This is the published version:


Available from Deakin Research Online:

[http://hdl.handle.net/10536/DRO/DU:30045201](http://hdl.handle.net/10536/DRO/DU:30045201)

Reproduced with the kind permissions of the copyright owner.

Copyright: 2008, Society for Tennis Medicine and Science
Warming up and stretching for athletes: A meta-analysis of the research literature from 2000 to 2006 in light of current athletic practice

Abstract
This review presents the methods used to investigate the effects of various stretching protocols on muscular force and performance, in light of current individual and elite athlete stretching practices in their warm-up routines. A meta-analysis of peer-reviewed articles between the years of 2000 and 2007 revealed the majority of studies support the notion that static stretching is detrimental to muscular force and performance. However, the meta-analysis also revealed that the protocols used do not necessarily match current practice with many elite athletes. This article proposes, based on the mismatch between research and practice, that further studies must address this issue in further exploring the role of stretching in pre-training and competition warm-up routines.

Introduction
The seminal review and research paper of Shrier and Pope et al., suggesting that static stretching in the warm up does not protect individuals and athletes from injury, created a renewed interest in the role of pre-activity stretching in the warm up. Tennis is no exception with two recent articles appearing in Medicine and Science in Tennis reviewing the current literature on warm-ups, which question the clinical benefit and positive physiological effects of static stretching in the warm up. The aim of this paper is not to repeat reviewing the literature, nor is it to discuss and delineate between stretching in the warm-up and flexibility training. But rather, this paper presents a meta-analysis of the methodologies used in determining performance outcomes and how the methods used compliment current athlete (including tennis players) warm-up and stretching practices.

Methodology
Definitions
For the purposes of this review stretching was defined as either "static" being a form of muscle stretching taking the muscle to its end range and maintaining this position for the specific duration, or "dynamic" where the stretches move through a wide range of motion. Proprioceptive Neuromuscular Facilitation (PNF) was also included in the definitions under the category of static stretching.

Identification of studies
Potentially relevant literature was identified through computerized searches using PUBMED and SPORTSDISCUS databases for the period between January 2000 and May 2007 using the following keywords (MeSH): stretching, warm-up, dynamic stretching, static stretching, vertical jump, and lower limb peak power. Only English publications were included. Studies in the meta-analysis were included when: (1) population sample included healthy participants; (2) acute effects of pre-activity stretching was reported (and not used as a training method); and (3) outcomes were measured in terms of power, torque, force or jump height.

Results
The search strategy resulted in a list of 159 citations. Following the review process, 26 studies were identified as being...
relevant (Table 1). Out of 26 researched studies, 8-33 16 showed a significant decrease in muscular force following a bout of static stretching, 9-11,13-14,17-19,21,23-26,28,30,31 whilst four studies demonstrated an increase in muscular force post dynamic stretching. 15,22,32,33 Amongst the six remaining studies 8,12,16,20,27,29 of which no change was observed following static stretching, four studies 8,12,16,20 mentioned the use of an elite athlete population and two studies 27,29 included post stretching activities (4mins walking; 20mins of random basketball play) prior to testing. Current research analyzing the effects of this secondary bout of warm-up activity following various stretching routines, have been limited and research design questionable. Unick et al. 27 and Woolstenhulme et al. 29 did not measure heart rates during warm-up periods, nor did they provide alternative measures for controlling warm-up intensity. Furthermore, it is not clear how movement patterns within this secondary bout of activity (basketball or walking) were controlled.

Discussion and directions for future research
The meta-analysis in this short report has provided evidence that most studies suggest a reduction in performance following static stretching. 9-11,13-14,17-19,21,23-26,28,30,31 On the contrary, a growing body of research is suggesting power performance improvements following dynamic stretching. 15,22,32,33 This is leading many sports scientists and coaches to suggest the role of static stretching in the warm-up component prior to training or competition should not be implemented. The meta-analysis has also shown that the majority of studies have used a single bout paradigm to measure the effects of stretching on performance. Despite this, players in many sports (not just tennis) still appear to lean towards completing a range of static stretching exercises as part of a warm up routine. With sub-elite athletes, it is quite common to observe individuals complete a bout of static stretching and walk onto the court (Zois and Pearce, unpublished observations). However, in many cases, senior elite players may follow on from a bout of static stretching by a more vigorous warm-up, incorporating mimicking of movement patterns, such as on-court footwork and pre-match hitting. It is outside the scope of this paper to suggest why these practices still occur, however in our search we found a number of non-peer reviewed articles on the internet suggesting to incorporate static stretching but to follow up with “sport specific” and dynamic range of motion activities (for example see). Moreover, from a performance perspective, a secondary activity bout serves to familiarize athletes to the environments they are about to play or train in. However, it maybe hypothesized that a secondary exercise bout may also potentially reverse the negative effects of static stretching conducted prior to this second warm-up phase, which was initially addressed but poorly controlled in the studies of Unick et al. 27 and Woolstenhulme et al. 29 Given the current practices of athletes who still perform static stretching but follow up with activity, research questions should address this practice, with new intervention paradigms implemented in answering the effects that secondary warm up bouts have on static stretching effects. > >
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Participants</th>
<th>Methods and results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bazett-Jones &amp; Winchester BJ</td>
<td>2005</td>
<td>10 male athletes, 20.6±1.5yrs.</td>
<td>Pre-test: Post-test static stretching, potentiation activities and control on isometric squat peak force. 30min lower body static stretching; control consisted of 10 min of quiet sitting; and the potentiation protocol consisted of 90% (1RM x 3 sets leg press), followed by 6 isometric squats. No significant change in peak force readings amongst the 3 groups was evident.</td>
</tr>
<tr>
<td>Behm DG et al [9]</td>
<td>2001</td>
<td>12 healthy males, 20-43yrs.</td>
<td>Pre-test: Post-maximal voluntary contraction (MVC) 5 and 10 minutes following stretching; 5 min warm-up on cycle ergometer followed by 5 sets of static stretches. Analysis of maximum voluntary contraction force showed 12% decrement in MVC following static stretching.</td>
</tr>
<tr>
<td>Bradley S et al [10]</td>
<td>2007</td>
<td>18 healthy males, 24.3±32yrs.</td>
<td>Pre-test: Post-test 5, 15, 30, 45, and 60 minutes. Comparison of static, ballistic and PNF stretching on vertical jump performance. 3 trials of static and countermovement jumps prior to stretching and post stretching. Results showed a decrease in vertical jump height attained of 4% (post static stretching) and 5.1% (post PNF stretching).</td>
</tr>
<tr>
<td>Brandenburg J et al [11]</td>
<td>2007</td>
<td>8 healthy males (aged 22.3 ± 1.9 years) and 8 healthy females (21.4 ± 1.6 years).</td>
<td>Pre-test: Post-test examining the effects of static stretching on countermovement jump performance. Testing was completed immediately post treatment, followed by isokinetic testing at velocities of 60°.s⁻¹ and 300°.s⁻¹. Results showed a decrease from 47.1 (± 9.7cm) to 45.7 (± 9.2cm) post static stretching. This decrease was also evident during the 24min follow-up period.</td>
</tr>
<tr>
<td>Burkett NL &amp; Zuranitis J [12]</td>
<td>2005</td>
<td>29 elite male athletes, 18-23 yrs.</td>
<td>Pre-test: Post-test of jump height was implemented through the use of 4 separate protocols, sub-maximal jump warm-up (5 countermovement jumps performed at 75% max intensity), weighted jump warm-up protocol (5 countermovement jumps onto a box with athletes holding dumbbells), stretching warm-up protocol performing 14 different stretches, and no warm-up protocol (no activity prior to testing). Results showed utilizing a weighted resistance warm-up produced the greatest benefit when performing the vertical jump test, whilst no significant difference was found amongst other treatments.</td>
</tr>
<tr>
<td>Church JB et al [13]</td>
<td>2001</td>
<td>40 elite female athletes, 20.3±1.6yrs.</td>
<td>Pre-test: Post-test. Treatment groups undertook three protocols: general warm up protocol, general warm up followed by static stretching, and general warm up followed by proprioceptive neuromuscular facilitation (PNF) stretching of legs. Immediate testing post treatment only was conducted, with results showing a significant decrease in vertical jump performance following static and PNF stretching.</td>
</tr>
<tr>
<td>Cornwell A et al [14]</td>
<td>2002</td>
<td>10 healthy males, 20.6±2.2yrs.</td>
<td>Pre-test: Post-test countermovement and non-countermovement jumps. Test conducted on a force plate. Immediate testing post treatment only conducted. Results showed static stretching induced a significant decrease in vertical jump height in both static jumps (4.4 ± 1.3%) and countermovement jumps (4.3 ± 1.3%).</td>
</tr>
<tr>
<td>Duncan M &amp; Woodfield LA [15]</td>
<td>2006</td>
<td>40 children, 10.75 ± 0.4yrs.</td>
<td>Pre-test: Post-test. No warm-up, static stretching consisting of 8mins (stretching lower limbs and held for 10s each stretch) and dynamic warm-up consisting of 8 movement based activities (i.e. lateral shuffle, high knee skipping and high knee runs). Results showed vertical jump height to be significantly higher following the dynamic warm-up protocol compared to the static stretching or control protocols.</td>
</tr>
<tr>
<td>Egan A D et al [16]</td>
<td>2006</td>
<td>11 female elite athletes, 20.0 ± 1.1yrs.</td>
<td>Pre-test: Post-test 0, 5, 15, 30, and 45 min. Static stretching on peak torque and mean power output of the lower limbs. 5 min warm-up at 50W on a stationary cycle ergometer followed by isokinetic testing at velocities of 60°.s⁻¹ and 300°.s⁻¹. Results showed no decrease in peak torque and mean power output.</td>
</tr>
<tr>
<td>Faigenbaum D et al [17]</td>
<td>2005</td>
<td>60 children, 11.3±0.7yrs (27 girls/33 boys)</td>
<td>Pre-test: Post-test of vertical jump, long jump and shuttle run. 5min of walk followed by performance of each warm up in random order on non-consecutive days: 5 minutes of static stretching of lower limbs; 10min of 10 dynamic exercises from moderate to high intensity; and 10mins of 10 dynamic exercises followed by 3x15cm drop jumps. Results showed vertical jump performance declined significantly following static stretching compared to the dynamic warm-up and dynamic plus drop jump warm-up routines.</td>
</tr>
<tr>
<td>Fowles JR et al [18]</td>
<td>2000</td>
<td>8 healthy males, 22.3±0.9yrs; 4 healthy females, 20.3±0.1yrs.</td>
<td>Pre-test: Post-test at 5min, 10min, 15min, 30min, 45min and 60min. Isometric MVC before and immediately after warm-up and stretching. Following warm up, results indicated that prolonged stretching of single muscle decreases MVC strength for up to an hour post stretching.</td>
</tr>
<tr>
<td>Knudson D et al [19]</td>
<td>2001</td>
<td>10 healthy male, 10 healthy females, 23.7±4.5yrs.</td>
<td>Pre-test: Post-test of two treatment groups were implemented; control group (cycling protocol lasting 3 min at a resistance of 80 rpm) and static stretching group (3 sets of static stretches of the lower extremities). Results concluded 55% of tested participants showed a decrease in vertical velocities following static stretching (-7.5%).</td>
</tr>
<tr>
<td>Little T &amp; Williams GA [20]</td>
<td>2006</td>
<td>18 male elite soccer players.</td>
<td>Pre-test: Post-test on vertical jump and stationary 10m sprint. 4 min of jogging and varied movement pattern warm up, followed by either: no stretching, static stretching or dynamic stretching. Results showed the dynamic stretching group produced significantly faster 10-m sprint times (1.83±0.09s) than the no-stretch (1.85±0.08s) and static stretching (1.87±0.09s). There was no significant difference for vertical jump height amongst other treatments.</td>
</tr>
<tr>
<td>Author</td>
<td>Year</td>
<td>Participants</td>
<td>Methods and results</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------</td>
<td>--------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Marek S et al [21]</td>
<td>2005</td>
<td>10 healthy females, 23±3yrs.</td>
<td>Pre-test. Post-test. Static stretching and PNF stretching on peak torque and mean power. 5 min warm-up on a cycle ergometer. Isokinetic measurements were taken at velocities of 60°.s⁻¹ and 300°.s⁻¹. Results showed static and PNF stretching had significant deficits in strength, power output, and muscle activation in both slow (60°.s⁻¹) and fast speeds (300°.s⁻¹).</td>
</tr>
<tr>
<td>McMillian JD et al [22]</td>
<td>2006</td>
<td>30 military cadets 20.2±1.2yrs.</td>
<td>Pre-test. Post-test conducted included: 5 step jump, T-shuttle run times and medicine ball underhand throw for distance. The 3 warm up protocols that were implemented lasted 10min each in duration and included: no warm-up, static stretching and dynamic stretching. The dynamic warm-up protocol which included 10 repetitions of various calisthenics and movement drills, showed faster T-shuttle run times and an increase in 5-step jump distance (between 28-55cm) as compared to the static and control groups.</td>
</tr>
<tr>
<td>Nelson A et al [23]</td>
<td>2005</td>
<td>11 elite male athletes, 21±2 yrs; 5 elite female athletes, 19±1yr.</td>
<td>Pre-test: Post-test. athletes completed each of the 4 stretching protocols prior to completing a 20m sprint test. An increase in time of 0.04s in the 20m sprint was recorded post static stretching condition. Results from the study concluded that passive stretching should not be implemented prior to power events.</td>
</tr>
<tr>
<td>Nelson A et al [24]</td>
<td>2005</td>
<td>11 healthy males, 11 healthy females</td>
<td>Pre-test: Post-test of muscle strength endurance performance post static stretching. Participants completed 4 visits, performing prone knee flexion. Each test preceded one of the treatments: 10min of quiet sitting or 15 min of passive static stretching of the hip, thigh, and calf muscle groups. Static stretching significantly reduced strength by 24% following an exercise load of 60% participant’s body weight.</td>
</tr>
<tr>
<td>Papadopoulos G et al [25]</td>
<td>2005</td>
<td>32 healthy males, 20.7±1.0yrs.</td>
<td>Pre-test: Post-test. Static and dynamic stretching on maximal isokinetic torque of the knee extensor and flexor muscles. 3 protocols: a) warm-up only; b) warm-up and static stretch; c) warm-up and dynamic stretching. Results showed static stretching had a negative impact on maximal isokinetic torque production, 4.3% (for extensor muscles) and 5% for flexor muscles during slow speeds. Isokinetic evaluations showed a further decrease in torque output of 4.4% and 4.3% for extensor and flexor muscle groups respectively.</td>
</tr>
<tr>
<td>Power K et al [26]</td>
<td>2004</td>
<td>12 healthy males, 20-44yrs.</td>
<td>Pre-test: Post-test 30, 60, 90 and 120 min post protocols which included: isometric contractions (MVC) and vertical jumps, unilateral concentric (no-countermovement). Testing was conducted pre and post. Results showed a significant decrease in torque of the quadriceps following static stretching (9.5%).</td>
</tr>
<tr>
<td>Unick J et al [27]</td>
<td>2005</td>
<td>16 healthy trained women, 19.2±1.0yrs.</td>
<td>Pre-test: Post-test. Static and ballistic stretching on vertical jump, counter movement and drop jump, performance. A walking period of 4mins, directly post stretching interventions was incorporated prior to measuring vertical jump tests. Results showed no significant difference in vertical jump height between groups.</td>
</tr>
<tr>
<td>Wallmann WH et al [28]</td>
<td>2005</td>
<td>8 healthy males, 6 healthy females, 18-34 yrs</td>
<td>Pre-test: Post-test, static stretching on the gastrocnemius during vertical jump performance. 5 min warm-up on a treadmill at 3 mph followed by 3 baseline jump trials was administered. Participants completed maximal vertical jumps 30 seconds after stretching. The results from this study showed a 5.6% decrease post static stretching of the gastrocnemius.</td>
</tr>
<tr>
<td>Woolstenhulme TM et al [29]</td>
<td>2006</td>
<td>16 healthy males, 27 healthy females.</td>
<td>Pre-test: Post-test. Effects of ballistic stretching, static stretching, sprinting or basketball shooting only (control) combined with basketball activity on vertical jump height performance. 5 min light jog, with random allocation to 1 of 4 groups. Vertical jump was measured using a jump force plate. Best results were viewed through ballistic stretching followed by 20min of basketball play. There was no change in vertical jump height in other groups.</td>
</tr>
<tr>
<td>Wright Get al [30]</td>
<td>2006</td>
<td>36 healthy students,18-30yrs.</td>
<td>Pre-test: Post-test including 3 treatments in preparation for a strength-power activity. Treatments included: static stretching, dynamic stretching and 10 minute jogging warm-up. Results showed a significant increase in jump height with the warm-up group, whilst the dynamic treatment showed slightly less improvement. Static condition recorded the lowest jump height at of all 3 conditions with a decrement of between 1.27- 2.63cm.</td>
</tr>
<tr>
<td>Yamaguchi T et al [31]</td>
<td>2006</td>
<td>12 healthy men, 23.8 ± 2.3yrs.</td>
<td>Pre-test: Post-test. Static stretching group (6 different stretches, 4 sets of 30s each with 20 s rest periods), and a non-stretching group (control). Loads during assessment of power output were set to 5, 30, and 60% of maximum voluntary contractile torque with isometric leg extension in each participant. Results showed static stretching of the leg extensors reduced peak power output.</td>
</tr>
<tr>
<td>Yamaguchi T et al [32]</td>
<td>2005</td>
<td>11 healthy males, 22.8 ± 0.8yrs.</td>
<td>Pre-test: Post-test. Static stretching (held for 30s each) and dynamic stretching (range of motion activities performed at both fast and slow speeds) of leg extensor muscle groups was analyzed in relation to muscular power. Results significant power improvements following dynamic stretching protocol only.</td>
</tr>
<tr>
<td>Young WB et al [33]</td>
<td>2003</td>
<td>14 healthy male, 3 healthy female, 26.0±8.5yrs.</td>
<td>Pre-test: Post-test. 5 treatment groups were implemented; control, 4 min run, static stretching, run/stretch, and run/stretch/practice jumps. Concentric jumps and drop jumps were performed in the testing protocol. Results showed the stretching warm-up produced the lowest values and the run or run + stretch + jumps warm-ups produced the highest values of explosive force production.</td>
</tr>
</tbody>
</table>
References


About the authors

James Zois

James Zois has been involved in tennis as a professional, competing in ITF Futures and Challenger events for a number of years, as well as coaching talented juniors in state and national squad programs. His roles have encompassed both on court coaching and physical preparation while also being involved in talent identification programs for Tennis Victoria. James holds a degree in Bachelor of Exercise Science (Honours), and whilst being involved in sport science research at Victorian University, he also lectures in physiology and exercise prescription subjects geared towards athletes, coaches, and undergraduate sport science students.

Dr Alan J. Pearce

Alan Pearce is an academic and sports scientist with a passion for racket sports. He gained his PhD in Medicine (Neurophysiology) at the University of Western Australia in 2000. Dr Pearce is a young investigator but has published in well-recognized journals including (amongst others) Experimental Brain Research, British Journal of Sports Medicine (BJSM), Journal of Science and Medicine in Sport (JSMS), Journal of Sports Science and Medicine and Medicine and Science in Tennis. From a practical perspective, Dr Pearce also has extensive coaching and physical preparation experience in working with elite racket sport athletes (particularly in tennis and badminton).

Professor John S. Carlson

John Carlson is the Director of the University Research Centre for Ageing, Rehabilitation, Exercise and Sport (CAREES) at Victoria University. He has also recently been appointed Associate Faculty Dean for Research. His expertise is in the area of Exercise Physiology and the eff ects of exercise on human health and well being, researching and publishing in the area of Exercise and Sport Science for over 27 years.

Address for correspondence:
Dr Alan Pearce
Victoria University
PO Box 14428
Melbourne, Australia
alan.pearce@vu.edu.au