Short- and moderate-duration static stretching do not decrease vertical jump performance when performed with a complete, sport-specific warm-up

Alvin M. Goh

Edith Cowan University

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3rd November 2014

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Date
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Edith Cowan University

Short- and moderate-duration static stretching do not decrease vertical jump performance when performed with a complete, sport-specific warm-up.

A thesis submitted in partial fulfilment of the requirements for the Award of Bachelor of Exercise and Sports Science (Honours)

By

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Submitted November, 2014

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I declare that this thesis is my own work and does not include:
(i) Material from published sources used without proper acknowledgement;
or (ii) Material copied from the work of other students.
Abstract

Background: Research has shown that static stretching may improve muscle flexibility as well as minimise soft tissue injury. However, recent studies have recommended the removal of static muscle stretching from pre-exercise routines due to its deleterious effect on physical performance. Nonetheless, research has shown a duration-dependent effect of static stretching, with total muscle stretch durations < 45 s having little influence on subsequent sporting performance. Furthermore, some evidence indicates that muscle stretching may not influence performance when a sport-specific warm-up follows the stretching component. However, this protocol has not been implemented in most studies.

Purpose: The purpose of the present study was to compare the effects of shorter (5 s) and longer (30 s) periods of static stretching to dynamic stretching on vertical jump performance in sub-elite athletes when the stretches are completed early in a complete pre-exercise routine. It was hypothesised that none of the three stretching conditions would elicit reductions in jumping performance when compared to a no-stretch condition, but that both static stretch conditions would induce greater improvements in ROM.

Design and Methods: Twenty healthy, athletic men (age = 21.1 ± 3.1 years; body mass = 73.37 ± 6.83 kg; height = 179.2 ± 70.13 cm) volunteered for this study. The participants were tested under four experimental conditions where 1) 5 s static stretching, 2) 30 s static stretching, 3) dynamic stretching, or 4) no stretching was performed after a short warm-up but before a longer, task-specific warm-up. Following all conditions, participants were tested with standard laboratory- and field-based (squat, countermovement and depth jump) and sport-specific (3 m running vertical jump) tests as well as a test of static range-of-motion (ROM) (sit-and-reach). Repeated measures multiple analyses of variance (MANOVAs) were
used to compare the test performance between conditions with alpha level set at 0.05. Magnitude-based inference tests were then used to analyse the likelihood of an effect having a standardised (Cohen’s) effect size exceeding 0.20.

**Results:** There were no significant differences between conditions for vertical jump ($p > 0.290$) or sit-and-reach ($p = 0.076$) tests. The three stretch conditions were >85% likely to have trivial effects on the 3 m running vertical jump and countermovement jump scores when compared to the control (no stretch) condition. The dynamic stretch condition was 98% likely to elicit trivial effects on sit-and-reach score. There was a 96% likelihood that differences in countermovement jump height between the 5 s static stretch and dynamic stretch conditions were trivial.

**Conclusions:** Given that no significant differences were observed between stretching conditions, the current findings demonstrated no unfavourable effects of static stretching on subsequent jumping performance when included as part of a complete pre-exercise routine. Although these durations of static stretching did not tend to show improvements in ROM, other potential benefits such as injury prevention or peripheral feedback may exist. Hence, recommendations to exclude static stretching in a pre-exercise routine seem premature. However, further research is warranted to investigate the benefits of static stretching in order to recommend its inclusion.
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I certify that this thesis does not, to the best of my knowledge and belief:

i. incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

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iii. contain any defamatory material.

Signed

Date: 3rd November 2014
Acknowledgements

I would firstly like to thank my supervisors Assoc. Prof Anthony Blazevich and Dr Eric Drinkwater for their devotion, patience and guidance throughout this research. Your wealth of knowledge and expertise has helped me to complete this project and taught me to be a better writer, researcher and sports scientist. You have both inspired me to keep wanting to learn.

I would like to acknowledge my mother who has seen the family through the toughest of times and without her foresight, I would not even have made it to Australia. Mom, I owe all my ambitions and successes to you.

Special thanks goes out to the Howard family for taking me under their wing and making my academic journey as comfortable as they could, always treating me as one of their own. Also, I would like to acknowledge my post-graduate buddies Annika Kuck and Chantelle du Plessis for being incredible friends and keeping me sane through turbulent times.

Finally, I would like to thank all the participants and lab assistants, with special mention to Rhett Walker for being an incredible number two, who gave up their time to be a part of this research. Without them, this study would not have been possible.
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<td>5S</td>
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<tr>
<td>30S</td>
<td>30 s static stretch condition</td>
</tr>
<tr>
<td>DYN</td>
<td>Dynamic stretch condition</td>
</tr>
<tr>
<td>NS</td>
<td>No-stretch condition</td>
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<tr>
<td>POD</td>
<td>Point of discomfort</td>
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<tr>
<td>ROM</td>
<td>Range of motion</td>
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<td>SSC</td>
<td>Stretch-shortening cycle</td>
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Introduction

It is common practice for players of sport to engage in a pre-exercise routine, which usually consists of a period of muscle stretching, a dynamic warm-up or both, prior to the main exercise session or competition (Kay & Blazevich, 2008; Rubini, Costa, & Gomes, 2007; Young & Behm, 2002). Traditionally, the warm-up component consists of a submaximal aerobic phase (e.g. running, cycling) with the goal of raising the body temperature by 1-2° (Young, 2007; Young & Behm, 2002), which has been found to increase enzymatic cycling, nerve conduction velocity and muscle compliance allowing for improved muscular performance (Bishop, 2003).

Static and dynamic muscle stretching are also commonly employed in pre-exercise routines. Static stretching has been considered an essential component of a pre-exercise routine and usually involves moving a limb to the end of its range-of-motion (ROM) and holding in the stretched position for 15-60 s (Young & Behm, 2002). Whereas static stretching lengthens a muscle via slow, deliberate movements, dynamic stretching incorporates bouncing or jerking motions to stretch a muscle group (Woods, Bishop, & Jones, 2007). Given that these two types of stretching might elicit different physiological effects, many studies have compared the outcomes of each modality (Behm & Chaouachi, 2011; Hough, Ross, & Howatson, 2009; McMillian, Moore, Hatler, & Taylor, 2006; Samson, Button, Chaouachi, & Behm, 2012). Studying the influence of pre-exercise static and dynamic stretching is of particular relevance to athletic performance. The following section discusses the effects of these types of stretching by assessing the relations between pre-exercise stretching, injury prevention, flexibility and sporting performance.
**Role in improving joint range of motion (ROM) and reducing injury risk**

Flexibility is determined by both the resistance of a joint (and associated soft tissue structures) to a change in angle as well as its maximum (i.e. peak) ROM. With specific respect to ROM, improvements in flexibility could augment performance in a number of sports which require a pronounced ROM. Gymnasts and synchronised swimmers require a large ROM at the hips to achieve the split position and soccer goalkeepers capitalise on flexibility of the leg adductor muscles to make a low save. In this respect, the review of Thacker, Gilchrist, Stroup, and Kimsey Jr (2004) found a clear acute effect of static (passive) muscle stretching on joint flexibility of the hip, knee, trunk and ankle joints. Perrier, Pavol, and Hoffman (2011) have shown similar significant improvements in ROM (e.g. sit-and-reach score) when either pre-exercise static or dynamic stretching was performed. However, when implemented as part of a full pre-exercise routine (i.e. rather than in isolation), Samson et al. (2012) found an improvement in sit-and-reach ROM (2.8%) in the static stretch condition only without any change in the dynamic condition. This suggests a possible beneficial effect of static stretching on ROM when incorporated into a pre-exercise routine, which may be an important consideration for performance in sports that involve skills such as kicking, running, jumping or dance-type movements where large ROMs are necessary (Rubini et al., 2007).

Conventional wisdom indicates that the benefits of pre-exercise stretching include injury prevention and minimisation of delayed onset of muscle soreness (DOMS) (Power, Behm, Cahill, Carroll, & Young, 2004; Rubini et al., 2007). Recently, however, such conventional wisdom has been questioned. With respect to the effect of pre-exercise muscle stretching on injury risk, researchers have concluded that there is a lack of notable effect of static stretching on the prevention of injuries (Rubini et al., 2007; Thacker et al., 2004), at least when all
injuries are considered regardless of their aetiology. Nonetheless, there is recent evidence suggesting that an acute bout of static stretch is beneficial for the prevention of soft tissue injuries (Herbert & Gabriel, 2002; Pope, Herbert, Kirwan, & Graham, 2000). Studies have observed decreases in the number of muscle/tendon and ligament injuries in individuals who performed pre-exercise static stretching, when compared to individuals who performed no stretching in the same period (Amako, Oda, Masuoka, Yokoi, & Campisi, 2003; Bixler & Jones, 1992; Cross & Worrell, 1999). This information potentially justifies the inclusion of static muscle stretching within a pre-exercise routine due to the common occurrence of soft tissue injuries such as muscular strains and sprains in many sporting contexts. However, issues remain about how the inclusion of static or dynamic influence athletic performance when incorporated in a pre-exercise routine.

Effects of pre-exercise stretching on vertical jumping performance

Vertical jumping is performed in many sports, typically with the aim of catching a ball or other object, or preventing an opponent catching the ball or object. In other sports, jumping is also performed with the aim of increasing the likelihood of success in a task (e.g. basketball jump shot or volleyball spike). It is therefore of substantial practical importance to understand the effect of the pre-exercise routine, and in particular the potential influence of the muscle stretching component of this routine, on jumping performance. In this respect, there is evidence of an inadvertent adverse effect of pre-exercise static stretching on subsequent jumping performance. A wealth of evidence indicates that muscular force and power production, as well as athletic performance, may be negatively affected when static stretching is imposed before exercise (Behm, Bambury, Cahill, & Power, 2004; Behm & Chaouachi, 2011; Kay & Blazevich, 2012; McHugh & Cosgrave, 2010; Power et al., 2004), and this
effect has been shown specifically for vertical jumping (Nelson, Cornwell, & Heise, 1996; Wallmann, Mercer, & McWhorter, 2005; Young & Behm, 2003).

In contrast to the effect of static stretching, evidence suggests that athletic performance may be improved after dynamic stretching (Behm & Chaouachi, 2011; Torres et al., 2008). This appears to be partially true for vertical jump performance, with dynamic stretching either facilitating jump performance (Holt & Lambourne, 2008; Hough et al., 2009; Jaggers, Swank, Frost, & Lee, 2008; Pearce, Kidgell, Zois, & Carlson, 2009) or having no adverse effect (Christensen & Nordstrom, 2008; Samuel, Holcomb, Guadagnoli, Rubley, & Wallmann, 2008; Torres et al., 2008; Unick, Kieffer, Cheesman, & Feeney, 2005). The disparity in results between the two modes of stretching on vertical jump performance compels us to compare these effects when stretch duration, intensity and movement patterns are replicated as far as possible.

**Effect of stretching duration**

One area of research focus has been to understand the effects of stretch durations on subsequent exercise performance. Indeed, shorter durations of stretch (e.g. 5 s) have been shown to have a similar effect on muscle-tendon properties (i.e. stiffness) as longer durations of stretch (e.g. $4 \times 15$ s) (Kay & Blazevich, 2008). Furthermore, a bout of static stretching (45 s) did not affect vertical jump performance or influence the eccentric and concentric phase durations (Knudson, Bennett, Corn, Leick, & Smith, 2001), which is a good indicator of jump technique (Cormie, McBride, & McCaulley, 2009). This may indicate a duration-dependent effect of static stretching on jump performance, as indicated by Kay and Blazevich (2012) and Behm and Chaouachi (2011). Therefore, the possibility exists that short periods of static stretch (<45 s), which are insufficient to reduce muscular force and athletic performance (Kay & Blazevich, 2012), may still provide benefits in ROM or injury
prevention to athletes when used in a pre-exercise routine. As a result, the evidence is unclear regarding the potentially detrimental effects of pre-exercise muscle stretching during the pre-exercise routine, at least when stretch durations are shorter (e.g. <45 s).

**The effect static stretching when performed as part of a complete pre-exercise routine**

In the athletic setting, the stretching component is usually included as part of a pre-exercise routine and rarely occurs in isolation. The traditional warm-up comprises a three-step process in the sequence of an aerobic warm-up, a bout of static stretching and then skill-specific dynamic activities. It was suggested by Young (2007) that moderate volumes of static stretching have limited impact on subsequent performance when performed in this order. Young and Behm (2003) found that a run + static stretching + practice jump protocol was superior to both run-only and run + static stretching protocols on subsequent jump performance, showing that the sport-specific component (practice jumps) produced a positive effect. A study by Gelen (2010) found that a pre-exercise routine with the sequence of aerobic warm-up + static stretching + dynamic stretching had no effect on sprint time, soccer penalty kick distance or dribbling ability when compared to an aerobic warm-up + static stretching protocol. These findings suggest that the performance of either dynamic stretching or a sport-specific movement component immediately following static stretching may ensure that no deleterious effect of stretching on physical performance is observed. Thus, under specific conditions that are common in the athletic setting, the inclusion of static stretching may not pose a risk to sporting performance.

Nonetheless, most previous studies have not included a warm-up component (or only a short warm-up period was provided) prior to performance testing. Furthermore, in studies where a warm-up protocol was included, this component was often imposed before the muscle stretching period (Behm et al., 2004; Samson et al., 2012) whereas in a typical pre-exercise
In routine a complete warm-up is performed after any period of muscle stretching. In relation to this, two recent studies have reported a lack of effect of static stretching (compared to dynamic stretching) on sprint, jump and agility performance when a prolonged warm-up period was included after muscle stretching in the study protocol (Samson et al., 2012; Taylor, Sheppard, Lee, & Plummer, 2009). Thus, the small body of evidence to date indicates that the inclusion of a warm-up period after static stretching may allow performances equal to those provided by dynamic muscle stretching. It is of practical interest, therefore, to investigate how these findings translate to various measures of vertical jump performance when static stretching is completed before a complete, sport-specific warm-up. In particular, no studies have compared the effects of shorter stretch durations of static stretch (e.g. 30 s vs. 5 s) on athletic performance, or their effects relative to dynamic stretching. It would therefore be of practical interest to determine their effects when included as part of a complete, sport-specific warm-up.

**Purpose of the study and research hypothesis**

The purpose of the present study is to compare the effects of shorter (5 s) and longer (30 s) periods of static stretching to dynamic stretching on vertical jump performance in athletic subjects when the stretches are completed early in a complete pre-exercise routine. Given that jump tasks vary between sports, it was considered important to examine the impact of stretching on both standard laboratory- and field-based (squat, countermovement and depth jump) and sport-specific (3 m running vertical jump) tests. Additionally, a test of static ROM (sit-and-reach) was included to determine whether stretch condition affects it. It was hypothesised that none of the three stretching conditions would affect jumping performance when compared to a no-stretch condition; however both static stretch conditions were
predicted to induce greater improvements in ROM than dynamic stretching and the no-stretch control.

Methods

Participants

Twenty healthy males (age = 21.1 ± 3.1 years; body mass = 73.37 ± 6.83 kg; height = 179.2 ± 70.13 cm) were recruited for this study. The sample size matches or exceeds those used in previous repeated measures research designs examining the influence of pre-exercise muscle stretching (Kay & Blazevich, 2012; Rubini et al., 2007). Participants were recruited if they were: between 18 to 25 years of age; without recent injury or illness that would preclude exercise performance; competing in running-based sports or performing at least three running-based exercise sessions per week, and; available for a familiarisation and four testing sessions over a maximum of five consecutive weeks. The methodology and testing procedures used in this study were approved by the ethics committee (Project No. 11385) of Edith Cowan University, Western Australia. All participants were provided with a clear explanation of the study’s purpose and testing procedures as well as the risks and benefits of the study. They were required to read and sign an informed consent form prior to testing (see Appendix A).

General study design

This study used a randomised, repeated measures, cross-over design with a control group, and was designed to assess the effect of dynamic vs. both shorter (5 s) and longer (30 s) duration static muscle stretching on vertical jump performance. There were three experimental (stretching) conditions and a control condition, and four vertical jump tests were completed.
The experimental and control conditions were performed separately over four testing sessions, with each session separated by a minimum of 72 h. The order of the conditions and order of tests within each condition were randomised among the participants. The testing was performed after the completion of a pre-exercise routine that included one of the four conditions, as shown in Figure 1. A familiarisation session was completed by each participant prior to data collection to become accustomed with the stretching protocols, testing procedures, equipment and laboratory facility as well as the verbal stretch exercise and test instructions issued by the testers. Participants were permitted to consume plain water *ad libitum* throughout the testing sessions. A 7-min passive rest period separated the completion of the warm-up/stretching period from the commencement of testing in order to more closely simulate game-day situations where a short pre-competition briefing or an individual-specific sport preparation period is completed before match or competition commencement. This allowed the determination of the likely effect of the different pre-exercise routine conditions on game- or match-day performance. All sessions were conducted in the biomechanics laboratory at Edith Cowan University and performed under similar environmental conditions. Participants were required to: wear appropriate shoes and athletic clothing; refrain from intensive exercise in the 24-h period before testing; and abstain from caffeine or any form of stimulant 24 h prior to testing. A survey was issued prior to each testing session to ensure that no intense physical activity was conducted and no physical discomfort was felt (e.g. muscle soreness) in the previous 24 h (see Appendix B).
Figure 1. Diagrammatic representation of the experimental protocol during each testing session.

The performance testing battery was categorised into two testing stations: 1) running vertical jump test (Vertec, Swift Performance Equipment, Australia), and 2) three jump tests from on a force platform (9287B, Kistler Instrumente, Switzerland) - squat jump (SJ), countermovement jump (CMJ) and depth jump from 40 cm height (DJ40). After significant pilot testing it was determined that 4 min would be allocated to each test station with 30-s passive rest between jump trials so that constant test timing was achieved regardless of the order of tests. A free online shot clock (www.interval-timer.com) was used to signal the end of the 4-min periods, at which stage the participant would commence the next set of tests. Each jump test was performed twice and the best score was used for analysis. A third trial was allowed if test results varied >5%.

Independent variables

Details of the standardised short, pre-stretching warm-up and the complete, test-specific (i.e. sport-specific), post-stretch warm-up (see Figure 1) protocols are summarised in Table 1. Heart rate was obtained immediately after each warm-up phase by manual palpation of the carotid artery. High knees (to ~90° hip flexion) and heel-to-butt kick drills were performed at 50% (short warm-up) and 60% (test-specific warm-up) of perceived maximum intensity, with
arm movement allowed; note that the percentages of perceived intensities are different to percentages of maximal heart rate (Meyer, Gabriel, & Kindermann, 1999). A 30-s passive rest was imposed after the short warm-up before proceeding to the stretching condition allocated to the session. For the control condition, the subjects commenced the test-specific warm-up after this brief rest.

The complete, test-specific warm-up comprised a circuit with six exercise activities to provide a broad warm-up effect: 1) 20 m sprint, 2) 3-m running vertical jump, 3) squat jump, 4) countermovement jump 5), drop jump, and 6) agility T-test. Each activity was performed at 60, 80 and then 100% of perceived maximal exertion with a 30-s rest between each exercise before moving to the next activity.

Table 1. Summary of warm-up protocols used in the study.

<table>
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<th>Short warm-up (before stretch)</th>
<th>Complete, sport-specific warm-up (after stretch)</th>
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<tbody>
<tr>
<td>1. 3-min low-intensity jog (50% perceived intensity)</td>
<td>1. 2-min moderate intensity jog (60% perceived intensity)</td>
</tr>
<tr>
<td>2. 5 s high knees (50% perceived intensity)</td>
<td>2. 5 s high knees (60% perceived intensity)</td>
</tr>
<tr>
<td>3. 5 s heel-to-butt kicks (50% perceived intensity)</td>
<td>3. 5 s heel-to-butt kicks (60% perceived intensity)</td>
</tr>
<tr>
<td></td>
<td>4. Testing circuits, completed at 60, 80 and 100% perceived level of exertion, with 30 s walking recovery between each test.</td>
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<tr>
<td></td>
<td>a. 20 m sprint</td>
</tr>
<tr>
<td></td>
<td>b. 3 m running vertical jump</td>
</tr>
<tr>
<td></td>
<td>c. Squat jump, countermovement jump, drop jump (40 cm)</td>
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<tr>
<td></td>
<td>d. Agility T-test</td>
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</table>

Specifically, the four conditions were a 5-repetition (per muscle group) dynamic stretch (DYN), 5-s static stretch (5S), a 30-s static stretch (30S) and a no-stretch condition (NS) (see
details and photographs in Appendix C). The 5S, 30S and DYN stretching protocols each consisted of nine stretches that were close replicates of each other in order to minimise the likelihood that performance differences might be elicited by the different movement patterns achieved with the stretches, and therefore to more clearly isolate the effects of stretching mode. The static stretches were held at the point of discomfort (POD) and maximal ROM was achieved in the dynamic stretches by ensuring a secondary pulling-motion with each repetition (see Figure 2).

Figure 2. Pictures showing two examples of ‘secondary pulling-motion’ in dynamic stretching to achieve maximal ROM. The top row shows the quadriceps stretch before (left) and after (right) the pulling-motion. The bottom row shows the gluteal stretch before (left) and after (right) the pulling motion.
Dependent variables

**Sit-and-reach score**

The sit-and-reach test was conducted using the Flex-Tester apparatus (Novel Products Inc., USA). Previous studies have indicated reliability estimates as being consistently high (.96 < R < .99) (Jones, Rikli, Max, & Noffal, 1998) with moderate criterion-related validity (r = 0.51 – 0.72) when used to assess hamstring flexibility (Shimon, Darden, Martinez, & Clouse-Snell, 2010). A double-leg protocol was used following that of Hartman and Looney (2003) and prescribed by the Canadian Society for Exercise Physiology. Each participant was instructed to sit bare-footed with knees in maximal extension, with both feet together and flat against the device. The participant then exhaled and stretched forward with palms overlapping and fingertips aligned, holding the furthest end point for 2 s. The score was recorded to the nearest 0.1 cm and repeated after a 30-s rest, with the greatest ROM used for the analysis.

**3-m running vertical jump height**

A jump-and-reach system (Vertec, Swift Performance Equipment, Australia) was used for the running vertical jump to directly measure jump height based on the difference between reach height and jump height obtained. Reported reliability of the device is high in males (ICC = 0.94, CV = 4.6%) (Nuzzo, Anning, & Scharfenberg, 2011). The Vertec device had 100 colour-coded, movable vanes that were each spaced 1 cm apart. Reach height was obtained before each session with the participant standing in a static position underneath the Vertec device and reaching as high as possible with the arm touching their ear. Each participant’s take-off foot was pre-determined during the familiarisation session. A self-selected standing position was assumed 3 m from the device and the position was kept consistent across all testing sessions. At their own volition, the participant executed a running, single-leg jump to
displace the Vertec vanes with the opposite hand. The jump height was recorded as the number below the score reflected on the Vertec device to accurately show the vertical height jumped. Each participant was given a maximum of five attempts; however the test was stopped when the participant failed to further improve jump scores on two successive attempts. The best score was used for the analysis and a 30-s passive rest was imposed between each jump.

*Squat (SJ), countermovement (CMJ) and depth (DJ40) jump heights*

A piezoelectric force platform (987B, Kistler Instrumente, Switzerland) was used to measure vertical jump height based on flight time. Flight time (\(t_{\text{flight}}\)) was identified as the period between take-off and contact after flight and this was obtained in each jump via analysis of the force-time curve. The time was used to obtain vertical jump height using the following equation of uniform acceleration (Moir, 2008):

\[
\text{Vertical jump height} = \frac{1}{2} g \left(\frac{t}{2}\right)^2
\]

where \(g = 9.81 \text{ m} \cdot \text{s}^{-2}\), \(t = \text{time in air}\).

Estimation of jump height have been shown to be highly reliable (ICC > 0.92; CV < 5.6%) when calculated using the flight time method within and across testing sessions (McMaster, Gill, Cronin, & McGuigan, 2014). The analogue signal from the force platform was converted to a digital signal using Bioware software (Kistler Instrumente, Switzerland) sampling at 1000 Hz. A minimum of six two-footed jumps were performed on the force platform to obtain force data on a force-time curve to observe directional forces as well as to determine vertical jump distance via the time in the air method as described by Moir (2008). The weight (N) of the participant was set to zero using Bioware before each jump trial in order to determine relative force output. Length of trial was set at 5 s and sampling rate at
1000 Hz. A 30 s passive recovery was imposed between each jump, which allowed the tester to record vertical jump height and to reset the systems for recording of the next trial.

SJ trials were performed from a squatted position with heels in contact with the platform and with a self-selected knee angle (~75°). Each participant’s hands were kept on their hips throughout the jump and a countermovement was not allowed so as to avoid the possible effects of negative work (Driss et al., 2001). The participant was instructed to hold the squat position for at least 2 s before jumping. Visual observation of both jumping technique and the force-time trace was made to ensure that there was no countermovement in the jump. Trials were repeated if a countermovement was detected.

CMJ trials were performed from a vertical standing position with hands on hips and knees about shoulder-width apart. The participants then executed a two-footed, vertical jump immediately following an eccentric countermovement to a self-selected depth (although the thighs could not be lower than parallel to the floor; Samson et al., 2012).

In the DJ40, the participant stepped off a 40-cm box onto the force platform and then immediately jumped vertically. The instruction was given to jump with minimal ground contact time upon landing. The starting position on the top of the box was identical to the CMJ start position. Data from the force plate for the CMJ and DJ were collected and analysed as they were from the SJ.

**Data analysis**

Repeated measures MANOVAs were performed to compare test performances between conditions (5S, 30S, DYN, and NS). A repeated measures ANOVA was used to compare the performances between conditions for sit-and-reach scores. These analyses we completed using SPSS statistical software (version 22) with alpha level set at 0.05. In order to avoid
some of the limitations of null-hypothesis testing, magnitude-based inference tests were performed and the precision of estimation was calculated (Hopkins, Marshall, Batterham, & Hanin, 2009). Qualitative descriptors of standardised effects used the criteria: trivial < 0.2, small 0.2-0.6, moderate 0.6-1.2, large >1.2 (Hopkins, 2002). Effects with 95% confidence limits substantially overlapping the thresholds for small positive and negative effects (i.e. exceeding 0.2 of the SD on both sides of zero) were defined as unclear. Clear small or larger effect sizes (i.e., those with > 75% likelihood of being > 0.20, as calculated by a freely-available Excel spreadsheet; Hopkins (2007) were defined as definitive), as used by Liow and Hopkins (2003). Precision of estimates was indicated with 95% confidence limits, which defined the range representing the uncertainty in the true value of the (unknown) population mean (Batterham & Hopkins, 2006).

Results

Null Hypothesis testing

The mean heart rates (± SE) after the jogging warm-up periods at 50% (i.e. short warm-up) and 60% (i.e. sports-specific warm-up) of perceived maximum intensity are presented in Figure 3. The mean scores (± SE) for the vertical jump performance tests are presented in Figure 4. Mean scores (± SE) for sit-and-reach tests are shown in Figure 5.
Figure 3. Mean heart rate (HR) obtained after warm-up at 50% (pre-stretching) and 60% perceived intensity (post-stretching). Jogging at 60% perceived intensity elicited constantly higher HR than jogging at 50% perceived intensity, with differences between both intensities in each condition of less than 20 bpm. 5s: 5-s static stretch; 30S: 30-s static stretch; DYN: dynamic stretch and NS: no stretch. Percentage of perceived intensity is not equivalent to percentage of maximum HR.

Figure 4. Performances recorded in 5S, 30S, DYN and NS conditions for a) 3 m running vertical jump, b) countermovement jump, c) squat jump and d) depth jump vertical jump heights. There were no significant differences in all vertical jump performance measures between conditions. 5s: 5-s static stretch; 30S: 30-s static stretch; DYN: dynamic stretch and NS: no stretch. Error bars represent standard error of the mean.
Figure 5. Mean sit-and-reach scores recorded in 5S, 30S, DYN and NS conditions. There were no significant differences in scores between conditions. 5s: 5-s static stretch; 30S: 30-s static stretch; DYN: dynamic stretch and NS: no stretch. Error bars represent standard error of the mean.

Results of the analysis of variance revealed no significant differences between warm-up conditions for the field-based 3-m vertical jump height ($p = 0.471$) or the laboratory-based SJ, CMJ, or DJ40 heights ($p = 0.471$). The results also showed no statistically significant effect of condition on sit-and-reach score ($p = 0.076$).

Magnitude-based inferences

Standardised (Cohen’s) effect sizes for the differences in vertical jump height in the three stretching conditions compared to the control condition are shown in Figure 6. Using magnitude-based inferences, all three stretch conditions were found to definitively (>75%) elicit trivial effects on running vertical jump performance when compared to the no-stretch condition (5S = 95%; 30S = 92%; DYN = 86%). This was the same for the countermovement jumps (5S = 97%; 30S = 89%; DYN = 95%). However, the effects of the three stretch conditions on squat jump performance were less clear (5S = 44% trivial; 30S = 65% trivial;
DYN = 74% trivial). Similarly, results of magnitude-based analysis for depth jump scores were unclear (5S = 72% trivial; 30S = 38% trivial; DYN = 50% trivial).

Figure 6. Standardised effect sizes of dynamic, 30-second static and 5-second static stretches on a) 3 m running vertical jump, b) countermovement jump, c) squat jump and d) depth jump vertical jump distances. Plots represent the magnitude of difference between no-stretch condition scores on each variable. Negative values indicate decreases in performance. Error bars indicate 95% confidence limits. The shaded area of the graph indicates the region in which the difference between conditions is trivial (i.e. between -0.20 and 0.20 effect sizes). Asterisks (*) indicate conditions with > 75% likelihood that the observed effect had a trivial effect on performance.
Figure 7 shows the standardised effect sizes for the differences in sit-and-reach scores in the three stretching conditions compared to the control condition. The effects of the dynamic stretching protocol were definitely trivial (98% likely), however the effects of both static stretch protocols (5S and 30S) were unclear (<75% likely).

![Sit-and-reach](image)

**Figure 7.** Standardised effect sizes for performances recorded in DYN, 5S and 30 S conditions versus control for a) 3 m running vertical jump, b) counter-movement jump, c) squat jump and d) depth jump vertical jump heights. Plots represent the magnitude of difference from scores in the control (no-stretch) condition for each variable. Negative values indicate lower jump heights were achieved. Error bars indicate 95% confidence limits. The shaded area of the graph indicates the region in which the difference between conditions is trivial (i.e. between -0.20 and 0.20 effect sizes). Asterisks (*) indicate conditions with > 75% likelihood that the observed effect had a trivial effect on performance.

Jump heights recorded during the dynamic stretch condition were also directly compared to the 5-s static stretch condition, and these results are presented in Figure 8. The 5-s static stretching had clearly trivial (96%) effects on countermovement jump height when compared to the dynamic stretch condition. However, results for SJ, DJ40, 3-m running jump and sit-and-reach tests were less clear (<75%).
Figure 8. Standardised effect sizes 5 s static stretch condition on vertical jump and sit-and-reach measures. Plots represent the magnitude of difference between the 5 s static stretch and dynamic stretch conditions. Negative values indicate decreases in performance. Error bars indicate 95% confidence limits. The shaded area of the graph indicates the region in which the difference between conditions is trivial (i.e. between -0.20 and 0.20 effect sizes). Asterisks (*) indicate conditions with > 75% likelihood that the observed effect had a trivial effect on performance.

Discussion

The purpose of this study was to investigate the effects of short (5 s) and moderate (30 s) durations of pre-exercise static stretching as well as dynamic stretching on vertical jump performance in semi-elite athletes when included as part of a complete warm-up that was specific to the test movement patterns, similar to what is practiced in most running-based sports. There were three important findings resulting from this study. The main finding was that there were no statistically significant differences in jump height when either static (moderate durations; ≤ 30 s) or dynamic stretching were incorporated into a complete, specific warm-up as part of a pre-exercise routine. Thus, the addition of muscle stretching of the types and durations included herein to a full pre-exercise preparatory routine appears to have no effect on jumping performance. This is an important finding considering that current recommendations suggest the removal of static muscle stretching from pre-exercise routines...
on the grounds that such practices may reduce physical performance (Behm & Chaouachi, 2011; Kay & Blazevich, 2012; McHugh & Cosgrave, 2010; Rubini et al., 2007), especially when compared to dynamic stretching protocols. A secondary result was that sit-and-reach scores did not show statistically significant improvement when either moderate duration static stretching (5 or 30 s) or dynamic stretching was combined with a complete, sport-specific warm-up as a pre-exercise routine. Thus, it appears that short-duration stretching of the types used herein do not provide a benefit with respect to ROM and may not benefit individuals who require the attainment of large ROMs in their sports. A third and important finding was that there were no statistically significant differences in vertical jump performances when static and dynamic muscle stretching of similar movement patterns (type of stretch), muscle stretch duration (~ 5 s per muscle group) and stretch intensity (= POD) were directly compared. It should be pointed out that the 5S condition was included to more closely replicate the stretch duration used in dynamic stretching, and care was taken to adopt similar body positions during stretches in these conditions. Thus, the lack of differences between static and dynamic stretch conditions is unlikely to be attributable to these factors. Nevertheless, while statistically non-significant results ensured that the null hypothesis was not rejected (Thomas, Nelson, & Silverman, 2011), magnitude-based inferences allowed for the conclusion that many effects were definitively trivial (Liow & Hopkins, 2003).

**Effect of warm-up conditions on vertical jump performance**

It has previously been suggested that moderate duration static-stretching (<45 s) as well as dynamic stretching might be employed in a pre-exercise routine without reducing muscular force or athletic performance (Kay & Blazevich, 2012), especially if followed by a complete, sport-specific warm-up (Gelen, 2010; Kay & Blazevich, 2012; Little & Williams, 2006; Young & Behm, 2003). Hence, the first hypothesis of the study was that the three stretching
conditions would not elicit any reduction in jumping performance in subsequent tests when compared to the control condition. Results of the study showed that performance in the vertical jump tests were neither adversely affected nor enhanced by muscle stretching, which is supportive of our hypothesis.

Discrepancies between the results of the current and previous studies might be partly explicable by differences in study design. First, longer stretch durations than those imposed in the present study have been used previously (e.g. Cornwell, Nelson, Heise, & Sidaway, 2001; Wallmann et al., 2005; Young & Behm, 2003). Stretch durations from these studies exceeded the total stretch duration of 45 s per muscle group noted by Kay and Blazevich (2012) to be sufficient to affect performance and hence elicit an inhibition of force production via neural mechanisms (Fowles, Sale, & MacDougall, 2000; Nelson, Guillory, Cornwell, & Kokkonen, 2001; G. S. Trajano, Nosaka, Seitz, & Blazevich, 2014; Gabriel S Trajano, Seitz, Nosaka, & Blazevich, 2013; Gabriel Siqueira Trajano, Seitz, Nosaka, & Blazevich, 2014; Walshe & Wilson, 1997). Nonetheless, the longest stretch duration imposed in the current study was 30 s, which was unlikely to impair muscular performance (Kay & Blazevich, 2012). The shorter durations of stretch are probably more contextually valid as longer stretching protocols (e.g. > 1 min) are rarely performed in situ; studies documenting the pre-game routines of baseball, basketball, hockey and football players reported total stretch durations (per muscle) of 12 – 18 s (Ebben & Blackard, 2001; Ebben, Carroll, & Simenz, 2004; Ebben, Hintz, & Simenz, 2005; Simenz, Dugan, & Ebben, 2005). Thus, the findings from this study may be a better indication of what is likely to happen in a game-day situation.

The present study design further attempts to reproduce common warm-up routines by prescribing the complete warm-up after muscle stretching, thus better replicating pre-game warm-up practices as described by Behm et al. (2004) and Samson et al. (2012). However, in previous studies, performance measures have usually been conducted immediately before
stretching (Behm, Button, & Butt, 2001; Church, Wiggins, Moode, & Crist, 2001; Kokkonen, Nelson, & Cornwell, 1998; Nelson et al., 2001). Nevertheless, a few studies have demonstrated an absence of the deleterious effect on muscle strength caused by static stretching. It was demonstrated by Rosenbaum and Hennig (1995) that physical activity which immediately followed static stretching lessened the decrements in peak force, relaxation rate and the rate of force development (RFD) of the Achilles tendon reflex. Murphy, Di Santo, Alkanani, and Behm (2010) found that 5 min of running before and after static stretching can provide ROM improvements for 30 min with either facilitation or no impairment in performance. Little and Williams (2006) suggested that the retention of muscular force was because the extra muscular activity from the subsequent warm-up reversed the decrements in neural drive and muscle compliance from static stretching. The possibility also exists that this may instead be an outcome of the time delay created between stretching and exercise testing with extended warm-up protocols (i.e. time effect). Regardless of whether the lack of decrements in jump performance from the static stretching conditions were a result of a time effect or the physiological changes associated with a dynamic activity, the present study design suggests that vertical jump performance was not adversely affected by shorter (< 30 s) durations of static or dynamic stretch conditions when conducted as a complete, test-specific warm-up. Therefore, it is possible to utilise potential benefits of ROM and soft-tissue injury prevention from static stretching without compromising vertical jump performance in more realistic pre-exercise routines, as depicted in this study.

Further analysis of the data via magnitude-based inferences provided very clear results showing a lack of meaningful effect of the stretching conditions on running vertical jump and countermovement jump performance, although this lack of effect for the squat jumps and depth jumps performances remain unclear. Differences in statistical confidence between the four jump measures may be accounted for by the different jumping techniques involved in
each test. The running vertical jump and countermovement jump employs the stretch-shortening cycle (SSC) where agonist muscles undergo an eccentric (stretching) action followed immediately by the concentric (shortening) action (Nicol, Avela, & Komi, 2006). However, the squat and drop jump are only performed occasionally in movements such as a rugby scrum or navigating an obstacle during parkour (i.e. free running). The squat jump employs a concentric-only motion which relatively rare in human ground locomotion (Nicol et al., 2006). The drop jump used in the study is referred to as a bounce drop jump (BDJ) by Bobbert, Huijing, and van Ingen Schenau (1987) where participants are required to reverse the downward velocity as quickly as possible upon landing. Unlike a countermovement drop jump (Bobbert et al., 1987), the BDJ prevents participants from gradually obtaining a full downward movement and to complete an optimal eccentric phase, making it less similar to the SSC movement. As a result of the squat and depth jump tests requiring less familiar muscle movements, participants may have been less efficient at executing them when compared to the countermovement and running vertical jumps, resulting in less accurate results and hence a slightly lower reliability. Hence, result of this finding tells us definitively (> 75%) that the choice of shorter durations of static stretch (≤ 30 s) may be employed without negatively affecting sporting performances that employs the SSC (e.g. basketball, volleyball). However a larger sample size may be required in order to obtain definitive results for concentric-only (e.g. rugby scrum) or bounce-drop jump (e.g. parkour) types can be established.

Effect of stretching condition on sit-and-reach scores

Static stretching is often completed with the aim of improving joint range of motion (ROM; i.e. flexibility). The superiority of static stretching for increasing static ROM is observed in a number of other studies (Beedle & Mann, 2007; Covert, Alexander, Petronis, & Davis, 2010;
Power et al., 2004). This increased ROM can be attributed to increases in muscle compliance and decreases in muscle stiffness and viscosity (Behm & Chaouachi, 2011). For this reason, it was hypothesised that sit-and-reach scores would exceed scores attained by the dynamic stretching and no-stretch conditions when static stretching was implemented within the testing conditions. Nonetheless, results of the study showed that neither the dynamic nor the static stretching conditions elicited better sit-and-reach scores when compared to the no-stretch condition. Interestingly, magnitude-based inferences showed with high likelihood (98% likely) that the DYN condition had trivial effects on sit-and-reach performance when compared to the control condition, whereas the likelihood of the 5S and 30S conditions remained unclear. This confirms that the 5-repetition bout of dynamic stretching used herein followed by a test-specific warm-up definitively had no meaningful effect on sit-and-reach scores. Thus 5-repetition dynamic muscle stretching is not sufficient to be included in a pre-exercise routine with the specific aim of increasing static, passive ROM.

The effects of static stretching when included in a pre-exercise routine are unclear. A number of studies have shown a lack of effect on sit-and-reach performance (e.g. Amiri-Khorasani, Osman, & Yusof, 2011; Perrier et al., 2011), while other studies have indicated increases in hamstring ROM (Hopkins, 2007; Murphy et al., 2010; Samson et al., 2012). Murphy et al. (2010) reported increases in hamstring ROM after 6 repetitions of 6-s partner-assisted passive stretching, and the these effects persisted for 30 min. Results of the present study are also inconsistent with those of a similar study by Samson et al. (2012), which showed a 2.8% increase in sit-and-reach scores when static stretching was conducted before a sport-specific warm-up. These differences might be partly explained by differences in total muscle stretching duration (i.e. duration-dependent effect; Behm & Chaouachi, 2011; Kay & Blazevich, 2012) and/or persistence (duration) of enhanced ROM from stretching components (i.e. time effect; Murphy et al., 2010). In the static stretching conditions imposed
by Samson et al. (2012), 3 sets of 30-s stretches were used. This was three times the total duration (per muscle) of static stretching imposed in the present study. Furthermore, the specific warm-up imposed by Samson et al. (2012) comprised a total of six sprints over a 20-m distance (i.e. a relatively short warm-up duration) whereas the post-stretch warm-up in the present study lasted 12 – 13 min. As the time delay between the stretching component and the sit-and-reach test in the present study is longer than that in the protocols of Samson et al. (2012), ROM benefits may have been lost over time. Thus, pending future research that examines further aspects of a pre-exercise routine that incorporates static stretching (specifically the persistence of increased ROM of various stretch durations), shorter durations of static stretching (30 s or less) does not provide ROM benefits when included with a complete, sport-specific warm-up in a pre-exercise routine.

**Effects of static and dynamic stretching on vertical jump performance**

In order to isolate the effects of stretching mode on subsequent vertical jump performance, performances in the 5S and DYN conditions were compared. The 5S condition was designed to match the total stretch time per muscle group with the DYN condition as closely as possible. Participants were also instructed to hold each stretch (static) or achieve full ROM (dynamic) at POD to standardise stretch intensities. As previously mentioned, movement patterns (type of stretch), muscle stretch duration (~5 s per muscle group) and stretch intensity (= POD) were standardised between the two conditions. Examining performance outcomes in both conditions thus provide a direct comparison between the effects of static and dynamic stretching by isolating differences to the mode of stretching. Results of the multiple analysis of variance test showed no significant differences ($p = 0.290$) in the four vertical jump scores between the two conditions. Further analysis of the data via magnitude-based inferences showed that it was 96% likely that there were trivial effects of the two
stretching modes on the countermovement jump test, whereas effects on the other jump tests remain unclear. Results of the present study are consistent with Samson et al. (2012) and Little and Williams (2006) which showed no significant differences between static and dynamic stretching on countermovement jump performances when followed with a sport-specific warm-up. The lack of performance decrements in the static stretch condition might be due to performance benefits gained from the sport-specific warm-up component. As the warm-up is an active contractile process, there is increased muscle blood flow and elevated core/peripheral temperature, as well as facilitated motor control from the rehearsal of the specific movements (Little & Williams, 2006). As a result, sensitivity of the central nervous system and hence speed of nerve impulses is increased, thus encouraging muscle contractions to be more rapid and forceful (Meyer et al., 1999). Hence, contrary to previous studies that recommend dynamic stretching in place of static stretching to avoid the risk of impairment in subsequent vertical jump performance, this finding offers the alternative of a static stretching + sport-specific warm-up as a pre-exercise routine. This combination may be preferable to a dynamic stretching + warm-up routine, as the potential benefits of static muscle stretching (e.g. prevention of soft tissue injury) along with the physiological benefits (e.g. increase in muscle temperature) of an aerobic warm-up can be enjoyed without compromising vertical jump performance. Furthermore, discontinuing pre-exercise static stretching may also have negative psychological effects on an athlete with a habit or belief in engaging in it (Young, 2007). Others may also find the dynamic stretching more physically taxing or a less effective way of getting a feel of their muscles before an activity (i.e. peripheral feedback). Hence, as results of the study revealed no differences in subsequent vertical jump performance between static and dynamic stretching, the potential benefits of static stretching may provide a different perspective to its importance in a pre-exercise routine. On the other hand, further research examining the effects of a dynamic stretching component is required to justify its
inclusion in pre-exercise routines, as a subsequent sport-specific warm-up appears to satisfy its objectives.

**Limitations of the study**

This study offers a different perspective to what has been commonly agreed upon in current literature, suggesting the possibility of retaining static stretching in a pre-exercise routine. However, the results must be considered within the limitations of the study. The purpose of the study was to compare shorter durations of static stretching and their impact on vertical jump performance. Although a lack of adverse effect on vertical jump performance was established, the study showed no improvements in ROM with static stretching and is hence unable to justify its retention in a pre-exercise routine, although other benefits are likely. As the present study utilised a randomised, cross-sectional design to examine the outcomes of different stretching conditions, other aspects such as psychological impact and injury prevention could not be considered over time. As there is currently a lack of agreement of the potential benefits of static stretching, this study can only suggest why static stretching can be retained rather than why it should be retained.

Another limitation to the study was the lack of data to analyse the pre- and post-stretching changes in ROM. As the sit-and-reach test can in itself be considered a form of stretching, the conscious decision was made to not to include a sit-and-reach test at the start of the pre-exercise routine. Hence, the effect on ROM from each testing condition was established through repeated measures of these scores rather than the percentage change in ROM before and after the pre-exercise routine. Incidental changes in muscle flexibility from day-to-day activities are hence not considered in the present study.
The expression of our results may not be familiar to all readers. Although discussion of statistical significance from p-values was briefly included, focus was placed on magnitude-based inferences from 95% confidence limits. Although not traditionally used like p-values, 95% confidence limits provide much more clinically meaningful units. By expressing results using a mean in relation to upper and lower confidence limits allows clinicians to easily interpret the likely effects observed from an intervention. While the null-hypothesis tests of significance only allows the conclusion that there is insufficient evidence to indicate there is a difference (i.e. fail to reject the null hypothesis; p>0.05), that many of the results showed >75% likelihoods of being trivial, there is the ability to interpret the findings as the effects are probably trivial.

**Conclusion**

The use of shorter durations of static stretching in a pre-exercise routine does not appear detrimental to subsequent jumping performances when followed by a sport-specific warm-up in semi-elite athletes. Although increases in ROM was not observed, recommendations to exclude static stretching in a pre-exercise routine seem premature due to other potential benefits such as the prevention of injury (Pope et al., 2000; Small, Mc Naughton, & Matthews, 2008) or possible psychological factors (Young, 2007). However, it was established that dynamic stretching of shorter total stretch duration (<30 s) did not result in superior vertical jump performance than similar durations of static stretching when conducted before a sport-specific warm-up. This allows for the potential benefits of static stretching to be enjoyed without compromising vertical jump performance, at the same time reaping the benefits of dynamic stretching via a subsequent aerobic sport-specific warm-up.
Practical implications

The practical and clinical implications of this study extend beyond the target population. Practitioners in exercise and sports science and injury prevention as well as researchers in this topic area may benefit from these findings. Athletes or coaching staff are given new insight on how to optimally program athletic warm-ups and stretches. Findings of this study are also an important consideration given the time-constraints in game-day situations where players have limited time to perform pre-exercise routines.
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Appendix A

Participant Information and Consent Form

Effect of static and dynamic stretching during a full warm-up on athletic performance in trained athletes

Researcher contact details

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Information for participants

Thank you for showing an interest in this project. Please read this information document carefully before deciding whether or not to participate. Participation is voluntary. No explanation or justification is needed if you choose not to participate, and there will be no disadvantage to you.

Project background

Pre-exercise routines that typically include a task-specific warm-up and muscle stretching protocols are regarded as vital components for successful athletic performance. Traditionally, stretching has been considered to aid sporting performance and flexibility and decrease the incidence of soft tissue injuries among athletes. However, recent research has shown the potential for pre-exercise static muscle stretching to reduce muscle force production and athletic performance while pre-exercise dynamic stretching has shown to increase performance.

Nonetheless, many of these studies have used simplified study protocols that have provided little information regarding the effect of stretching when a task-specific (i.e. sports-specific) warm-up is performed prior to sporting performance/activity/testing. The proposed research will therefore be the first to investigate the effects of stretching before a full warm-up on athletic performance.

This project will be run at Edith Cowan University, using the facilities of the School of Exercise and Health Sciences. The data collection process will run from June 2014 - September 2014.

Project aims and importance

This project will examine the effect of short-duration dynamic (5 stretch repetitions per muscle) and static (5 s per stretch) muscle stretching when compared to moderate-duration static stretching (30 s of total stretch, 10 s per stretch) on lower body flexibility and sprint running, jumping and agility performances when stretches are performed as part of a complete task-specific warm-up. This will be the first project to accurately examine the effect different stretching methods on athletic performance when a full task-specific (i.e. sports-specific) warm-up is performed before activity. The results will provide a unique insight into the effects of pre-exercise stretching on performance in athletic individuals performing a typical warm-up.

Methodology

50 athletic participants (i.e. individuals currently competing in running-based sports or who perform at least 3 running-based exercise sessions per week) will be invited to
participate in the study. You will need to be healthy with no recent history of injury or illness.

The training you complete outside the study will be monitored to ensure significant changes in your program do not occur over the study period. However, if your standard training program is not adhered to in a given week, the testing session can be postponed until the following week.

**What you have to do**

If you choose to participate, you will attend one familiarisation session and four testing sessions at the same time of day over a 5-week period. In the familiarisation session you will be taught the correct technique for each of the stretches as well as become familiar with the test protocols. We will also record your height, body mass and age. The four testing sessions will include a short general warm-up (described below) followed by one of the four stretching conditions, (1) dynamic stretch (5 repetitions per stretch), (2) short-duration (5 s) static stretch, (3) moderate-duration (30 s; as 3 × 10 s) static stretch, and (4) no stretch (control). In each session, a longer, task-specific warm-up (described below) will then be completed before the testing of athletic performance.

During the familiarisation session you will also be asked to nominate the order in which you believe the experimental conditions will improve or reduce performance (equal weightings are allowed) in order to determine whether your expectations aligned with the study results, and thus may have been an influencing factor.

You will commence testing sessions with a low-intensity, short warm-up period including a 3-min jog, 5 s of ‘high knees’ and 5 s of ‘butt kicks’. You will then complete your assigned stretch routine, with stretches done to your maximum joint range of motion or until any pain is experienced (8 out of 10 in a discomfort scale). Subsequently, a moderate intensity task-specific warm-up including a 2-min jog followed by 2 min of passive rest, 5 s high knees, 5 s butt kicks and three mini-circuits will be completed; each of the mini-circuits will require the performance of a 30-m run, two agility T-tests (i.e. running and sideways shuffling), a three step running vertical jump and squat, countermovement and drop jumps (jumping from 40 cm box) with short rests in between. Each circuit will be interspersed by a 3-min walk recovery and will be performed at an increasing level of maximum perceived exertion (60%, 80% then 100%).

Once the pre-exercise routine is completed, you will rest (standing) for 5 min before commencing the tests; this is because athletes often have a period of self-preparation and coach instruction prior to performance after the completion of a warm up. At the end of this period, a sit-and-reach test will be performed in order to measure any changes in lower body range of motion and therefore determine whether the stretch
protocol had an effect. If you are completing the no stretch (control) condition will complete the entire warm-up, rest for 5 min and then perform the performance tests.

**Testing (measurements)**

All testing will be conducted in an indoor athletic facility on a synthetic surface.

Sit-and-reach test: A common lower back and hamstring flexibility test (using a sit and reach box) will be conducted in order to measure lower body range of motion and to test whether the stretching procedures influenced lower limb joint range of motion.

20-m sprint: You will run 20 m as fast as possible from a stationary start. Photocell timing gates will be placed at 0, 5, 10 and 20 m in order to measure times to these distances.

Agility T-test: You will run forward 10 m to a cone, shuffle to the left for 5 m, right for 10 m and left again for 5 m before running backwards for 10 m (continuously). Time to complete the T-shape course will be recorded by timing gates.

Leg-swing test: You will execute two sets of 5 rapid leg swings (in front to behind the body with the knee straight) whilst holding a rail for support. There will be a 30-second rest between each set of leg swings, and both hip joint range-of-motion and angular velocity (i.e. speed of swing) will be recorded. Reflective markers will be placed on your hip, knee and ankle joints and a video camera will be used to record your movements; you will be required to wear dark compression clothing so that accurate results are obtained.

Running vertical jump test: This is a functional vertical jump test with a 3-step run-up. You will jump as high as you can and displace slats with your hand as you jump, which will indicate the jump height. You will be allowed a maximum of five attempts.

Vertical jumps: You will jump as high as possible (1) from a crouched stationary start (squat jump; SJ), (2) from a standing position with a dip of your body before the upward jump (countermovement jump; CMJ), and (3) immediately after dropping from a 40-cm box (drop jump; DJ). Three trials will be allowed for each jump type.

**Benefits of participation**

You will learn about the effects of muscle stretching duration and type (i.e. static vs. dynamic) on your own sporting performance and have the opportunity to ask questions about the topic area. The information gained can be directly applied to your sport and will allow you to determine the effects of the different stretch protocols on your own performances. You will also obtain a first-hand understanding of how research is
performed, which will allow you to make better decisions as to the importance of examining/reading research in a sporting context.

**Potential risks of participation**

As you will be instructed to perform various types of muscle stretching, small levels of discomfort may be experienced (8 out of 10 on a discomfort scale). There is also a potential risk of musculoskeletal injury/strain due to the performance of maximal exercise tests; however, these potential risks will be minimised through the use of an appropriate warm-up procedure and clear instructions on how to correctly and safely perform the tests. Demonstrations of how to perform the muscle stretches will be provided by an experienced supervisor (i.e. the named researchers). These safety talks and demonstrations will be conducted during the familiarisation session. Also, a trained first aider will be present at all testing sessions. You will most likely be familiar with the tests, and therefore will already be aware of the potential risks. However, if you ever feel uncomfortable or are in any pain and do not wish to continue please inform a researcher and the testing session will be stopped immediately. Please note: applicants who are paid to participate in their sport need written approval and medical clearance from medical staff at their club/organisation to volunteer for the study.

**Data collection and storage**

All the data collected will be stored securely by the named researchers. This will ensure that any personal information can only be accessed by the research team and not the general public. Electronic data files will be stored on the researchers’ personal computers each locked with a password, while paper data sheets will be stored in a locked filing cabinet.

**Confidentiality of information**

The data will be transferred as soon as practicable from lab-based computers (which are locked when researchers are not present) to computers and hard disks owned by the named researchers. These computers and hard disks are password protected and locked when not in use.

The data collected may be used in future studies in which the ethics committee has granted permission and in which the study has shown that its data handling procedures (e.g. ensuring confidentiality) are appropriate. These data may be used in grant applications as well as future publications by the named investigators in collaboration with other researchers who may replicate these study procedures. In these circumstances, full anonymity of all participants will be maintained.
The data will be stored for a period of 5 years after the publication of the final paper. They will be stored on a password protected computer and hard disks locked in cupboards. Subject identification keys will be kept separate from the data. Data will be deleted from disk drives, or the computers/drives destroyed no sooner than 5 years after the publication of the final paper.

**The use of the project results**

The results obtained from the project will be used as part of Mr Hilton’s and Mr Goh’s Honours research theses. The results of the study will also be presented at conferences and in scientific publications, however full participant anonymity will be maintained.

**Withdrawing consent to participate**

You are free to withdraw your consent to further involvement in the research project at any time. If you choose to withdraw from the research you can also request all your data up to that point to be withdrawn. You have the right to receive information regarding your own data/results at any time during the project from a member of the research team.

This project has been approved by the Edith Cowan University Human Research Ethics Committee.
If you have any concerns or complaints about the research project and wish to talk to an independent person, please feel free to contact:

Research Ethics Officer  
Edith Cowan University  
270 Joondalup Drive  
JOONDALUP WA 6027  
Phone: (08) 6304 2170  
Email: research.ethics@ecu.edu.au
Participant Consent Form

Effect of static and dynamic stretching during a full warm-up on athletic performance in trained athletes

Principal Investigator: Dr Anthony Blazevich, School of Exercise and Health Sciences, Edith Cowan University. a.blazevich@ecu.edu.au, Phone: (08) 6304 5472

Participant consent

- I confirm that I have read and understood the provided information regarding the purpose, methodology, benefits, potential risks and my rights as a participant.
- I have been given the opportunity to ask any questions with the responsible researcher.
- I have been informed that I am able to withdraw from the project at any time without having to provide justification.
- I agree to the conditions of the project and give my consent participate in the testing protocols.
- I feel confident that the confidentiality of my results will be maintained throughout the entirety of the project.

A copy of the informed consent form has been provided to me. I freely agree to take part in this project:

Participant taking the consent __________________________

Signature of participant taking the consent __________________________

Date __________________________

Day/month/year

This study has been approved by the Edith Cowan University Human Research Ethics Committee. If you have any concerns about the ethical conduct of the research you may contact:

Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
Joondalup WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au
Appendix B

Session Information for Participant

Session number: __________
Date: ________________
Day: ________________

Full name: ____________________________
D.O.B: ______________
Condition: ___
SS = Short static (5 s), 30S = Moderate static (30 s), DYN = Dynamic (5 reps), NS = No stretch

Order of testing: ____/____/____/____/____

A = 20 m sprint, B = Vertec jump, C = Agility T-test, D = Leg swing test, E = Force platform jumps
Age: __________ yrs
Body mass: __________ kgs
Body height: __________ cm

Physical Activity (if any) in past 24 hours:
Be as descriptive as you can, describe intensity/any soreness or injury felt, etc

__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

Muscle soreness = __________ (out of five)
Appendix C

Static and Dynamic Stretching Protocols

A) Calves

B) Quadriceps

C) Hamstrings

D) Hip flexors

E) Ankles

F) Adductors

G) Gluteal muscles

H) Chest and arms

I) Back

See next page for instructions.
**Stretch Protocols/Verbal Instructions**

**A. Calves**

*Static*

1. Assume push-up position, keeping knees and elbows straight.
2. Allow one knee to drop by rolling onto ball of foot.
3. Gently lower heel of planted foot down as low to the ground as possible until stretch is felt at the calf.
4. Hold at point of discomfort (POD) for 5 or 30 s before switching legs.

*Dynamic*

1. Assume push-up position, keeping knees and elbows straight.
2. Allow one knee to drop by rolling onto ball of foot.
3. Gently lower heel of planted foot down as low to the ground as possible until stretch is felt at the calf.
4. Pause for about 0.5 s at stretch position before lifting the heel up again, alternating between each leg.
5. Repeat for 5 repetitions per leg.

*Performance points*

1. Point grounded foot straight ahead.
2. Keep the back straight.
3. Lower the heel as close to the ground as possible to POD.

**B. Quadriceps**

*Static*

1. Grasp ankle and gently pull your heel up and back until you feel the stretch in the front of your thigh.
2. Tighten your stomach muscles to prevent your stomach from sagging outward, and keep your knees close together.
3. Hold for at point of discomfort for 5 or 30 s.
4. Switch legs and repeat.

*Dynamic*

1. Grasp ankle and gently pull your heel up and back until you feel the stretch in the front of your thigh.
2. Tighten your stomach muscles to prevent your stomach from sagging outward, and keep your knees close together.
3. Add a secondary pulling/tugging motion before releasing the ankle and switching legs.
4. Repeat for 5 repetitions per leg in an ‘up-tug-down’ motion.

C. Hamstrings

**Static**

1. Lie on back and lift knee up, keeping knees straight as far as possible and maintaining dorsiflexion.
2. Grasp behind thigh near knee with both hands and pull knee close to chest.
3. Hold stretch for 5 or 30 s.
4. Release and repeat with opposite leg.

**Dynamic**

1. Lie on back and lift knee up, keeping knees straight as far as possible and foot maintaining dorsiflexion.
2. Grasp behind thigh near knee with both hands and pull knee close to chest.
3. Add a secondary pulling/tugging motion before releasing leg.
4. Repeat with opposite leg, 5 repetitions per leg.

**Performance points**

1. Maintain foot dorsiflexion.
2. Keep knee extended.

D. Hip Flexors

**Static**

1. Stand with hands on hips and with one leg approximately a leg length in front of the other, with the forward leg slightly bent at the knees and rear leg maximally extended.
2. Slowly lunge forward by bending forward leg.
3. With chest high, straighten hip of rear leg by pushing hips forward.
4. Hold stretch for 5 or 30 s and repeat with opposite side.

**Dynamic**

1. Stand with hands on hips and with one leg approximately a leg length in front of the other, with the forward leg slightly bent at the knees and rear leg maximally extended.
2. Slowly lunge forward by bending forward leg.
3. With chest high, straighten hip of rear leg by pushing hips forward.
4. Hold stretch position for about a second before returning to starting position.
5. Repeat for 5 repetitions in a forward-pause-back motion before switching to opposite leg.

**Performance points**

1. Keep torso upright, close to vertical.

**E. Hip Adductors**

**Static**

1. Stand with feet facing forward and slightly more than shoulder width apart.
2. Lean to one side by dropping one knee, causing the muscles of the other leg to go into tension.
3. Hold the stretch for 5 or 30 s seconds.
4. Switch legs and repeat.

**Dynamic**

1. Stand with feet facing forward and slightly more than shoulder width apart
2. Lean to one side by dropping one knee, causing the muscles of the other leg to go into tension.
3. Pause and hold at stretch position for about a second before leaning to the other side.
4. Repeat for 5 repetitions per side in a ‘lean-pause-back’ motion.

**Performance points**

1. Maintain vertical upper body.

**F. Ankles**

**Static**

1. Stand with hands on hips and feet shoulder-width apart.
2. Supporting bodyweight on one leg, roll ankle of other leg laterally until stretch is felt.
3. Hold for 5 or 30 s seconds.
4. Return and repeat with opposite ankle.

**Dynamic**

1. Stand with hands on hips and feet shoulder-width apart.
2. Supporting bodyweight on one leg, roll ankle of other leg laterally until stretch is felt.
3. Hold stretch position for about a 0.5 s before returning to starting position.
4. Repeat for 5 repetitions in a ‘roll-pause-back’ motion before switching legs.
G. Gluteals

*Static*

1. Standing on one leg, grasp below the knee of the other leg and pull it as close to your chest as possible.
2. Hold the stretch position for 5 or 30 s.
3. Release and repeat with other leg.

*Dynamic*

1. Standing on one leg, grasp below the knee of the other leg and pull it as close to your chest as possible.
2. Add a secondary tugging motion before releasing and switching legs.
3. Repeat for 5 repetitions per leg.

H. Upper chest and shoulder

*Static*

1. Interlock fingers of both hands behind your back, palms together, and lift both arms up and back as high as possible while maintaining full elbow extension.
2. Hold the stretch position for 5 or 30 s.

*Dynamic*

1. Interlock fingers of both hands behind your back, palms together, and lift both arms up and back as high as possible while maintaining full elbow extension.
2. Pause at stretch position before releasing.
3. Repeat for 5 repetitions in a stretch-pause-release motion.

*Performance points*

1. minimise shoulder shrug.

I. Upper back

*Static*

1. Interlock fingers of both hands in front of torso, palms together, and lift both arms forward and up until it is directly above your head.
2. Hold the stretch position for 5 or 30 s, feeling the stretch through the back muscles.
Dynamic

1. Interlock fingers of both hands in front of torso, palms together, and lift both arms forward and up until it is directly above your head.
2. Pause at stretch position before releasing, feeling the stretch through the back muscles.
3. Repeat for 5 repetitions in a stretch-pause-release motion.