
Figure 30-34 Paper VI dynamic stretches ...................................................82
LIST OF APPENDICES

Appendix 1
List of works which the candidature is to be based........................................60

Appendix 2
Limitations and future work..................................................................................61

Appendix 3
Stretches performed as part of this thesis...............................................................72

Appendix 4
Location and date of work......................................................................................84
ACKNOWLEDGMENTS

I would like to thank a number of people who have helped in the completion of this study and the associated series of publications. Firstly I would like to thank my co-authors Bethan Jones, Ruth Anness and Matthew Monte-Colombo who helped in the data collection and analysis in a number of studies. I would also like to thank Mr Gareth Rose, Mr Neil Wilmore and Mr Warwick Reilly who provided technical support for this series of publications. I am also grateful to the numerous participants of the studies, who gave up their valuable time free of charge to support the furthering of the study of human performance.

I am grateful to my supervisor, Professor Mark Lewis for his guidance in putting this thesis together and in his comments on the provisional drafts of the report.

Finally I am indebted to my family, thanking my girls, Eleanor and Olivia, for their forbearance when their dad had to work and couldn’t play and to my wife Natalie, whose patient support has made it possible for me to even think I could complete this study.
Author’s Declaration
I declare that this report is my own unaided work. It is being submitted for the degree of Ph.D by Publications at the University of Bedfordshire.

It has not been submitted before for any degree or examination in any other university

Name of candidate: Signature:
Iain M. Fletcher
Date: 29/07/11
Operational Definitions

**Active Dynamic Stretch**
A controlled movement through the active range of motion for one or more joints, performed while moving

**Active Static Stretch**
An active contraction of the agonist muscle to its full inner range, stretching the antagonist's outer range

**Ballistic Stretch**
Repeated small bounces at the end range of movement

**Dynamic Stretch**
A controlled movement through the active range of motion for one or more joints (Paper V, VI)

**Electromyography**
Measurement of the electrical activity in muscle (muscle action potentials)

**Extrafusal Fibres**
Contractile muscle fibres

**Intrafusal Fibres**
Muscle spindles

**Fasciae**
Connective tissue fibres, primary collagenous, to attach, stabilize, enclose and separate muscles

**Massage**
A mechanical stimulation of tissues by means of rhythmically applied pressure and stretching

**Musculotendinous Unit**
Single functional unit incorporating the contractile tissue and the associated connective tissue (including tendon)

**Passive Static Stretch**
Slowly applied stretch torque to a muscle, maintaining the muscle in a lengthened position

**Post-Activation Potentiation**
Acute contractile history of a muscle, holding a role in any subsequent muscle contraction
Sarcomere
Smallest contractile unit of a striated muscle cell

Stationary Dynamic Stretch
A controlled movement through the active range of motion for one or more joints, performed while in situ (referred to as static dynamic stretch in Paper I and II)

Stiffness
The slope of the force-length relationship (N/m)

Stretch Shortening Cycle
A common pattern of muscle activation, with an eccentric-concentric sequence of muscle activation

Stationary Dynamic Stretch
A controlled movement through the active range of motion for one or more joints, performed while in situ

Tendon
A collagenous band that connects a skeletal muscle to an element of the skeleton
CHAPTER 1

1.0 INTRODUCTION
1.1 Structure of the report

The first chapter of this report sets out to outline the background and rationale for this series of publications. It focuses on the aims of the body of work brought together for this thesis, while discussing how the related objectives of the enclosed publications have been met. Chapters 2 – 7 represent the publications (I-VI) in chronological order of acceptance for publication. Finally chapter 8 includes a summary of findings from the published work, recommendations for future research in this area and the limitations to the body of work. Note that throughout the text, reference to the published work is made using roman numerals.

1.2 Study Overview

The thematic area of study was to investigate exercise modalities commonly used as components of pre event/training preparation. The effect of active warm-up and massage is explored, but this body of work concentrates on the different stretch modalities used by athletes as part of a warm-up designed to prepare athletes for subsequent performance. The publications start by systematically exploring the effect of each intervention on trained sports performers, before exploring the possible mechanisms behind negative and positive performance changes associated with the interventions used in each study.

Data for paper I was collected in 2003; this was designed to explore the effect of four different commonly used stretch types on 20m sprint performance. The study attempted to try to explore the effect of dynamic and static stretches in a valid field based protocol. Paper I’s results indicated that an increase in performance was linked to dynamic stretches and decreases in performance were linked to static stretches. In light of this Paper II explored combining static and dynamic stretches as part of a warm-up, recognised as a popular method of athletic preparation. Data for Paper II was collected in 2004. The data for paper III was collected in 2005. As a result of Paper I and II suggesting that static
stretches decreased sprint performance when compared to dynamic stretch interventions, it was decided to investigate the efficacy of another popular pre-performance preparation strategy; therefore massage was compared to a traditional active warm-up and stretch. The results of this paper indicated that massage was not an effective preparation strategy; therefore it was decided to examine the stretch dominated active warm-up regimes in greater detail. Data for Paper IV was collected in 2006; it was designed to expand on Paper I and II by exploring more than the linear sprint performance previously studied, therefore agility and counter movement jumps were also examined.

Papers I-IV were designed to help find the best preparation structure to help increase sprint, jump and agility performance, by exploring preparation warm-up strategies commonly used by athletes. These papers seem to suggest the benefit of dynamic stretch dominated warm-ups, compared to other preparation strategies; therefore the last two studies were designed to explore the effect dynamic stretches have on performance and the mechanisms behind the changes in the field test performances linked to the warm-up stretch components in Papers I, II, IV. Data for Paper V was collected in 2007; designed to examine the mechanisms behind static stretches negative effect on performance and dynamic stretches positive effect on performance. This involved measuring changes in temperature, heart rate, kinematics, kinetics and muscle activation caused by pre-performance warm-up modalities. Data for Paper VI was collected in 2008. This paper was designed in light of the previous papers in this thesis indicating the superiority of dynamic stretch dominated warm-ups in promoting acute performance increases. It was decided to explore this phenomenon in a far more in-depth way, by looking at the effect dynamic stretch velocity may have on performance.
1.2.1 General Limitations for Presented Papers

All of the presented papers involve the study of human subjects; therefore a number of limitations arise linked to human behaviour. Individuals respond to exercise modalities differently due to factors such as age, sex and training status, as well as genetic differences such as muscle fibre type. Attempts to control some of these factors included only examining trained subjects, with experience of the modalities studied. Subjects were of a homogeneous age, while different sexes were not combined for analysis. Though genetic differences were not explored, subjects in each paper performed similar sporting activities at a similar level, therefore factors such as mixing endurance and sprint athletes as a subject group was not relevant.

A number of the presented papers would be considered to be field studies; therefore they inherently have a number of limitations. Paper I and IV were conducted outside, as they were repeated measures designed studies the problem of different weather conditions and changing ground conditions arises. These factors were monitored and kept fairly stable through the studies, with each test day being dry, with light wind and similar temperature conditions. The other studies were performed indoors, were temperature and humidity could be stabilised throughout the testing process. Subject’s behaviour was controlled during testing. Health screens were used to ensure subjects were not performing in an injured state, while clothing (including footwear) was standardised to prevent that being an extraneous factor. All subjects were required to refrain from fatiguing exercise for at least 24 hours prior to testing, while food and drink intake was also controlled, particularly caffeine intake as this has been shown to be an ergogenic aid and could mask the performance changes attempting to be explored. Lastly, each papers test sessions were performed at the same time of day to prevent the potential effect of diurnal variations.

To reduce the effect of some of these limitations the studies were designed in a randomised, counter balanced way, while reliability statistics were used to
establish that any main effects were real and not an artefact of the measurement process.

1.3 Background and rationale for the series of publications

Traditionally athletes have achieved peak performance goals through long-term structured training schedules. Investigations have explored a variety of methods for optimising training protocols, from increasing strength to improving aerobic endurance (Anderson and Aagaard, 2010, Aagaard and Anderson, 2010). However, until recently, little work has been done on one of the most fundamental parts of training, the acute preparation strategies that athletes use, in the attempt to maximise performance.

The 'active' component of a warm-up, designed to increase core and muscle temperature, blood flow and prepare the body for exercise, has long been shown to benefit performance (Karvonen, 1978; Bergh and Ekblom, 1979; Blomstrand et al. 1984; Shellock and Prentice, 1985; Febbraio et al. 1996; Bishop, 2003; Brown et al. 2008). This has usually involved some form of low intensity continuous aerobic exercise, to elevate the heart rate and increase cardiovascular response. However, the applicability of this type of warm-up to prepare athletes for high intensity maximal exercise, using large ranges of movement, is limited as it fails to prime the musculoskeletal and nervous system to a desirable level. This problem has traditionally been addressed by using other exercise modalities to complement the active warm-up process and to get the musculoskeletal system more ready to achieve high intensity exercise loads over a large range of movement. Recently, it is these exercise modalities which have come under scrutiny; in particular, the stretch component used in pre-performance preparation has been heavily criticised with regard to its effectiveness in promoting performance improvements (Herda et al. 2008, Bacarau et al. 2009; Pearce et al. 2009).
Traditionally, part of the active warm-up process has involved the use of passive static stretches, defined as a slowly applied stretch torque to a muscle, maintaining the muscle in a lengthened position (Mohr et al. 1998). These stretches have been used by coaches and their athletes in a widespread manner, for many years, in the belief that they will help increase performance and decrease the likelihood of injury (Garrett, 1990). In fact for much of the sporting population static stretching was seen as an essential prerequisite prior to performance. However, these claims are now being refuted, with injury prevention regarded as unlikely (Shier, 1999; Thacker et al. 2004), while there is compelling evidence to indicate that static stretching actually decreases subsequent performance. Early research in this area showed a reduction in muscular power output (Rosenbaum and Hennig, 1995; Kokkonen et al. 1998; Avela et al. 1999; Fowels et al. 2000; Behm et al. 2001; Nelson and Kokkonen, 2001), however the validity of this research has been criticised in terms of it being applied to the preparation strategies that athletes habitually use as part of their training programmes.

In particular these studies have been criticised in terms of their stretches hold times, which have ranged from 90 seconds per muscle group (Kokkonen et al. 1998; Nelson and Kokkonen, 2001) up to 1 hour (Avela et al. 1999); routines unlikely to be used by athletes in preparation for competition, where a typical stretch lasts no more than 10-15 s, repeated no more then twice per muscle group. Also the methods of determining power output in studies investigating this area have usually involved maximum voluntary contraction (MVC) of isolated muscle groups, including, maximum knee flexion/extension (Kokkonen et al. 1998; Behm et al. 2001; Nelson and Kokkonen, 2001), or plantar flexion (Avela et al. 1999; Fowels et al. 2000). These types of muscular function tests can be criticised due to their severely limited ability to reflect changes in performance (Murphy and Wilson, 1997). It is recommended that the effect of interventions or training should be based on changes in performance rather than changes in test scores of muscle function (Murphy and Wilson, 1997). Therefore, it can be
questioned that the apparent decrease in power output reported in these studies may not be applicable to the multi-joint, co-ordinated actions that many athletes perform as part of their sport.

Later work has focused on more ecologically valid protocols, with more representative stretch hold times (10-30 seconds) and more sport specific performance measures. The findings from these studies are compelling, with evidence to show a decrease in strength (Herda et al. 2008; Morse et al. 2008; Bacarau et al. 2009; Costa et al. 2009), power (Manoel et al. 2008; Samual et al. 2008), speed (Paper I; Nelson et al. 2005; Paper II; Sayers et al. 2008; Paper IV), jump performance (Holt et al. 2008; Pearce et al. 2009; Paper IV and V) and agility (Little and Williams 2006; Paper IV) linked to the incorporation of static stretches as part of a warm-up routine.

Not surprisingly, these findings have led many athletes to move away from the static passive approach to stretching in the warm up, in favour of implementing a dynamic stretch component, defined as a controlled movement through the active range of motion for each joint (Paper I). This can involve the implementation of a complex movement, such as a full range squat or lunge, or the isolation of specific parts of a running cycle, in the form of sprint drills, going through the full active range of motion of joints specific to the performance task chosen to be explored. (See Appendix 2 for a range of stretch example used in the enclosed studies).

Despite its increasing popularity little research, until comparatively recently, has been done on the effects of dynamic stretching as part of a warm-up prior to performance. Indeed, an increase in short term high intensity muscular performance is apparent, when compared to post static stretch performance tests (Paper I; Faigenbaum et al. 2005; Nelson et al. 2005; Wallmann et al. 2005; Little and Williams, 2006; Paper II; Holt and Lambourne, 2008; Manoel et al. 2008; Moran et al. 2009; Pearce et al. 2009; Winchester et al. 2008; Paper IV and V).
Importantly, the mechanisms behind the performance changes associated with dynamic stretch regimes have not been explored in any systematic way.

**Table 1: Outline of Papers I-VI Main Findings**

<table>
<thead>
<tr>
<th>Paper</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>In comparison to an active warm-up 20m sprint performance was improved by 1.9% after moving dynamic stretches ($p \leq 0.05$) and decreased by static active (1.6%) and passive (1.3%) stretches ($p \leq 0.05$). Stationary dynamic stretches had no effect ($p &gt; 0.05$) on performance.</td>
</tr>
<tr>
<td>II</td>
<td>50m sprint performance was significantly faster ($p \leq 0.05$) when dynamic stretches were employed, compared to a warm-up strategy of combining static and dynamic stretches. This increase was calculated as 1.9%, the adding of stationary dynamic stretches did not further alter performance ($p &gt; 0.05$).</td>
</tr>
<tr>
<td>III</td>
<td>20m sprint performance significantly decreased ($p \leq 0.01$) by 2.7% when a massage trial was compared to an active warm-up combined with static stretch condition. Differences mirrored when massage was combined with an active warm-up with static stretches, 2.4% increase in performance ($p \leq 0.05$) compared to massage only. Massage significantly decreased ($p \leq 0.05$) sprint step frequency (3.4%) and knee velocity (15.3%). No significant differences ($p &gt; 0.05$) in step length or core temperature between conditions were found.</td>
</tr>
<tr>
<td>IV</td>
<td>Compared to an active warm-up a static stretch method significantly decreased ($p \leq 0.05$) counter movement jump (4.1% decrease), 20m sprint (2% decrease) and Balsom agility performance (1.4% decrease). A dynamic stretch modality significantly increased ($p \leq 0.05$) sprint (3% increase) and agility (2.5% increase) in performance compared to the active warm-up trial. Heart rate was significantly increased ($p \leq 0.05$) in the dynamic stretch and the active warm-up condition compared to the static stretch condition.</td>
</tr>
</tbody>
</table>
When compared to an active warm-up jump performance and isokinetic force were significantly decreased \( (p \leq 0.01) \) by a static stretch trial (4.2% decrease in jump height and 4.6% decrease in torque). The dynamic stretch trial had a significantly increased \( (p \leq 0.01) \) of 2.5% in jump height and 7.9% peak torque compared to the active warm-up intervention. Heart rate, core temperature and muscle stiffness significantly decreased \( (p \leq 0.05) \) in the static stretch trial compared to active warm-up. The dynamic stretch trial had significantly greater \( (p \leq 0.05) \) muscle activity compared to the static trial and significantly greater \( (p \leq 0.01) \) heart rate and core temperature compared to the active warm-up condition.

Compared to an active warm-up jump performance was significantly increased \( (p \leq 0.01) \) by slow (4%) and fast (6.4%) dynamic stretch trials. The faster dynamic stretch condition had significantly higher \( (p \leq 0.01) \) jump heights compared to the slower condition. Heart rate and core temperature were significantly increased \( (p \leq 0.01) \) in both stretch conditions compared to an active warm-up. Muscle activation was significantly greater \( (p \leq 0.05) \) in the fast dynamic condition compared to the other trials.

### 1.4 Overall aim and related objectives

The overall aim of this series of publications was to explore commonly used preparation strategies, to see what might be the best strategy for promoting short term maximal performance.

#### 1.4.1 Objective 1

To investigate the effect of active warm-up, static and dynamic stretch protocols as pre-competition preparation strategies on the performance of sport specific movement tasks (Publication I, II and IV).
1.4.2 Objective 2
To investigate the effect of pre competition massage as a preparation strategy compared to a traditional warm-up protocol (Publication III).

1.4.3 Objective 3
To investigate the potential mechanisms behind any changes in performance associated with an active warm-up combined with static or dynamic stretch protocols (Publication IV and V).

1.4.4 Objective 4
To explore the effect of different dynamic stretch velocities as part of pre-competition preparation on short term maximal performance parameters (Publication VI).

1.4.5 Objective 1
Publications I, II and IV were produced to explore more ecologically valid pre-performance preparation strategies. The need for these types of studies was due to criticism of early research in terms of the extended static stretch hold times and the lack of sport specific performance measures employed (Kokkonen et al. 1998; Avela et al. 1999; Fowels et al. 2000; Behm et al. 2001; Nelson and Kokkonen, 2001).

Publication I explored the use of passive and active static stretches, as well as stationary and moving dynamic stretches, on a rugby union specific 20m sprint test. Static active and static passive stretches led to a significant decrease in sprint performance compared to an active standardised jogged warm-up. In contrast, the moving dynamic stretch protocol significantly increased sprint performance, while the stationary dynamic stretches increase in sprint performance was found to be non significant.
Publication II was designed in light of Publication I’s findings. It addressed the criticism that many studies have used relatively untrained subjects; paper II’s subjects were trained track sprinters rated at regional level or above, performing a specific 50m sprint test. Publication II was also designed to explore whether the negative effects of static stretching, as part of a warm-up, could be negated by employing dynamic stretches after the static stretch component, recognised as a protocol, used by many track and field athletes (Jones, 2002). Publication II’s findings showed that when the active warm-up incorporated moving dynamic stretches, athletes ran significantly faster over 50m when compared to a preparation strategy which had an active warm-up followed by a static passive stretch before the dynamic stretches were employed. It was also found that when stationary and moving dynamic stretches were combined athletes were significantly faster than when static and dynamic stretches were combined. However, this preparation strategy was still slower than when moving dynamic stretches were used exclusively; it should be noted this difference in performance was marginal and found to be not statistically significantly. It was concluded that for short distance sprint performance, even if a combination of static and dynamic stretches are used as part of a warm-up strategy performance will still be significantly inferior to the use of dynamic stretches alone. It appears the negative effect of static stretches on sprint performance (Publication I and II) is not mitigated by inclusion of dynamic stretches after the static stretch. This should re-warm athletes after the relative rest of the static stretch component creating more optimum performance conditions. This does not appear to be the case with any warming effect countered by other (as yet unknown) physiological changes. Interestingly, the adverse effects associated with static stretching are long lasting, with evidence of performance decreases lasting for over one hour post stretch (Fowles and Sale, 1997; Power et al. 2004).

Publication I and II explored the effects of different preparation strategies on straight line running speed. With this in mind, there was a change in emphasis in paper IV. It was designed to examine whether the negative effects linked to
static stretching and the positive effects linked to dynamic stretches could also be seen in specific high speed motor skills, considered important components of soccer performance (Hoff, 2005; Svensson and Drust, 2005). Therefore, the effect of static and dynamic stretch modalities on counter movement jump, 20m sprint and Balsom agility tests was explored. Paper IV found that passive static stretching combined with an active warm-up significantly decreased performance in all tests compared to an active warm-up or dynamic stretch as part of an active warm-up. It was also shown that sprint and agility performances were significantly better when dynamic stretches were included in the preparation strategy, compared to just an active warm-up.

From the findings in studies I, II and IV, it can be concluded that static stretching has a significant negative impact on performance in a wide range of performance tasks, while the inclusion of a dynamic stretch component has a significant positive effect on performance measures. This is despite the static stretch warm-ups employed in these studies being the preferred preparation strategies for the subjects examined. This might have caused a reverse placebo effect (Knudson et al. 2001), as subjects might have felt unable to perform to their maximum capacity without going through their normal pre performance routine, however this was not the case in these papers, giving even greater weight to their findings.

1.4.5.1 Contribution to the advancement of the field of study

Paper I was one of the first ecologically valid attempts to look at the effect of both active and passive static stretches on sport specific movement skills. It was also the first publication to explore the use of both moving and stationary dynamic stretch components as part of an active warm-up. Paper II was the first study to examine whether the negative effects linked to static stretching could be reversed by being combined with dynamic stretches. Paper IV was the second study, after Little and Williams (2006), to examine the effect of pre-performance static stretches on specific soccer movements. They found that though agility
performance was negatively affected, jump performance was not. However, their method was substantially different to the present study and can be criticised for not isolating the static stretch component. Little and Williams (2006) combined their stretches with a number of re-warming exercises, which could have diminished the negative effects of the static stretch component. No studies have explored the effect of dynamic stretches on soccer related movement skills.

The findings from papers I, II and IV provide strong evidence that dynamic stretching as part of an active warm-up produces superior performance for a range of sports performers in a number of different short term maximal activities, when compared to an active warm-up or static stretch condition. Therefore, the use of dynamic stretching rather than static stretching would be recommended for athletes attempting to maximise acute high intensity performance.

1.4.6 Objective 2
Having established, in publications I and II, that moving dynamic stretches, as part of an active warm-up, were superior to other stretch modalities commonly used as part of an athlete’s preparation processes, it was decided to investigate another commonly used pre-competition preparation strategy. Massage is frequently used by athletes as part of pre-performance preparation, but its effects are poorly documented; most evidence on massages reporting efficacy is anecdotal in terms of benefits to acute performance. There is a belief, in the related literature, that acute performance can be increased by pre-competition massage, as long as it is a superficial stimulating intervention (Cafarelli and Flint, 1992; Goats, 1994; Cash, 1996; Angus, 2001). However, when paper III’s research was conducted, no peer reviewed publications had shown massage to have any positive effect on acute performance. Therefore, it was decided to explore what effect massage, as a commonly used passive warm-up modality, would have on 20m sprint performance, when compared to the subjects preferred warm-up regime.
Paper III’s results indicated that massage on its own significantly decreased 20m sprint performance, even when followed by specific active warm-up (4 x 20m strides), compared to the subjects preferred warm-up, consisting of an active jogged warm-up, a series of static passive stretches and 4 x 20m strides. Interestingly, when the massage and normal warm-up regimes were combined performance was significantly better than massage alone, but not different to the normal warm-up protocol. The negative effects attributed to massage were not thought to be temperature related, no differences could be found in the aural temperature after any of the chosen interventions. The kinematic data collected seemed to be more fruitful in terms of explaining performance changes. Analysis showed that massage significantly decreased step frequency and knee velocity in the 20m sprint, both vital to fast sprint performance (Mero et al. 1992). This could be the result of a decrease in musculotendinous unit (MTU) stiffness associated with massage (Hilbert et al. 2003; Weerapong et al. 2005). Massage elongates muscle fibres helping increase acute range of movement, but it will also cause the MTU to become softer and more pliable and less likely to be able to transfer force efficiently from the active to the passive (tendinous) component of an MTU (Weerapong et al. 2005). This could be important as a stiff MTU is seen as a vital contributor to high-intensity performance (Kokkonen et al. 1998; Nelson and Kokkonen, 2001) including running velocity (Chelly and Denis, 2001) as it is linked to a decrease in the electro mechanical delay associated with less stiff MTUs. It was concluded that pre competition massage was not an effective way of enhancing short distance sprint performance. It should be born in mind that massage was compared to a warm-up that incorporated static stretches, with the evidence from papers I, II and IV indicating the superiority of dynamic stretches as part of an active warm-up compared to static stretches. It is entirely possible that massages negative effects would have been greater if it had been compared to a dynamic stretch modality. With this in mind it was decided that massage as a pre performance enhancement strategy was not effective and that concentrating on the role of dynamic stretching, as part of a preparation strategy, would be more rewarding.
1.4.6.1 Contribution to the advancement of the field of study
Massage, though used by a large number of sports performers as part of their warm-up regimes, has had very little peer reviewed research conducted on its effects as a preparation strategy. When this article was published it was the first to explore massages acute effects on sprint performance; it helps refute many unsubstantiated claims, in terms of massage positively helping athletic performance in short term maximal exercise.

1.4.7 Objective 3
This objective was an attempt to move from the field based work reported in papers I, II and IV, which had shown differences in performance when static and dynamic stretches were performed as part of an active warm-up process, to a more controlled laboratory environment, were the mechanisms behind these performance changes could be investigated. It was felt that though the initial research findings had been useful for the coaching and performance communities, in helping to formulate better pre-performance strategies; little was understood about the reasons behind these performance changes.

A number of mechanisms have been put forward to explain the negative effects of static stretching on performance. There has been a view that static stretches have a dampening effect on the nervous system, demonstrated by a significant decrease in electromyographical (EMG) activity (Rosenbaum and Hennig, 1995; Cramer et al. 2004; Marek et al. 2005), though it should be noted that the stretch hold times in these studies were far beyond what would be normal for an athlete’s pre-performance preparation (1 or 2 x 10-15 seconds), compared to a minimum hold time of eight minutes in these studies. A static stretch is designed to invoke the stretch reflex, by initiating a muscle spindle response, when stretches are held for extended periods (a minimum of 6 sec, Enoka, 2002). This causes the muscle spindle to relax, allowing elongation of the muscle and an increase in ROM, as reflex muscle contraction is inhibition (Moore, 2007). This
could lead to the reflex arcs ability to respond to subsequent muscle spindle outputs to be diminished, causing a slower, less forceful response when movement is performed. This decrease in neural drive (Avela et al. 1999) could be the reason for the decrease in performance associated with static stretch modalities.

The other main mechanism for static stretches decreasing performance, is believed to be due to mechanical factors linked to an increase in musculotendinous unit (MTU) compliance; as Cornwell et al. (2001) explained, too much 'slack' has to be taken up in the initial part of the contraction, leading to alterations in the force-length relationship (Cramer et al. 2004). It could be that the decrease in MTU stiffness associated with static stretching prevents efficient transfer of force, generated by muscular contraction, to be transmitted effectively from the active to passive components of the MTU (Kokkonen et al. 1998). This could be due to the way the collagen content of tendons responds to mechanical loading (Franchi et al. 2001), where collagen will elongate and align along the long axis of the tendon (in the direction of a static stretch). This would make an increase in the time until forceful movement can be demonstrated, by causing a greater electro mechanical delay, slowing stretch shortening cycle muscle actions, so important to many high intensity sports performances.

A number of mechanisms have been proposed to explain why dynamic stretches have a positive effect on acute high intensity exercise performance. Yamaguchi and Ishii (2005) proposed that the active nature of this type of stretch would increase heart rate and core temperature and therefore produce a more optimal muscle temperature. Faigenbaum et al. (2005) hypothesised that there may be an increase in neuromuscular activity, possibly linked to postactivation potentiation (PAP) (Sale, 2002), where the previous acute contractile history of a muscle positively effects subsequent muscular performance. Lastly, Papers I and II proposed that the rehearsal of specific movement prior to exercise may have a role to play. This would allow the human system to be primed through a
repetitive learned movement, to be more ready to perform a similar performance task. Papers IV and V were therefore designed to explore the effects of static and dynamic stretch routines on heart rate, core temperature, kinematic and kinetic parameters and EMG, to start to examine some of the mechanisms proposed in the literature and in the initial studies (I and II).

The results in Paper IV showed that dynamic stretching had a significant positive effect on jump, short distance sprints and agility performance compared to static and no stretch warm-up protocols. This was linked to a significant decrease in post intervention heart rate in the static stretch condition compared to the dynamic stretch and the no stretch active warm-up trials. However, the dynamic stretch condition showed significantly better performance measures compared to the active warm-up trial, but no differences in heart rate. It was concluded that although temperature related mechanisms may explain some of the performance differences linked to the static stretch condition compared to the other interventions, other mechanisms were responsible for dynamic stretches superiority to an active warm-up only condition.

Paper V was designed to explore potential mechanistic data in a more systematic fashion, particularly examining different stretches effects on kinetic, kinematic and muscle activation variables. It demonstrated a significant decrease in jump height and isokinetic dynamometry force when the static stretch trial was compared to the active warm-up and the dynamic stretch condition; reinforcing the findings on sprint, jump and agility performance from papers I, II and IV. Paper V hypothesised that the static stretches negative effects on performance were linked to significantly lower heart rate, core temperature and a decrease in muscle stiffness compared to the active warm-up only trial. However, although the dynamic stretch trial showed the same heart rate and temperature patterns as the static stretch trial, no difference in muscle stiffness was found, but significantly greater muscle activation, as measured by average EMG, and significantly greater peak torque and significantly faster time to peak torque was
found when the dynamic and static stretch conditions were compared. It was concluded that the negative effects of static stretching on performance, compared to dynamic stretching, are linked to a decrease in heart rate, core temperature, peak torque and muscle activity.

The dynamic stretch condition also showed significantly greater performance measures compared to the active warm-up trial; this was linked to a significant increase in participant’s heart rate and core temperature during the dynamic stretch trial. This could lead to an increase in nerve conduction velocity, encouraging muscle contraction to be more rapid and forceful (Shellock and Prentice, 1985; Bishop, 2003; Girard et al. 2009). The increase in the motor systems biomechanical performance, linked to temperature changes, is associated with decreased contraction and ½ relaxation time. This changes the force-velocity relationship by increasing the maximum velocity of muscle shortening (Enoka, 2002). Indeed, Enoka (2002) suggested that while force is not affected, for every 1°C increase in temperature, max velocity will shift to the right by 12%, therefore increasing peak power. Whether the effects of temperature are linked only to global stimulation of the nervous system, and/or to the micro level, stimulating Andenosine Triphosphate (ATP) turnover, is as yet unknown. There is some evidence of this positive effect on the nervous system, peak torque, and more importantly, time to peak torque was significantly superior in the dynamic condition compared to the active warm-up trial. This indicates a potential increase in nerve conduction velocity; however, this nervous system stimulation is a tentative conclusion as no significant difference was found in the average EMG for these two conditions. Interestingly, MTU stiffness was actually inferior in the dynamic stretch trial, compared to the active warm-up intervention, which could have led to a decrease in jump performance. A decrease in MTU stiffness should cause a slower transmission of active muscular force to the passive muscular components, slowing force transmission to the tendon bone insertion, causing a increase in time until movement can be expressed (Kubo et al. 2001). It seems that this potentially negative physiological change is
mitigated by an increase in peak torque and an increase in rate of force development (RFD), as shown by a decrease in time to peak torque. To conclude, the increased performance in the dynamic condition, compared to the active warm-up trial, seems to be linked to increased heart rate and core temperature, leading to improvements in peak torque and time to peak torque. Importantly, EMG activity was not significantly affected; logically the greater intensity of warm-up exhibited by the dynamic stretch intervention could cause a further stimulation of the nervous system, but this does not appear to be the case. It was therefore hypothesised that though temperature related mechanisms could explain some of the performance differences between the dynamic stretch and the active warm-up conditions, rehearsal of specific movement patterns helping more complex motor skills performance can not be discounted. This could explain why movement dynamic stretching was found to be superior to stationary dynamic stretching in papers I and II. The movement stretches more closely resemble the sprint tests used to measure performance, helping proprioception and pre-activation, possibly allowing a more optimal switch from the eccentric to the concentric components of the stretch shortening cycle, which is vital to efficient maximum sprint performance.

1.4.7.1 Contribution to the advancement of the field of study

Though the mechanisms behind the effects of static stretching on performance have been explored extensively (Rosenbaum and Hennig, 1995; Avela et al. 1999; Fowels et al. 2000; Church et al. 2001; Cramer et al. 2004; Marek et al. 2005) the mechanisms behind the positive effects of dynamic stretching on performance have only been alluded to (Paper I and II; Faigenbaum et al. 2005; Yamaguchi and Ishii, 2005). To date no study has looked at heart rate, core temperature or neuromuscular activity in relation to the dynamic stretch component of a warm-up.
1.4.8 Objective 4
Publications I, II, IV and V have cast doubt on the efficacy of static stretching as part of a pre-performance preparation strategy designed to increase acute high intensity muscular performance. While paper III has thrown doubt upon the use of pre-performance massage as a preparation strategy; it appears that dynamic stretching as part of an active warm-up has the effect of helping subsequent muscular capacity and specific performance tests. Therefore the aim of paper VI was to explore the effect of the dynamic stretch component more fully. The magnitude of the myotatic reflex is related to MTU stretch velocity (Gollhofer and Rapp, 1993); therefore, by increasing the stretch velocity, greater action potential of the myotatic reflex may result. If this is the case, then performance actions, which rely on rapid Stretch Shortening Cycle (SSC) actions, where a forceful eccentric contraction is followed by a short isometric contraction, helping increase the following concentric movement, should be enhanced. In light of this, paper VI was designed to investigate the effect of two differing movement velocities for a range of specific dynamic stretches. The performance tests chosen were a counter movement jump (CMJ), a drop jump (DJ) and a squat jump (SJ); in the hope that the use of different jump types would help explore the effect that dynamic stretching may have on the myotatic reflex. The CMJ has a comparatively slow SSC, with the DJ having a much faster SSC, while the SJ is performed with only a concentric component and therefore no SSC.

The findings from paper VI indicated that both slow and fast dynamic stretch modalities proved to be significantly superior in increasing jump height compared to an active warm-up alone. The faster stretch trial also led to significantly greater jump performance compared to the slower stretch condition. It was hypothesised that the significant increase in EMG activity in the faster stretch trial led to the significantly greater take off velocity observed in subsequent jumps, which in turn led to the greater jump heights recorded in the faster stretch intervention. Interestingly, as the velocity of the eccentric component of the jump types increased (SJ to CMJ to DJ), so the increase in performance, associated
with the faster dynamic stretches, became significantly greater. It appears that the faster stretch modality may prime skeletal muscle for acute performance, while the slower stretch failed to reach a threshold intensity necessary to stimulate the nervous system. This could be an example of PAP, where rehearsal of skilled movement through specific warm-up design may condition muscles to bring about more rapid/forceful contraction (Sale, 2002). It should be remembered that the magnitude of twitch force depends on the activation history of the muscle concerned (Enoka, 2002), with this potentiation effect linked to maximum and sub-maximum contractions (Vandervoort et al. 1983). Interestingly sub maximal activation can increase twitch force with a series of twitches in close succession, as exhibited by the fast dynamic movements employed in paper VI. This phenomenon is known as treppe (Krarup, 1981) and may help explain the findings in paper VI. Paper V certainly demonstrated an increase in peak torque and a decrease in time to peak torque in its dynamic stretch intervention, indicating an increase in RFD, which would certainly help explain increases in jump performance associated with dynamic stretch protocols. It was therefore concluded that the priming nature of dynamic stretching could be further enhanced by making the stretches as specific to the movement velocity of the subsequent performance measure as possible. A conclusion supported by the greater improvements in performance linked to moving dynamic stretches, employing SSC actions, compared to stationary dynamic stretches with much reduced involvement of the SSC (papers I and II).

1.4.8.1 Contribution to the advancement of the field of study
No author has as yet examined whether the velocity of movement employed in a dynamic stretch protocol would have an effect on subsequent performance. These results also give support to the mechanistic data collected in paper V, helping to cast some light over the physiological effects underpinning the efficacy of dynamic stretches as part of a pre-performance preparation strategy.
1.5 Potential Mechanism Associated with Different Preparation Strategies
In sporting events athletes are striving for efficient movement, to either perform maximal actions, such as a throw, jump or a short sprint, or repetitive sub-maximal actions, such as rowing, cycling or long distances running. How efficiently they perform these tasks will impact on their performance outcome. Preparation strategies are supposed to help improve the efficiency of movement in subsequent training or competition scenarios. Therefore, a discussion on how the neuromuscular system produces force and what efficiency at a neuromuscular level actually is seems prudent.

1.5.1 An Outline of Force Production and the Neuromuscular System
Muscular force is produced when α motor neurone fires, this action depends on the input of higher centres, such as the motor cortex, and reflex inputs, such as muscle spindles. If there is sufficient excitatory input then a threshold will be reached causing α motor neurones to fire, muscle fibres to contract at the sarcomere level, by the interplay of actin and myosin fibrils and force to be generated.

The amount of force produced by an MTU depends on two sections of the neuromuscular system. Firstly, neuromuscular activation is dependant on the following; the firing rates of α motor neurones involved the number of α motor neurones that innervate a muscle and the co-ordination of the movement (innervation of the agonists versus antagonistic muscles). Secondary, the actual force produced by a muscle fibre is dependant on fibre size and fibre phenotype, with type I (slow twitch, low force), type IIa (fast oxidative glycolytic, intermediate force) and type x (fast glycolytic, high force) fibres the 3 main categories.

Skeletal muscle functions at the level of the motor unit, which is the α motor neurone and all the fibres it innervates. Three main categories have been identified. Slow units are easily recruited, fatigue resistant, linked to small α motor neurones and type I fibres; importantly, in light of this thesis, they produce
low tension and are related to endurance rather than peak force actions. Fatigue resistant motor units fatigue slowly, but have a higher recruitment threshold than slow units. They are associated with intermediate size α motor neurones and type IIa fibres. Fast fatiguing motor units are associated with large α motor neurones and type IIx fibres, they fatigue easily, but produce very high tension. They are recruited for high speed and force activities; similar to the muscle capacity and performance tests used in this thesis, but importantly they need a larger recruitment threshold than the other motor unit types. This may be important in light of the relative low intensity of static stretches compared to the higher intensity movement in dynamic stretch actions.

1.5.2 Muscle Efficiency and the Stretch Shortening Cycle (SSC)
For human movement to take place there needs to be a conversion of metabolic energy into mechanical work; the more efficient this conversion the more forceful, or less energy costly a sporting action will be. Therefore, muscle efficiency can be seen as work done as a proportion of metabolic cost (Ettema, 2001). It is generally believed that SSC work loops, (where an eccentric lengthening of the MTU is followed by an isometric contraction, before instigation of a concentric contraction) are an energy saving mechanism in human locomotion (Biewener and Roberts, 2000). In this system the passive components of an MTU store mechanical work as elastic energy during eccentric contractions, before subsequently releasing that energy during the concentric phase of a SSC. This storage and release of series elastic energy is crucial in efficient movement, exemplified by in increases in countermovement jump performance (where a SSC action is performed) compared to actions without a counter movement, such as a squat jump.

How efficiently a SSC action is performed can be expressed as locomotion or net efficiency, it is how the positive work loop (concentric contraction) interacts with a negative work loop (eccentric contraction), and with regard to what metabolic
cost the action produces (Barclay, 1994). The following equation helps to explain this interaction:

\[
\text{Locomotion Efficiency} = (\text{Work } + \text{ve} - \text{Work } - \text{ve}) \times (\text{metabolic energy})^{-1}
\]

(Barclay, 1994)

How this works in reality is highlighted when a series of SSC actions are applied in a running or hopping action, were the storage and re-utilisation of elastic energy is necessary to maintain efficiency of locomotion, rather than to enhance the movement. The energy absorbed by an MTU during impact (ground contact) originates from a prior SSC action (previous take off phase), this energy will be wasted if not stored in the series elastic components of the MTU during the eccentric phase, than effectively released in the concentric phase. Therefore, the muscle work produced during the take off phase in running is converted into potential energy (top of the flight phase) than kinetic energy (descent from the top of the flight phase). This energy is subsequently reduced to zero at ground contact, before the muscles elastic components are stretched (storing potential energy) for release in the concentric muscle action (kinetic energy), before the process is repeated. If energy is not stored and reutilisation it is wasted, resulting in extremely low efficiency (Ettema, 2001), with any shortfall in energy required to continue moving at the same or increased velocity made up by metabolic work.

The ability of the MTU to store and reutilise energy is based on its stiffness. The utilisation of elastic energy cannot enhance muscle efficiency, because it does not contribute to the conversion of metabolic energy to mechanical work, it should be thought of as a temporary deposit box, with energy released after a delay, leading to an extra loss of energy and decreased efficiency (Van Ingen Schenau et al. 1997). Therefore, if this delay can be reduced less energy will be lost. Muscle with a stiff serial elastic element performs well if a mainly concentric contraction (positive work loop) is required. In these types of actions muscle
movement and contractile element movements are almost identical; the active muscle components work is directly converted to external work as little energy is absorbed in a muscle with stiff serial elastic element properties, resulting in high efficiency, if little active stretch occurs, resulting in a faster build up of force to higher peak levels when compared to less stiff MTUs (Ettema, 2001). Therefore, activities involving acceleration or constant velocity would benefit from stiff MTU's. Compliant serial elastic elements behave in a different way; they tend to store and release series elastic energy, which is less suited for predominantly positive work loops. For the efficient release of series elastic energy a highly compliant muscle requires a long period of relaxation during shortening (Lou et al. 1998), this will lead to a decrease in locomotion efficiency as there will be little transfer to muscle efficiency, therefore more energy will be wasted in terms of transfer from the eccentric to concentric component of a SSC action when compared to a stiff MTU (Ettema, 2001). So actions such as stopping, or landing and absorbing impact, should be enhanced by a compliant muscle compared to a stiff muscle.

1.5.3 Evidence Supporting Different Mechanism Associated with Changes in Performance
The general findings from this thesis would indicate that an active warm-up alone was a superior preparation strategy for short term maximal performance tests, compared to an active warm-up combined with static stretches. However, when an active warm-up was combined with dynamic stretches, improvements in performance were significantly greater than when an active warm-up was used in isolation.

The amount of force produced by a muscle or group of muscles is dependant on muscle length, shortening velocity and the level of neural activation (Hawkins and Bay, 1997), therefore the effect warm-up practices have on these variables is vital in terms of optimising or inhibiting subsequent performance.
The mechanisms behind these findings were multifaceted with the most obvious cause being temperature related. It appears that incorporating a static stretch component caused a decrease in heart rate and core temperature compared to other warm-up modalities. An increase in core temperature is linked to a number of mechanisms which could cause positive physiological changes likely to increase performance. Increases in nerve conduction velocity, encouraging muscle contraction to be more rapid and forceful (Shellock and Prentice, 1985; Bishop, 2003; Girard et al. 2009) have been linked to core temperature increases. The increase in the motor systems biomechanical performance linked to temperature changes is associated with decreased contraction and ½ relaxation time; this changes the force-velocity relationship by increasing the maximum velocity of shortening (Enoka, 2002). Indeed Enoka (2002) suggests that while force is not affected, every 1°C increase in temperature max velocity will shift to the right by 12%, therefore increasing peak power. The temperature changes found in this work were not of this magnitude; therefore the changes in musculo-tendinous stiffness may be as or more important in helping to explain performance changes.

MTU stiffness decreased when the static stretch modality was compared to an active warm-up. A stiff MTU is seen as a vital contributor to high-intensity performance (Kokkonen et al. 1998; Nelson and Kokkonen, 2001) and in particular efficient performance of SSC actions (Watsford et al. 2010). MTU stiffness therefore warrants a more detailed discussion. MTU stiffness is defined as the amount of tension residing in the muscle-tendon unit (Watsford et al. 2010). It indicates the relationship between joint angle and passive torque of the MTU; reducing the slope of the relationship leads to a decrease in stiffness and an increase in the end range of motion (Wilson et al. 1992; Morse et al. 2008). It is an important performance factor as a decrease in MTU stiffness should cause a slower transmission of active muscular force to passive muscular components slowing force transmission to the tendon bone insertion, causing slower limb movements (Kubo et al. 2001) and less efficient
locomotion patterns. The cytoskeleton of the sarcomere and intramuscular connective tissue constitute parallel elastic components (endomysium, perimysium, epimysium) contribute to passive tension; modification could lead to changes in MTU stiffness (Gajdosik, 2001). However, of particular importance is the tendons role in MTU stiffness as it is the tendon that transmits muscular force directly to the skeleton with minimal dispersion of energy (Screen et al. 2004), with the time to take up tendon slack linked to MTU stiffness, with less stiff MTU’s taking a longer time to real in any tendon slack and therefore delaying external movement. Static stretching seems to decrease stiffness (Wilson et al. 1992; Morse et al. 2008; paper V), which could be linked to tendon morphology.

Tendons are mainly dense connective tissue consisting of Type I collagen fibres assembled in parallel bundles responding to mechanical loading aligned along the long axis of the tendon (Franchi et al. 2007). As part of this structure there are periodic wave forms known as tendon crimps, which disappear in the direction of load when tendons are stretched (Hansen et al. 2002), possibly leading to a decrease in tendon stiffness. Interestingly, the mechanical properties of tendons are influenced by their loading history (Legerlotz et al. 2010), therefore the effect of static stretches decreasing MTU stiffness, related to decreases in performance in stretch shortening cycle tasks (Watsford et al. 2010), could be linked to changes in tendon structure, particularly in relation to changes in tendon crimps, helping to lengthen and decrease tendon stiffness. Rat studies have shown that hind limb suspension (static stretch) decreases the stiffness in the serial elastic component of muscle and therefore alters tendon structure (Canon and Goubel, 1995). It was also noted that EMG output was decreased when static stretches were employed (Marek et al. 2005). This again could be linked to decreases in tendon stiffness. A decrease in the stiffness of tendinous elements may cause lower muscle spindle involvement as spindles will experience a lower degree of muscle stretch with a more compliant tendon (Rack et al. 1983) causing a decrease in reflex actions and a dampening of the nervous
system. This will result in less efficient locomotion, particularly when a series of SSC actions are linked together.

However, when the mechanisms behind the increase in performance associated with dynamic stretches are explored different physiological changes were noted. Dynamic stretching seemed to decrease MTU stiffness to the same extent as static stretch modalities (paper V), which could lead to the same negative physiological changes, in terms of performance, as seen in static stretch interventions. However, these MTU changes seemed to be mitigated by the nervous system, possibly linked to the PAP phenomenon, where the acute contractile history of a muscle will positively influence a subsequent muscular performance. The magnitude of twitch force depends on the activation history of the muscle concerned (Enoka, 2002), with the potentiation effect linked to maximum and sub-maximum contractions (Vandervoort et al. 1983). Interestingly sub maximal activation can increase twitch force with a series of twitches in close succession, as exhibited by the dynamic movements employed in the present thesis studies, this phenomenon is known as treppe (Krarup, 1981) and may help explain the performance increases linked to dynamic stretches.

Although maximal PAP is usually linked to high intensity tasks, all skeletal muscle actions induce some level of PAP (Sale, 2004), the level of this phenomenon depends on the intensity, volume and rest period employed between the initial conditioning exercise and the performance task employed (commonly referred to as complex training). Rassier & MacIntosh (2000) explain PAP as a balance between fatigue and neuromuscular excitation. If the preconditioning exercise is of a low intensity then little fatigue will be caused, but also little excitation; as you increase exercise intensity than excitation will increase, but so will fatigue. This is due to increased intensity actions recruiting greater numbers of type IIa and type IIx motor units, linked to increases in high force, high velocity actions (Siff, 2003), but also associated with greater fatigue then type I motor units (Martini, 2006). Therefore, PAP and fatigue coexist, both
will peak immediately post any conditioning exercise, with the effects of each fading over time; increases in the performance task are linked to when fatigue has diminished to a greater extent than potentiation, leaving the muscle primed for subsequent performance. The dynamic stretches used in the presented papers seem to cause bigger increases in performance when they are more intense, by either increasing contraction velocity (paper VI) or increasing ground contact force in a SSC action, by using moving dynamic stretches (paper I and II) compared to stationary dynamic stretches. It appears that this level of intensity causes excitation, but because of the rest periods between each individual stretch component used in these papers methods, any fatigue associated with PAP has time to be dissipated throughout the muscles being utilised in the dynamic stretches.

Two major mechanisms have been put forward to explain the PAP effect. In the past mechanistic data has been looked at only sporadically, despite this, most researchers suggest that phosphorylation of the myosin regulatory light chains (MRLC) (Chui et al. 2006; Comyns et al. 2006; Batista et al. 2007), or enhanced neuromuscular excitation (Gullich & Schmidtleicher, 1995; Tubman et al. 1996; Trimble & Harp, 1998; Esformes et al. 2010) are the reasons behind a pre-conditioning exercise, causing a post performance exercise to be enhanced. Phosphorylation of the MRLC is unlikely to be the cause of performance changes linked to the dynamic stretches performed in papers I, II, IV, V and VI. Phosphorylation of the MRLC is linked to very high intensity and most often isometric contractions (Chatzopoulos et al. 2007; Tillin & Bishop, 2009; Esformes et al. 2011). This is because these exercise modalities are slow enough to allow a high percentage of motor units, and therefore muscle fibres, to be recruited. As a high percentage of muscle fibres are recruited, a greater propensity exists for phosphorylation of the MRLC in the active component of muscle to be triggered, therefore leading to increases in performance post exercise (Tillin & Bishop, 2009).
However, the idea of enhanced neuromuscular excitation may be a more fruitful avenue of research in terms of dynamic stretches. Gullich & Schmidtbleicher (1995) proposed that, in a complex training situation, the conditioning exercise stimulates the afferent nerves, activating the adjacent α-motor neurons, elevating the transmission of excitation potentials across the synaptic junction at the spinal level allowing a consequent performance exercise to benefit from increased post-synaptic potentials, for the same pre-synaptic potential. This causes an improvement in the RFD and therefore can lead to an increase in performance, linked to the dynamic stretch component of an active warm-up. Paper V certainly found an increase in peak torque and a decrease in time to peak torque, in its dynamic stretch intervention; indicating an increase in RFD, which would help explain increases in performance associated with dynamic stretch protocols and help support Gullich & Schmidtbleicher’s (1995) proposal.

Further, Tillin & Bishop (2009) hypothesised that dynamic exercise used as a pre-conditioning modality (such as dynamic stretches) induces PAP through the eccentric phase of an action by increasing the firing of the muscle spindles. This activates the Ia neural fibres enhancing the afferent neural volley at the spinal level. Transmission failure from the Ia neural fibres decreases, allowing bordering α-motor neurons to cause an enhanced recruitment of higher order (type II) motor units in the post conditioning performance exercise. The findings from the papers presented in this thesis, seem to support this excitation proposal. Paper VI’s results indicated that faster dynamic stretches exhibited greater EMG output, when compared to no stretch and slower dynamic stretch conditions. While paper I and II showed superior performance after moving dynamic stretches were employed, compared to stationary dynamic stretches. This would support Tillin & Bishop’s (2009) ideas behind the importance of the eccentric phase of a conditioning exercise, increasing muscle spindle sensitivity and raising spinal excitability of the α-motor neurons. It seems that the dynamic stretches, employed in this thesis, with the biggest effect on performance, are also the movements with the highest intensity and the most pronounced
eccentric component, making neuromuscular excitation through the PAP phenomenon a realistic mechanism behind the increases in performance associated with dynamic stretch components of a warm-up.

Therefore, it can be concluded that the more intense and specific the dynamic stretch, particularly in terms of an enhanced eccentric component in a SSC action, the more likely the dynamic stretch modality will help increase subsequent performance.

It should be noted that there is evidence that MTU stiffness determines the shock absorption characteristics of an individual system, such as a leg (Watsford et al. 2010), where a stiffer MTU is less able to attenuate applied forces in ground contact during running, jumping, stopping and changing direction, all actions associated with sports performance. This may lead to a greater susceptibility to soft tissue injury (McHugh et al. 1999; Granata et al. 2002), as external forces are absorbed more quickly then with a soft MTU leading to greater trauma applied to musculo tendinous tissue. This may have lead to the common belief that static stretching may help prevent injuries if used as part of an active warm-up. However if dynamic stretching has a similar effect on decreasing MTU stiffness, but has none of the negative effects on performance associated with static stretching, not only can performance be enhanced, but a degree of injury prevention could also be linked to dynamic stretches implementation. This is a speculative assumption, but warrants further study in the future.

It should be noted that a detailed discussion of the presented papers limitations and proposed future work, to further establish the exact mechanisms behind these findings, can be found in appendix 2.
1.6 Statistical Methods Employed

The general statistical methods employed in the studies used to form this thesis were based on the recommendations of Thomas and Nelson (1996) and Field (2000).

Initially sample size was estimated using a priori power analysis based on past literature findings, published in the area of the effect of static stretching on performance (Cornwell et al. 2001; Young & Elliot, 2001). This was through the statistical programme G*Power2 (Erdfelder et al. 1996), which allows an estimate of the sample size required to produce an appropriate data set for statistical analysis. Papers I, II and III also employed a post sample size estimate (Hopkins, 2000) because paper I employed an independent group’s design, while paper II and III had comparatively small sample sizes.

Reliability of measures was estimated using coefficient of variation and/or intraclass correlation coefficient. This was to assure that the performance measures employed in the series of papers was reliable and therefore sensitive enough to represent the changes in human performance shown in these studies. This made any problems with Type I errors occurring in statistically significant data less likely. Appropriate statistical tests were chosen only after the normality of data distribution was assessed. A Shapiro-Wilks test for normality was employed, as the number of subjects was <50; if the alpha level was above 0.05 then data were considered to be normally distributed.

Generally, the performance tests employed within these studies, involved the repeated measures of multiple tests and their potential interaction effects. These effects were statistically explored through exploring the main effects and main interactions first, before using post hoc analysis to examine the simple effects and interactions between individual variables. This would indicate what has caused the performance changes demonstrated in the papers used in this thesis.
Alpha levels were reported in each paper, to indicate which findings were statistically significant, this value was supported by reporting effect sizes; designed to explore the interventions effect in light of the error associated with that effect, to produce an idea of what the actual effect of an intervention may be (Erdfelder et al. 1996). Effect size was determined using partial $\eta^2$. This is recommended for repeated measures designs that have dependant cells, or dependant repeated measures designs (Thompson, 2006; Brown, 2008), which is the design of the studies in this thesis. Partial $\eta^2$ shows the percentage variance in each effect or interaction and its associated error that is accounted for by that effect or interaction. Effect size values were interpreted as $>0.2$ (small effect), $>0.5$ (moderate effect), $>0.8$ (large effect), from Cohen (1988).
CHAPTER 4

4.0 PAPER III
CHAPTER 5

5.0 PAPER IV
CHAPTER 6

6.0 PAPER V
CHAPTER 7

7.0 PAPER VI
CHAPTER 8

8.0 Thesis Impact and Recommendations
8.1 Thesis Impact

The impact of the research articles, forming the basis of this thesis, were assessed through a computer search engine (Harzing, 2007), which systematically searches academic citations available on Google Scholar.

Paper I was cited 132 times in a range of different peer reviewed journals. Applied sport science journals such as the Journal of Strength and Conditioning Research and Journal of Sports Medicine and Physical Fitness and higher impact factor applied human physiology journals such as European Journal of Applied Physiology and Journal of Science and Medicine in Sport were the major contributors to the list of citing publications. However, a number of medical based journals such as Athletic Therapy Today, Musculoskeletal Disorders, Current Sports Medicine Reports and International Journal of Sports Medicine were also in the list of publications citing paper I. These articles were mostly original reports, with some meta analysis papers (such as Behm and Chaouachi, 2011). None of these papers showed an increase in performance from static stretching, with most of the findings supporting paper I’s findings of a decrease in performance after static stretching and an increase in performance after dynamic stretch conditions compared to static stretch modalities This is exemplified by Little and Williams (2006), who found an increase in high speed performance after dynamic stretching, and Brandenburg (2006) who found that even short duration static stretches decreased force production. While, Winchester et al. (2008) found that sprint performance was decreased if static stretching was performed following an active warm-up.

Paper II was cited 61 times in similar journals to those citing Paper I. Applied performance and physiology journal titles such as the Journal of Strength and Conditioning Research and European Journal of Applied Physiology were represented, with sports medicine journals such as Medicine and Science in Sports and Exercise, Journal of Physical Therapy Science and Musculoskeletal Disorders also included in the list of publications. Meta analysis and original
papers were represented, with the majority of the citing works findings being similar to paper II’s. Interestingly, very few studies citing this paper actually combined static and dynamic stretches, which could be an important area of research, considering this has long been a traditional warm-up strategy in many sports. Of the studies that did combine stretch regimes, it seems the second dynamic bout of stretching does not reverse the negative effects of the static stretch component of the warm-up (Pearce et al. 2009), mirroring the findings from paper II.

Objective 1 of this thesis was linked to paper I, II and IV, and involved exploring the effect of active warm-up, static and dynamic stretches on performance of sport specific actions. These papers findings show the superiority of dynamic stretches in promoting acute performance, this conclusion is supported by the majority of papers citing these publications, with no paper finding static stretches as superior to dynamic stretches as part of a warm-up regime.

Paper III was cited 2 times, both in the Journal of Strength and Conditioning Research. Arroyo-Morales et al. (2011) looked at pre event massage, concluding that it negatively affected subsequent muscle performance. None of these papers found evidence that massage helps in increasing acute performance, agreeing with the conclusions of paper III.

Objective 2 was to investigate the effect of pre-competition massages effect on acute performance, the general finding of a decrease in acute performance has been born out by all the papers citing this research, helping to question massages efficacy as a pre-performance preparation strategy.

Paper IV has only been cited once, and that was in a book chapter entitled warm-up recommendations (Cardonale, 2011). The chapter supports the use of dynamic stretches over static stretch dominated warm-ups, using paper IVs findings to help support this premise. Interestingly, paper IV has not been
included in a recent meta analysis paper on static stretching (published in Medicine and Science in Sports and Exercise), though it fulfils the papers criteria for inclusion and supports many of the papers conclusions.

Paper V has been cited 6 times, all in high impact factor journals (lowest impact factor 1.93) including the Journal of Strength and Conditioning Research, Physiology Nutrition and Metabolism, European Journal of Applied Physiology and Medicine and Science in Sports and Exercise. These articles seem to support paper V conclusion, of dynamic stretches superiority in enhancing performance when compared to static stretch preparation strategies. Turki et al. (2011) cites paper V to support their work indicating that 10 minutes of dynamic stretching potentiates the neuromuscular system to produce increases in vertical jump height; indicating very similar findings to paper V.

Objective 3 was linked to paper IV and V. It aimed to investigate the potential mechanisms behind changes in performance linked to static and dynamic stretches. Though papers citing these articles support the superiority of dynamic stretches compared to static stretches, they fail to explore the mechanisms fully. Measures of muscle function or performance are used, with simple measures, such as heart rate, while EMG and kinematic analysis of movements are only utilised as methods to look at mechanisms in a limited number of papers.

Paper VI has been cited 4 times in the following journals, Research in Sports Medicine, Journal of Strength and Conditioning Research and European Journal of Applied Physiology. The articles broadly support the use of dynamic stretches as part of a warm-up strategy, though interestingly none look at the effect of stretch velocity as paper VI does. However, paper VI has been misused in support of an injury prevention paper. Stojanovic and Sergej (2011) use the increase in core temperature findings from paper VI as an example of this type of stretching helping injury prevention, but they state that this is an example of ballistic stretching. Stojanovic and Sergei (2011) seem not to understand the
fundamental difference between ballistic and dynamic stretching, (repetitive bounces at the end range of a muscle, ballistic, and controlled movement through the full active range, dynamic) which could be dangerous as they seem to suggest that ballistic stretching has a role to play in injury prevention, when in fact it is dynamic stretching they should be espousing.

Objective 4 was based on paper VI’s findings. It was designed to explore the effect dynamic stretch velocity has on acute performance. Papers citing this article support dynamic stretches efficacy as a pre-competition preparation strategy, but none examine the effect that changing dynamic stretch velocity may have on performance.

This series of papers has helped inform practice in sport and exercise pre-competition recommendations. In general practitioners are moving away from the use of static stretches as part of a preparation strategy towards a more dynamic approach. Organisations such as Sports Coach UK and the United Kingdom Strength and Conditioning Association now endorse the use of dynamic stretches as a preparation strategy, this is used in their published literature and in the workshops they provide for coach education. Importantly, the latest American College of Sports Medicine (ACSM) position stand (Garber et al. 2011) (seen as the leading authority on exercise prescription recommendations); recommends that dynamic warm-up routines should be carried out instead of static stretches, if the aim is to maximise acute performance; this is due to the evidence of static stretches decreasing performance and dynamic stretches helping increase acute performance. The present thesis papers are not expressly cited, but the meta analysis paper used to come to the ACSM’s conclusions on warm-up practices does cite paper I and II (McHugh and Cosgrave, 2010).

The papers forming this thesis have been cited widely; from peer reviewed academic papers through to book chapters and sports governing body
publications. They have helped to inform both research and brought about a change in recommendations by organisations involved with participation in sport and exercise practice.

8.2 Practical Application
The findings from this series of papers would suggest the following recommendations, with regards to athletes and coaches employing the best warm-up strategy, to optimise maximal acute performance. Firstly, an active warm-up, such as a sub maximal jog, should be employed, before incorporating specific moving dynamic stretches. These stretches should invoke a SSC action, performed at a relatively fast velocity, before performing any maximal training or competition related activity. It appears that a traditional active warm-up process, which uses a static stretch component, either with or without a final dynamic stretch exercise, does not promote an optimal post preparation performance, as this has been linked to a significant decrease in a range of performance parameters, when compared to a dynamic stretch dominated preparation strategy. While the inclusion of pre-performance massage seems to have no benefit in terms of increasing acute maximal sprint performance, though not detrimental when combined with an active warm-up, it does not seem to further increase performance. Therefore massage may be viewed as a waste of an athlete’s time, when more beneficial strategies, such as dynamic stretches, could be used, if aiming to increase an acute maximal performance task.
References


Appendix 1

List of works on which the candidature is to be based


Appendix 2

Limitations and Future Work

Limitations
The contribution of this series of papers to the advancement of this field of study has been highlighted within the introduction and in particular within the discussion of the thesis objectives. However, the findings from the series of publications put forward for this thesis, need to be viewed in the light of their methodological limitations in order to understand their reliability and validity, in terms of explaining the actual effect on performance of the interventions, which have been chosen to be explored. With this in mind, this subsection will also explore the delimitations of the submitted studies to ensure what applicability the findings have to sport and exercise populations and provide some ideas for future work to be based upon.

Paper I
Paper 1 was the first ecologically valid study to explore the effects of both passive and active static stretches and stationary and moving dynamic stretches in a field based study. It utilised a large number of trained athletes as part of its design, however one of the main limitations of the study is that it is an independent groups design. The original study was to be a dependent repeated measures design, but this was changed because of the large number of subjects used (n=97), from a number of different rugby clubs, leading to a large drop out rate. This resulted in different group sizes for the different interventions, were pre and post differences in sprint times could be analysed, but any interaction between interventions could not be explored. The stretches employed were demonstrated to and practised by subjects, with the hold time and number of repetitions controlled and standardised. However, the actual intensity of the static stretches and the speed of the dynamic stretches were left up to individuals, causing some difficulty in comparing interventions. This was further
born out in light of paper VI’s findings in terms of the superiority of faster dynamic stretches causing greater increases in performance.

Importantly, no mechanistic data was collected, due to the difficulty of collecting physiological data for a large field study. It was felt that isolating the actual effect on performance of the different interventions should take priority in this initial study, therefore physiological changes that subjects experienced can only be assumed.

The studies findings are applicable to trained, but not elite level athletes. While a large cohort was studied, it was a male only subset performing only a straight line short distance sprint. The effect of the chosen interventions on other performance variables important to rugby players can only be theorised.

**Paper II**

Paper II was the first study to explore the effect of combining static and dynamic stretch modalities in a preparation strategy, making this an important study in exploring what is seen as a normal preparation strategy for many athletes. Subjects in much of the past work in this area have been categorised as recreational, paper II studied a group of highly trained individuals, classed as sub elite to elite level, however because of this a comparatively small group was recruited. The sample size estimate of 16 was higher than the group’s n (10 for males and 8 for females) therefore the findings need to be viewed with this caution. The interventions chosen to be tested were compared against the athlete’s usual warm-up regime, however it was not possible to explore the effect of an active warm-up alone due to the athlete volunteers and their coaches being unwilling to sprint without a stretch component, of some sort, being employed as part of the preparation strategy, due to the belief that removing a stretch component would lead to an increase in injury likelihood. This is particularly important as the active warm-up (800m jog) was not standardised, but left to the individuals to judge the running intensity, as changes in warm-up intensity can
effect subsequent performance (Bishop, 2003). This is a confounding factor in relation to the finding in paper II. The stretch interventions employed were only partially controlled; with the hold time for static stretches and number of repetitions for the dynamic stretches standardised. Static stretch intensity and dynamic stretch velocity were individualised and should be treated as a confounding variable in the same way as paper I’s findings.

Paper II’s findings are applicable to male and female sprint athletes, but can not be broadened to other sports performers because of the specialised equipment used, spiked running shoes, starting blocks and tartan running surface and the linear nature of the performance test chosen. Mechanisms behind performance changes were not explored; this was in order to allow a more naturalistic performance for subjects, in an attempt to explore what the actual effect on a specific performance parameter might be, rather then introduce confounding factors such as taking heart rate or core temperature, which could have affected performance.

Paper III

Paper III was the first study to explore the effect of massage on sprint performance, helping refute many unsubstantiated claims made by massage practitioners. However, limitations in the study design do exist. Though the same type and application time of massage was used by the same therapist, the description of pressure used being light to medium, could lead to a level of human error in terms of the therapist’s understanding and application of the terminology. Though the therapist tried to perform the same pressure to subject’s muscles on each massage intervention, this can not be guaranteed. It was also not possible to isolate the effect of the massage completely, because in the pilot work, subjects refused to perform sprints to any degree of intensity, without doing some sort of running exercise prior to the 20m sprint test. Therefore, the 4 x 20m strides were included into all the preparation strategies (an activity all the subjects said they would usually do before any maximum effort
running action), however these runs were self paced, and though subjects were asked to do the same pace strides for each intervention, this can not be guaranteed. The possibility that any increase in stride velocity from one intervention to the next could cause an increase in the warm-up intensity, potentially positively effecting subsequent sprint performance, can not be discounted. The traditional active warm-up employed in this study involved the use of static passive stretching, even though the first two studies showed a decrease in performance when this type of intervention was used. However, this warm-up was similar to the pre-performance preparation that subjects habitually utilised. It was felt that changing the active warm-up to something subjects were not used to may have introduced a confounding variable that could have potentially masked the effect of the massage interventions chosen to be studied.

Mechanism behind performance changes were explored, however the variables examined had some limitations associated with their collection. It could have been insightful to have collected EMG and kinetic data, to see the effect massage might have had on the nervous system and the subsequent amount of force that could be produced, but the equipment needed for this type of analysis was not available. Therefore, core temperature and kinematic changes were examined to view potential physiological mechanisms. The core temperature method chosen was aural, which, though convenient and relatively non invasive, can be criticised in terms of its accuracy when compared to rectal and oesophageal measures (Moran and Mendal, 2002). It may have been more insightful to have used heart rate, as a better indicator of global changes to the human system (as used in papers IV, V and VI). Kinematic variables were recorded in two dimensions, due to the relatively single plane action of a 20m straight line sprint. A manual digitisation process was used, although, automated systems have been shown to have greater accuracy and reliability (Yeadon and Chalis, 1994). However this equipment was not available.
Paper III's findings are only applicable to males, though they do encompass a cohort that is trained, though not elite, and applicable to a range of team based multi sprint sports. However, only straight line sprinting was analysed, and therefore the effect of these interventions on other team sport performance indicators, such as jumping, changing direction or repeated sprint ability remains unknown.

**Paper IV**

Paper IV was only the second study to explore the effect of static stretches on soccer specific movements, and the first to examine dynamic stretches, it therefore broadens the range of performers and athletic movements that have been used in this field of study. However, the active warm-up chosen was a self selected 5 minute jog. Although each subject reproduced the same distance in each intervention, different subjects ran different distances at different relative intensities; this may be a confounding variable, which could have had an impact on this papers findings. The stretch protocols used in this study consisted of lower body static and dynamic stretches only. However, some of the performance tests, namely, sprint and agility had a degree of upper body involvement. The effect of including upper body stretches is unknown; their inclusion could have lead to different results being found. The design of the experiment could have been altered to explore differences within interventions. Subjects were disinclined to perform maximally prior to an active warm-up, but it could have been possible to perform the capacity tests post active warm-up and then post stretch component, to try to isolate the effect of the stretches chosen. However, it was felt that performing these tests prior to the stretch component could have raised the intensity of the warm-up beyond the player’s normal warm-up intensity and have provided a specific rehearsal of the chosen tests, possibly priming the body to perform at a greater rate in the post stretch tests. The within interventions effects are explored in a far more structured way in paper VI.
The main limitation of this paper is that the physiological mechanisms behind the performance changes linked to the stretch modalities is only explored superficially, using heart rate measures to explore the relative intensity of each preparation strategy. The detailed effects on the core temperature, neuromuscular system, kinetic and kinematic parameters are only alluded to, while paper V is designed to explore the mechanistic aspects of performance to a much greater degree.

Paper IV’s findings are of particular interest to football players, but the cohort is all male and of a semi professional standard, therefore the effect on elite and female players is unknown. Though a range of football specific performance parameters were tested; the interventions chosen examined only their effect on maximum acute performance. The player’s ability to produce repeated high intensity bursts of activity was not explored. The ability to repeat high intensity actions for a whole football match is vital for players (Hoff, 2005; Svensson and Drust, 2005), but no study, including this one, has explored the effects of dynamic stretching on repeated performance tasks.

**Paper V**

Paper V was the first study to explore the physiological changes linked to dynamic stretches and compare them to changes linked to static stretches, in particular the effect on EMG, as an indicator of neuromuscular activity, is important within this field of study. However, the warm-up strategies chosen for exploration within paper V do have some limitations associated with them. The active warm-up component was a self selected jog on a treadmill, with the treadmill velocity repeated for each intervention. However, the velocities that were used by subjects ranged from 7-10 km·h⁻¹, indicating that active warm-up intensity could have been different for individual subjects, though specific to their preferred warm-up running velocity, the differing intensities could have effected the findings outlined within the paper. The static stretches chosen were held at a ‘point of mild discomfort’, with subjects informed that this intensity should be what
they would normally experience in their own normal warm-up sessions. This could have led to a range of stretch intensities being used which could have lead to different neuromuscular responses for each subject. There is evidence that stretch intensity effects range of motion (Fletcher, 2009), but whether this will have a subsequent effect on performance has not been established. The dynamic stretches chosen can also be criticised. Due to laboratory restrictions stationary dynamic stretches were utilised, these have been shown to have less of an effect on performance (paper I and II). Therefore, differences between static and dynamic stretch mechanisms behind performance changes are limited to in situ stretches.

The methods used for exploring mechanistic data have some limitations. The kinematic data was explored at only 50Hz using a manual digitising system. If the equipment was available, a sampling rate of 100Hz, with an automatic digitisation system, would be preferable (Yeadon and Challis, 1994). Knee peak torque was measured isokinetically, similar to a number of past studies (Kokkonen et al. 1998; Behm et al. 2001; Nelson and Kokkonen, 2001). However, it is generally recommended (Murphy and Wilson, 1997) that training studies should be based around performance changes, such as the jump heights recorded in this paper, and not changes in muscle function scores. Peak torque measurements are generally thought to be a reliable measure of muscle function, as long as strict experimental parameters are observed in the isokinetic test (Baltzopoulos, 1997). The isokinetic test was designed to stabilise limbs to isolate specific muscle actions and help to decrease cable artefact in the EMG analysis, but the effect on peak force production in a more valid performance test such as a 1 repetition squat test would be interesting to explore. The EMG equipment used passive electrodes to detect muscle activity, it is recommended that active electrodes are more reliable and less prone to cable artefact and waveform distortion (Burdon, 2008), this equipment was not available at the time, but would be recommended in future studies and was utilised in paper VI.
Paper V was designed to start to explore mechanisms behind the changes in performance that previous papers (I, II and IV) have documented; with this in mind its findings are less applicable to a particular sporting group. However, the findings from paper V do support the general findings that have been detailed in the initial papers more sport specific performance tests.

**Paper VI**

Paper VI was the first study to explore what effect stretch velocity may have in terms of promoting performance increases. However, stationary dynamic stretches were chosen for this study, despite the evidence (paper I and II) that moving dynamic stretches caused a bigger increase in performance. This was because in pilot work it was found that only in situ stretches could be reproduced at the required set velocity reliably. Subjects found it too difficult to co-ordinate forward movement and the dynamic stretch movements at an appropriate rate, through the designated active ROM, but found it fairly easy to keep to the metronome beat when stationary.

Jump height was assessed using a jump mat, though this is a reliable method of measuring performance, if available, a force plate analysis would have given an insight into kinetic aspects such as force and impulse, which this paper can only allude to. Tympanic temperature was again used to measure core temperature (similar to paper V), though criticised in paper III, it was felt that the drawback of using more time consuming invasive methods could effect the performance tasks negatively. It would be a useful study to fully explore not only core temperature, but muscle temperature changes with different warm-up modalities; however this was beyond the scope of the present study.

The use of knee movement in the jumps was used to predict MTU stiffness (similar to paper V). This method can measure functional stiffness (Knudson et al. 2001), when a whole limbs response to a given movement is assessed. However, functional stiffness does not differentiate between active and passive
structures in a movement. This was beyond the scope of these studies due to a lack of appropriate equipment, would be interesting to explore in the future. An examination of the effects of different preparation strategies on the stiffness of the different components which make up functional stiffness would be insightful, particularly with regards to joint and tendon stiffness. Therefore, this paper indicates the effects of dynamic stretches on the whole body’s reaction to mitigating knee ROM in a CMJ and DJ; it would be useful in a future study to explore the effects of different preparation strategies tendon and joint stiffness as well as, MTU stiffness, because of their importance in any performance requiring rapid SSC actions (Kubo et al. 2001).

Paper VI’s findings are limited to male games players, a criticism for a number of the papers presented (I, III, IV and V). Future studies should attempt to explore if the same patterns of response are found in female and elite performers, as well as in different performance tasks. The findings are also only applicable to the two chosen velocities of movement, the optimal stretch velocity has not been established, it may be between 50 and 100 b/min. or found at even faster movement velocities. Most of the performance tasks presented in this group of papers have involved a SSC action, in a rapid maximal intensity motor capability. Would the same results be found in different modes of exercise with out a SSC, such as cycling or rowing, or in slower actions linked to more anaerobic or aerobic endurance activities? These are aspects of performance which warrant in depth study in later papers.

Future Work
A number of mechanisms have been linked to the effects of static and dynamic stretches. The following section outlines potential ways to explore these mechanisms in more detail to ascertain which mechanisms are most important when explaining the negative effects of static stretches and the positive effects of dynamic stretches.
Effects of Muscle Temperature
The presented studies have looked at core temperature, but it would be interesting to explore whether muscle temperature is a more important factor. Both active and passive warming strategies could be examined to see if it is the actual warming of muscle (passive) or the movement used to cause temperature rise (active) that is behind performance changes. This could be done in vivo with a muscle temperature probe used to ascertain increases in muscle temperature, to find the optimum temperature range. Interestingly, in vitro work could be even more insightful, as changes in temperature can be carefully controlled and muscle fibre performance isolated from nervous system. This might help answer the question, do temperature increases help muscle fibre contraction through ATP turnover, or have a more global effect on stimulating the nervous system to cause increases in velocity of shortening.

Musculo-Tendinous Stiffness
MTU stiffness is an important contributor to locomotion efficiency and needs to be thoroughly explored in terms of the effects of different preparation strategies, in order to start to explain what effect different stretch modalities have on performance. There are a number of different tests for MTU stiffness, designed to measure different structures, which make up the MTU system.

Stiffness of passive structures can be isolated by measuring tendon and joint stiffness. Tendon stiffness can be measured by applying a ramped isometric force over a 3-4 second period, to a maximal contraction, to a joint in a fixed position. Ultrasonography can then be used to measure changes in tendon length during the isometric contraction, to construct a force-elongation curve. The gradient of this curve records force per mm of tendon movement and therefore tendon stiffness (Reeves, 2006). Ultrasonography can also be used to measure tendon dimensions, to yield tendon Youngs modulus, allowing data to be normalized and therefore intra and inter tendon comparisons to be made (Reeve, 2006).
Joint stiffness can be measured through isokinetic dynamometry. The dynamometer is set to move a limb, isolating a joint, at a set angular velocity, measuring the torque angle relationship. The speed force is detected will indicate resistance to the dynamometer and a measure of joint stiffness (Stein and Thompson, 2006).

A global measure of functional/system stiffness, were passive and active stiffness is combined in performing a task, is vital to ascertain how preparation tasks effect whole limb stiffness. This can be measured when the whole body is released from a height and needs to land, dissipate ground reaction forces and try to reverse the direction of movement. This will also look at a SSC action and give an indication of efficiency. Tests such as 2 legged bounce jumps on a force plate (Korff et al. 2009), were functional stiffness is calculated as the subjects body mass multiplied by the resonant frequency of the bounce jumps. Interestingly, by using a force plate than ground contact time, force output, rate of force development and impulse can be measured, if used in conjunction with electrogonimeters, measures of joint angle and velocity can be synchronised to force plate data. This will lead to a measure of change in force per change in leg length, functional stiffness, and also explore changes in force for individual joint movements, joint stiffness.

**Measurement of Post-Activation Potentiation**

The two main mechanisms put forward to explain the PAP phenomenon, are Phosphorylation of the Myosin Regulatory Light Chains or neuromuscular excitation. The neuromuscular excitation model can be further explored using EMG measures of specific performance tasks pre and post conditioning exercises, similar to the EMG methods employed in this thesis. To explore the myosin regulatory light chain theory the use of muscle biopsies pre and post conditioning exercise would need to be employed. Combining these two methods should allow a more insightful examination of PAP.
Appendix 3

Stretches Performed as part of this Thesis

Paper I
Passive Static Stretches

Fig. 1 Gluteal Stretch

Fig. 2 Hamstring Stretch

Fig. 3 Quadriceps

Fig. 4 Adductors
Fig. 5 Hip Flexors

Fig. 6 Gastrocnemii

Fig. 7 Solei Stretch
Active Dynamic Stretches

Fig. 8 High Knees

Fig. 9 Flick Backs

Fig. 10 Hip Roles

Fig. 11 Running Cycles

Fig. 12 Straight Leg Skipping
Active Static Stretches

Fig. 13 Gluteals

Fig. 14 Hamstrings

Fig. 15 Quadriceps

Fig. 16 Adductors
Paper II

Active Dynamic Stretches
Straight Leg Skipping, Walking High Knees, Skipping High Knees, Running High Knees Flick Backs (See paper I)

Static (Stationary) Dynamic Stretches
Standing Flick Backs, Standing High Knee Raises (See Paper I)

Fig. 20 Seated Plantar/Dorsi Flexions

Fig. 21 Standing Straight Leg Raises
Static Passive Stretches
Standing Quadriceps Stretch, Gluteal Stretch

Fig. 22 Gastrocnemius Stretch  Fig. 23 Hamstring Stretch

Fig. 24 Hip Flexor Stretch
Paper III

Static Passive Stretches
Gastrocnemius, Hamstrings, Quadriceps (See Paper I)

Fig. 25 Tibialis Anterior

Paper IV

Static Stretches
Hamstrings, Quadriceps, Adductors, Gluteus Maximus, Hip Flexors, Gastrocnemius, Solei (See Paper I)

Fig. 26 Abductors
Dynamic Stretches
Heel Flicks, High Knees, Hip Roles, Straight Leg Skipping (See Paper I)

Fig. 27 Walking on Toes

Fig. 28 Walking Lunges
Paper V

Static Passive Stretches
Hamstrings, Quadriceps, Abductors, Adductors, Gluteus Maximus, Hip Flexors, Gastocnemius, Solei (See Paper IV)

Static (Stationary) Dynamic Stretches
Heel Flicks, High Knees, Hip Roles, Straight Leg Skipping, Lunges (See Paper IV)

Fig. 29 Calf Raises
Paper VI

Dynamic Stretches
Forward Lunge (See Paper IV), High Knees, Heel Flicks (See Paper I)

Fig. 30 90° Squat

Fig. 31 Sit Ups

Fig. 32 Forward Leg Swings
Fig. 33 Side Leg Swings

Fig. 34 Ankle Dorsi/Plantar Flexors
Appendix 4

Location and Date of Work
THE EFFECT OF DIFFERENT WARM-UP STRETCH PROTOCOLS ON 20 METER SPRINT PERFORMANCE IN TRAINED RUGBY UNION PLAYERS

IAIN M. FLETCHER AND BETHAN JONES

Exercise Physiology Laboratory, University of Luton, Luton, Bedfordshire, UK.

ABSTRACT. Fletcher, I.M., and B. Jones. The effect of different warm-up stretch protocols on 20-m sprint performance in trained rugby union players. J. Strength Cond. Res. 18(4):000-000. 2004.—The purpose of this study was to determine the effect of different static and dynamic stretch protocols on 20-m sprint performance. The 97 male rugby union players were assigned randomly to 4 groups: passive static stretch (PSS; n = 28), active dynamic stretch (ADS; n = 22), active static stretch (ASST; n = 24), and static dynamic stretch (SDS; n = 23). All groups performed a standard 10-minute jog warm-up, followed by two 20-m sprints. The 20-m sprints were then repeated after subjects had performed different stretch protocols. The PSS and ASST groups had a significant increase in sprint time (p < 0.05), while the ADS group had a significant decrease in sprint time (p < 0.05). The decrease in sprint time, observed in the SDS group, was found to be nonsignificant (p ≥ 0.05). The decrease in performance for the 2 static stretch groups was attributed to an increase in the musculotendinous unit (MTU) compliance, leading to a decrease in the MTU ability to store elastic energy in its eccentric phase. The reason why the ADS group improved performance is less clear, but could be linked to the rehearsal of specific movement patterns, which may help increase coordination of subsequent movement. It was concluded that static stretching as part of a warm-up may decrease short sprint performance, whereas dynamic stretching seems to increase 20-m sprint performance.

KEY WORDS. dynamic stretching, static stretching, musculotendinous unit compliance, coordination

INTRODUCTION

Traditionally, athletes have achieved peak performance goals through long-term structured training schedules. Investigations have observed a variety of methods for optimizing training protocols, from increasing strength to improving aerobic endurance. However, until recently, little work has been done on one of the most fundamental parts of training: the stretch component of warm-up.

The “active” component of a warm-up, designed to increase core temperature, blood flow, and prepare the body for exercise, has long been shown to benefit performance (3, 4, 10, 20). However, less is known about the traditional Western warm-up model, and particularly the passive stretches used as part of the warm-up process. Recent research has highlighted that far from helping athletes, passive stretching may inhibit performance by reducing power output (1, 2, 5, 7, 12, 19, 22, 24). The most widely held rationale for this decrement in performance is that passive stretching causes the musculotendinous unit (MTU) to become more compliant, reducing force development by decreasing MTU stiffness (1, 7). This reduction in MTU stiffness leads to acute neural inhibition and a decrease in the neural drive to muscles, resulting in a reduction in power output (1, 11, 13, 19).

These results have led, not surprisingly, to a great deal of interest from coaches, athletes, and sport scientists. However, there appears to be some issues with much of this research when its ecological validity, in terms of practical sports application, is examined. The length stretches are held (ranging from 90 seconds per muscle [12, 17] up to 1 hour [1]) are unlikely to be used by athletes in preparation for competition (where typical stretch routines last no more than 10–15 seconds per muscle group).

The methods of determining power output in studies investigating this area have usually involved maximum voluntary contraction of isolated muscle groups, including maximum knee flexion/extension (2, 12, 17) or plantar flexion (1, 7). However, the ability of tests of muscular function to reflect changes in performance are severely limited (16). It is recommended that the effect of interventions or training should be based on changes in performance, rather than changes in test scores of muscle function (16). Therefore, it is the apparent decrease in power output reported in these studies applicable to the multi-joint, coordinated actions that many athletes perform as part of their sports.

Despite the obvious difficulties of applying much of the research on passive stretching and its effect on sport preparation strategies, many athletes have moved away from the static passive approach to the warm-up in favor of dynamic stretching (defined by this author as a controlled movement through the active range of motion for each joint). This should not be confused with ballistic stretching (repeated small bounces at the end range of movement), which is linked to muscle damage and shortening (18). However, despite the increasing popularity of dynamic stretching, very little research has been done on its effects as part of a warm-up prior to performance.

The aim of this study was to investigate the effect of static and dynamic stretch protocols on the performance of a sport-specific action (20-m sprint running performance) in amateur rugby union players.

METHODS

Experimental Approach to the Problem

Four different stretch protocols (passive static, active dynamic, active static, and static dynamic) were performed in an independent groups design. Time over 20-m was recorded in a pre- and poststretch intervention.

Each group performed a standard pulse-raising activity followed by two 20-m sprints. A set stretch protocol
was carried out followed by a repeat of the two 20-m sprints.

Reliability of the 20-m sprint measure was assessed using a coefficient of variation and an intraclass correlation coefficient on pretest measures. A good level of reliability was observed, with a mean coefficient of variation of 1.7% and an intraclass correlation coefficient of 0.94 between the 2 sprint times.

Subjects

The 97 male rugby union players were recruited from local amateur clubs. Subjects had participated in regular training programs and had been playing rugby union for at least 1 year. Subjects' age, height and body mass were 23 ± 8.4 years, 181 ± 8 cm and 86.5 ± 14.4 kg (mean ± SD, respectively). The procedures used were approved by a Departmental Committee for Ethics. Subjects were required to read a health questionnaire, complete it, and sign an informed consent document.

Sample size was estimated by Eq. 1, (8)

\[ n = \frac{8s^2}{d^2} \]

where \( s \) = typical error and \( d \) = confidence limits. Sample size estimate was 23. Subjects were randomly assigned to 4 groups; passive static stretch (PSS; \( n = 28 \)), active dynamic stretch (ADS; \( n = 22 \)), active static stretch (ASST; \( n = 24 \)), and static dynamic stretch (SDS; \( n = 23 \)).

Testing

All groups performed a standard 10-minute jog warm-up (2,000 m around a rugby pitch). This was followed by 2 sprints over 20 m through Omron portable electronic timing gates (Omron Electronics Ltd., Milton Keynes, UK). A timed recovery between sprints was set at 2 minutes. Researchers chose 20 m because that is the mean sprint distance rugby union players perform in match situations (6). The gates were set 1 m high, 1 m apart, and 1 m from a premarked start point. All sprints were performed from a standing start, in rugby boots, with the dominant foot to the front. No feedback was provided to subjects. This procedure was repeated after the stretch intervention, with the same starting technique employed.

Stretch Interventions

Stretch interventions were carried out immediately upon completion of the 20-m sprints. Supervision of stretch protocols was provided by a qualified sports therapist. The PSS group carried out passive stretches (slowly applied stretch torque to a muscle, maintaining the muscle in a lengthened position) (15) of the lower body (gluteals, hamstrings, quadriceps, adductors, hip flexors, gastrocnemii, and solei). Stretches were held for 20 seconds per muscle group.

The ADS group carried out a series of lower body dynamic stretches (controlled movement through the active range of motion for each joint) at a jogging pace. Exercises were designed to stretch the same muscles as those in the PSS group: high knees (gluteals and hamstrings), flick backs (quadriceps), hip rolls (adductors), running cycles (hip flexors, gluteals, hamstrings, and quadriceps) and straight leg skipping (gastrocnemii and solei). Participants performed 20 repetitions on each leg independently, with a walk-back recovery.

The ASST group performed active stretches (an active contraction of the agonist muscle to its full inner range, stretching the antagonist's outer range) (18). Stretches were the same as those performed by the PSS group, but in a stationary position for 20 repetitions per leg.

Statistical Analyses

The 2 pre- and 2 poststretch times were averaged. Interactions between groups and differences between pre- and postintervention scores were analyzed using a factorial analysis of variance (ANOVA). Post hoc analysis was carried out using Bonferroni. Statistical analysis was carried out using SPSS 10 for Windows (SPSS, Inc., Chicago, IL). Significance was set at an alpha level of \( p \leq 0.05 \).

RESULTS

Table 1 shows the mean sprint times pre- and poststretch, and the mean difference in sprint times for each group. When the pre- and poststretch data was analyzed (using a factorial ANOVA), the PSS group showed a significant increase (\( p \leq 0.05 \)) in sprint time after the passive static stretch intervention, matched by a significant increase (\( p \leq 0.05 \)) in sprint time for the ASST group. The ADS group showed a significant decrease (\( p \leq 0.05 \)) in sprint time after the active dynamic stretch intervention, but the SDS group's decrease in sprint time, was found to be non-significant (\( p \geq 0.05 \)). There were no significant differences between group data either pre- or postintervention (\( p \geq 0.05 \)).

DISCUSSION

The main finding from this study was a significantly faster sprint time when active dynamic stretching was incorporated into a warm-up, with significantly slower sprint times observed for subjects employing either static active or passive stretching regimes. The decrease in performance with the use of static passive stretching provides supporting evidence for a number of studies (1, 2, 5, 7, 12, 19, 22, 24). Knudson et al. (11) hypothesized that the decrease in vertical jump performance they saw was the result of a decrease in neural transmission, because they found no change in the kinematics of the movement. They concluded that this was attributable to acute neural inhibition from passive stretching, which decreased the neural drive to the muscle (1, 13, 19). Kubo et al. (13) suggests that passive stretching changes tendon structure, in effect making it more compliant, leading to a lower rate of force produc-

### Table 1. Mean ± SD pre- and poststretch sprint times.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean difference (sec)</th>
<th>Mean prestretch (sec)</th>
<th>Mean poststretch (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSS (n = 28)</td>
<td>3.23 ± 0.17</td>
<td>3.27 ± 0.17</td>
<td>3.27 ± 0.17</td>
</tr>
<tr>
<td>ADS (n = 22)</td>
<td>3.24 ± 0.2</td>
<td>3.18 ± 0.18</td>
<td>3.18 ± 0.18</td>
</tr>
<tr>
<td>ASST (n = 24)</td>
<td>3.24 ± 0.18</td>
<td>3.29 ± 0.2</td>
<td>3.29 ± 0.2</td>
</tr>
<tr>
<td>SDS (n = 23)</td>
<td>3.25 ± 0.22</td>
<td>3.22 ± 0.21</td>
<td>3.22 ± 0.21</td>
</tr>
</tbody>
</table>

* Denotes significant differences before and after stretch intervention (\( p \leq 0.05 \)).
tion and a delay in muscle activation. This change in muscle stiffness is important; as Kokhonen et al. (12) argue, a stiff MTU allows force generated by muscular contraction to be transmitted more effectively than a compliant MTU. Rosenbaum and Hennig (19) and Avela et al. (1) support this argument by demonstrating a decrease in electromyographic (EMG) excitation with muscle contraction after passive stretching.

However, these studies employed a very slow eccentric component, or none at all, prior to concentric contraction. When sprinting is analyzed, the need for a rapid switch from eccentric to concentric contraction is paramount. Although no studies have looked at running performance, clues to the negative effect of static stretching may be found in the work of Young and Elliot (24). They found that there was a decrease in muscle activation, but that this was particularly important in regard to the preactivation of the MTU (stiffening of the MTU prior to ground impact). This is a vital component in the drop jumps Young and Elliot (24) examined; it is just as important for successful sprint performance. The researchers concluded that passive stretching mainly affects the eccentric phase of movement, reducing the elastic return from the stretch-shortening cycle. Cornwell et al. (5) explains that the decreases in performance in the countermovement jumps they employed, caused by passive stretching, was the result of a decreased ability of the MTU to store elastic energy. Interestingly, the amount of elastic energy that can be stored in the MTU is a function of the units' stiffness (9, 21); therefore, the more compliant muscle observed after passive stretching (23) is less able to store elastic energy in its eccentric phase. This may well explain the decrease in performance exhibited in the static stretch groups in this study.

The changes in performance shown by the ASST group have not been demonstrated before. Although active static stretching is considered to be less effective than passive stretching in terms of increasing muscle length (23), the prolonged isometric contraction could lead to reduced sensitivity of neural pathways, reducing muscle spindle sensitivity. This is because this type of stretch occurs when an agonistic muscle contracts while the opposite antagonistic muscle relaxes, thereby decreasing excitatory impulses through the nervous system to the motor units (reciprocal inhibition). Therefore, in a complex movement pattern (such as sprinting) where muscle pairs need to work in conjunction with one another, one set of muscles may be in a position of being "switched off" by a decrease in nervous system stimuli.

The reason active dynamic stretches positively affect performance may be because core temperature has a greater increase than with other forms of stretching. Increases in core temperature have shown an increase in the sensitivity of nerve receptors and an increase in the speed of nerve impulses, encouraging muscle contractions to be more rapid and forceful (20). Core temperature was not recorded in this study; however, all testing was performed on warm summer evenings after a substantial warm-up (2,000-m jog). Any temperature increase was kept to a minimum by the static dynamic stretching being performed in a slow, controlled manner and the active dynamic stretching having built-in walk-back recovery. In addition, active static stretches also involve an amount of isometric muscle contraction, which may affect temperature. In this study, whether temperature differences between interventions would have been great enough to cause the performance changes demonstrated is debatable.

The other possibility for the positive changes in performance observed in the ADS group may be the rehearsal of movement in a more specific pattern than static stretching. Proprioception is required in sprinting, particularly for preactivation to help the rapid switch from eccentric to concentric contraction required to generate running speed. It may be that active dynamic stretching helps rehearsal of movement pattern coordination allow muscles to be exited early and quickly, producing more power and therefore decreasing sprint time. Evidence is available to demonstrate that passive stretching has a negative effect on coordination. Avela et al. (1) attributes the decrease in motoneuron excitability observed after passive stretching to the depression of the H-reflex. There may then be a reduction in discharge from the muscle spindles, because of increased muscle compliance. This may lead to reduced efficiency in self-regulation and adaptation to differences in muscle load and length (14), modifying running mechanics through loss of control and therefore affecting optimum power output.

In conclusion, the results from this study suggest that static stretching (active or passive) has a negative effect on 20-m running time. This could be due to an increase in MTU compliance, because as Cornwell et al. (5) explains, too much "slack" has to be taken up in the initial part of the contraction. However, active dynamic stretching appears to improve 20-m running time. The reasons for the positive increase in performance brought about by allowing active dynamic stretching are not clear, but could be linked to rehearsal of specific movement patterns which may help increase coordination of subsequent movement. There is a clear need for confirmatory studies, as well as for more fundamental research to investigate the mechanisms underlying the effects of warm-up stretch protocols on athletic performance.

**Practical Applications**

The 20-m sprint performance in trained rugby union players can be improved by using an active dynamic stretch protocol. The use of static stretching appears to decrease 20-m sprint performance (static dynamic stretching was found to have no significant effect on performance). Coaches and athletes need to be aware of the potentially negative effects of both passive and active static stretching on immediate performance of short sprints, as well as the potential positive effect of doing specific movement pattern rehearsal (active dynamic stretching) before performance.

However, though this study demonstrated an increase in performance over 20 m with active dynamic stretching and a decrease in performance with static stretching, it must be remembered this is a mean change recorded for a number of subjects. Some subjects did not follow this trend; a small minority had a decrease in performance through the dynamic intervention and had an increase in performance after the static stretch. It can be concluded, therefore, that for the majority of sports performers needing to optimize sprint performance over a relatively short distance, a dynamic stretch (particularly active dynamic exercises, mimicking specific aspects of the sprint cycle) is advisable instead of the standard static stretch approach. But care should be taken, for a minority of indi-
individuals may not exhibit the positive changes in performance that this study has demonstrated.

REFERENCES


Address correspondence to Iain M. Fletcher, ifletcher@herts.ac.uk.
Copyright of Journal of Strength & Conditioning Research is the property of Alliance Communication Group and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.
The Acute Effects of Combined Static and Dynamic Stretch Protocols on Fifty-Meter Sprint Performance in Track-and-Field Athletes

Iain M. Fletcher and Ruth Anness

Exercise Physiology Laboratory, University of Luton, Hatfield, Hertfordshire, United Kingdom.

Abstract. Fletcher, I.M., and R. Anness. The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. J. Strength Cond. Res. 21(3):784–787. 2007.—The purpose of this study was to investigate the effect of manipulating the static and dynamic stretch components associated with a traditional track-and-field warm-up. Eighteen experienced sprinters were randomly assigned in a repeated-measures, within-subject design study with 3 intervention blocks: active dynamic stretch (ADS), static passive stretch combined with ADS (SADS), and static dynamic stretch combined with ADS (DADS). A standardized 800-m jogged warm-up was performed before each different stretch intervention, followed by two 50-m sprints. Results indicated that the SADS intervention yielded significantly (p \leq 0.05) slower 50-m sprint times than either the ADS or DADS intervention. The decrease in sprint time observed after the ADS intervention compared to the DADS intervention was found to be nonsignificant (p > 0.05). The decrease in performance post–SADS intervention was attributed to a decrease in the musculotendinous unit (MTU) stiffness, possibly due to a reduction in muscle activation prior to ground contact, leading to a decrease in the MTU’s ability to store and transfer elastic energy after the use of passive static stretch techniques. The improved 50-m sprint performance associated with the ADS and DADS interventions was linked to the rehearsal of specific movement patterns, helping proprioception and preactivation, allowing a more optimum switch from eccentric to concentric muscle contraction. It was concluded that passive static stretching in a warm-up decreases sprint performance, despite being combined with dynamic stretches, when compared to a solely dynamic stretch approach.

Key Words. dynamic stretching, static stretching, musculotendinous unit stiffness, warm-up, preactivation

Introduction

Track-and-field athletes have traditionally employed extensive warm-up and stretch routines as part of their preparation for training and competition, with the belief that these routines will lead to enhanced performance. In recent years these practices have been brought into question, in particular, the value of static stretching as part of a warm-up, with research showing a reduction in muscular performance post–stretch intervention (1, 2, 5, 6, 9–11, 18, 19, 27, 29, 36, 37).

This phenomenon has been linked to two main processes. Static stretching causing a decrease in musculotendinous unit (MTU) stiffness (35), leading to a lower rate of force production and a delay in muscle activation (1, 8, 19, 20), possibly resulting in an increase in tendon slack, which would require time to be taken in when the muscle attempts to contract (27), thereby leading to a less effective transfer of force from muscle to lever (19, 34).

The other theory involves acute neural inhibition, resulting in an increase in autogenic inhibition, which decreases neural drive to the muscle (1, 7, 18, 20, 27), leading to a decrease in muscle activation after a muscle is stretched (1, 14, 31).

However, the question has to be raised about the applicability of such research to the actual warm-up regimes athletes conduct prior to performance. Many study protocols have tended to require holding stretches for extended periods, ranging from 90 seconds (19, 25) up to 1 hour per muscle (1). While methods of determining performance have focused on muscular power, as determined by maximum voluntary contraction of isolated muscle groups (1, 2, 7, 8, 11, 19, 25), such tests of muscle function have been viewed as severely limited in terms of their reflection of performance changes (24). Despite the difficulties of applying this research to the sports environment, many athletes have moved away from the static passive approach to stretching in warm-up, in favor of using dynamic stretching, defined as controlled movement through the active range of motion for one or more joints (9).

However, to date only 2 studies (9, 29) have looked at the performance changes associated with the acute effects of static and dynamic stretching on running performance. Siatras et al. (29) found a significant decrease in running speed post–static stretch interventions, but no change in running speed, after dynamic stretches were used, while Fletcher and Jones (9) found a significant decrease in 20-m sprint performance after static stretching and a significant increase in performances post–dynamic intervention, compared to the results yielded by warm-up alone.

One area that has not been researched is the combination of both static and dynamic stretching, even though this is considered to be the classical model for a warm-up protocol (17). Here aerobic exercise is used to raise the athlete’s core temperature, and this exercise is followed by static stretching and, lastly, dynamic drills, specific to the event, before competition occurs.

The aim of this study was to investigate the preferred warm-up protocols for track-and-field sprinters and to determine the effect of manipulating static and dynamic stretch components in a sprinter’s warm-up on 50-m sprint performance.

Methods

Experimental Approach to the Problem

Three different stretch protocols, active dynamic stretch (ADS), static dynamic stretch combined with ADS (DADS), and static passive stretch combined with ADS...
(SADS), were performed in a randomized repeated-measures, within-subject design. Fifty-meter sprint time was recorded after each intervention. Each subject performed a standard pulse-raising activity, a randomly ordered stretch protocol, and two 50-m sprints. Reliability of the 50-m measure employed was assessed using an intraclass correlation coefficient, with the level of reliability observed at 0.99 between the two sprint times.

**Subjects**

Ten men and 8 women sprinters were recruited from 2 track-and-field clubs. Subjects had to have been competitive sprinters with a background in resistance training (plyometrics, weight training, and circuits) for at least 2 years and had to meet at least the regional standard (men personal best: 10.69 ± 0.19 seconds; women personal best: 12.05 ± 0.18 seconds; mean ± SD for 100 m). The subjects’ age, height, and body mass, respectively, were as follows: men: 19.2 ± 1.14 years, 179.3 ± 2.27 cm, and 71.9 ± 6.77 kg; women: 20.2 ± 2.86 years, 170.2 ± 3.1 cm, and 61.72 ± 3.2 kg (mean ± SD). Testing was carried out in January, prior to the indoor season, to coincide with a decrease in training volume associated with this mesocycle. The protocols carried out were approved by a departmental committee for ethics. Subjects were required to read and complete a health questionnaire and to provide written informed consent prior to participation. Subjects were asked to rest for 2 days prior to testing and to eat and drink as they normally would before a competition. The sample size was estimated by Equation 1 (15), thus:

$$n = \frac{8s^2d^2}{\varepsilon^2}$$  \[1\]

where $s$ = typical error and $d$ = confidence limits. The sample size estimate was 16.

Subjects were required to complete 3 randomly assigned interventions: ADS, SADS, and DADS.

**Procedures**

Notational analysis was used to investigate the athletes’ usual warm-up practices. Each athlete was observed twice; length, type, and intensity of warm-up and length, type, and position of stretches used in their warm-up were recorded. From this information an average warm-up protocol was established as the control intervention. Testing was carried out on a tartan athletic track in an indoor facility. Subjects performed a self-paced jogged warm-up of 800 m followed by a designated stretching protocol before completing a 50-m sprint through Omoron portable electronic timing gates, designed to mimic the acceleration phase of a 100-m sprint (33). After the last stretch 4 minutes was allowed for 2 self-passed practice starts before the first sprint was performed. The timing gates were set at a height of 1 m, at a standard lane width, and 2 m from the start line. All sprints were out of blocks; athletes used their normal block set-up, wore spikes and normal running clothing, and standard track-and-field instructions and a gun were used to start subjects. After 2 minutes of recovery the sprint was repeated. The fastest sprint time was used for statistical comparisons. A 1-week gap was allocated between stretch interventions.

**Stretch Interventions**

Each intervention consisted of a self-paced 800-m jogged warm-up prior to a stretch component. The SADS protocol (designed as the control intervention) consisted of $3 \times 22$ seconds of passive stretches (slowly applied stretch torque to a muscle maintaining the muscle in a lengthened position) (22), with a 10-second rest between stretches (total time: 7 minutes, 12 seconds). Stretches employed were a gastrocnemius stretch (against a wall), a hamstring stretch (lying straight leg raise), standing quadriceps stretch, gluteal stretch (lying knee to chest), and hip flexors stretch (static lunge). Each stretch was held at the point of mild discomfort. This was immediately followed by the same stretches as required for the ADS intervention.

The ADS intervention consisted of a rest period of 7 minutes, 12 seconds followed by a series of lower-body dynamic stretches (controlled movement through the active range of motion for one or more joints) (9). Drills were repeated twice over 20 m with a walked-back recovery. Exercises were designed to mimic parts of the sprint cycle and to stretch the lower-body musculature mainly used in sprinting (gastrocnemius, gluteals, hamstrings, quadriceps, and hip flexors). Straight leg skipping, walking high knees, skipping high knees, running high knees, and flick backs were employed before subjects performed 2 × 50-m strides at a self-paced 80% of maximum velocity.

The DADS protocol consisted of the same movements as were required in the ADS intervention, but the DADS protocol was conducted in a stationary position. Each stretch was repeated 2 times on each leg, consisting of 8 repetitions, with 10 seconds of rest; exercises consisting of seated plantar/dorsi flexion of the ankle, standing straight leg raise, standing flick backs, and standing high knees raises. Stretches were performed in a controlled manner in a 2-second tempo. The ADS intervention was then performed before the test protocol.

**Statistical Analyses**

Interactions between stretch interventions were analyzed using a repeated-measures analysis of variance. Post-hoc analysis was carried out using Bonferroni. Statistical analysis was carried out using SPSS, version 12 for windows (SPSS, Inc., Chicago, IL). Significance was set at an alpha level of $p \leq 0.05$.

**RESULTS**

Table 1 shows the mean ($\pm$ SD) sprint times for the 3 interventions for men and women. When intergroup differences were analyzed using a repeated-measures ANOVA, the ADS intervention showed a significant decrease in sprint time (men: $p = 0.001$; women: $p = 0.03$), calculated as a mean decrease of 0.16 seconds for men and 0.1 seconds for women over 50 m, when compared to the SADS intervention. The DADS intervention showed a significant decrease in sprint time (men: $p = 0.002$; women: $p = 0.043$), calculated as a mean decrease of 0.11 seconds for men and 0.09 seconds for women over 50 m, when compared to the ADS intervention.

<table>
<thead>
<tr>
<th>Intervention†</th>
<th>Mean time men (s) Mean time women (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS</td>
<td>6.33† ± 0.32</td>
</tr>
<tr>
<td>SADS</td>
<td>6.49‡† ± 0.40</td>
</tr>
<tr>
<td>DADS</td>
<td>6.38§† ± 0.32</td>
</tr>
</tbody>
</table>

* ADS = active dynamic stretch; SADS = static passive stretch combined with ADS; DADS = static dynamic stretch combined with ADS.
† and ‡ Denotes significant differences between stretch interventions ($p \leq 0.05$).

**TABLE 1. Mean ($\pm$SD) scores for men and women after different stretch interventions.**

---

---

---
compared to the sprint time of the SADS intervention. The marginal decrease (0.05 seconds for men and 0.01 seconds for women) in 50-m time between the ADS and DADS intervention was found to be nonsignificant (men: \( p = 0.18 \); women: \( p = 0.31 \)). No differences in response pattern were shown between men and women.

**DISCUSSION**

The main findings of this study were that passive static stretching, despite being combined with active dynamic stretching, lead to a significant (\( p \leq 0.05 \)) increase in sprint time when compared to static dynamic combined with active dynamic or active dynamic stretches alone.

A decrease in performance associated with passive static stretches has been established in a number of studies (1, 2, 5, 6, 9–11, 18, 19, 27, 29, 36, 37), while the positive effect of dynamic stretches, though not researched to the same degree as static stretches, has also been shown (9, 29).

The decrease in performance associated with static passive stretch routines has been felt to be the result of a decrease in neural transmission, which thereby decreases the neural drive to the muscle (1, 18, 20, 27). This is supported by the work of Knudson et al. (18), who showed no effect on kinematic variables during vertical jump performance, and by Power et al. (26), who showed a significant increase in muscle inactivation post–static stretch, linked to a significant decrease in isometric force generated by the quadriceps. This was attributed to a neurological deficit caused by static stretching; interestingly, Power et al. (26) found that this did not result in a significant change in jump performance. However, many of these studies have employed an isometric, isokinetic, or a very slow or no eccentric component prior to a concentric contraction. How applicable this type of methodology is to the rapid eccentric/concentric coupling vital in sprinting is debatable.

The reasons for a decrease in sprint performance are more likely to be linked to changes in the compliance of the MTU structure. Passive static stretching has been shown to decrease MTU stiffness (1, 8, 20, 27, 35, 36), while the amount of elastic energy that can be stored in the MTU is a function of the unit's stiffness (16, 28). Young and Elliot (36) found a decrease in muscle activation with regard to the preactivation of the MTU, reducing the stiffness of the MTU prior to ground impact, which helps to explain the decrease in drop jump performance. Young and Elliot (36) could also help explain the results demonstrated in our study, because of the importance of preactivation of muscle prior to ground contact in sprinting. In the work of Cornwall et al. (6), the drop jump performance decreases observed were reported to be the result of the decreased ability of the MTU to store and transfer elastic energy after the use of passive stretch techniques. However, some researchers have shown contrary results. Wilson et al. (34) demonstrated an increase in compliance resulting in an increase in bench press performance. This is also the supposition of Walsh and Wilson (32), who showed an increase in depth jump performance at above 80 cm with a more compliant MTU; Walsh and Wilson (32) believed it was the ability to stretch, store, and release elastic energy that allowed subjects to mitigate high loads placed on the MTU. However, the performance measures used in these studies have a far slower velocity of contraction than do the sprints that exercise subjects were asked to perform in the present study. Belleie and Bosco (3) showed that stretch-shortening actions (like sprinting) were enhanced by a stiffer MTU, though they used hopping as their mode of exercise: this activity is far closer to the speed and coordination required in sprinting then are the exercise modalities of Wilson et al. (34) or Walsh and Wilson (32).

Therefore, the more compliant muscle observed after passive stretching (35) is less able to store elastic energy in the rapid eccentric phase associated with sprinting while changing tendon structure (20), making it more compliant and leading to less efficient force transfer from the muscle to the tendon (19), thereby resulting in a lower rate of force production. This may lead to improved running economy through a decrease in the visco-elasticity of the musculature (30), but at the cost of a decrease in the force and velocity of contraction (4, 21), resulting in an increase in time until external force can be expressed in powerful movements (5).

The phenomenon of active dynamic stretches enhancing performance has been linked to the rehearsal of specific movement patterns, helping proprioception and preactivation, allowing an optimum switch from the eccentric to the concentric muscle contraction required to generate high running speeds (9). Static stretching seems to have the opposite effect, with mechanoreceptors responding to a decrease in muscle stiffness by producing a reflexive inhibition of both agonistic muscles and their synergists (23). The magnitude of this myotatic reflex is related to stretching velocity (12, 13); by increasing stretch speed (as demonstrated in dynamic stretching), greater action potential of the myotatic reflex may result. This could have a great mechanical effect in terms of increasing MTU stiffness, thus helping to explain the increased running speeds shown in this study and others (9, 29). Interestingly, combining static dynamic stretches prior to active dynamic stretches had no greater effect on performance over active dynamic stretches alone. It may be that for dynamic stretches to be an aid to an athlete’s warm-up, the action must involve some form of movement that not only mimics part of the sprint cycle but also involves ground contact, invoking the myotatic stretch reflex.

However, by combining the static and dynamic stretching in a warm-up, many coaches have believed that any negative effects from short-duration passive stretching would be mitigated by the post-use of dynamic stretches (a normal pattern of warm-up for many athletes [17] that was established by notational analysis, as usual for the subjects in this study). However, the effects of passive stretching have been shown to be long lasting, with Fowles and Sale (10) demonstrating a decrease in voluntary contraction for up to 1 hour poststretch, with the neurological deficit linked to static stretching still being present after 2 hours (26). Though these studies used far longer hold times than the present study, they also used far less complex movement patterns to measure performance. Therefore, the decrease in motoneuron excitability observed after passive stretching through the depression of the Hoffman reflex (1) could lead to a reduction in discharge from the muscle spindles because of the increase in muscle compliance. This may lead to a reduced efficiency in the self-regulation and adaptation to differences in muscle load and length-modifying running mechanics through loss of control and may therefore negatively affect optimum power output. This seems to be the case even with a dynamic stretch routine, included in an attempt to offset the apparent acute negative responses associated with passive static stretching.


**PRACTICAL APPLICATIONS**

Fifty-meter sprint performance in trained sprinters seems to be optimized by the use of active dynamic stretch protocols in warm-up, while using passive static stretching (even when combined with dynamic stretching) seems to result in an increase in 50-m sprint time. The inclusion of static dynamic work (standing drills) seems to offer no increased benefit to the athlete’s performance beyond that offered by active dynamic work alone.

It is important to remember that the subjects’ usual warm-up practice was to include static stretching, which could have led to a reverse placebo effect (18), as subjects may have felt unable to perform their best without going through their usual routine. However, despite this concern, all subjects, both men and women, improved their performance when passive static stretching was removed from their warm-up routines. It can therefore be concluded that for athletes wishing to optimize sprint performance, active dynamic stretches, mimicking specific components of the sprint cycle, should be performed rather than the traditional static stretch approach, which appears to have a negative effect on sprint performance.

**REFERENCES**


Address correspondence to Iain Fletcher, i.fletcher@herts.ac.uk.
THE EFFECTS OF PRECOMPETITION MASSAGE ON THE KINEMATIC PARAMETERS OF 20-M SPRINT PERFORMANCE

IAIN M. FLETCHER

Exercise Physiology Laboratory, School of Physical Education and Sports Sciences, University of Bedfordshire, Bedfordshire, United Kingdom

ABSTRACT

Fletcher, IM. The effects of precompetition massage on the kinematic parameters of 20-m sprint performance. J Strength Cond Res 24(6): 1179-1183, 2010—The purpose of this study was to investigate what effect precompetition massage has on short-term sprint performance. Twenty male collegiate games players, with a minimum training/playing background of 3 sessions per week, were assigned to a randomized, counter-balanced, repeated-measures designed experiment used to analyze 20-m sprints performance. Three discrete warm-up modalities, consisting of precompetition massage, a traditional warm-up, and a precompetition massage combined with a traditional warm-up were used. Massage consisted of fast, superficial techniques designed to stimulate the main muscle groups associated with sprint running. Twenty-meter sprint performance and core temperature were assessed post warm-up interventions. Kinematic differences between sprints were assessed through a 2-dimensional computerized motion analysis system (alpha level p < 0.05). Results indicated that sprint times in the warm-up and massage combined with warm-up conditions were significantly faster than massage alone. Also, step rate and mean knee velocity were found to be significantly greater in the warm-up and massage combined with warm-up modalities when compared to massage alone. No significant differences were demonstrated in any measures when the warm-up and massage and warm-up combined conditions were compared. Massage as a preperformance preparation strategy seems to decrease 20-m sprint performance when compared to a traditional warm-up, although its combination with a normal active warm-up seems to have no greater benefit than active warm-up alone. Therefore, massage use prior to competition is questionable because it appears to have no effective role in improving sprint performance.

KEY WORDS: sprint kinematics, musculotendinous unit stiffness, core temperature, warm-up

INTRODUCTION

Interest in warm-up methods—and, in particular, which type of stretch modality to choose as part of the warm-up process—has become a much debated area (3,12,13,30). Massage is another frequently used method to help acute preparation before performance, yet it has received comparatively little attention. Massage, defined as a mechanical stimulation of tissues by means of rhythmically applied pressure and stretching (31), has been widely used for therapeutic purposes in most cultures since early civilization, with a long tradition of use in the sporting arena (9,16).

The claims for massage benefiting sports performers are numerous, ranging from improved stretching of connective tissue (33), to relieving muscle tension/tightness (32,36), to increasing blood volume and promoting the acceleration of venous blood flow (14) and release of trigger points, which are associated with increased internal resistance, muscle weakness, and poor timing/rhythm (28). Of interest, both increased (59) and decreased (10) neurological excitability is claimed to be caused by massage, depending on the type of massage employed (superficial and stimulating, which usually is used precompetition, or deep and relaxing, which is linked to postexercise recovery). With this in mind, the type of massage recommended for acute response is superficial at a fast rate effleurage (stroking) and pétrissage (kneading) (10,18). However, most claims for massage’s positive effect seem to be anecdotal, with the empirical evidence to support its use limited. Indeed, Tedes et al. (38) and Shoemaker et al. (34) found no effect on blood flow or muscle temperature when they looked at the physiological effects of massage. Despite the belief in its ability to increase acute performance (1,8,10,17), no peer-reviewed article to date has shown massage to have a positive acute benefit.

Warm-up modalities before high-intensity performance are designed to increase muscle temperature, increase enzyme
reaction rates during energy production (37), increase functional range of motion to its optimal range (17), and stimulate the nervous system in preparation for performance. Both active and passive warm-ups have been shown to increase short-term high-intensity performance (6,12). Therefore, massage, as a passive warm-up modality, may have some benefits for the short sprint performance analyzed in this study.

Sprint performance is a vital component in many sports, with coaches searching for ways to help improve sports performers' short sprint ability. It is recognized that sprint performance is made up of two vital components: stride length and stride frequency (22,27), which are linked to musculoskeletal function (MTU), stiffness, regarded as one of the most important aspects in determining short-term high-intensity performance (11,24,29). If massage's reported effect on stimulating the nervous system or release of trigger points does occur, then muscle stiffness and therefore stride length/frequency could be positively affected, making massage a useful addition to increasing performance.

The aim of this study was to investigate whether massage on its own or when combined with a traditional warm-up effects short-term sprint performance. It is hypothesized that there will be a significant increase in sprint performance when massage is combined with a traditional warm-up compared to a traditional warm-up alone and a precompetition massage alone.

METHODS

Experimental Approach to the Problem

Three different warm-up protocols were used as independent variables. Precompetition massage (PM), precompetition massage combined with traditional active warm-up (PM&AW), and traditional active warm-up alone (AW), were performed in a randomized, counterbalanced, repeated-measures, within-subjects design experiment used to analyze 20-m sprint performance (dependent variable). Independent variables were chosen as popular precompetition strategies used by subjects in an attempt to start to establish optimum warm-up protocols. The dependent measure was felt to be a relevant performance parameter important to success in all the sports in which subjects were involved. Each subject performed the prescribed warm-up protocol followed by 4 × 20-m sprints with each 2 × 20-m timed sprints. Testing was performed at weekly intervals. Reliability of the 20-m sprint measure used was assessed using intraclass correlation coefficient, with the level of reliability observed at 0.99 between the 2 sprints.

Subjects

Twenty male collegiate team sports players (age 22 ± 1.9 years, mass 83 ± 12.4 kg, stature 1.80 ± 0.19 m) from rugby union, soccer, and basketball volunteered to be part of this study. Subjects were all experienced participants in their prospective events (minimum of 4 years) and trained or played a minimum of 3 times per week. All subjects undertook regular short-acceleration sprint training as part of their physical preparation; although none were specialist sprint athletes, they should be considered experienced in terms of sprinting in game-play situations. Testing was carried out in the middle of the subjects' competitive seasons (February).

Procedures

Sample size was estimated as follows (21):

\[ n = \frac{8 \cdot s^2}{d^2} \]

Where \( s \) = typical error and \( d \) = confidence limits. The sample size estimate was 15.

Each subject underwent 3 randomized warm-up conditions prior to the completion of 2 × 20-m sprints. The fastest sprint was used for comparisons between interventions. Conditions employed were a precompetition massage (PM) modality, designed to stimulate the muscles most associated with sprint performance (26,27). The massage applied involved superficial and fast techniques with subjects supine on a massage couch and were administered by an experienced and qualified massage therapist. This involved 9 minutes of effleurage (triple pressure strokes along the muscles' longitudinal axis in a distal to proximal fashion) at 30 strokes per minute and pétrissage (kneading and squeezing motions over the muscle mass) at 60 strokes per minute (19). As each leg was massaged, the subject was positioned with the knee flexed to 90 degrees and the foot resting on the couch, thereby allowing the therapist to access all the muscles requiring massage. The muscles massaged were the gastrocnemius (1 min per leg), tibialis anterior (30 s per leg because of the relative size of this muscle group), hamstrings group (1 min per leg), gluteals (1 min per muscle), and quadriceps group/hip flexor groups (1 min per limb). The first half of each period of massage used effleurage with pétrissage applied for the remainder. The effleurage was applied with light pressure and the pétrissage used light to medium pressure to focus solely on stimulatory effects for the targeted muscles. This was considered to be a general passive warm-up and was followed by a specific active warm-up of 4 × 20-m self-paced strides. The warm-up condition consisted of 4 laps of a standard sports hall at 30 s per lap pace (timed for reproducibility purposes), followed by 1 × 10 s of static stretching on the lower limb musculature at a point of mild discomfort. Muscle groups stretched were the same as those massaged in the PM intervention (stretch technique was demonstrated and enforced by the experimenter), followed by 4 × 20-m self-paced strides. The third intervention was precompetition massage combined with warm-up, which followed the PM format and, after 1 minute of rest, the
WU format. Each sprint was electronically timed (Brower Timing Systems, Draper, Utah, USA) with a digital video recorder (Sony HVR-HD 1000R, Sony Corporation, Japan) set on a tripod, horizontal to the center of the hip joint of each subject and perpendicular to the 15-m point of a 20-m sprint (4). The camera was positioned 12 m from the 15-m point and zoomed to obtain a clear picture of 1 step (defined as 1 foot contact to the next foot contact of the opposite leg) (22). A 1-m calibration marker was taped to the floor at the 15-m point to aid kinematic analysis. The fastest of each sprint was analyzed kinematically (100 Hz) using a manual 2-dimensional digitizing system (KAN desktop version 6.0, San Francisco, CA, USA) measuring step length, step rate, and angular velocity. Aural temperature (Omron, MC-63B, Japan) was taken prior to each intervention started and directly after each condition, before the 2 maximal sprints. The thermometer was placed in the ear and temperature allowed to stabilize, following Arnett's (2) recommendations.

Statistical Analyses
All data collected were assumed to be normally distributed because the Shapiro-Wilk's (<50 subjects) test for normality was found to have an alpha level of \( p > 0.05 \). A 1-way repeated-measures analysis of variance (ANOVA) was used to investigate any differences observed between interventions. Post-hoc analysis was carried out using Bonferroni, with the alpha level set at \( p = 0.05 \).

RESULTS
The results from Figure 1 indicate the differences between sprint times per warm-up trial. A repeated-measures ANOVA showed a significant difference between conditions for the 20-m sprint test (effect size = 0.838, \( p < 0.01 \)). Pairwise comparisons found that sprint times for the WU condition resulted in a 2.74% significant decrease in sprint time when compared to the PM condition (\( p = 0.001 \)). This was matched by a 2.44% significant decrease in sprint time when the PM&WU condition was compared to the PM modality (\( p = 0.025 \)). All assumptions for linear statistics were met; therefore, the marginal differences between the WU and PM&WU condition were found to be nonsignificant. It should be noted that all subjects performed their slowest sprint under the massage-only condition.

Table 1 shows the kinematic differences in the sprint cycle. A repeated-measures ANOVA showed significant differences between conditions for the knee velocity (effect size = 0.783, \( p < 0.01 \)). Pairwise comparison demonstrates that the WU and PM&WU modality were found to have a 15.3% and 17% greater knee velocity then the PM condition (\( p = 0.032 \) and \( p = 0.025 \), respectively), whereas the 2% increase in knee velocity for the PM&WU condition compared to the WU intervention was found to be nonsignificant. When step length was examined, it was found that none of the modality had a significant effect (\( p > 0.05 \)) despite an increase in step length of 1.03% between the WU and PM&WU conditions. However, the repeated-measures ANOVA found significant differences in step rate (effect size = 0.815, \( p < 0.01 \). When the pairwise comparison was examined, it was found that WU and PM&WU modality were significantly faster (\( p = 0.03 \) and \( p = 0.021 \), respectively) than the PM modality. The small differences between WU and PM&WU conditions were found to be nonsignificant. Aural temperature was found to have no significant patterns post the 3 test conditions (WU 36.64°C ± 1.08, PM 36.48°C ± 0.97, PM&WU 36.89°C ± 1.05).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Knee velocity (degree·s⁻¹)</th>
<th>Step length (m)</th>
<th>Step rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up alone</td>
<td>408.39 ± 25.6</td>
<td>1.57 ± 0.14</td>
<td>4.18 ± 0.2</td>
</tr>
<tr>
<td>Precompetition massage alone</td>
<td>345.94 ± 22.15</td>
<td>1.6 ± 0.11</td>
<td>4.08 ± 0.21</td>
</tr>
<tr>
<td>Precompetition massage and warm-up</td>
<td>416.58 ± 22.13</td>
<td>1.61 ± 0.12</td>
<td>4.2 ± 0.17</td>
</tr>
</tbody>
</table>

*Significant differences between conditions (\( p < 0.05 \)).
Precompetition Massage and Sprint Performance

DISCUSSION

The results indicated that the PM condition had a significantly longer sprint time than the WU or PM&WU conditions, despite being combined with a specific warm-up component (4 × 20-m strides). The reasons for this change in performance are possibly linked to a significant increase in step rate and knee velocity for the WU and PM&WU interventions compared to the PM condition. These kinematic changes may be linked to massage's effect on decreasing MTU stiffness (20,29). This is important because an increase in MTU stiffness has been reported to have an important contribution to high-intensity performance (24,29), including maximum running velocity (11). A decrease in MTU stiffness is associated with a decrease in the elastic storage of energy in the eccentric phase of muscle contraction (23,35); possibly disrupting the serial elastic component, which could be linked to a decrease in MTU power output and therefore the decrease in performance observed in this study. Of note, Bellic and Bosco (8) showed that stretch shortening actions (e.g., sprinting) were enhanced by a stiffer MTU, although it should be borne in mind that they used hopping rather than running as their mode of exercise. However, the results seem to show that massage's negative impact on sprint performance is mitigated by including an active warm-up component prior to performance.

Stride frequency is important in terms of sprint running because it determines running speed to a far greater degree than stride length at maximal running speeds (27). Cheek and Denis (11) believed that a stiffer MTU contributes an elastic component to the leg muscles that in turn provides additional power needed to sustain high stride frequencies. If massage leads to more compliant tissue (39), this could decrease neural drive through the depression of the H reflex (3), which could lead to the significant decrease in step rate observed. No evidence was found in this study of the increased neural excitability that Cash (10) and Weerapong et al (39) believe can occur, despite using recommended acute preparation massage methods. Indeed, it appears that the changes more likely to occur postmassage are in parasympathetic activity following massage, resulting in a relaxation response (59).

It appears massage helps produce a more compliant tissue, which could increase range of motion and therefore step length (15). This would be a result of muscle relaxing and enhancing joint flexibility by reducing the passive tension of antagonistic muscles (16–18) but at the cost of the compact and coordinated running mechanics associated with good step rate and high running speeds. Increases in muscle temperature (passive or active) have been linked to increases in performance (6,12). However, changes in performance in this study are unlikely to be temperature related because no significant difference was found between the anodal temperatures recorded post each modality, despite the belief that temperature is increased in massage through its rubbing/needling action (59). Future work using muscle rather than core temperature may be needed to ascertain massage's specific effects in terms of temperature changes.

The more compliant muscle associated with massage modalities (20,39) is less able to store elastic energy in the rapid eccentric phase associated with sprinting while changing tendon structure (25). This makes it more compliant and leads to less efficient force transfer from the muscle to the tendon, which leads to a lower rate of force production (24) and velocity of contraction (7), resulting in an increase in time until external force can be expressed in powerful movements (12). This effect does not appear to be mitigated by including specific warm-up exercises (4 × 20-m strides) prior to performance of short sprint work.

Of note, combining massage with a traditional active warm-up had no greater effect on performance over a traditional warm-up alone. Therefore, at best massage may be time wasted in a warm-up, when more productive acute modalities could be introduced. Thus, the decrease in step rate and knee velocity observed after massage alone could be the result of a reduction in discharge from the muscle spindles because of an increase in muscle compliance. This may lead to a reduced efficiency in self-regulation and adaptation to different muscle loads and lengths, modifying running mechanics through loss of control and therefore negatively affecting optimum power output.

It can be concluded that precompetition massage is inferior to active warm-up as preparation for 20-m maximal sprint performance, whereas combining massage and active warm-up has no effect on 20-m sprint performance above warm-up alone.

PRACTICAL APPLICATIONS

It appears that the use of precompetition massage as a warm-up modality has little benefit for enhancing short-distance sprint performance. It should not be used as a replacement for a traditional active warm-up, and its combination with an active warm-up, although not detrimental to performance, does not improve performance beyond what an active warm-up achieves. Therefore, the inclusion of a massage as part of precompetition preparation seems to be a waste of an athlete's time, that more productive training methods could be explored within. It should be noted that any negative effects associated with massage may be time dependent. This has not been as yet established; therefore, recommendations for massage would be to use it as a recovery modality and avoid it as part of a precompetition strategy.

ACKNOWLEDGMENTS

All funding for this project was provided by the University of Bedfordshire. The results of this study do not constitute endorsement of any product by the author or by the NSCA.

REFERENCES


AN INVESTIGATION INTO THE EFFECTS OF DIFFERENT WARM-UP MODALITIES ON SPECIFIC MOTOR SKILLS RELATED TO SOCCER PERFORMANCE

IAIN M. FLETCHER1 AND MATHEW M. MONTE-COLOMBO2

1Department of Sport and Exercise Science, School of Physical Education and Sports Sciences, University of Bedfordshire, Bedfordshire, United Kingdom; and 2University of Hertfordshire, Langley Park, Hatfield, United Kingdom

ABSTRACT

Fletcher, IM and Monte-Colombo, MM. An investigation into the effects of different warm-up modalities on specific motor skills related to soccer performance. J. Strength Cond. Res. 24(8): 2096–2101, 2010—The aim of this study was to investigate the effect of different warm-up stretch modalities on specific high-speed motor capabilities important to soccer performance. Twenty-seven male soccer players performed 3 warm-up conditions, active warm-up (WU), WU with static stretching (SPS), and WU with dynamic stretching (ADS). Heart rate, counter-movement jump, 20-m sprint, and Balsom agility tests were performed after each intervention. Vertical jump heights were significantly greater (p < 0.01) in the WU and ADS conditions compared to those in the SPS trial. The 20-m sprint and agility times showed that the SPS condition was significantly slower (p < 0.01) than the WU and ADS conditions, with the ADS trial being significantly faster (p < 0.05) than the WU condition. Heart rate was significantly higher (p < 0.01) for participants post-WU and ADS trials compared to the SPS condition. These findings suggest that the superior performance of the dynamic stretch and warm-up-only conditions compared to the static stretch condition may be linked to increases in heart rate. The reasons for the dynamic stretch trial superiority compared to the warm-up condition are less clear and as yet to be established. We recommend for optimal performance, specific dynamic stretches be employed as part of a warm-up, rather than the traditional static stretches.

KEY WORDS dynamic stretching, static stretching, muscle-tendon unit stiffness, preparation for soccer

INTRODUCTION

One of the fundamental considerations for coaches and athletes alike is to employ a warm-up strategy designed to optimize performance levels (4); however, the structure of the warm-up, and particularly the stretch component incorporated as part of this process, has had conflicting evidence in terms of its effectiveness in aiding performance.

Most soccer players will perform an active warm-up (WU), involving jogging or calisthenics, with the intention of inducing muscle and core temperature increases and positive metabolic and cardiovascular changes (4). This type of WU has been shown to increase performance (4,5), with a mixture of temperature related mechanisms, such as increased O2 delivery to muscles (because of a shift to the right in the oxyhemoglobin dissociation curve), vasodilatation of blood vessels (25), an increase in anaerobic metabolism, and increase nerve conduction rate (4) and pre-temperature related mechanisms, such as an increase in postactivation potentiation (31), breaking of the actin–myosin bonds (which helps cause muscle-tendon stiffness), and an increase in psychological state of readiness (4), proposed to occur. There seems little argument in the literature that a WU is a desirable part of precompetition preparation; however, there is more equivocation over what type of stretch, if any, to employ as part of warm-up strategies.

There are a number of different stretch modalities that have been used as part of the warm-up process. These include static passive stretches, slowly applied stretch torque to a muscle maintaining the muscle in a lengthened position (26), which has been associated with a decrease in strength, power, and running speed (2,11,16,32,33,39) active static stretches, an active contraction of the agonist muscle to its full inner range, stretching the antagonist's outer range (28) associated with decreases in short sprint performance (12) and dynamic stretches, controlled movement through the active range of motion for each joint (12), associated with an increase in short-term high-intensity muscular performance (10–12,18,22,23,29) when compared to performance poststatic stretching.
From the limited amount of literature examining dynamic stretching, there seems to be a consensus that dynamic stretching as part of a warm-up has a positive effect on performance. However, this is not the case when the literature on static stretching is examined. Although a number of studies have shown a negative impact on performance, just as many have shown no effect on performance linked to static stretching (6,8,37). Though it should be borne in mind that no studies, to date, have shown an increase in performance after static stretching has been employed as part of a warm-up. The reasons for these differing findings may be linked to methodological variance. Some work in the area of static stretch effects on performance has not been representative of stretches used in warm-up modalities. Stretch durations such as Behm et al. (3) who used 5 × 45 seconds and Marek et al. (24), who used 16 × 30-second stretch duration are common, when 1 or 2 × 10–15-second stretch holds would be considered a more normal warm-up stretch routine before sports performance. Also measures employed have looked at muscle function rather than athletic performance. Work such as that of Fowles et al. (13), Behm et al. (3), and Yamaguchi et al. (38) has looked at the effect static stretches have on isokinetic or isometric torque, which though a reliable measure of muscle function can be questioned in regards to its ecological validity. Tests of human performance should be used where possible (27) if it is athletic performance changes you wish to examine. Therefore, the need to examine specific sports movements in realistic warm-up scenarios is needed before recommendations to athletes can be made.

With this in mind, an examination of soccer's fitness requirement seems appropriate. Soccer is a sport that involves repeated high-intensity short-term motor capabilities, with speed, power, strength, and agility components of fitness of particular importance (35). Indeed Hoff (17) demonstrates that players sprint for up to 2–4 seconds at a time, regularly jump for headers, and perform up to 50 changes in direction per match.

To date, only one study (22) has examined the effect of warm-up static stretches on specific soccer movements, without incorporating dynamic stretches. Therefore, this study aims to look at the effect of more ecologically valid warm-up stretch modalities on the specific high-speed motor skills that are important components of soccer performance. It is hypothesized that a WU incorporating dynamic stretches will show a significant increase in performance when compared to a WU or a WU combined with static stretches.

METHODS

Experimental Approach to the Problem

Three different warm-up protocols were employed as independent variables. Active warm-up, WU combined with static stretching (SPS), and WU combined with dynamic stretching (ADS). These were performed in a randomized, counterbalanced, repeated measures within-subject designed experiment employed to analyze a range of high-speed motor capabilities specific to soccer performance (dependent variables). The independent variables were chosen in an attempt to investigate whether the subject's preferred warm-up strategy (SPS) was superior to a warm-up combined with dynamic stretching exercises.

Subjects

Twenty seven healthy male semiprofessional soccer players (age 20.5 ± 2.2 years, height 180.3 ± 5.9 cm, and body mass 74.8 ± 7.5 kg) volunteered for this study. Procedures were approved by the Institutional Committee for Ethics. All subjects were asked to complete a health screen and, if approved, were informed of the experimental protocol and possible risks of participation and signed a written informed consent document before the investigation. Subjects were asked not to consume alcohol or perform any strenuous activity in the previous 24 hours before each intervention. Subjects were required not to consume food or any caffeine products for 2 hours before testing. There was a minimum period of 2 days between each of the 3 test conditions to prevent any fatigue or training effects and trials took place at the same time of day to avoid any diurnal variations. All subjects were considered experienced soccer players (at least 8 years of experience) who trained in soccer-specific movement skills at least 3 times per week for between 1.5 and 2 hours per session. All subjects used the test protocols chosen for this intervention regularly as part of training sessions. The study was conducted during the summer season; therefore, recovery from games was not a factor needing consideration.

Procedures

All subjects performed the 3 randomized warm-up conditions. The WU trial involved the subjects jogging for 3 minutes at a self-selected pace; this was used as the subject’s base line measure. The SPS protocol involved the subjects performing the 5-minute self-selected–paced jog, before incorporating a stretching routine of the lower body musculature. Muscles stretched were the hamstrings, quadriceps, adductors, abductors, gluteus maximus, hip flexors, gastrocnemius, and solei. Stretches were held at a point of mild discomfort for 15 seconds per muscle (a feeling of tightness in the musculotendinous unit but without pain) (10,39), repeated twice for the hamstring, quadriceps, gastrocnemius, and solei muscle and repeated once on the adductors, abductors, hip flexors, and gluteus maximus, totaling 3 minutes per leg of static passive stretching of the lower limbs musculature. This warm-up protocol was based on notational analysis of the warm-up’s performed by subjects before normal training sessions, it should be considered to represent the subjects self-selected preferred warm-up modality. The ADS protocol consisted of the 5-minute self-selected–paced jog followed by a series of lower body dynamic stretches. The exercises chosen were head flicks, high knees, hip rolls, walking on toes, straight leg skipping, and walking lunges. Stretches were designed to stretch the same muscles as the SPS protocol. The movements were
Warm-Up Modalities

carried out 12 times for each muscle and repeated twice totaling 144 repetitions (a walk back recovery was employed between exercise sets to minimize any chances of fatigue). Stretches should be considered active dynamic stretches as the movements were carried out while jogging (12). The 5-minute self-selected jog used as a WU for each test condition was measured at 941.7 ± 57.6 m, players replicated the same distance covered in their first trial in all subsequent trials.

**Measurements**

Each test session was organized with the coaches of the soccer clubs and took place at the same facility and time to avoid diurnal variation. The weather was clear, and there had been no rain in the previous 48 hours. The temperature was recorded (mean 18.2 ± 1.9°C) on each occasion. On arrival at the training grounds, the participants' height (Seca 225 height gauge stadiometer, Hamburg, Germany), mass (Seca 770 132101H, Hamburg, Germany), and age were recorded. Subjects were instructed to wear the same football kit on each occasion. The subjects resting heart rate (Polar ar, Polar Electro, Oy, Finland) was then recorded after a 5-minute seated rest period.

Subjects performed one of the 3 warm-up protocols: with heart rate recorded within 30 seconds post the chosen protocol. After a 1-minute Recovery, subjects performed 2 countermovement vertical jumps on a jump mat (Jastoremms Inc., Huntsville, TX, USA). Subjects were instructed to jump as high as possible, with the exact technique self-selected, apart from placement of hands on their hips to avoid using their arms as extra leverage. 1-minute rest was allowed between jumps. Subjects were then required to perform 3 20-m maximal sprints (20 m was chosen as footballers on average sprint between 10 and 30 m at a time) (35). Electronic timing gates (Bower Timing Systems, Draper, UT, USA) were positioned 0.5 m in front of the start line at 1 m height and a further 20 m away. Subjects were allowed a rest period between sprints of 2 minutes. Upon completing the 3 sprints, participants performed the Balcomb agility run (see Figure 1) (35). This test was electronically timed repeated twice with a 2-minute recovery between runs. Timing gates were set up at the beginning and at the end of the course with subjects starting 0.5 m behind the first gate. Starting and turning techniques were self-selected, but no discernable change in technique was noted.

The test involved the subject starting at point A and running to B turning and running back to A then running through C to D and back through C before running through B and finishing at E.

**Statistical Analyses**

All data were considered to be Normally distributed as the Shapiro-Wilk's (<=.05 subjects)

**TABLE 1. Mean and SD of performance measures for test conditions (n = 27).**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Countermovement jump (cm)</th>
<th>20-m sprint (s)</th>
<th>Balcomb agility (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WU</td>
<td>51.8 ± 5.6†</td>
<td>3.01 ± 0.13†</td>
<td>11.22 ± 0.40†</td>
</tr>
<tr>
<td>SPS</td>
<td>49.7 ± 5.1†</td>
<td>3.07 ± 0.16†</td>
<td>11.37 ± 0.55†</td>
</tr>
<tr>
<td>ADS</td>
<td>52.0 ± 5.1†</td>
<td>2.92 ± 0.13†</td>
<td>10.94 ± 0.47†</td>
</tr>
</tbody>
</table>

*WU = active warm-up; SPS = active warm-up with static stretching; ADS = active warm-up with dynamic stretching.
†Significant differences between WU, SPS, and ADS conditions.
‡Significant differences between SPS and ADS conditions (p < 0.05),

![Figure 1. Balcomb agility run course.](image)
between conditions for the countermovement jump test ($F=50.56$, effect size = 0.898, $p < 0.01$). Pairwise comparisons found that vertical jump scores for the WU condition were significantly ($p < 0.01$) higher than the SPS condition, found to be an increase in performance of 4.1%. The 2% decrease in performance for the WU trial compared to the ADS trial was found to be nonsignificant ($p > 0.05$). The SPS condition was also found to have a significantly ($p < 0.01$) lower (5.9%) jump height compared to the ADS conditions.

**Sprint Time**

When the 20-m sprint results were examined, a significant difference between conditions ($F=47.226$, effect size = 0.791, $p < 0.01$) was shown. The WU condition had a significant increase in performance ($p < 0.01$) of 2% compared to the SPS condition and a significant ($p < 0.05$) 3% decrease in performance compared to the ADS condition. The SPS trial was also significantly ($p < 0.01$) slower (4.9%) than the ADS trial.

**Agility Time**

The agility run times showed a similar pattern of response to the 20-m sprint times ($F=21.789$, effect size = 0.635, $p < 0.01$). Pairwise comparisons showed the WU condition was significantly faster ($p < 0.05$) than the SPS condition (1.8% increase in performance) but was significantly ($p < 0.01$) slower (2.5%) than the ADS condition. The SPS condition was found to be significantly ($p < 0.01$) slower than the ADS condition, calculated as a 3.8% decrease in performance.

**Heart Rate**

Figure 2 shows the differences between heart rates for the 3 trial conditions. A main effect between conditions was shown ($F=127.341$, effect size = 0.914, $p < 0.01$). Participants heart rates pre-exercise were similar on each occasion (WU = 68 ± 6, SPS = 71 ± 10, ADS = 65 ± 6); however, postinterventions heart rates were found to have increased significantly ($p < 0.01$) for the WU and ADS conditions compared to the SPS condition (42.3 and 35.9%, respectively). The increase in heart rate between the ADS and WU conditions was found to be nonsignificant ($p > 0.05$).

**Discussion**

The results demonstrated significant patterns of response in all 3 soccer-specific movements tested. In the countermovement jump test, a significant increase in jump height was observed when the WU condition was compared to the SPS condition and when the ADS condition was compared to the SPS trial. These findings have been demonstrated before with Fagenbaum et al. (10), Holt and Lambourne (18), and Pearce et al. (29) finding a decrease in performance of countermovement jumps when a warm-up with a static stretch component was compared to a warm-up with a dynamic stretch component. However, Little and Williams (22) found no significant change in countermovement jump height after their static stretch protocol with elite soccer players, but it should be borne in mind that participants carried out 4 minutes of incremental intermittent sprint and agility runs post the static warm-up stretch; this may have helped mask any possible negative effects from the static stretch regimen, particularly in light of the significant decrease in heart rate linked to the present studies static stretch warm-up condition compared to other interventions.

The 20-m sprint and Baskom agility times showed a significant increase in performance for the WU condition compared to the SPS, but a significantly slower time compared to the ADS trial, whereas the ADS trial was significantly slower than the ADS condition. This decrease in sprint performance between static and dynamic conditions has been shown a number of times (11,12) in distances ranging from 15 to 50 m. The only study to show a significant improvement in sprint performance when a static stretch was compared to a general warm-up was Little and Williams (22). However, their warm-up design was substantially different from that of other studies, with the possibility of the reverse placebo effect (19) occurring as the players routinely used static stretching in their warm-ups. The increase in agility performance with dynamic stretching compared to static stretch conditions has also been demonstrated in a number of studies over a range of agility tests (10,22).

A number of mechanisms have been put forward to explain the decrease in performance associated with static stretch modalities. Neuromuscular mechanisms have been suggested...
Warm-Up Modalities

as one possibility, with acute neural inhibition thought to occur, decreasing the neural drive to the muscle (21). Of more specific relevance to the present study could be the effect on the eccentric phase of the stretch shortening cycle, vital for good performances in all 3 physical capacity measures from the present study. In the eccentric phase of a stretch shortening cycle, a myoelectric potentiation is initiated; this increases muscle activation during any following concentric contraction. The magnitude of this reflex is decreased post an acute bout of static stretching (30). This significant decrease in reflex sensitivity post static stretch (1) is linked to a decrease in motor neuron excitability and a significant decrease in the Hoffman reflex (30), which is associated with rapid forceful muscle contraction.

Mechanical factors have also been hypothesized as a reason for decreases in performance (16). Static stretching has been shown to decrease muscle tendon unit (MTU) stiffness (1,29), increasing the length of the passive components of muscle, which is thought to be detrimental to performance because of an increase in the force length relationship of skeletal muscle (13). This increased compliance in the passive components (particularly tendon) results in a brief moment when force is taking up tendon slack instead of contributing to gross movements (14) limiting muscular performance. Muscle stiffness is vital in efficient force transfer, a stiff MTU allows force generated by muscular contraction to be transmitted more effectively than a compliant MTU (20); however, static stretching seems to result in MTU relaxation (56) decreasing a statically stretched muscle ability to store elastic energy in the stretch shortening cycle eccentric phase for subsequent usage in a powerful concentric contraction (7).

The dampening of neuromuscular activity associated with static stretching in a warm-up (5,13,20) and the decrease in MTU stiffness (1,9,21,36,59) may explain the decreases in performance measures this and other studies have shown, but the mechanism behind the significant performance increases associated with dynamic stretches is less clear. It is thought by some authors (10,38) that increases in neuromuscular function, increasing the force and power that a muscle can generate, are linked to the use of dynamic stretches, whereas other authors (11,12) have hypothesized that increases in running speed are associated with rehearsal of specific movement patterns helping the complex coordination and facilitated motor control (22) linked to high-speed running mechanics. However, these mechanisms to date are theoretical, with no empirical evidence to refute or suggest that they do occur.

The most obvious explanation for the results from this present study is the differences shown in the heart rate data. The WU and ADS conditions had a significantly greater increase in heart rate compared to the SFS trial, a similar pattern demonstrated by Faigenbaum et al. (10). This increase in heart rate could have positive metabolic effects, increasing blood flow and core temperature. This may cause an increase in sensitivity of nerve receptors, increase in speed of nerve impulses, therefore encouraging muscle contraction to be more rapid and forceful (34). If this increase in heart rate was mirrored by an increase in core temperature (which seems likely), then the decrease in resistance of muscles and joints and the increase in nerve conduction associated with temperature increases (4) could help explain the performance increase in muscle function for the WU and ADS conditions. However, all the changes associated with the ADS condition cannot be linked to heart rate alone. The more complex motor capabilities (20-m sprint and agility test) had a different pattern of response to the more simple motor skill of jumping. In each performance test, the ADS condition was inferior to the WU and ADS trials, matched by significantly increased heart rates in both these trials. However, in the 20-m and Balsom agility tests, the ADS condition was also superior to the WU modality, despite no significant difference in the mean heart rate. This may indicate that mechanisms other than heart rate and temperature could be involved in the superior performance linked to dynamic stretching. Interestingly, the magnitude of the myotatic reflex is related to stretching speed (15), by increasing the stretch speed (as demonstrated in dynamic stretching) greater action potential of the myotatic reflex may result. This could help explain why the more rapid stretch-shortening cycle (SSC) actions (sprinting and agility) rather than the slower SSC exhibited in countermovement jumps are superior for the dynamic stretch condition compared to a no-stretch condition.

This study has demonstrated that an increase in the performance of soccer-specific movements is possible when dynamic stretches are incorporated in a warm-up protocol. This finding is supported in much of the literature but is unique in soccer-specific studies. Differences in performance can be linked to significant increases in heart rate in the dynamic stretch intervention compared to the static stretch condition but does not apply to the superior performance of the dynamic stretch trial compared to the WU intervention, the mechanisms associated with this need to be examined in a more controlled laboratory setting.

Practical Applications

It appears that static passive stretch modalities performed as part of a warm-up strategy are detrimental to the performance of short duration high-intensity specific movement skills linked to soccer performance. However, it appears that by replacing static stretches with active dynamic stretches performance is improved compared to a WU with no stretch component. Therefore, we recommend that to optimize physical performance in soccer games or training, any warm-up static stretch routines be replaced by active dynamic stretches, which should specifically stretch the musculature that is required to the movements that are going to be attempted during any game scenario. However, it must be borne in mind that the subjects used in this study were well trained, male, adult players and not fulltime professionals. Other subgroups of soccer players may have different responses to warm-up stretches and need to be examined independently.
ACKNOWLEDGMENTS

All funding for this project was provided by the University of Bedfordshire. The study was conducted by the National Strength and Conditioning Association.

REFERENCES


An investigation into the possible physiological mechanisms associated with changes in performance related to acute responses to different preactivity stretch modalities

Iain M. Fletcher and Mathew M. Monte-Colombo

Abstract: The aim of this study was to explore the potential mechanisms underlying performance changes linked to different warm-up stretch modalities. Twenty-one male collegiate–semiprofessional soccer players (age, 20.8 ±2.3 years) performed under 3 different warm-up conditions: a no-stretch warm-up (WU), a warm-up including static passive stretches (SPS), and a warm-up incorporating static dynamic stretches (SDS). Countermovement jump, drop jump, peak torque, heart rate, core temperature, movement kinematics, and electromyography (EMG) were recorded for each intervention. Significant increases (p < 0.001) in performance were recorded for the countermovement, drop jump, and peak torque measures when the SDS was compared with the WU and SPS trials. When mechanism data were analysed, heart rate was significantly higher (p < 0.001) in the SDS condition compared with the SPS and WU conditions (a pattern also shown with core temperature), whereas the WU condition heart rate was also significantly higher than the SPS condition heart rate. When EMG data were examined for the rectus femoris muscle, significantly greater (p < 0.01) muscle activity was observed in the SDS condition compared with the SPS condition. It seems the most likely mechanisms to explain the increase in performance in the SDS condition compared with the SPS condition are increased heart rate, greater muscle activity, and increased peak torque.

Key words: dynamic stretch, static stretch, electromyography, musculotendinous unit stiffness, core temperature.

Introduction

Warm-up stretch modalities have recently come under close scrutiny in terms of their effect on short-term, high-intensity performance. Indeed, a slow shift away from static stretches to dynamic stretches as part of the warm-up process has become evident. This is due to the evidence that warm-ups involving static stretching exercises have been found to cause a decrease in the performance of high-intensity motor capabilities, when compared with warm-up interventions that incorporate dynamic stretches (Faigenbaum et al. 2005; Fletcher and Anness 2007; Fletcher and
A number of mechanisms have been put forward to explain the decrease in performance linked to static stretching. These have been neural, including a decrease in muscle activation (Fowles et al. 2000) and failure of excitation; contraction coupling; or weakened neuromuscular propagation (Avela et al. 1999). A decrease in activation, recruitment, and contraction of muscle fibres linked to static stretching (Church et al. 2001) has 2 possible mechanisms, at either the local muscle level or the global central system level. Avela et al. (1999) has argued that decreased neural drive could be linked either to supraspinal fatigue, or changes in inhibitory as well as disfacilitory signals originating from the contracting muscle. The level of nervous system disruption has yet to be established. Static stretches’ dampening effect on the nervous system has been demonstrated by significant decreases in electromyography (EMG) (Cramer et al. 2004; Marek et al. 2005; Rosenbaum and Hennig 1995); however, all these studies used extended stretching times, the minimum being 8 min of stretching per muscle, a duration of stretch that would not be attempted on one muscle in a normal sporting warm-up, where one or two 15-s hold times is a more normal protocol.

The other main mechanism is attributed to mechanical factors. Effects linked to static stretches could be stretch-induced damage to the myotendinous junction and breakages of stable cross bridges (Avela et al. 1999), or changes in viscoelastic properties of the muscle due to a reduction in passive and active stiffness of the musculotendinous unit (MTU) (Fletcher and Anness 2007; Fletcher and Jones 2004). This could be linked to alterations in the force–length relationship (Cramer et al. 2004), because more compliant tissue takes time to take up slack from passive components of the MTU. Static stretching is also associated with decreases in muscle stiffness. A stiff MTU allows force generated by muscular contraction to be transmitted more effectively than a compliant MTU (Kokkonen et al. 1998); however, static stretching seems to result in the contractile element of muscle relaxing (Taylor et al. 1990), which may help explain the decreases in performance of strength, power, and running speed associated with static stretching (Avela et al. 1999; Bacurau et al. 2009; Behm et al. 2001; Church et al. 2001; Fletcher and Anness 2007; Fletcher and Jones 2004; Fowles et al. 2000; Herda et al. 2008; Knudson et al. 2001; Kokkonen et al. 1998; Rosenbaum and Hennig 1995; Samuel et al. 2008; Sayers et al. 2008).

Dynamic stretching has had much less emphasis placed on it by the research community but it shows significant increases in performance or muscle function tests when compared with static stretch modalities (Faigenbaum et al. 2005; Fletcher and Anness 2007; Fletcher and Jones 2004; Holt and Lambourne 2008; Manoel et al. 2008; McMillian et al. 2006; Moran et al. 2009; Pearce et al. 2009; Yamaguchi and Ishii 2005). A number of mechanisms have been proposed as causing this phenomenon, including specific rehearsal of movement prior to exercise (Fletcher and Anness 2007; Fletcher and Jones 2004); an increase in muscle and core temperature (Yamaguchi and Ishii 2005); and increases in neuromuscular activity (Faigenbaum et al. 2005), possibly linked to postactivation potentiation (Sale 2002), where the previous acute contractile history of a muscle positively affects subsequent muscular performance. However, these mechanisms have not been explored fully. To date, no study has looked at heart rate, core temperature, or neuromuscular activity in relation to the dynamic stretch component of a warm-up.

Therefore, the aim of this study was to investigate the mechanisms behind changes in performance associated with warm-ups, including static and dynamic stretch exercises. It was hypothesized that a warm-up combined with a dynamic stretch component would exhibit significant increases in short-term maximum performance capabilities when compared with a warm-up combined with static passive stretches.

Materials and methods

Subjects

Twenty-one healthy male collegiate–semiprofessional soccer players (age, 20.8 ± 2.3 years; height, 179.8 cm ± 6.4 cm; body mass, 75.6 kg ± 8.1 kg) volunteered and completed a randomized, counterbalanced, repeated-measures designed study. Procedures were approved by the University of Hertfordshire’s (Hatfield, UK) Departmental Committee for Ethics. All subjects were asked to complete a health screen and, if approved, were provided with written and verbal information regarding the experimental protocol and possible risks of participation. Written consent was then obtained from subjects. Subjects were asked not to consume alcohol or perform any strenuous products for 2 h prior to testing. There was a period of 2 days’ rest between each of the 3 test conditions to prevent any training effect, and trials took place at the same time of day to avoid any diurnal variations.

Experimental design

One week prior to the study, subjects were put through all test protocols as a familiarization session to minimize any learning effect from unfamiliar equipment. Subjects performed under 3 randomized warm-up conditions: no-stretch warm-up (WU), warm-up combined with static passive stretches (SPS), and warm-up combined with static dynamic stretches (SDS). The WU trial involved the subjects jogging for 5 min at a self-selected pace, which was considered the baseline measure, and this running velocity was reproduced in each condition. The SPS protocol involved the subjects performing a 5-min jog followed by a static stretching routine of the lower limbs musculature within 30 s of the run. Muscles stretched were the hamstrings, quadriceps, abductors, adductors, gluteus maximus, hip flexors, gastrocnemius, and solei. Stretches were held at a point of mild discomfort for 15 s per muscle (Faigenbaum et al. 2005). Subjects were instructed to hold stretches at the same level of discomfort as would be normal for their individual training warm-up procedures. Stretches were repeated twice (bilateral), with a 5-s pause between stretches, for the hamstring, quadriceps, gastrocnemius, and solei muscle, and repeated once for the adductors, abductors, hip flexors, and gluteus maximus, totaling 360 s of static passive stretching. This warm-up pro-
tocol was chosen after a notational analysis of the warm-ups performed by subjects prior to normal training sessions, and should be considered as representing their self-selected, preferred warm-up modality. The SDS protocol consisted of a 5-min jog followed by a series of lower body dynamic stretches. The exercises chosen were heel flicks, high knees, hip rolls, calf raises, straight leg skipping, and lunging. Movements were designed to take the joints associated with the muscles statically stretched in the SPS protocol through their full active range of motion (ROM) in a systematic, controlled manner. The movements were carried out 12 times for each exercise and repeated twice, with a total of 144 repetitions performed in the same time frame as the static stretches. Stretches were considered stationary dynamic stretches because subjects remained in situ while movements were performed (Fletcher and Jones 2004).

Instrumentation

Each subject’s age, height (Seca 225 height gauge stadiometer, Seca, Hamburg, Germany), and body mass (Seca 770 1321004) were recorded. Resting heart rate (Polar al, Polar Electro, Oy, Finland) was recorded after a 5-min rest and core temperature was measured tympanically (TH809 infrared ear thermometer, Radiant Innovation Inc., Hsin Chu City, Taiwan). The temperature of the laboratory was recorded on each visit (mean 20.1 °C ± 0.5 °C). Subjects then performed 1 of the trial conditions. The 5-min, self-selected paced jog was carried out on a treadmill (H/P/Cosmos Pulsar 4.0, Medical Application MDD class IIb, H/P/ Cosmos Sports and Medical gmbH, Nussdorf, Germany); subjects jogged at a velocity of 7–10 km·h⁻¹ (mean 8.8 ± 0.7 km·h⁻¹). Subjects reproduced the same treadmill velocity for each of the subsequent trials. Once subjects had completed the warm-up condition, heart rate was measured and recorded within 30 s. The core temperature was measured 3 times pre and post intervention (in a 1-min time slot) and an average was recorded.

Countermovement and drop jumps

Subjects were fitted with reflective markers (40-mm self-adhesive paper discs) on the surface of the fifth metatarsal, ankle, knee, and hip, and on the midaxillary line in line with the sternum on the right side of the body, representing the projected position of the joint centre, prior to beginning the warm-up. After each warm-up condition, subjects were first required to perform a randomized mix of 3 maximal countermovement or 3 drop jumps on a jump mat (Just Jump, Probiotics Inc., Huntsville, Alabama); jumps were performed 1 min post intervention, with 30 s of recovery between each jump. Subjects were instructed to place their hands on their hips throughout both jumps, in an attempt to use only the force provided by the leg musculature; they were instructed to jump as high as they could and to land back on the mat. Drop jumps were performed from a bench (0.3 m high) by stepping off the bench but landing with both feet simultaneously before jumping off the mat. Subjects were instructed that they would need to jump as high as they could with minimal ground contact and land back on the mat. Each jump was digitally recorded, with the camera (Sony HC19E, Sony Corp., Tokyo, Japan) set 4.5 m from the jump mat, perpendicular to the sagittal plane at the mid-point of each subject’s hip. The highest countermovement and drop jumps were kinematically analysed (50 Hz) using a manual 2D digitizing system (KA basic version 6.0, San Francisco State University, San Francisco, Calif.). Kinematic variables analysed at the hip, knee, and ankle joints were ROM, peak angular joint velocity in the descent and ascent, and movement time in the descent and ascent.

Isokinetic and electromyography test protocols

Following countermovement and drop jumps, subjects performed 5 maximal repetitions (flexion and extension of the knee joint) on an isokinetic dynamometer (Isokinetic dynamometer Biodes systems 2, Biodes Medical Systems Inc., New York, N.Y.) with their dominant leg. This involved a 5-min rest while the dynamometer was set up, with a 30-s rest between each exercise repetition. Knee centre was aligned to the dynamometer axis of rotation under isometric conditions at a knee angle of 135°, with the ankle and hip stabilized at a standardized angle (Balzopoulos 1997). The subjects performed 5 repetitions at a slow velocity (30°·s⁻¹) and 5 repetitions at a fast velocity of (300°·s⁻¹). These velocities were chosen to elicit maximum peak torque and to replicate the velocity of a soccer kick (Rahmama et al. 2003). Peak torque (Nm) readings were established, ensuring that values were recorded under the actual isokinetic velocities set (Balzopoulos 1997) for both knee flexion and extension. Subjects’ EMG was measured during knee flexion and extension activity for the rectus femoris and biceps femoris muscles. They were fitted with 40-mm silver chloride EMG electrodes (Cardiocare Limited, Romford, UK) after completing each warm-up intervention. These electrodes were attached to the skin on the belly of the rectus femoris and the belly of the biceps femoris muscle under contraction, with an interelectrode distance of 2 cm, aligned parallel to the direction of the underlying fibres (Clarys and Cabri 1993). EMG activity was recorded at a sampling frequency of 1000 Hz; the high pass filter was set at 20 Hz and the low pass filter at 500 Hz, with a mains notch filter (50 Hz) also used (Enoka 2002). The EMG was recorded using a Powerlab isolated amplifier (Powerlab AD Instruments 4/25T, AD Instruments, Sydney, Australia). These data were analyzed using a computer program (Chart version 5.4.1, AD Instruments, Chalgrove, UK). The raw EMG signal was processed by full wave rectification, integrated and averaged (average rectified value) for the peak torque repetition at the 2 set velocities, and for knee flexion and extension. EMG signals were normalized by measuring the average rectified value of a maximal isometric contraction at a knee angle of 135° performed after the main isokinetic tests to limit the effect of any possible fatigue. This represented the EMG activation at maximal voluntary contraction (MVC). This was then used for comparisons between the EMG amplitude of the repetition with the greatest peak torque at both velocities and for knee flexion and extension. This allowed the calculation of EMG activation as a percentage of subjects’ MVC (Burden et al. 2003).

The total time frame for each test condition was 27 min. This involved 5 min of active warm-up followed by 6 min of stretching. The jump protocol took 2.5 min to complete, with the dynamometry time frame 4.5 min. The remainder
of the time was either rest between exercise repetitions or used for set up of experimental equipment.

Data analysis and statistics
Data were considered to be normally distributed if the Shapiro–Wilk (<50 subjects) test for normality was found to have an α level of p > 0.05. A repeated-measures analysis of variance (ANOVA) was used to investigate any differences between conditions. Following the ANOVA, a pairwise comparisons post hoc test was performed with a Bonferroni adjustment. Variables found to be not normally distributed (Shapiro–Wilk’s p ≤ 0.05) required nonparametric tests to be carried out; a Friedman’s 2-way ANOVA was carried out for peak velocity of the ankle during extension in the vertical jump, peak velocity of the knee during the concentric phase of the drop jump, movement time of the knee joint during the concentric phase of the drop jump, and time to peak torque for 30°/s–1 during flexion. Statistical analysis was performed using SPSS, version 12 for Windows (SPSS Inc., Chicago, Ill.) with the α level set at p ≤ 0.05. Reliability of measures was assessed using a coefficient of variation (CV). Reliability was calculated for the tympanic temperature (CV = 1.35%).

Results
Countermovement and drop jump height
When jump performance was examined by repeated-measures ANOVA, countermovement jump differences were found to be significant (F = 38.802, effect size = 0.803, p < 0.001). Pairwise comparison showed jump height was significantly higher in the WU (p = 0.005) condition compared with the SPS condition (3.4% increase), but significantly (p = 0.005) lower (3.9% decrease) compared with the SDS trial. Jump height in the SDS condition was significantly (p < 0.001) higher than in the SPS trial (7.5% increase) (Table 1).

Significant differences in drop jump performance (F = 9.669, effect size 0.504, p < 0.001) showed a slightly different pattern of response compared with the countermovement jump. The WU condition jumps were 4.9% greater than the SPS condition jumps (p = 0.016) and the SDS condition had a 5.9% (p = 0.001) greater jump height than the SPS condition. The 1.1% increase in performance from the SDS to the WU trial was found to be nonsignificant (p = 1.0).

Countermovement and drop jump kinematics
When the kinematic variables associated with vertical jump performance were examined, the only data that were found to have a main effect (F = 9.107, effect size 0.503, p < 0.05) were the knee ROMs. These were recorded as 82.3 ±11.3° in the WU trial, 87.9 ±14° in the SPS trial, and 90.7 ±16.7° in the SDS condition, equating to a significant increase in ROM in the SDS (p = 0.002) and SPS (p = 0.012) conditions compared with the WU trial. The kinematic variables for the drop jump performance showed that none of the components examined were significantly different (p > 0.05) when the 3 interventions were compared (Fig. 1).

| Table 1. Countermovement and drop jump results (n = 21). |
|-----------------|-----------------|-----------------|
| Condition       | Countermovement jump (cm) | Drop jump (cm) |
| WU              | 47.7±5.1*        | 47.5±5.6*       |
| SPS             | 45.9±4.7*†       | 45.2±3.7*†      |
| SDS             | 49.6±4.6*†       | 48+4.9†         |

Note: Values are means ± standard deviation. WU, no-stretch warm-up; SPS, warm-up with static passive stretches; SDS, warm-up with static dynamic stretches.
*Significant differences among WU, SPS, and SDS conditions (p ≤ 0.05).
†Significant differences between SPS and SDS conditions (p ≤ 0.05).

Heart rates
Precondition heart rates were very similar across all modalities (WU: 70 ± 6, SPS: 69 ± 8, SDS: 68 ± 7 beats·min⁻¹); however, postexercise heart rates were very different (F = 201.413, effect size = 0.955, p < 0.001). The WU heart rate was 130 ± 12 beats·min⁻¹, significantly higher (p < 0.001) than in the SPS condition (92 ± 14 beats·min⁻¹). The SDS heart rate (158 ± 15 beats·min⁻¹) was found to be significantly higher (p < 0.001) than in the SPS and WU conditions (Fig. 2).

Core temperature
When the differences between pre- and post-core temperatures were examined, the ANOVA showed significant differences between the 3 conditions employed (F = 39.181, effect size = 0.805, p < 0.001). The SDS condition had the largest increase in temperature (0.18 °C more than in the WU condition and 0.19 °C more than in the SPS condition). The post hoc comparison found this to be a significant increase (p < 0.001) for the SDS trial compared with the other experimental interventions (Table 2).

Peak torque
Peak isokinetic torque for knee extension had a main effect (F = 8.671, effect size = 0.477, p < 0.01), indicating that, at the slow contraction velocity (30°·s⁻¹), the WU and
SDS conditions produced significantly more torque ($p = 0.017$, 4.6% and $p = 0.019$, 6.2%, respectively) than the SPS trial. However, when flexion of the knee ($30^\circ \cdot s^{-1}$) was examined ($F = 6.706$, effect size = 0.401, $p < 0.05$), post hoc analysis showed the SDS condition's torque was significantly ($p = 0.038$ and $p = 0.021$) higher than those of the WU or SPS trials, respectively. This equated to an increase in performance of 5% and 6.7%, respectively, in the SDS condition. The same significant pattern was demonstrated with flexion in the fast isokinetic test ($300^\circ \cdot s^{-1}$) ($F = 10.936$, effect size = 0.535, $p < 0.01$), with that of the SDS condition significantly greater ($p = 0.042$, 10.8%) than that of the WU condition and significantly greater ($p = 0.001$, 16.5%) than that of the SPS condition. Time to peak torque was also found to exhibit a main effect for flexion at $30^\circ \cdot s^{-1}$ ($F = 4.173$, effect size = 0.305, $p < 0.05$); the SDS condition was 7.72% faster ($p = 0.034$) than the WU condition and 12.8% faster ($p = 0.027$) than the SPS condition. The SPS trial had a 5.47% significant increase ($p = 0.039$) in time to peak torque compared with the WU intervention (Table 3).

Electromyography

The main effect for the rectus femoris muscle at $30^\circ \cdot s^{-1}$ ($F = 6.479$, effect size = 0.405, $p < 0.01$) and $300^\circ \cdot s^{-1}$ ($F = 10.583$, effect size = 0.527, $p < 0.001$) showed that the SDS condition showed a significant increase in muscle activity compared with the SPS condition at both the slow ($30^\circ \cdot s^{-1}$) ($p = 0.006$) and fast ($300^\circ \cdot s^{-1}$) ($p = 0.001$) isokinetic velocities. The increases in activity in the SDS condition compared with the WU condition, and the WU condition compared with the SPS condition, were found to be non-significant ($p = 0.463$ and $p = 0.338$, respectively).

Discussion

The results of this study demonstrated a significant increase in countermovement and drop jump performance in the WU and SDS conditions compared with the SPS trial. The SDS condition also had a significant increase compared with the SPS condition in the countermovement jump test. This pattern of response, in which dynamic stretches have improved performance measures in comparison with static stretches, has been demonstrated by a number of studies (Fletcher and Anness 2007; Fletcher and Jones 2004; Faigenbaum et al. 2005; Holt and Lambourne 2008; Manoel et al. 2008; Moran et al. 2009; Nelson et al. 2005; Pearce et al. 2009; Wallmann et al. 2005).

The most obvious explanation for these results is the significant differences shown in the heart rate and core temperature data. The WU and SDS conditions had a significantly greater increase in heart rate than the SPS trial, with the SDS heart rate also significantly greater than the WU heart rate. This linked to a core temperature increase in the SDS trial that was significantly higher than in the WU or SPS conditions. Increases in heart rate and core temperature can increase positive metabolic factors. Increased blood flow, decreased resistance of muscles and joints to movement, and increased sensitivity of nerve receptors have been established. This is linked to increases in nerve conduction velocity, which encourages muscle contraction to be more rapid and forceful (Bishop 2003; Girard et al. 2009; Shellock and Prentice 1985), possibly helping to explain the performance differences among trial conditions shown in this study. However, a note of caution is appropriate with these findings. The small increases in core temperature associated with the SDS condition (0.19 °C), although statistically significant, are unlikely to have any clinical significance, particularly because the core temperature recorded was tympanic because of its practicality. Measurements, although reliable, were lower than expected and can be questioned in terms of accuracy when compared with rectal or oesophagus measurements (Moran and Mendal 2002). This is an area that warrants further investigation to determine the true effect of dynamic stretching on core temperature.

Another theory to explain changes in performance through stretch modalities is that of changes in muscle stiffness. Static stretches have been shown to decrease the stiffness of the MTU (Avela et al. 1999; Evetovich et al. 2003; Kubo et al. 2001; Rosenbaum and Hennig 1995; Wilson et al. 1991), leading to decreases in performance due to an increase in the force–length relationship of a muscle (Fowles et al. 2000). In the present study, total knee movement was used to compare relative functional stiffness (taking into account both the active and passive components of the MTU) between conditions, as suggested by Knudson et al. (2001). In the vertical jump test, knee movement was significantly less in the WU condition compared with either intervention, which was to be expected in the SPS condition, but not in the dynamic stretch condition. This may help explain the decrease in performance in the static stretch condition but does not help explain why dynamic stretching seems to be superior to an active warm-up without any stretch component. Indeed, the lack of any change in kinematic variables in the drop jump could be revealing. In drop jumping, extremely high eccentric loads are transferred through the lower limb musculature. A stiffer MTU is required for a good rebound, ensuring a fast transmission of muscular force to bones, producing explosive forceful movement (Kubo et al. 2001).
shown in both jump tests and peak torque performance. In-
shown in the majority of measures when the SDS and SPS conditions were compared.

In conclusion, it seems that the most likely mechanisms for explaining the increase in performance when comparing dynamic with static stretch modalities as part of a warm-up are increases in heart rate, greater nervous system stimulation, and an increase in peak torque associated with the dynamic stretch modality. However, the increases in performance associated with the dynamic stretch condition, compared with a no-stretch warm-up, are less clear. Heart rate was significantly different, but that does not explain all the performance changes demonstrated; the possibility of rehearsal of specific movement patterns helping more complex motor skills performance cannot be discounted and warrants further investigation.

References


The effect of different dynamic stretch velocities on jump performance

Iain M. Fletcher

Abstract Dynamic stretching has gained popularity, due to a number of studies showing an increase in high intensity performance compared to static stretch modalities. Twenty-four males (age mean 21 ± 0.3 years) performed a standardised 10 min jogging warm-up followed by either; no stretching (NS), slow dynamic stretching at 50 b/min (SDS) or fast dynamic stretching at 100 b/min (FDS). Post-warm-up, squat, countermovement and depth jumps were performed. Heart rate, tympanic temperature, electromyography (EMG) and kinematic data (100 Hz) were collected during each jump. Results indicated that the FDS condition showed significantly greater jump height in all tests compared to the SDS and NS conditions. Further, the SDS trial resulted in significantly greater performance in the drop and squat jump compared to the NS condition. The reasons behind these performance changes are multi-faceted, but appear to be related to increases in heart rate and core temperature with slow dynamic stretches, while the greater increase in performance for the fast dynamic stretch intervention is linked to greater nervous system activation, shown by significant increases in EMG. In conclusion, a faster dynamic stretch component appears to prepare an athlete for a more optimum performance.

Keywords Dynamic stretch velocity · Vertical jump · Electromyography · Post-activation potentiation

Introduction

Pre competition preparation is a vital component in maximising athletic performance, but the optimal preparation strategy is proving elusive to establish. An active warm-up is universally agreed to help increase performance if an increase in core temperature can be attained (Bishop 2003). There should be an increase in heart rate and metabolic rate helping to improve O₂ and fuel transport to tissue, increasing rates of glycolysis and high energy phosphate degradation (Brown et al. 2008; Febbraio et al. 1996) and an increase in nerve transmission rate helping to improve muscle contraction velocity (Bishop 2003).

Part of the active warm-up process has traditionally involved some form of a stretch component, this has often been a static stretch, used in the belief that it would help performance and decrease injury likelihood. However, these claims are now refuted, with injury prevention regarded as unlikely (Shier 1999; Thacker et al. 2004), while there is compelling evidence to show a decrease in strength (Bacurau et al. 2009; Costa et al. 2009; Herda et al. 2008; Morse et al. 2008), power (Manoel et al. 2008; Samuel et al. 2008), speed (Fletcher and Anness 2007; Fletcher and Jones 2004; Nelson et al. 2005; Sayers et al. 2008), jump performance (Holt and Lambourne 2008; Pearce et al. 2009) and agility (Little and Williams 2006) linked to the incorporation of static stretches in a warm-up routine. In response to this evidence there has started to be a drift towards replacing the static stretch component of a warm-up with dynamic stretching (defined as controlled movement through the active range of motion for each joint, Fletcher and Jones 2004). Dynamic stretches as part of a warm-up have almost universally demonstrated an increase in performance when compared to static stretches in a range of high intensity, short duration, performance and muscular

A number of mechanisms have been proposed to explain these observations. It has been shown that dynamic stretches help in the warm-up process, increasing heart rate and core temperature (Yamaguchi and Ishii 2005), therefore linking to the performance enhancement processes of an active warm-up, increasing muscle and tendon suppleness, stimulating peripheral blood flow and enhancing the co-ordination of dynamic movement (Smith 1994). However, other authors (Fletcher and Jones 2004) have controlled the heart rate response by in built rest periods between sets of dynamic stretches, but still showed an increase in performance compared to no stretch and static stretch warm-ups. Therefore, other mechanisms have been proposed. Mann and Jones (1999) suggest that the key attributes of dynamic stretching include enhanced motor unit excitability and improved kinaesthetic sense, leading to improved proprioception and pre-activation. Bishop (2003) hypothesised that dynamic stretches could maintain or improve musculo-tendinous unit (MTU) stiffness and increase nerve impulse transmission, leading to favourable changes in the force-velocity relationship. It has also been postulated, that the reheasal of specific movements prior to performance, could explain dynamic stretches superior performance (Fletcher and Anness 2007). However, these mechanisms have not been fully explored and the reason behind why dynamic stretching seems to help performance is as yet unknown.

One mechanism, of particular relevance to the present study, which has been put forward, is post-activation potentiation (PAP). This is the process when the contractile history of a muscle holds a role in any subsequent muscle contraction (Bishop 2003). There is evidence (Sale 2002) that a conditioning activity prior to performance will increase muscular force, power and speed in subsequent performance. If this is the case, than it may be important to look at the velocity at which dynamic stretches are performed. It is therefore hypothesized that compared to slow dynamic stretches, faster dynamic stretches, as part of an active warm-up, will have a significantly greater effect on performance. This will lead to an increase in any subsequent fast co-ordinated actions required in sport.

Methods

Participants

Twenty-four healthy male collegiate games players (age 21 ± 0.3 years, height 176 ± 6.17 cm and body mass 77 ± 8.2 kg), volunteered and completed a randomised, counter balanced, repeated measures, designed study. Procedures were approved by a Departmental Committee for Ethics. All participants were asked to complete a health screen and if approved were provided with written and oral information regarding the experimental protocol and possible risks of participation; written consent was then obtained. Participants were asked not to consume alcohol or perform any strenuous activity in the previous 24 h prior to each trial. Participants were required not to consume food or any caffeine products for 2 h prior to testing. There was a minimum period of 2 days rest between each of the three test conditions, to prevent any training effect, and trials took place at the same time of day to avoid any diurnal variations.

Experimental procedures

Familiarisation and reliability

Three familiarisation sessions were performed. These consisted of one session practicing the different warm-up procedures, one session examining the reliability of the counter movement jumps (CMJ) drop jumps (DJ) and squat jumps (SJ), chosen to examine performance, and a last session examining the jump reliability with electromyography (EMG) set up included. Each jump was repeated five times, with 3 min rest between maximal efforts, this was then repeated 1 week later to ascertain reliability. The mean jump score was used to produce an intra class correlation coefficient comparing the second and third familiarisation session.

Warm-up protocols

Three different warm-up protocols were used to assess their effect on CMJ, DJ and SJ performance. These consisted of a no stretch (NS) intervention, which involved jogging on a treadmill (H/P/Cosmos Pulsar 4.0, Nussdorf, Germany) for 10 min at 10 km h⁻¹. A slow dynamic stretch (SDS) intervention which incorporated the same jogging warm-up as the NS trial followed by dynamic stretches set at a rhythm of 50 b/min by a metronome (Seiko, DM70 Digital Metronome, China). The other intervention was classified as a fast dynamic stretch (FDS), which involved the NS warm-up and the same dynamic stretches as the SDS trial, but performed at 100 b/min. Exercises used were adapted from Frederick and Frederick’s (2006) work and consisted of 2 × 10 repetitions for the following sub maximal activities, 90° squats, forward lunge and sit-ups and dynamic stretches, forward leg swings, ankle dorsi/plantar flexions, side leg swings, high knees and heel flicks. Dynamic activities and stretches were designed to affect the musculature.
most closely related to jump performance, therefore concentrating around the ankle, knee, hip and torso.

Measurements

Warm-up interventions were performed in a randomised counter balanced manner, with a 1 week gap between trials. Participants were required to perform the designated warm-up protocol followed by a series of jumps (after a 2 min seated rest) in a randomised order. Each jump type was performed 3 times with 2 min seated rest between each repetition. The SJ was performed from a stationary position with a knee angle of 90° with hands placed on hips, knee angle was established using a Universal Goniometer (Baseline, UK) and correlated to a bar set at an appropriate height to reproduce the correct knee angle when subjects touched the bar with their ischial tuberosities (established during the familiarisation process). Hip angle was reviewed kinematically at a later date, resulting in jumps with inconsistent hip angles being removed from analysis. The CMJ was also performed with hands on hips, with participants having a self selected knee flexion, but with no pause between the downward and upward phases of the jump. The DJ was performed from a 0.3 m height, with hands on hips and participants encouraged to jump as high as possible with a minimum of ground contact. The highest correctly performed jump was analysed for each of the three jump types. Jump height was established using a jump mat (Just Jump, Probiotics Inc., Huntsville, USA); participants were encouraged to jump as high as possible with a minimum of ground contact. The highest correctly performed jump was analysed for each of the three jump types. Jump height was established using a jump mat (Just Jump, Probiotics Inc., Huntsville, USA); participants were instructed to jump and land on a central mark to prevent horizontal distance being included in the estimation of vertical height. Jumps not correctly spotted were removed from analysis. Heart rate (Polar Electro, Oy, Finland) and tympanic temperature (TH809 infrared ear thermometer, Radiant Innovation Inc., Hsin Chu City, Taiwan) was recorded pre and post each warm-up intervention.

Electromyographical analysis

EMG analysis of the gastrocnemius, tibialis anterior, biceps femoris and vastus lateralis of the dominant leg, was performed using a Blue Tooth telemetry EMG system (Biometrics Ltd, Gwent, Wales, UK). EMG sites were shaved and cleaned with an alcohol swab (to reduce electrode impedance to below 55 (kΩ), with the reference electrode strip attached to the right ankle in a line with the lateral malleolus. Electrodes were attached onto the skin on the belly of each muscle, with the muscle under contraction; with a standardised inter electrode distance of 2 cm, aligned parallel to the direction of the underlying fibres (Clarys and Cabri 1993). SX230 surface pre-amplified (1 k) electrodes were used at a sampling frequency of 1,000 Hz. A main amplifier (0.3–1 k) was used with a common mode rejection ratio of >96 (dB), with an input impedance of 10,000,000 (MΩ) and input referred noise <5. A pre-amplified high pass eight order elliptical filter (550 Hz) was set, with EMG measured using analogue inputs directly via a PC using a DLK900 Datalink and Datalink software. Raw EMG wave forms were rectified, integrated and averaged over time (average rectified value) for jumps; the CMJ EMG was recorded from the start of the descent phase until take off, the DJ from the point of landing until take off and the SJ from the start of the upward movement until take off, then compared to a normalised EMG wave form (Burdon 2007). Normalisation was conducted at the end of each test session, by performing a maximum isometric contraction (MVC) back squat against a Smith Machine (Marcy Co., Beijing, China) at 90° of knee flexion (established using a Universal Goniometer), with feet hip width apart, with the hip angle controlled and standardised for each participants normalisation session (measured by Universal Goniometer). A 5 s MVC was performed with 0.5 s of the middle second of the MVC used to establish a maximum isometric EMG reading. This allowed the calculation of EMG activation as a % of participants MVC (Burdon et al. 2003).

Kinematic analysis

EMG was synchronised with a Digital Camcorder (Sony HVR-HD 1000E, Sony Corporation, Japan) to establish which parts of the EMG trace represented what movement. The camera was mounted on a tripod recording movement in the sagittal plan. Joint markers were placed on the right side of the body at the mid axillary line level with the sternum, the greater trochanter, the lateral side of the knee joint (lateral collateral ligament), the lateral malleolus, the lateral side of the calcaneus and the head of the fifth metatarsal (Kovacs et al. 1999). The camera was set at a 10 m distance from the performers and at the height of each individual greater trochanter in standing. Kinematic variables were sampled at 100 Hz for the ankle, knee, hip joints and centre of mass, images were analysed through a manual 2D digitising system (KA basic version 6.0, San Francisco, USA).

Data analysis

All data were considered to be normally distributed as the Shapiro–Wilk’s (<50 subjects) test for normality was found to have an alpha level of P > 0.05. A three-way repeated measures ANOVA comparing stretch intervention, jump type and time (pre warm-up, post-warm-up and post-stretch), was used to investigate any differences between conditions. Following the ANOVA a pairwise comparisons post hoc test was performed with a Bonferroni adjustment. Statistical analysis was performed using SPSS version 16 for Windows (SPSS Inc., Chicago, IL, USA) with the alpha
level set at $P \leq 0.05$. Reliability of measures was assessed using an intraclass correlation coefficient (ICC) comparing repeated test measures. Reliability was calculated for resting heart rate (ICC = 0.8) resting core temperature (ICC = 0.83), centre of mass take off velocity (ICC = 0.92) the SJ (ICC = 0.91) and CMJ (ICC = 0.97) and DJ (ICC = 0.98).

### Results

When the data linked to changes in jump height measurements was examined by a three-way repeated measures ANOVA, it was found that the three experimental interventions had a main effect on jump performance ($F = 4.083$, effect size = 0.271, $P < 0.05$), the change over time was significantly different ($F = 28.837$, effect size = 0.724, $P < 0.001$), the interaction of different interventions combined with the three time intervals was also significantly different ($F = 7.702$, effect size = 0.606, $P < 0.001$). These patterns of response were further examined by post hoc analysis to examine the effect of the interaction of individual experimental factors on the variables measured.

**Effect of warm-up interventions on jump height performance**

When main effects for jump performance (Table 1) were examined by pairwise post hoc analysis, countermovement jump height was found to be significantly higher for the FDS intervention compared to the SDS ($P < 0.01$) and NS ($P < 0.001$) conditions (4.1 and 4.9% increase in performance, respectively). The DJ data indicated that the FDS condition’s jumps were significantly higher than the SDS intervention ($P < 0.05$) and the NS intervention ($P < 0.001$) (5.6% and 9.4% increases in performance). There was also a significant increase in performance between the SDS and NS trials ($P < 0.05$) (3.6% increase). The same pattern of response was recorded in the SJ data with a significant increase in performance between the FDS trial and the SDS ($P < 0.01$) and the NS intervention ($P < 0.001$) (a relative increase in performance of 1.9 and 5.6%, respectively). The 3.6% increase in jump height for the SDS trial compared to the NS trial was also significant ($P < 0.05$).

**Effect of individual components of warm-up interventions on jump performance**

When the effects of time on jump performance were examined (Table 2), the NS intervention CMJ indicated that jump performance significantly increased (3.1%) from the pre warm-up to post-active warm-up state ($P < 0.05$), but the rest interval did not change jump performance further. The same pattern of response was shown in the SJ measure, with a significant increase in jump performance when the pre warm-up and post-warm-up ($P < 0.05$) and 2 min rest states ($P < 0.01$) were compared (calculated as a 3.1 and 3.4% increase, respectively). The DJ tests showed a significant increase in DJ performance (4.4%) from pre to post-warm-up state ($P < 0.001$) but, after a 2 min rest a significant decrease ($P < 0.01$) in performance (2.8%) was found.

The SDS intervention found the same main effect for all three jump types; a significant increase ($P < 0.01$) in performance from pre to post-active warm-up was found, but no further change in performance when SDSs were employed.

The FDS intervention had a very different pattern of response; the CMJ performance indicated that there was a non significant ($P > 0.05$) increase in performance (2.3%) pre to post-warm-up, but that post-warm-up, the FDSs had a

### Table 1 Mean (±SD) of jump type measures post-experimental interventions ($n = 24$)

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Countermovement jump (cm)</th>
<th>Drop jump (cm)</th>
<th>Squat jump (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>48.0 ± 7.9*</td>
<td>47.5 ± 7.6*</td>
<td>45.1 ± 7.5*</td>
</tr>
<tr>
<td>SDS</td>
<td>48.4 ± 8.4**</td>
<td>49.2 ± 7.7***</td>
<td>46.7 ± 7.6***</td>
</tr>
<tr>
<td>FDS</td>
<td>50.4 ± 8.5***</td>
<td>51.9 ± 8.9***</td>
<td>47.6 ± 8.5***</td>
</tr>
</tbody>
</table>

* Significant differences between NS, SPS and ADS conditions.
** Significant differences between SPS and FDS conditions ($P \leq 0.05$)

### Table 2 Mean (±SD) of jump type measures during each experimental intervention ($n = 24$)

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Countermovement jump (cm)</th>
<th>Drop jump (cm)</th>
<th>Squat jump (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>Pre warm-up 46.5 ± 8.4*</td>
<td>46.7 ± 8.3*</td>
<td>43.6 ± 8.5*</td>
</tr>
<tr>
<td></td>
<td>Post-warm-up 47.9 ± 8.7*</td>
<td>48.8 ± 8.3***</td>
<td>45.0 ± 8.5*</td>
</tr>
<tr>
<td></td>
<td>2 min rest 48.0 ± 7.9*</td>
<td>47.5 ± 7.6**</td>
<td>45.1 ± 7.4*</td>
</tr>
<tr>
<td>SDS</td>
<td>Pre warm-up 47.0 ± 7.7*</td>
<td>47.2 ± 7.3*</td>
<td>45.1 ± 7.6*</td>
</tr>
<tr>
<td></td>
<td>Post-warm-up 48.5 ± 8.7*</td>
<td>48.9 ± 7.5*</td>
<td>46.6 ± 8.3*</td>
</tr>
<tr>
<td></td>
<td>Post-intervention 48.4 ± 8.4*</td>
<td>49.2 ± 7.7*</td>
<td>46.7 ± 7.6*</td>
</tr>
<tr>
<td>FDS</td>
<td>Pre warm-up 47.2 ± 8.4*</td>
<td>47.6 ± 7.9*</td>
<td>45.1 ± 8.1*</td>
</tr>
<tr>
<td></td>
<td>Post-warm-up 48.3 ± 9.2**</td>
<td>48.7 ± 8.3***</td>
<td>46.1 ± 8.5***</td>
</tr>
<tr>
<td></td>
<td>Post-intervention 50.4 ± 8.5***</td>
<td>51.9 ± 8.9***</td>
<td>47.6 ± 8.5***</td>
</tr>
</tbody>
</table>

* Significant differences between pre warm-up, post-warm-up and post-intervention conditions. ** Significant differences between post-warm-up and post-intervention conditions ($P \leq 0.05$)
significant increase (4.4%) in performance ($P < 0.001$). The DJ tests pattern of response was found to show a significant increase ($P < 0.05$) in jump performance pre to post-active warm-up (2.4%) and a further increase ($P < 0.001$) post-stretch intervention (6.6%). The same pattern was exhibited in the SJ test showing a significant increase ($P < 0.05$) in jump height pre to post-warm-up (2.3%), with a large increase ($P < 0.001$) post-stretch (3.3%).

Effect of warm-up interventions on heart rate and core temperature

When heart rate main effect was examined ($F = 73.797$, effect size = 0.855, $P < 0.001$), the post-intervention heart rate showed (Table 3) that there was a significant increase in heart rate for the SDS ($P < 0.001$) and the FDS ($P < 0.001$) interventions compared to the NS trial. Core temperature interaction effects ($F = 48.328$, effect size = 0.845, $p < 0.001$), indicated that the difference between the pre and post-core temperatures for the FDS intervention (0.2°) and the SDS intervention (0.2°) increases were found to be significantly greater ($P < 0.001$) then the NS temperature increase (0.1°).

Effect of warm-up interventions on jump kinematic variables

The kinematic main effects found to be significant were knee movement between interventions ($F = 9.612$, effect size = 0.410, $P < 0.05$) and take off velocity between interventions ($F = 8.827$, effect size = 0.317, $P < 0.01$). Pairwise comparisons (Table 4) showed the same pattern of response for the CMJ and the DJ, with a significant increase ($P < 0.05$) in the knee ROM for the CMJ and DJ tests when the SDS and FDS trials were compared to the NS condition, but no difference between the SDS and FDS interventions. Take off velocity’s main effects (Table 4) indicated a significant increase ($P < 0.01$) in performance in all three jump tests for the FDS condition compared to the NS and SDS trials. The SDS intervention was also significantly superior ($P < 0.01$) to the NS trial.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Mean (±SD) for heart rate pre and post-interventions (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention</td>
<td>Pre intervention heart rate (b/min)</td>
</tr>
<tr>
<td>NS</td>
<td>68.3 ± 4.4</td>
</tr>
<tr>
<td>SDS</td>
<td>69.9 ± 6.6</td>
</tr>
<tr>
<td>FDS</td>
<td>68.2 ± 8.3</td>
</tr>
</tbody>
</table>

* Significant differences between NS, SDS and FDS conditions. ** Significant differences between SDS and FDS conditions ($P \leq 0.05$)

Effect of warm-up interventions on EMG output

When the EMG data were analysed (Table 5) the significant interaction effect was the three interventions, the jump measurements and the muscles analysed ($F = 82.193$, effect size = 0.998, $P < 0.05$). Post hoc analysis indicated that the gastrocnemius in the CMJ in the FDS condition had a significantly higher ($P < 0.05$) EMG output than the NS trial. The DJ data for the biceps femoris indicated that the FDS trial was significantly higher ($P < 0.05$) than the NS condition; a pattern of response matched in the vastus lateralis ($P < 0.05$). In the SJ the vastus lateralis EMG analysis for the FDS trial was significantly higher ($P < 0.05$) than the NS intervention.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Mean (±SD) for knee movement and centre of mass (CoM) velocity for jump tests (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention</td>
<td>Counter movement jump</td>
</tr>
<tr>
<td>NS</td>
<td>Knee joint (°) 84.2 ± 10.3*</td>
</tr>
<tr>
<td>SDS</td>
<td>Knee joint (°) 92.6 ± 14.6*</td>
</tr>
<tr>
<td>FDS</td>
<td>Knee joint (°) 91.2 ± 14.3*</td>
</tr>
</tbody>
</table>

* Significant differences between NS, SDS and FDS conditions. ** Significant differences between SDS and FDS conditions ($P \leq 0.05$)

Discussion

The results from this study indicate that jump height was significantly increased in all three vertical jump types when an active warm-up was employed. This change in performance was further increased when dynamic stretches were added to the warm-up process. This increase in performance linked to dynamic stretching has been shown a number of times (Faigenbaum et al. 2005; Fletcher and Anness 2007; Fletcher and Jones 2004; Holm and Lombaure 2008; Manoel et al. 2008; Moran et al. 2009; Nelson et al. 2005; Pearce et al. 2009; Wallmann et al. 2005; Winchester et al. 2008). However, the velocity of the dynamic stretches involved in these studies has not been examined. In the present study slow dynamic and FDSs were compared, with the faster stretch modality showing a significant increase in jump performances compared to the slow stretch regime.

The increases in jump height linked to the employment of an active warm-up are not surprising and well
documented (Behm et al. 2001; Smith 1994), linked to a stimulation of blood flow and an improvement in the force velocity relationship (Behm et al. 2001). The present study demonstrates an increase in heart rate and core temperature, suggested by Bishop (2003) to lead to positive metabolic effects, increased vasodilatory tone and blood flow, though in light of the short-term maximal exertions conducted in the present study, it may be of more relevance to note that an increase in nerve receptor sensitivity and nerve impulse velocity, can be the result of increases in muscle temperature, resulting in a more rapid and forceful muscle contraction (Faigenbaum et al. 2005).

The use of dynamic stretches increases warm-up intensity and seems to increase heart rate and core temperature above changes found in an active warm-up alone, but it fails to explain the further increase in performance through employing faster dynamic stretches compared to SDSs, as core temperature was not significantly different between these interventions. One theory put forward to explain these performance changes was the possible positive effect of increasing MTU stiffness (Bishop 2003). A stiffer MTU is required for a good rebound ensuring a fast transmission of muscular force to bones producing explosive forceful movement (Kubo et al. 2001). In the present study MTU stiffness was not measured directly, but the functional stiffness can be estimated from the knee movement in vertical jumping (as suggested by Knudson et al. 2001). Knee ROM was found to be greater in the CMJ and DJ for the SDS and FDS compared to the NS warm-up, probably due to increases in muscle extensibility linked to greater temperature increases than in the NS condition. As the amount of elastic energy stored in the MTU is a function of its stiffness (Ingen 1984; Shorten 1987), this could have lead to a decrease in performance in the stretch shortening cycles (SSC) seen in the DJ and CMJ. However this is not the case, suggesting that MTU stiffness changes do not help explain the findings in this study; of greater relevance could be the EMG findings.

There seems to be an increase in EMG in the FDS compared to the NS condition (highlighted by significant increases in EMG activity in the vastus lateralis in the DJ and SJ tests and the biceps femoris in the DJ and the gastrocnemius in the CMJ). No significant changes were found when SDSs were employed, which could indicate that a faster action, closer to the movement velocity seen in vertical jumps, may prime skeletal muscle for acute performance. It has been demonstrated that the contractile history of muscle holds a role in subsequent muscle contraction (Bishop 2003). This is known as PAP, where rehearsal of skilled movement through specific warm-up protocol design may condition muscles to bring about more rapid/forceful contraction (Sale 2002) linked to increasing the rate of force development; which would certainly have a positive effect on jump performance. PAP is considered to be non temperature related (Bishop 2003) and, though often linked to maximal contractions prior to performance, can be evoked by sub maximal priming exercises (Ce et al. 2008). If PAP is being induced in the dynamic stretch warm-up modalities, it is more likely to be linked to the higher intensity movements in the FDS condition causing the increase in motor neurone excitability demonstrated by the increase in EMG in the FDS intervention compared to the NS trial, rather than the SDS intervention. It should be remembered that the magnitude of the myotatic reflex is related to stretching velocity (Gollhofer and Rapp 1993; Gottlieb and Garwal 1979), by increasing stretching speed greater action potential of the myotatic reflex may result. This is demonstrated by the velocity of CoM at take off, which indicates that the SDS condition had significantly faster take off then the NS condition (possibly linked to temperature changes), while the FDS condition had significantly faster take offs compared to the SDS trial due to an increase in neural stimulation. This increase in take off velocity is likely to explain the increases in performance that the SDS and FDS conditions have demonstrated.

The different jump tests results are interesting, with the jumps with a faster SSC exhibiting a greater increase in performance in the FDS condition. The DJ has a 6.6% increase in performance from post-warm-up to post-stretch, compared to the CMJ increase of 4.4% and a SJ increase of 3.3% (a pattern of response shown to be significant.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Counter movement jump (%)</th>
<th>Drop jump (%)</th>
<th>Squat jump (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>Biceps femoris 116.4 ± 26.7</td>
<td>95.0 ± 29.6*</td>
<td>127.5 ± 35.0</td>
</tr>
<tr>
<td></td>
<td>Vastus lateralis 115.9 ± 13.1</td>
<td>98.5 ± 7.9*</td>
<td>115.5 ± 9.7*</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius 113.1 ± 8.0*</td>
<td>122.1 ± 14.7</td>
<td>140.1 ± 27.1</td>
</tr>
<tr>
<td></td>
<td>Tibialis anterior 103.1 ± 31.0</td>
<td>105.9 ± 37.8</td>
<td>103.2 ± 20.8</td>
</tr>
<tr>
<td>SDS</td>
<td>Biceps femoris 116.3 ± 26.2</td>
<td>128.6 ± 27.7</td>
<td>125.7 ± 37.1</td>
</tr>
<tr>
<td></td>
<td>Vastus lateralis 113.7 ± 19.8</td>
<td>107.1 ± 33.7</td>
<td>116.6 ± 21.5</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius 120.1 ± 19.6</td>
<td>119.4 ± 39.2</td>
<td>129.7 ± 31.6</td>
</tr>
<tr>
<td></td>
<td>Tibialis anterior 111.6 ± 28.5</td>
<td>117.7 ± 34.3</td>
<td>108.0 ± 21.4</td>
</tr>
<tr>
<td>FDS</td>
<td>Biceps femoris 125.4 ± 18.1</td>
<td>133.7 ± 21.8*</td>
<td>131.7 ± 33.7</td>
</tr>
<tr>
<td></td>
<td>Vastus lateralis 128.9 ± 35.9</td>
<td>116.1 ± 17.5*</td>
<td>129.3 ± 15.5*</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius 128.6 ± 11.5*</td>
<td>132.4 ± 19.6</td>
<td>140.1 ± 27.1</td>
</tr>
<tr>
<td></td>
<td>Tibialis anterior 127.4 ± 34.9</td>
<td>116.3 ± 11.4</td>
<td>119.0 ± 19.5</td>
</tr>
</tbody>
</table>

* Significant differences between NS and FDS conditions ($P \leq 0.05$)
It seems possible that the faster stretch regime, which would have a faster SSC (particularly in actions such as the squat and lunge), could have primed muscle for subsequent action to a greater extent in the more complex test (DJ) with a greater invocation of the eccentric phase of the SSC. The more rapid the eccentric phase of a SSC, the greater the stored energy in the MTU, which is transferred to the concentric phase. Therefore, it is possible that the FDS condition evoked segmental reflexes potentiating the subsequent muscle activation (supported by the EMG results), this excitation could decrease the electromechanical delay (Ettema 2001) decreasing the amortization phase and increasing subsequent power production. This was the conclusion of Little and Williams (2006) to explain their results; vertical jump performance was not enhanced by dynamic stretches, but the more complex and faster movements in an agility test were significantly improved. However this should be viewed with some caution, as their dynamic stretch warm-up method was substantially different to the present study, but is an area that deserves future research.

In conclusion, dynamic stretches as part of an active warm-up appear to cause significantly greater performance increases compared to warm-up with NS, related to core temperature increases. However, the faster dynamic stretch intervention had no greater increase in temperature compared to the SDS regime; therefore the significant increase in performance in the FDS trial is probably due to a priming of the muscle, linked to a significantly greater increase in EMG magnitude. Therefore, it is recommended that for athletes needing to perform short-term maximal motor capabilities, faster dynamic stretches should be employed rather than any other stretch modality.

Acknowledgments This is to confirm that the experiments in this article comply with the current laws of the country they were performed in.

Conflict of interest statement None.

References


Frederick A, Frederick C (2006) Stretch to win. Human Kinetics, Champaign


