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Our Special Topic section in this issue looks for the first time at exploring the warm-up. This crucial aspect of preparation affects all athletes’ performances, but has been far less studied from the practical point of view than, for example, training methodology, rest and regeneration, biomechanics or nutrition. Among the articles provided in this issue is a report on an unusual project that looked at the last days of training and the warm-up routines of the elite athletes taking part in the 2009 IAAF World Championships in Athletics in Berlin. It is a starting point to provide some of the needed answers to the age-old question of how to structure the final preparations for a peak performance. I am thankful to our German colleagues for initiating this project and for sharing their results, which provide added value from the championships to athletes of all performance levels.

The project was not the only innovation in the field of coaching that was realised at the championships in Berlin. That year also saw the staging of the very first IAAF World Coaches Conference, an event that was repeated at last year’s championships in Moscow. Both conferences provided quite unique opportunities for the top-level coaches assembled at the championships to exchange views and experiences with their peers, and both conferences were well received. These conferences demonstrated the IAAF’s commitment to further advancing the art and applied science of coaching even beyond the work we have been doing over many years in our Coaches Education and Certification System (CECS).

It therefore gives me great pleasure to announce that this year we will be again the opening up of a new area with a Coaches’ conference focused on the coaches of junior athletes, which will take place on the University of Oregon campus in Eugene, Oregon, USA, on 28 July, right after the IAAF World Junior Championship in Athletics.

The topics to be addressed will include the physiological, psychological and training issues relevant to junior athletes, especially prodigious performers at an elite level, and the speakers will include Dr Randall L Wilber (USA), Helmar Hommel (GER), Dr Keith Barr (USA), Professor Dr Ulrich Hartmann (GER) and Dr Craig Poole (USA).

If you are able to make it to Eugene for the championships and the conference, we look forward to welcoming you there. But if you cannot join us, we invite you to share the comprehensive reports on our IAAF website and, of course, in NSA.s!

Abdel Malek El Hebil
Editor in Chief
malek@iaaf.org
Warm-up

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- Blow up During Warm-up: Introduction of a Novel Method to Improve Athletic Performance
  by Dick H.J. Thijssen, Tom G. Bailey, Timothy Cable, Maria Hopman, Greg Atkinson and Helen Jones
Introduction

In essence, the warm-up is a very simple concept. In athletics, the athlete does whatever is needed to be 100% physically and mentally prepared for a training session or competition. Individuals have different needs requiring different routines, which is acceptable, but if the warm-up is well planned and executed it will result in improved performance.

A lot has changed since the earliest days of athletics, when the concept of warming up was being developed, and even the more recent times of the classic warm-up, consisting of a few laps of jogging followed by plenty of static stretching. Currently, coaches and sport scientists put a lot of thought into the warm-up process in an effort to help athletes achieve maximum performance and an edge over other competitors.

In this article the development of the thought behind warming up will be covered as well as why a warm-up is important. Sample warm-ups for sprinters and throwers will be provided as both a general guide and a starting point for further discussion.

History and Trends

Sport science has paved the way to new methods of warming up. Below are some important thoughts developed over the past 130 years:

Loosening up: The idea of limbering or loosening up to prepare for a race goes back to the beginnings of the sport. Throughout the history of modern athletics, one could see athletes getting ready for competition by shaking their links, slapping the surface of their legs with their hands, and doing mobility exercises such as jumping jacks or making arm movements imitating large imaginary circles.

Jogging to raise core temperature: One of the earliest references to a warm-up routine can be attributed to Archie Hahn (USA), who won the 60m, 100m, and 200m titles at the 1904 Olympic Games in St Louis. In his coaching book, How to Sprint - The Theory of Sprint Racing, Hahn recommended a one-lap jog of 400m, followed by a 50-yard sprint at 50% speed for a warm-up, and then three to four practice starts.

Staying warm: The concept of maintaining body temperature between the warm-up and a competition stems from the days of Percy Williams (CAN), who won both the 100m and 200m at the 1928 Olympic Games in Amsterdam. Williams was well known for wearing several sweat suits as he approached the starting line. Prior to this, his coach massaged cocoa...
butter on his legs and kept him under several blankets in the dressing in an effort to keep him warm and loose.

**Static stretching:** The advent of static stretching in sports followed a military study in the 1920’s, in which a direct correlation between musculoskeletal injuries and muscle and joint range of motion was found. Since tighter or shorter muscles were more susceptible to injuries, it was believed static stretching would reduce the frequency of these injuries.

**Dynamic stretching:** Research in recent years has indicated that static stretching can actually inhibit performance. The thought now is leaning towards the use of dynamic stretching and flexibility, or range of motion exercises designed to get the muscle length and range to its optimal state. Range of motion exercises are not to be confused with drills, as the latter are simply repetitive cues to correct or adjust a biomechanical movement and positioning.

**Post-activation potentiation:** The generation of force and power comes from the muscles and tendons, and the motor units of these tissues are dependent on the excitation of the motor neurons by the CNS (central nervous system). Research has shown that greater recruitment is possible when the relevant nerve pathways are stimulated, or activated, as this strengthens subsequent impulses along the same pathways. An example of efforts to create a post-activation potentiation (PAP) effect is the tuck jumps or vertical jumps – many sprinters perform before getting into their starting blocks. The ergogenic stimulus of PAP has been found to last between two and 30 minutes. However, further research is required to determine if PAP is beneficial for both maximal and supra-maximal efforts.

**Back to basics?** Eyewitnesses at the 2012 Olympic Games in London, where David Rudisha (KEN) ran 1:40.91 for an 800m World Record, saw him perform a 45-minute jog and nothing else. No drills, no mobility exercise, no stretching. If raising the core temperature and achieving the correct muscle tension is all that is required to perform at optimal levels, then perhaps we should not be trying to over-complicate the warm-up and just stick with what is essential once the training is in place?

**Shorter warm-ups:** Research in cycling has shown a shorter warm-up can reduce fatigue and increase power output.

**Why is the Warm-up Important?**

Each aspect of a warm-up has different benefits:

**Muscle tone or pliability:** In a way, the term “stretching” should be renamed to “checking”. If one can normally touch his/her toes before a race, but is a few centimetres short of the toes an hour before the race, basically he/she is “checking” if the muscle length is optimal. Psychologically, athletes feel they need to stretch or lengthen the muscles because they do not have the correct muscle tone.

**Activation and mobilisation:** Along with raising the core temperature of the body, there is the need to activate the muscles and motor neurons specific to the event and mobilise specific joints to a range of motion. Like muscle tone, the body requires the optimal full range of motion to perform at maximal effort. Activation and mobilisation work together. The athlete cannot perform a specific movement by contracting and relaxing muscles if the joints do not have the range.

**Potentiation:** Sprinting fast or making the fast movements in a jumping or throwing event is all about muscle contraction and relaxation of the agonist and antagonist muscles. Therefore, any means to increase potentiation, the strengthening of nerve impulses leading to muscle contraction, immediately prior to training or competition is a logical goal for a warm-up.

**Improved oxygen delivery:** Increasing oxygen delivery is accomplished by increasing blood flow to active muscles. This is helpful for the delays between the end of the warm-up and the start of the competition. A warmer body takes longer to “cool down” or return to homeostasis than a cooler body.
Injury prevention: The athlete is simply trying to prevent a muscle pull or cramp prior to performing a maximal effort. A warmer, looser muscle ready for contraction is believed to be less likely to cramp than a colder, tighter muscle.

Mental preparation: The athlete’s mind needs to be ready, not just his/her body. In the case of training, the warm-up is a time for the athlete to focus prior to the session. In the case of competition, the warm-up is a great time to prepare for the performance, though athletes should be mentally preparing before getting on the bus to the stadium!

Principles and Considerations

Standard coaching textbooks tell us that the ideal warm-up starts slowly and gradually and involves all muscles and body parts in exercise that prepares the athlete for the training or competition to follow. All exercises should be ones that the athlete can do well. The warm-up is not the time for the coach to be teaching skills, although feedback may be provided to remind the athlete of the correct movement.

Coaching texts also tell us that in principle, an effective warm-up should progress from:
- slow to fast
- active to dynamic
- general to specific
- simple to more complex

Other generally accepted considerations about warming up include the following points:

The warm-up is PART OF the workout: Some younger athletes may feel the warm-up is a waste of time. So it is important for the coach to reinforce that the warm-up is the first unit of the actual workout. Moreover, what the athlete does on the day of competition should closely match what is done in training, so learning and refining the warm-up routine in training is important.

Event type: The longer the activity, and the less intense the activity, the shorter the warm-up required. This is assuming that less intense activity generally means longer duration. For a sprinter performing a maximal effort of 10 or 20 seconds, an hour warm-up is reasonable. A four-hour marathoner has different requirements than a 2:08 marathoner because the intensity and speeds are much different. Jumpers and especially throwers have even different requirements.

Ambient temperature and humidity: This is common sense, as a warmer body requires less time to get warm and ready. The 1972 Olympic 100m gold medallist Valery Borzov (URS) would start his warm-up 60 minutes before his race in warm weather, and 70 minutes in colder weather.

Timing and prior events: Borzov would only do a 40 minute warm-up if he had run a race in the two hours prior to a competition, as is often seen in championships between semi-finals and finals.

Timing of checking in: Athlete should be sure to know the schedule when they need to check in and get to the Call Room or marshalling area. Once inside, they can sit, or get up and do light drills and mobility exercises. They may not be able to do sprints!

Preparation for the unexpected: Of course, there are things that cannot be controlled, and two good examples are multiple false starts in sprint races and delays from a protest. One has to simply look back at the cases of Linford Christie (GBR) at the 1996 Olympic Games 100m final, or Jon Drummond (USA) at the 1993 World Championships in Athletics 100m quarter finals. In both cases, the race was delayed because of the athlete’s refusal to leave the starting area after being charged with a false start and subsequent disqualification. Their actions were at the expense of the other seven sprinters waiting for the race to commence, but the subsequent performances showed that a well-tuned body with a good cardiovascular and circulatory system should stay warm with the optimal muscle tone for a long period of time before eventually cooling off. For the athlete, the better the general fitness, cardiovascular and circulatory systems,
the longer they can stay physically warm and ready. This is why low intensity tempo runs (i.e. 10 x 100m at 70% speed) on recovery days are beneficial for sprinters. Of course, being mentally ready is critical in such situations, but that aspect is beyond the scope of this article.

Sample Warm-up for Throwers

The warm-up for throwers is similar to a sprinter’s, with the key difference being the emphasis on the muscle groups specific to their events (i.e., more upper body without ignoring the lower body). Similar to a sprinter, maximising power and speed are very important for enabling the thrower to accelerate the implement. Therefore, the key role for the warm-up is the increase in the rate and force of muscle contraction.

Typically, a thrower’s warm-up begins with a five to 10 minute jog at speeds much slower than a sprinter’s, in order to increase the core temperature. The jog, resembling a shuffle at times, is followed by dynamic stretches of the muscles of the: upper body (shoulders, chest and arms), the abdominals (core region) as well as the legs. Given the nature of their event, throwers will also perform range of motion exercises.

Part of the warm-up for throwers consists of accelerations and drills. Throwers need to move their legs quickly. Four to eight accelerations of 10 to 20m with a full slow walk back for recovery is sufficient. The drills can be of any type with emphasis on explosive movement and agility. Lunges (full and half), hops, bounds, plyometrics, quick foot turnover drills, and sideways running with twisting are some drills that can be used.

Finally, the thrower should perform specific throwing movements mimicking the motion of the throws such as the use of a lighter implement or weighted tennis balls. Given the nature of the forces generated, this is a vital stage in the warm-up allowing the athlete to determine if they are ready or not.

Please send all correspondence to:
Jimson Lee
jimson@speedendurance.com
REFERENCES


Final Preparations for Peak Competitions: Observations from the 2009 IAAF World Championships in Athletics

by Wolfgang Killing, Eckhard Hutt, Jan May, Jörg Peter, Rainer Pottel, Maria Ritschel, Jürgen Schult and Adi Zaar

ABSTRACT

Classic training methodology tells us that there is little athletes can do in the four to ten days before a competition to improve their performance level. But what are the effects, positive or negative, of activities in the period after the last hard training session? From the practical point of view, what is the ideal structure for the final preparations, and even for the warm-up on the day of the competition itself? This article, adapted from a more extensive report of a project conducted under the auspices of the German Athletics Federation (Deutscher Leichtathletik-Verband – DLV) addresses these questions with an informal compilation of observations of world-class athletes going about their preparations for the 2009 IAAF World Championships in Athletics. After outlining the methodology used, the authors present observations of interest to athletes, coaches and team managers preparing for a peak competition. These are supplemented by brief case studies of well-known athletes in each of the main event groups.

AUTHORS

Wolfgang Killing is scientific director of the German Athletics Federation (DLV) Academy.

Eckhard Hutt is a former German national Head Coach for triple jump.

Jan May is the German national Head Coach for men’s hurdles events.

Jörg Peter is the German national Youth Coach for the long sprint events.

Rainer Pottel is the German national Head Coach for decathlon.

Maria Ritschel is the German national Head Coach for women’s javelin.

Jürgen Schult is the German national Head Coach for all throwing events.

Adi Zaar is the German national Youth Coach for women’s middle distance events.
Introduction

In a peak competition, athletes are expected to be in their best possible form and to deliver a top performance, ideally in the shape of a personal best and or the highest possible placing. The preparation for a season’s peak competition is a year-round process and, in extreme cases, it can even involve several years of work.

Classic training methodology tells us that the time period between the last intensive training session and a peak performance should be seven to ten days while recent findings show that for women this time period might be four to seven days. After that, it would seem there is little the athlete can do to increase his/her performance level. At that point it is no longer a question of developing one’s form or even fine-tuning, because trying to do so would lead to fatigue, which would then have a negative impact on the performance.

But exactly what are the effects, positive or negative, of the athlete’s activities in the period after the last hard training session? This question has long been of interest to coaches of athletes of all levels. From the practical point of view, coaches and athletes are looking for an ideal structure for the activities of the final preparations, and even for the warm-up on the day of the competition itself, or at least a confirmation that the approach they use for peak competitions is a good one. Studying the behaviour of elite athletes during their final preparations and warm-up is interesting in itself as it enables a critical reflection for future preparation.

It is the nature of a peak competition that it represents the athlete’s most challenging competition of the season. For elite athletes, this usually means a major event such as the Olympic Games, or a championships at the world or area level. Therefore, the peak competition must first of all be seen as a stress factor that can either enhance or reduce performance. In addition, the procedures necessary at major events are different and more complex than at smaller competitions. Major events usually mean trips abroad and extended absences from home, long periods of simply waiting for the competition, different sleeping, eating, leisure and training possibilities, longer lead-up times and distances to be covered at the competition venue, tense Call Room stays and tightly controlled conditions in the stadium. Last but not least, the competition conditions (temperature, humidity rain, wind), at major events are not uniform: they are sometimes good and sometimes bad. All these factors are additional stressors that can affect performance, and they tend to affect younger and less experienced athletes more than experienced athletes with a very high performance level. Experience, therefore, is a valuable component of dealing with the stress at a major event.

Our aim in this article is share information that will supplement the experience of the coach-athlete team in the hope that it can assist with the realisation of improved performances. In the following, readers will find an informal compilation of observations of world-class athletes going about their final training and warming up for the 2009 IAAF World Championships in Athletics in Berlin. Of course, at such an event it is not possible to follow the activities of all athletes at all times and, therefore, we cannot claim to have produced a comprehensive study. What we tried to do was collect what relevant information we could on the activities in semi-public and public spaces - the official training, warm-up and competition areas for the championships – of athletes we could identify.

After outlining the methodology used, we present a set of general observations on topics that will be of interest to coaches and team managers. This is followed by sections containing specific observations on the training in the days leading up to the competition and the warm-up and final preparations before the start of the competition. These sections include a small number of brief case studies of well-known athletes in each of the main event groups.
This article is adapted from a more extensive report on a project conducted under the auspices of the host federation of the championships, the German Athletics Federation (Deutscher Leichtathletik-Verband – DLV), as a complement to the biomechanical studies conducted at the event.

**Methodology**

**General**

Our methodology is presented here to a) provide context for the observations given below and b) as the starting point for the planning of future surveys with aims similar to ours.

**Techniques**

The techniques we used for our observations included the following:
- Notes on form sheets and sketches
- Dictaphone
- Video recordings
- Unsystematic observation
- Conversations with athletes and coaches

**Aspects observed**

The aspects we observed, recorded and considered for our final report included the following:
- Training programme
  - In the days before the competition
  - After the early rounds of the competition (training between competitions)
  - Relay training
- Training contents
  - Which exercises? Intensity, volume?
  - Rest intervals
  - Instructions on how to carry out the exercises
  - New exercises
- Physical and physiotherapeutic measures before the warm-up
  - Cooling
  - Passive warm-up
  - Massage
  - Adjustment of joints
  - Taping and bandages
- Warm-up timeframe
  - How many minutes prior to the start does the athlete arrive at the warm-up area?
  - When does the athlete start his/her preparation?
  - When does the athlete start his/her special warm-up?
  - Schedule from the first call until the start of the competition
- Warm-up activities
  - General warm-up (jogging, stretching, running ABC, accelerations)
  - Special warm-up (starts, sprints, jumps, throws, strengthening, tempo runs)
  - Behaviour in the Call Room (stretching, running ABC, etc.)
- Immediate competition preparation in the stadium
  - General behaviour on the track or field (jogging, stretching, running ABC, accelerations, etc.)
  - Test starts (plus acceleration over the first or second hurdles)
  - Warm-up jumps, warm-up throws, imitations
  - Consultation with the coach, type of corrections
- During the competition
  - General behaviour (jogging, stretching, imitations, accelerations, sprints)
  - Communication with the coach
- Competition results
  - Individual results
  - Biomechanical evaluations
- After the competitions and between competitions
  - Duration of the warm-down jog, the complete warm-down, the follow-up treatment
  - Jogging, stretching
  - Passive measures, massage
  - Doing nothing
Instead, in our observations, the coaches of these athletes normally did their best to support and reinforce their athletes’ movements during technique sessions in the last days before the competition. Only sometimes was there an attempt to correct movements (see Chinese throwers below).

Preliminary stimulus

The setting of a preliminary stimulus means training done on the day before the competition to activate the functional systems, especially the central nervous system and the muscles (build-up of tension). In the power events, the traditional way to do this is by strength, jumping or throwing exercises; in the jumping events a short intense series of jumps and squats with medium weights, small bending angles and high speed is used. Although for organisational reasons not all athletes could be observed, it seems that the importance of this preparation technique has abated somewhat. Only a few athletes could be observed executing appropriate programmes. More frequently, so-called preliminary sessions could be observed that either included only jogging and gymnastic exercises or consisted of running and jumping-ABC exercises and several acceleration runs. Sometimes, even starts plus accelerations, run-up checks or jumps and throws could be observed during these preliminary sessions.

Warm-up for elite sprinters

Among our most interesting observations was that instead of the classic warm-up starting with easy jogging, many, but not all, of the sprinters from the great sprint nations of the Caribbean and North America had a different approach. Used in both their training and pre-competition warm-ups, it started with six to eight acceleration runs over 80 to 100m on the grass, interspersed with walking breaks. After this, they did gymnastic exercises and passive mobilisation activities as described below. Against the background of the many single starts of some sprinters (eight in the case of Usain Bolt (this behaviour should not be underestimated. In such a situation, relieved or assisted warm-up work is probably quite economical.

General Observations

Orientation

The majority of the athletes we observed visited the competition stadium and training facilities in Berlin during the days before the competition. As would be expected, the reasons for these visits were to train, get to know the procedures for the warm-up area and Call Room, do practice starts with the official starters or measure their approach runs. Some throwers performed preliminary swings or gliding movements to make themselves familiar with the throwing circles. Other athletes only watched the procedures on the warm-up field.

Self-assurance

In the days before or immediately prior to the competition, athletes often want to reassure themselves of their performance potential, either in training or the during the warm-up. In Berlin, this was especially the case with the throwers and some of the jumpers. However, in addition to the risk of not reaching the desired performance and being put off by this fact, we found that success in the competition was certainly not guaranteed by a good warm-up. For example, discus thrower Gerd Kanter, who went on to take the bronze medal, and some high jumpers did not replicate observed warm-up performances in the actual competition (Gregorz Sposob for example cleared 2.25m in the warm-up vs. 2.20m in the competition). Sometimes it is problematic when good warm-up performances are achieved by fouling. This was especially the case for the rotational shot putters. For example, we saw that defending champion Reese Hoffa, who took fourth in Berlin, and others achieve over 21.50m in their warm-ups, performances they could not repeat in the competition itself.

Technique corrections

Although they do not normally enter new technical ground, it is known that some coaches try to address old, firmly established faults during the final training sessions and even during competitions. However, this was not the case among the stronger athletes in Berlin.
Passive mobilisation

Many of the athletes we observed spent a lot of their time working on flexibility and mobility, either immediately before they competed and or in the days before their competitions. We noted that some used the traditional means, i.e., gymnastic and stretching exercises, while others used rubber bands to assist their exercises. However, athletes from the great sprint nations and China tended to use exercises assisted by the coach or physiotherapist, sometimes on the massage table, sometimes in a standing or sitting position, often with stretching their legs up to or even beyond the split position (Chinese hurdlers and shot putters). Most of these athletes did flexibility exercises for their back, hips, knees, upper- and lower- ankle joints. When doing so, they demonstrated a great (passive) flexibility.

Behaviour during the competition

We observed that between their attempts, the throwers and high jumpers generally moved about only a little: getting up, walking around (especially the throwers), short jogging, light mobilisation exercises, imitations and only rarely running or jumping-ABC exercises. Only in the horizontal jumps and pole vaults, events with long, fast approach runs, did the athletes do warm-ups that also included acceleration runs after longer breaks (i.e. qualifications in all horizontal jumps, where there were a lot of participants).

Training between rounds

Some athletes trained between the qualification rounds and the finals. Most athletes that we observed performed warm-up exercises with subsequent tension exercises (short starts plus acceleration, jumps, strength).

Physical applications

Large vats of ice water were available in the warm-up and the training stadiums. These were used by some of the athletes after intensive training loads. Other athletes contented themselves with rubbing their legs with ice packs. During training, we did not see any cooling jackets being used and during competition such a jacket was only used by a German decathlete.

Warm-down

We noted that after both training and competition, many but not all, of the top sprinters gave the warm-down much more emphasis than just the standard short jog. The elements and the order seen most regularly among North American and Caribbean athletes were as follows:

• Five minutes of warm-down walking with limbering movements.
• Immediately after this, the flexor-extensor chain as well as the hip flexors and extensors are lightly moved and stretched; slight loosening and massage by a physiotherapist.
• Ice baths.
• Jogging on the grass.

For the jumpers there was a variation in approach. At the end of their training sessions, some did warm-down jogging others did not. As with the sprinters, in some cases one could observe jumpers being treated with ice.

Weather conditions

When evaluating the warm-up behaviour and unexpected approaches, such as the replacement of the warm-up jog by acceleration runs, the weather conditions should not be disregarded. Due to the very high temperatures in the early days of the championships, the starting temperature of the athletes was already raised even before beginning their sports activity. Since many of the athletes from the Caribbean and Central America region have such a heat all year, they can do without the non-specific and, in some cases counterproductive, jogging warm-up.

Organisation

It was pleasant to watch the relaxed, helpful and friendly organisational staff, which included the marshals on the competition and training fields, the drivers and the helpers in the accreditation offices and the hotels. Of particular note was the behaviour of the judges, who in the technical competitions permitted as much warm-up jogging, throwing and jumping as was possible during the time period available (which often led to a 10-15 min break between the last warm-up attempt and the start of the competition or the presentation).
Training Observations

When we speak of training in this context, we mean the application of loads up to and including the day before the competition. With few exceptions most of the top athletes known to us were not seen in the training areas during the days before the competition; only some could be observed doing general warm-up sessions, probably to activate their functional systems.

Of course, training programmes must really be analysed individually but we can say that for those athletes we could observe training during this period, the sessions normally were, as described in the textbooks, of low volume but highly intensive and specific. This was the case for sprinters, jumpers and throwers.

For each group we saw highly intensive sessions introduced by a warm-up and characterised by a specific content (sprint drills and runs over very short distances, approach run-up checks, jumps, submaximal throws). Many jumpers carried out a technique-related training session. This normally consisted of a warm-up, strides, technique jumps of varying intensity followed by general exercises or weight training, and more or less warm-down jogging. Here, one could see a two-day cycle with some athletes (e.g. Maggi), but not with others. Interestingly, we did not observe any of the throwers carrying out intensive strength loads but there was a variation in the number of throws taken during this period and some athletes completed very intensive programmes.

Table 1: Selected case studies – Sprints and Hurdles

<table>
<thead>
<tr>
<th>Alyson Felix (USA) - 200m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competition result: 1st, 22.02 sec</td>
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</table>

<table>
<thead>
<tr>
<th>August 8 (11 days before heats)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm-up:</strong> 5 min stretching, 8 x 80m (rest intervals: 80m walking, sometimes backward)</td>
</tr>
<tr>
<td><strong>Mobilisation:</strong> 12:15 min dynamic mobilisation and stretching</td>
</tr>
<tr>
<td><strong>Sprint drills:</strong> 30-40m - knee lift: left-left-right-right, long legs, hops with bringing the rear leg up to the front leg</td>
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<tr>
<td><strong>Loading:</strong> 1x 80m, 1x 60m - stride pattern: from short to long, from powerful to relaxed (rest interval: 3 min), run-off: 1 x 50m</td>
</tr>
<tr>
<td><strong>Tempo runs:</strong> 200m – 23.0 sec, 250m – 29.5 sec, 100m -11.4 sec, (rest intervals: 10 min)</td>
</tr>
<tr>
<td><strong>Warm-down:</strong> 400m easy jogging, massage by physiotherapist</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>August 15 (4 days before heats)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start of training:</strong> 18:00h</td>
</tr>
<tr>
<td><strong>Warm-up:</strong> 5 min stretching, 10 min warm-up jogging</td>
</tr>
<tr>
<td><strong>Mobilisation:</strong> 15 min stretching: first statically for only a short time, then longer into the movement using a band</td>
</tr>
<tr>
<td><strong>Therapy:</strong> Ice bath, knee-joint check, 10 min massage</td>
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<table>
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<tr>
<th>August 16 (3 days before heats)</th>
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<tbody>
<tr>
<td><strong>Start of training:</strong> 14:00h</td>
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<tr>
<td><strong>Warm-up:</strong> 8 x 100m tempo runs (rest intervals: 2 min)</td>
</tr>
<tr>
<td><strong>Mobilisation:</strong> 20 min stretching and trunk-strength exercises</td>
</tr>
<tr>
<td><strong>Loading:</strong> 3 x 80m acceleration runs (rest intervals: 4 min)</td>
</tr>
<tr>
<td><strong>Warm-down:</strong> 10 min massage</td>
</tr>
</tbody>
</table>
### August 17 (2 days before heats)

<table>
<thead>
<tr>
<th>Training Session</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start of training:</strong></td>
<td>13:30h</td>
</tr>
<tr>
<td><strong>Warm-up:</strong></td>
<td>8 x 80m (rest intervals: 80m)</td>
</tr>
<tr>
<td><strong>Mobilisation:</strong></td>
<td>20 min physiotherapy, mobilisation exercises, and stretching</td>
</tr>
<tr>
<td><strong>Loading:</strong></td>
<td>2 x 100m, 2 x 60m (rest intervals: 5 min)</td>
</tr>
<tr>
<td><strong>Tempo runs:</strong></td>
<td>2 x 150m tempo at about 85% (rest interval: 12 min)</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>5 min jogging on the grass, ice bath, massage from physiotherapist</td>
</tr>
</tbody>
</table>

### August 18 (day before heats)

<table>
<thead>
<tr>
<th>Training Session</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start of training:</strong></td>
<td>15:15h</td>
</tr>
<tr>
<td><strong>Warm-up:</strong></td>
<td>800m jogging on the grass, 10 min static stretching, 20 min relaxation and listening to music</td>
</tr>
<tr>
<td><strong>Sprint drills:</strong></td>
<td>6 x 40m, easy</td>
</tr>
<tr>
<td><strong>Loading:</strong></td>
<td>2 x 30m (rest interval: 3 min)</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>20 min relaxation, 10 min massage</td>
</tr>
</tbody>
</table>

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**Tyson Gay (USA) - 100m**

**Competition result:** 2<sup>nd</sup>, 9.71 sec (NR)

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### August 14 (day before heats)

<table>
<thead>
<tr>
<th>Training Session</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start of training:</strong></td>
<td>10:00h</td>
</tr>
<tr>
<td><strong>Warm-up:</strong></td>
<td>6 x 100m low intensity (walking the curves, running the straights)</td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
<td>Intense stretching of all major muscle groups assisted by physiotherapist</td>
</tr>
<tr>
<td><strong>Sprint drills:</strong></td>
<td>20m, knee lift, knee lift with gripping movement, skips with gripping movements</td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
<td>80m, 60m, 50m, 40m</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>600m jogging</td>
</tr>
<tr>
<td><strong>Physiotherapy:</strong></td>
<td>15 min massage, then mobilisation assisted by physiotherapist</td>
</tr>
</tbody>
</table>

---

**Wei Ji (CHN), Dongpeng Shi (CHN), Jing Yin (CHN) – 110m hurdles**

**Competition results:**
- Ji: 8<sup>th</sup>, 13.51 sec (13.41 sec (SB) in semi-final)
- Shi: 3<sup>rd</sup> in semi-final, 13.42 (SB)
- Yin: dns

---

### August 14 (4 days before heats)

<table>
<thead>
<tr>
<th>Training Session</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm-up:</strong></td>
<td>10-15 min jogging</td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
<td>30 min intense stretching exercises, sometimes assisted by coach (standing split, etc.)</td>
</tr>
<tr>
<td><strong>Running ABCs:</strong></td>
<td>In combination with many swinging exercises</td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
<td>3 x 50-70m easy</td>
</tr>
<tr>
<td><strong>Hurdles work:</strong></td>
<td>With 4 hurdles: 4 x trailing leg exercise, 2 x 5-step rhythm, 5-8 starts and runs up to the fourth hurdle, in one case the eighth hurdle, rest intervals: 5-10 min</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>10 minutes jogging</td>
</tr>
</tbody>
</table>

(Total duration of the session: 2.5 hours)
| **Jennifer Barringer** (USA) - 3,000m steeplechase |  
| **Competition result:** 5th, 9:12.50 (AR) |  
| **August 14 (day before heats)** |  
| **Warm-up:** | 15 min jogging |  
| **Exercises:** | 10 min general stretching exercises, 10 min hurdle exercises with hurdles |  
| **Run-offs:** | 4 x 80-100m, walking breaks |  
| **Trunk Strength:** | 15 min, each exercise repeated 40 times |  
| **Warm-down:** | Nothing |  

| **Pamela Jelimo** (KEN) – 800m |  
| **Competition Result:** dnf semi-final (2:03.5 in first round heat) |  
| **August 14 (2 days before heats)** |  
| **Warm-up:** | About 45 min of jogging, fast |  
| **Exercises:** | 10 min swinging and stretching exercises |  
| **Accelerations:** | 2-3 x 60-80m |  
| **Tempo runs:** | 400m (ca. 58 sec), 200m walking break, 200m (27-28 sec), 100m walking break, 100m (13.5 sec), 50m walking break, 80m (11 sec) |  
| **Warm-down:** | 20 min jogging |  

| **Shannon Rowbury** (USA) – 1500m |  
| **Competition result:** 3rd, 4:04.18 |  
| **August 14 (4 days before heats)** |  
| **Warm-up:** | 45 min jogging |  
| **Exercises:** | 10 min dynamic stretching assisted by physiotherapist |  
| **Running ABC:** | 10 x 25m |  
| **Accelerations:** | 1 x 200m, 1 x 80m |  
| **Run-offs:** | 2 x 5 x 100m, fast with jogging intervals, 3 min rest between series |  
| **Exercises:** | Leg swings: 2 x 4-10 |  
| **Warm-down:** | No jogging |
Table 3: Selected training case studies - Throws

<table>
<thead>
<tr>
<th>Athletes</th>
<th>Competition results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lijlao Gong (CHN), Meiju Li (CHN), Xiangrong Liu (CHN) – Shot Put</td>
<td>Gong 3rd, 19.98m (PB) Li 7th, 18.76m Liu 10th, 18.52m</td>
</tr>
</tbody>
</table>

August 14 (2 days before the competition)

<table>
<thead>
<tr>
<th>Warm-up</th>
<th>10 min jogging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises</td>
<td>15 min stretching exercises, sometimes assisted by the coach</td>
</tr>
<tr>
<td>Standing puts</td>
<td>6-8 puts (4-16m) in quick succession</td>
</tr>
<tr>
<td>Gliding puts</td>
<td>20-23 puts (around 16-18m), only few corrections by the coach</td>
</tr>
<tr>
<td>Strength</td>
<td>Half squats, 140-160kg, imitations (in weight room)</td>
</tr>
<tr>
<td>Warm-down</td>
<td>No warm-down activity observed</td>
</tr>
</tbody>
</table>

Xuejun Ma (CHN), Amin Song (CHN), Shaoyang Xu (CHN) – Discus

Competition results: Ma 11th, 58.79m (63.38m (SB) in qualification) Song 5th, 62.42m Xu 13th in qualification, 61.02m (SB)

August 15, 4 days before qualification round

<table>
<thead>
<tr>
<th>Warm-up</th>
<th>15 minutes jogging, with walking breaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercises</td>
<td>15 min stretching, 10 min preparation of the shoulder using an elastic band</td>
</tr>
<tr>
<td>Standing throws</td>
<td>6-8 throws, about 45-50m</td>
</tr>
<tr>
<td>Rotational throws</td>
<td>20-25, about 53-60 m (a few corrections by the coach, mostly by using short gestures)</td>
</tr>
<tr>
<td>Athletic exercises</td>
<td>Medicine ball throws 20-30m, five sprint and multi-hop series over about 20-25m each</td>
</tr>
<tr>
<td>Exercises</td>
<td>5-10 min stretching, with assistance</td>
</tr>
<tr>
<td>Massage</td>
<td>30 min treading massage on the back and legs (by female fellow athletes), foot massage</td>
</tr>
</tbody>
</table>

(Duration of the session: At least 2.5 hours.)
Table 4: Selected training case studies – Jumps

| Anna Chicherova (RUS), Svetlana Shkolina (RUS), Elena Slesarenko (RUS) – High Jump |
| Competition results: Chicherova 2\textsuperscript{nd}, 2.02m (SB) |
| Shkolina 6\textsuperscript{th}, 1.96m |
| Slesarenko 10\textsuperscript{th}, 1.92m |

August 17 (day before qualification round)  
\textbf{Warm-up:} 8 min jogging  
\textbf{Exercises:} 15 min stretching  
\textbf{Running ABC:} 6-8 x 30m  
\textbf{Accelerations:} 2-3 x 50-70m  
\textbf{Preliminary stimulus:} Chicherova: third-squat 100-120 kg, Slesarenko: 5 x 5 jumps over hurdles placed with large spacings  
\textbf{Exercises:} Stretching and strengthening exercises with rubber band  
\textbf{Warm-down:} 5-8 min jogging

| Chaunté Howard Lowe (USA) – High Jump |
| \textit{Competition result:} 7\textsuperscript{th}, 1.96m |

August 14 (4 days before qualification round)  
\textbf{Warm-up:} 10 min jogging  
\textbf{Exercises:} 10 min stretching, including some facilitation exercises assisted by a physiotherapist  
\textbf{Running ABC:} 3 x 40-60m  
\textbf{Jumps:} From both a short run-up and competition run-up, several jumps over 1.90 and 1.93m  
\textbf{Warm-down:} 5 min jogging, stretching exercises
Maureen Higa Maggi (BRA) – Long Jump

*Competition result:* 7th, 6.68m

**August 17 (4 days before qualification round)**
- **Warm-up:** 10 min jogging
- **Exercises:** 15 min intense stretching
- **Running ABC:** 6 x 30m
- **Accelerations:** 60m and 80m
- **Jumping ABC:** 4 x 30m
- **Technique:** 2x run-up checks, three competition jumps
- **Bounding runs:** 40 and 60m
- **Exercises:** 5 min stretching
- **Warm-down:** 5 min jogging

**August 19 (2 days before qualification round)**
- **Warm-up:** 10 min jogging
- **Exercises:** 20 min intense stretching
- **Running ABC:** 4 x 30m
- **Accelerations:** 60m and 80m
- **Bounding runs:** 40m and 60m
- **Technique:** 3-4 run-up checks
- **Standing long jump:** 5 attempts (weak impression, 2.50m)
- **Exercises:** 5 min stretching
- **Warm-down:** 5 min jogging
Table 5: Selected warm-up case studies – Sprints and Hurdles

<table>
<thead>
<tr>
<th>Usain Bolt (JAM) - 100m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>August 15, heat</strong></td>
</tr>
<tr>
<td><strong>Getting into the mood:</strong></td>
</tr>
<tr>
<td><strong>Warm-up running:</strong></td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>August 15, quarter-final</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Getting into the mood:</strong></td>
</tr>
<tr>
<td><strong>Warm-up running:</strong></td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>August 16, semi-final</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Getting into the mood:</strong></td>
</tr>
<tr>
<td><strong>Warm-up running:</strong></td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>August 16, final</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Getting into the mood:</strong></td>
</tr>
<tr>
<td><strong>Warm-up running:</strong></td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
</tr>
<tr>
<td><strong>Call Room:</strong></td>
</tr>
<tr>
<td><strong>Competition Result:</strong></td>
</tr>
</tbody>
</table>
### Asafa Powell (JAM) – 100m

<table>
<thead>
<tr>
<th>August 15, heat</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm-up running:</strong></td>
<td>5 x 80m with slight acceleration, 3 x 50m run-offs, various drills</td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
<td>5 min stretching</td>
</tr>
<tr>
<td><strong>Accelerations:</strong></td>
<td>2 x 80m fast</td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
<td>30m, 30m, 40m, 50m from the blocks</td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;, 10.38 sec (relaxed)</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>400m jog, 10 min massage, mobilisation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>August 15, quarter-final</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm-up running:</strong></td>
<td>2 x 80m accelerations</td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
<td>5 min stretching</td>
</tr>
<tr>
<td><strong>Accelerations:</strong></td>
<td>2 x 60m fast</td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
<td>2 x 50m, 2 x 30m, 3 x 40m, rest intervals 5 min each:</td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;, 9.95 (relaxed)</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>400m jogging, 10 min massage, mobilisation</td>
</tr>
</tbody>
</table>

### Sanya Richards (USA) - 400m

<table>
<thead>
<tr>
<th>August 15, heat</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm-up:</strong></td>
<td>Easy jogging and skipping alternately, limbering up, and walking (one lap), eight very easy accelerations down the straight, walking through each curve</td>
</tr>
<tr>
<td><strong>Exercises:</strong></td>
<td>35 min swinging exercises, stretching and intense stretching (passive stretching assisted by physiotherapist)</td>
</tr>
<tr>
<td><strong>Run-offs:</strong></td>
<td>1 x 30m, fast and relaxed, 1 x 50m, 1 x 80m (10.1 sec), then to the Call Room</td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;, 51.06 sec</td>
</tr>
<tr>
<td><strong>Warm-down:</strong></td>
<td>2 laps warm-down jogging</td>
</tr>
</tbody>
</table>
Table 6: Selected warm-up case studies – Middle and Long Distance

<table>
<thead>
<tr>
<th>Jeniffer Barringer (USA) - 3,000m steeplechase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>August 15, heat</strong></td>
</tr>
<tr>
<td>Warm-up: 25 min, easy jogging</td>
</tr>
<tr>
<td>Exercises: 5 min active stretching exercises</td>
</tr>
<tr>
<td>Running ABC: 8 x 20m</td>
</tr>
<tr>
<td>Technique: 8 x hurdle clearances</td>
</tr>
<tr>
<td>Run-offs: 5 x 90m</td>
</tr>
<tr>
<td>• In the stadium:</td>
</tr>
<tr>
<td>Run-offs: 3 x 80m at race pace</td>
</tr>
<tr>
<td>Competition result: 9:26.81, 3rd</td>
</tr>
<tr>
<td>Warm-down: 15 min jogging</td>
</tr>
<tr>
<td>Ice bath: 5-7 min</td>
</tr>
<tr>
<td>Exercises: 5 min</td>
</tr>
</tbody>
</table>

| **August 17, final** |
| Warm-up: 30 min, easy jogging |
| Exercises: 5 min active stretching exercises |
| Running ABC: 6 x 20m |
| Technique: 4x hurdle clearances |
| Run-offs: 6 x 90m |
| • In the stadium: |
| Run-offs: 3 x 80m at race pace |
| Competition result: 5th, 9:12.50 (AR) |
| Warm-down: 15 min jogging |
### Augustino Choge (KEN) - 1,500m

**August 15, heat**
- **Warm-up:** 40 min jogging
- **Exercises:** 15 min in combination with running ABC
- **Run-offs:** 1 x 80m easy, 4 x 80m at race pace followed by 10 min inactive

  - In the stadium:
    - **Run-off:** 1 x 100m
    - **Competition result:** 3<sup>rd</sup>, 3:44.73
    - **Warm-down:** 30 min easy jogging, no stretching

**August 17, semi-final**
- **Warm-up:** 40 min jogging
- **Exercises:** 15 min in combination with running ABC
- **Run-offs:** 1 x 80m easy, 5 x 80m at race pace, stretching during rest intervals followed by 10 min inactive

  - In the stadium:
    - **Run-offs:** 2 x 100m
    - **Competition:** 2<sup>nd</sup>, 3:36.43
    - **Warm-down:** 40 min easy jogging, no stretching

**August 19, final**
- **Warm-up:** 35 min jogging
- **Exercises:** 15 min in combination with running ABC
- **Run-offs:** 2 x 80m easy, 4 x 80m at race pace, stretching during rest intervals followed by 10 min inactive

  - In the stadium:
    - **Run-offs:** 2 x 100m
    - **Competition result:** 5<sup>th</sup>, 3:36.53
### Pamela Jelimo (KEN) – 800m

**August 15, heat**

- **Warm-up:** 20 min jogging  
- **Exercises:** 10 min swinging exercises  
- **Run-offs:** 4 x 80m, easy

- **In the stadium:**
  - **Run-offs:** 2 x 60m into the curve  
  - **Competition result:** 1st, 2:03.50  
  - **Warm-down:** No jogging

**August 17, semi-final**

- **Warm-up jog:** 25 min, easy  
- **Exercises:** 10 min swinging exercises  
- **Run-offs:** 4 x 80m, easy, 1 x 80m, fast  
- **Exercises:** 5 min

- **In the stadium:**
  - **Run-off:** 1 x 100 m at race pace  
  - **Competition result:** 1st, 2:03.27

### Maryia Savinova (RUS) – 800m

**August 17, heat**

- **Warm-up:** 20 min jogging  
- **Exercises:** 10 min stretching assisted by physiotherapist  
- **Running-ABC:** 8 x 25m fast wearing spikes  
- **Accelerations:** 3 x 70m fast  
- **Run-off:** 1 x 120m at race pace  
- **Exercises:** 5 min

- **In the stadium:**
  - **Run-off:** 1 x 100 m at race pace  
  - **Competition result:** 1st, 2:03.27

**August 17, semi-final**

- **Warm-up:** 25 min jogging  
- **Exercises:** 10 min stretching assisted by physiotherapist  
- **Running ABC:** 10 x 25m wearing spikes  
- **Accelerations:** 3 x 70m  
- **Run-off:** 1 x 100m  
- **Exercises:** 5 min

- **In the stadium:**
  - **Run-off:** 1 x 90m  
  - **Warm-down:** 20 minutes jogging  
  - **Exercises:** 5 min stretching  
  - **Competition result:** 1st, 1:59.30
**Mehdi Baala (FRA) – 1,500m**

<table>
<thead>
<tr>
<th>Date</th>
<th>Details</th>
</tr>
</thead>
</table>
| August 15, heat | **Warm-up:** 20 min jogging  
**Exercises:** 15 min, followed by 20 min inactive  
• In the stadium:  
**Run-offs:** 2 x 60m  
**Competition result:** 1st, 3:42.77  
**Warm-down:** No jogging |
| August 17, semi-final | **Warm-up:** 10 min jogging, 20 min inactive  
• In the stadium:  
**Run-offs:** 2 x 70m  
**Competition result:** 3rd, 3:37.07  
**Limbering-up:** 15 min assisted by physiotherapists |
| August 19, final | **Warm-up:** 15 min jogging  
**Exercises:** 5 min stretching exercises, followed by 20 min inactive  
• In the stadium:  
**Run-offs:** 2 x 100m at race pace, rest interval: walking slowly  
**Competition result:** 7th, 3:36.99 |
### Kipruto Kiprop (KEN) – 1,500m

#### August 15, heat
- **Warm-up:** 40 min jogging
- **Exercises:** 15 min in combination with running ABC
- **Run-offs:** 1 x 80m easy, 2 x 80m at race pace, stretching during rest intervals, followed by 10 min inactive
  - In the stadium:
    - **Run-offs:** 1 x 100m
  - **Competition result:** 2nd, 3:41.42
  - **Warm-down:** 30 min easy jogging

#### August 17, semi-final
- **Warm-up:** 45 min jogging
- **Exercises:** 20 min in combination with running ABC
- **Run-offs:** 1 x 80m easy, 5 x 80m at race pace, stretching during rest intervals 10 min inactive
  - In the stadium:
    - **Run-offs:** 2 x 100m
  - **Competition result:** 2nd, 3:36.24
  - **Warm-down:** 30 min easy jogging, no stretching

#### August 19, final
- **Warm-up:** 35 min jogging
- **Exercises:** 15 min in combination with running ABC
- **Run-offs:** 2 x 80m easy, 4 x 80m at race pace, stretching during rest intervals, followed by 10 min inactive
  - In the stadium:
    - **Run-offs:** 2 x 100m
  - **Competition result:** 4th, 3:36.47
  - **Warm-down:** 30 min easy jogging, no stretching
Table 7: Selected warm-up case study – Jumps

<table>
<thead>
<tr>
<th>Nelson Evora (POR) – Triple Jump</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>August 16, qualification</strong></td>
</tr>
<tr>
<td><strong>Warm-up:</strong> 300m run easy jogging, bouncing jog (including arm circles), 100m slightly accelerating, lunge right + left, reaching and knee-lift exercises, jogging</td>
</tr>
<tr>
<td><strong>Exercises:</strong> Passive stretching assisted by a physiotherapist, especially hip joint</td>
</tr>
<tr>
<td><strong>Warm-up jumps:</strong> 3x easy triple jumps from 3 run-up steps, 1 long run-up (48m) with long jump from the board</td>
</tr>
<tr>
<td><strong>• In the Stadium</strong></td>
</tr>
<tr>
<td><strong>Warm-up jumps:</strong> 1x approach check with hop, 1x approach check with triple jump (ca 16.50m), 1x triple jump from 11 run-up strides, ca. 16.30m</td>
</tr>
<tr>
<td><strong>Competition result:</strong> 17.44m</td>
</tr>
<tr>
<td><strong>August 18, final</strong></td>
</tr>
<tr>
<td><strong>Warm-up:</strong> 600m easy jogging, bouncing jog (including arm circles), including easy triple-jump rhythms</td>
</tr>
<tr>
<td><strong>Exercises:</strong> Passive stretching assisted by a physiotherapist, especially hip joint</td>
</tr>
<tr>
<td><strong>Run-offs:</strong> 2 x 40m with high knee lift and indicated take-off</td>
</tr>
<tr>
<td><strong>Warm-up jumps:</strong> 3x two-legged jumps, three easy triple jumps from 4, 10 and 12 approach strides, 1x long run-up (48m) with take-off from board</td>
</tr>
<tr>
<td><strong>• In Stadium</strong></td>
</tr>
<tr>
<td><strong>Warm-up jumps:</strong> 1x approach check with hop, 1x approach check (wearing competition kit), 1 x triple jump from 11 approach strides</td>
</tr>
<tr>
<td><strong>Competition result:</strong> 2nd, 17.55m</td>
</tr>
</tbody>
</table>
Table 8: Selected warm-up case studies – Throws

<table>
<thead>
<tr>
<th>Christian Cantwell (USA), Reese Hoffa (USA), Adam Nelson (USA) – Shot Put</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>August 15, final</strong></td>
</tr>
<tr>
<td><strong>Warm-up jog:</strong> Walking, short jogging sections (start 40-45 min before going to the callroom)</td>
</tr>
<tr>
<td><strong>Exercises:</strong> Easy stretching exercises</td>
</tr>
<tr>
<td><strong>Standing shot puts:</strong> 3-4 easy puts, 17-19.5m</td>
</tr>
<tr>
<td><strong>Rotational shot puts:</strong> 5-8 puts up to or beyond the performance limit (21.5-22m), with fouling</td>
</tr>
<tr>
<td>• In the stadium:</td>
</tr>
<tr>
<td><strong>Rotational shot puts:</strong> 5-8 puts up to or beyond the performance limit (21.5-22m), with fouling</td>
</tr>
<tr>
<td><strong>Gliding shot puts:</strong> 2-3 puts, distance: around 21m</td>
</tr>
<tr>
<td><strong>Competition results:</strong></td>
</tr>
<tr>
<td>Cantwell 1st, 22.03m (WL)</td>
</tr>
<tr>
<td>Hoffa 4th, 21.28m</td>
</tr>
<tr>
<td>Nelson 5th, 21.11m (SB)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tomasz Majewski (POL) - Shot Put</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>August 15, final</strong></td>
</tr>
<tr>
<td><strong>Warm-up jog:</strong> 300 m (start only 30 min before going to the callroom)</td>
</tr>
<tr>
<td><strong>Exercises:</strong> 10 min easy, including a lot of hip stretching exercises</td>
</tr>
<tr>
<td><strong>Standing shot puts:</strong> 6 x 18-19m</td>
</tr>
<tr>
<td><strong>Gliding shot puts:</strong> 4 x 20-21m (easy)</td>
</tr>
<tr>
<td><strong>Exercises:</strong> For hands and shoulders</td>
</tr>
<tr>
<td>• In the stadium:</td>
</tr>
<tr>
<td><strong>Gliding shot puts:</strong> 3 x 20-21m (tense)</td>
</tr>
<tr>
<td><strong>Competition results:</strong></td>
</tr>
<tr>
<td>2nd, 21.91m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Valerie Vili (NZL) - Shot Put</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>August 16, final</strong></td>
</tr>
<tr>
<td>Note: Start of the warm-up less than 30 minutes before going to the Call Room</td>
</tr>
<tr>
<td><strong>Warm-up jog:</strong> 400m run, dynamic</td>
</tr>
<tr>
<td><strong>Exercises:</strong> 10 min stretching exercises, interrupted by jogging</td>
</tr>
<tr>
<td><strong>Warm-up putting:</strong> Only with glide, 3-4 attempts, 18-20m</td>
</tr>
<tr>
<td>• In the stadium</td>
</tr>
<tr>
<td><strong>Warm-up putting:</strong> Two attempts, 18.6m and 20m</td>
</tr>
<tr>
<td><strong>Competition result:</strong></td>
</tr>
<tr>
<td>1st, 20.44m</td>
</tr>
</tbody>
</table>
## Table 9: Comparison of the warm-up routines of top discus throwers for the final of the 2009 IAAF World Championships in Athletics

<table>
<thead>
<tr>
<th>Discus Thrower</th>
<th>Arrival Time</th>
<th>Stay in the Tent</th>
<th>Warm-up Time</th>
<th>Warm-up Activities</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Harting (GER)</td>
<td>18:00</td>
<td></td>
<td>18:05</td>
<td>Arrival</td>
<td>On Field 18:40</td>
</tr>
<tr>
<td></td>
<td>18:10</td>
<td>Stay in the tent</td>
<td>18:20</td>
<td>Jogging (3 min)</td>
<td>6th, 65.17m</td>
</tr>
<tr>
<td></td>
<td>18:25</td>
<td>Stay in the tent</td>
<td>18:30</td>
<td>Jogging (3 min)</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>18:35</td>
<td>Stay in the tent</td>
<td>18:40</td>
<td>Jogging (3 min)</td>
<td>3 throws: ca 59m, ca 59m, 77m</td>
</tr>
<tr>
<td></td>
<td>18:45</td>
<td>Stay in the tent</td>
<td>18:50</td>
<td>Jogging (3 min)</td>
<td>3 throws: ca 59m, ca 59m, 77m</td>
</tr>
<tr>
<td></td>
<td>19:00</td>
<td>Stay in the tent</td>
<td>19:05</td>
<td>Walking, limbering-up exercises</td>
<td>1 throw: ca 64m</td>
</tr>
<tr>
<td></td>
<td>19:10</td>
<td>Stay in the tent</td>
<td>19:15</td>
<td>No warm-up throws at the warm-up area</td>
<td>3 throws: ca 62m, ca 62m, 18:00</td>
</tr>
<tr>
<td></td>
<td>19:20</td>
<td>On Field</td>
<td>19:25</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>19:30</td>
<td>On Field</td>
<td>19:35</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>19:40</td>
<td>On Field</td>
<td>19:45</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>19:50</td>
<td>On Field</td>
<td>19:55</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>20:00</td>
<td>On Field</td>
<td>20:05</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>20:10</td>
<td>On Field</td>
<td>20:15</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>20:20</td>
<td>On Field</td>
<td>20:25</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>20:30</td>
<td>On Field</td>
<td>20:35</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>20:40</td>
<td>On Field</td>
<td>20:45</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>21:00</td>
<td>On Field</td>
<td>21:05</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>21:10</td>
<td>On Field</td>
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<td>Call Room</td>
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</tr>
<tr>
<td></td>
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<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
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<td>21:35</td>
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<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
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<td>Call Room</td>
<td>2 throws: ca 67m</td>
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<tr>
<td></td>
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</tr>
<tr>
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<td>22:25</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
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<td>22:35</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>22:40</td>
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<td>Call Room</td>
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<tr>
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<tr>
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</tr>
<tr>
<td></td>
<td>24:30</td>
<td>On Field</td>
<td>24:35</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
<tr>
<td></td>
<td>24:40</td>
<td>On Field</td>
<td>24:45</td>
<td>Call Room</td>
<td>2 throws: ca 67m</td>
</tr>
</tbody>
</table>

Note: All events took place on the 4th day before the event.
It was noticeable that three groups of Chinese athletes (110m hurdlers, discus throwers, shot putters) did workouts of considerable length (2.5-3 hours) just four or even three days before their competitions started. In addition to highly intensive training in their competition events, some of them did what appeared to be intensive general sprinting, jumping, throwing and strength exercises (see tables for details). Based on this, one arrives at the assumption that in their normal training the loads used must be much higher.

Finally, there is the case of the 2008 Olympic 800m Champion Pamela Jelimo, who was in the middle of a season in which she was generally off form. In Berlin she did not complete her semi-final race. Only two days before her first race, she did what German coach Paul Schmidt calls a classic pre-loading for the 800m, which is normally done five days before an important competition (see Table 2 for details). One assumption could be that she is used to very high training loads and this is her normal procedure; another might be that she was trying to gain a psychological boost by reassuring herself of her fitness.

Warm-up Observations

As with training programmes, the warm-up procedures used by athletes on competition days must be assessed individually. Generally, however, we can say that the majority of the observed athletes demonstrated restraint regarding the duration and intensity of their warm-ups. There were only a few who carried out what we consider complex programmes.

Although in some cases pre-loads could be observed in the warm-ups of long sprinters or middle-distance runners, for example using under-distance runs, one cannot speak of a consistent standard. Even in these events, as with the short sprints, a rather easy warm-up was the rule. In the technical disciplines, we normally saw that after a general warm-up, the throwing/jumping would begin. Here, the rule of thumb is that the less stressful the competition exercise is for the whole organism (e.g., shot put), the more frequent the repetitions in the warm-up. Often, the throwers threw both on the warm-up field and then again in the stadium, but sometimes they did so only in the stadium. Here, the athletes were always allowed by the judges to do as many attempts as they liked.

Focusing on the sprint events, observations of athletes from the great sprint nations of North America and the Caribbean led us to the following statements:

1. All warm-up programmes and the behaviour during the last few days before the competition are highly tailored to the individual athlete.

2. The classic warm-up jog is often replaced by five to ten sprints or starts plus acceleration runs at low intensity (approx. 60-70%). The length of the sprints is chosen on an individual basis and ranges from 50 to 100m. According to coaches’ statements, it is only important during these warm-up sprints to “hit” the steps and to run with little effort.

3. In the rest intervals between warm-up sprints, the athletes either walk back to the starting point, or they perform light stretching, mobilisation or core-muscle exercises.

4. After the warm-up sprints, dynamic stretching and mobilising exercises are very popular. The athletes either perform these exercises on their own, with the help of rubber bands or tubes, or they are assisted by a physiotherapist. In some cases, however, static stretching could be seen in conjunction with swing exercises.

5. If sprinting drills are performed, these are used to prepare for fast actions and are done in a deliberately relaxed way. There is a clear differentiation into coordination and frequency drills. Frequency comes
usually after coordination. In most cases, depending on the training or competition, three to six sprint drills are performed.

6. Accelerations are mostly done in such a way that long and relaxed accelerations are followed by short and fast accelerations. During crouch starts and run-offs, the focus is on powerful knee extension (0-20m), followed by hip extension (20-40m) and lifting of one’s head (40-60m). The high frequency of the first steps and the slow lifting of the head is a priority.

7. Spikes are only used when the athletes want to run very fast.

In the middle- and long-distance events it was striking that most athletes did their warm-up jogging at very low intensity. Warm-ups were rather short and intense pre-loads as recommended and done in the past could only be observed in a few individual cases. As far as flexibility exercises are concerned, one could see differences by nation. For example, the Kenyans preferred swinging exercises, while the Russians did static stretching exercises.

The jumpers’ preparations included warm-up jogging, stretching (active and/or passive assisted by physiotherapists), running ABCs with the use of combinations to a greater extent than was the case with athletes from other event blocks, jumping ABCs, strides, imitations, then, in the stadium, start checks. In the different jumping events, the preparation ended as follows:

- Horizontal jumps: long and triple jumps from shortened run-ups at a moderate intensity.
- Pole vault: performing elements and sometimes the whole exercise, more female than male vaulters actually cleared the bar.
- High jump: jumps over the bar with increasing bar height.

In general, it can be said that the greater the safety and stability of the athlete, the more moderate the warm-up jumps. Hooker’s concentration on only a few jumps, due to an injury, shows what is possible with a good mental preparation even without warm-up jumps or a competition with increasing heights. More than 10 intensive run-up and jump combinations, as was observed in a German horizontal jumper, are not only a sign of considerable uncertainty but can also be tiring.

Minimal jogging, gymnastic exercises and only few throws were the hallmarks of the top throwers’ warm-ups. In some cases, a passive preparation assisted by a physiotherapist was observed (e.g. Kozmus, Thorkildson, Spotakova). Many throwers, particularly the javelin throwers, also used elastic bands when preparing for their competitions. Intensive preparation with lots of movement and relatively many warm-up attempts were observed in the shot put and javelin. Often, one had the impression that some of these athletes “killed” themselves on the warm-up field. The rotational throwers, i.e., the discus and hammer throwers, were very economical when moving, and some of them did their warm-up throws only in the competition stadium.

Please send all correspondence to:
Wolfgang Killing
wolfgang.killing@leichtathletik.de
Introduction

The ultimate goal for all athletes is to achieve their individual maximal performance. To a large extent, maximal performance level is determined by physiological function and it is axiomatic that all legal avenues optimising physical function should...
be investigated. The Fick equation describes that physiological function is determined by the weakest link in the chain of central and peripheral factors that contribute to oxygen delivery and extraction, starting in the lungs by oxygen uptake and ending in the peripheral tissue by oxygen consumption. Interventions that improve oxygen delivery and/or extraction, therefore, are likely to improve exercise performance (e.g. “live high–train low” regimens, sleep in hypoxic chambers, increasing oxygen carrying capacity of erythrocytes).

The intervention introduced here relates to ‘ischaemic preconditioning’ (IPC). This technique represents a novel, simple, cheap, legal and easy applicable method that immediately improves peripheral vascular and muscular function. In this report, we describe a series of experiments that provide the first data in humans to support the potential of IPC to enhance athletic performance, but also to reveal underlying mechanisms of these benefits of IPC.

**What is ischaemic preconditioning?**

IPC was introduced in the mid-1980’s by cardiologists. It describes the fact that arteries are protected from injury when they are repeatedly exposed to short periods of transient blood flow restriction or ischaemia. Exposure of a dog’s coronary artery to four cycles of five minutes of ischemia (i.e. IPC) results in a 75% reduction in cardiac injury after a 40-minute ischemic insult. Such procedures are associated with obvious practical limitations for clinical use in humans. However, cardioprotective effects of IPC are also present when the repeated bouts of ischemia are applied to a remote vascular bed. For example, a previous study published in *The Lancet,* found that repeated cuff inflation around the forearm in patients with an acute myocardial infarction (performed in the ambulance) is associated with a significantly smaller infarction area (Figure 1). Studies also found beneficial effects when IPC is applied before cardiac surgery.

The upper panel of Figure 1 represents the situation in which prolonged occlusion of an artery is followed by necrosis of cardiac tissue. When occlusion is preceded by ischaemic preconditioning (four periods of 5-min occlusions of a limb) cardiac injury is at least partly reduced (lower panel).

---

*Figure 1: Effects of ischaemic preconditioning*
Although the exact mechanisms for IPC are unclear, studies have found that IPC has well-established effects on the vasculature (e.g. adenosine), resulting in an increased blood supply. In addition, previous studies in animals have shown that IPC can enhance muscle efficiency in ATP-usage via ATP-sparing, augmented function of the mitochondrion or increased efficiency in the excitation-contraction coupling. Based on the effect of IPC on the vasculature and muscle function, IPC may potentially contribute to beneficial effects of IPC to exercise performance.

**Effect of ischaemic preconditioning on human performance**

We performed a pilot study in 15 moderate-to-highly trained subjects who performed two maximal cycling tests; 1. Control test, 2. Test preceded by IPC (Figure 2). Remarkably, cycling exercise preceded by IPC was associated with an immediate 3% higher maximal oxygen consumption and 1.6% higher maximal workload. To put these numbers in perspective, such improvements are normally observed after prolonged, intensive exercise training of several weeks. These pilot data were recently published and represent the first description of the effect of IPC to enhance performance in the literature.

**Aims of this research project**

The general aim was to gain further insight into the potential of IPC to enhance performance in humans. First, we were interested whether, in addition to cycling exercise, IPC could also improve running exercise, i.e. the most common type of exercise during sports. Therefore, Aim 1 is to examine the impact of IPC to enhance running exercise performance.

No previous study has attempted to understand the potential mechanisms that underlie the remarkable effects of IPC on exercise performance. Data from animal studies indicate that improvement in mitochondrion function is a key mechanism underlying the beneficial effect of IPC. Such changes may alter ATP usage and, therefore, the build-up of lactate in muscle tissues. In addition, IPC improves muscle blood flow, potentially improving removal of lactate. Finally, IPC improves muscle contraction efficiency, possibly by enhancing muscle force and contractility and/or via increased efficiency of excitation-contraction coupling.

![Figure 2: Individual and mean maximal oxygen consumption (VO\textsubscript{2max} in mlO\textsubscript{2}/min/kg, n=15) during the maximal exercise test without (black square) and with ischaemic preconditioning (open squares) (Both tests were given in a randomised order to prevent potential improvement in oxygen consumption induced by familiarisation. Error bars represent SE. *P=0.003.)](image)
This suggests that IPC may alter lactate production and/or removal, consequently contributing to an improved exercise performance. Therefore, Aim 2a of the present study was to examine the potential of IPC to alter the onset of blood lactate accumulation.

High-intensity, strenuous exercise is associated with immediate vascular injury, leading to a decrease in vascular function. A reduction in function of vessels may potentially be detrimental for exercise performance, but also seems to be associated with a lower blood flow to the exercising limb. Previous studies found that vascular injury after prolonged ischemia can be prevented by IPC. Similarly, IPC may prevent vascular injury associated with strenuous exercise. Therefore, Aim 2b was to examine the effect of IPC on brachial artery vascular function after running exercise.

In general, this series of experiments will improve our understanding of the impact of IPC to enhance exercise performance and provides insight into the underlying mechanisms. Specifically, we will examine:

**AIM 1** (‘performance’): the impact of IPC on running performance (5km time trial) in healthy subjects

**AIM 2a** (‘mechanism: lactate’): the impact of IPC on the onset of blood lactate accumulation during running exercise in healthy subjects

**AIM 2b** (‘mechanism: vascular’): the impact of IPC on the acute impairment in vascular function in healthy subjects after strenuous running exercise

How is this series of experiments relevant for the development of athletics?

We propose a novel and potentially efficacious approach to enhance the benefits of training to improve performance for athletes at all levels. Combining this novel intervention into sports is unique and it will not interfere with normal preparations for a match/race or with race (pacing) strategy. Another advantage is that this technique can be implemented immediately during the daily practice of athletes. Therefore, IPC directly relates to the most important aspect of athletics: i.e. performance improvement. In addition to the clear beneficial effects for daily practice of athletes, this study also provides important and novel mechanistic insight into pathways that eventually limit human performance. Such novel knowledge may mark an important and significant step forward in exercise physiology.

**Methods**

**Participants**

In a randomised, single-blind, crossover study, thirteen healthy moderately-trained males (25±6 years; 176±4cm; 77±7kg) volunteered to participate. Based on their medical history, participants were free of health problems and did not use any medication. Prior to testing, all participants were informed of the methods of the study, but remained naive of study rationale to prevent any placebo effect of IPC. All subjects provided written informed consent before participation. The study was approved by the Liverpool John Moores University ethics committee and adhered to the Declaration of Helsinki (2000).

**Experimental Design**

All participants refrained from alcohol, caffeine and additional nutritional training supplements for 24 hours prior to all exercise testing. Participants reported twice to the laboratory to perform the same testing procedure, either preceded by four cycles of five-minute bilateral cuff inflation to 220 mmHg (i.e. IPC-intervention) or cuff inflation to 20 mmHg (i.e. SHAM-intervention). In a randomised, single-blind, crossover study, participants performed five three-minute stages of treadmill running at 10-14 km/h to assess blood lactate accumulation (Aim 2a), which was then followed by one km/h increments every two min until voluntary exhaustion. Heart rate and oxygen consumption was continuously monitored throughout exercise. Following a 45-minute rest in the supine position, subjects performed a 5km running...
time trial on a treadmill (after being familiarised with this time trial three to four times before performance of this test) (Aim 1). For Aim 2b, brachial artery endothelial function was examined before and after the IPC- or SHAM-intervention as well as immediately after the 5km time trial (Figure 3).

**Ischemic Preconditioning:** IPC was performed in the supine position using bilateral arterial occlusion. Automated occlusion cuffs were placed proximally around the upper thigh and inflated to 220 mmHg to block arterial inflow for five minutes. The ischemic procedure was repeated four times bilaterally, with each ischemic episode separated by five minutes of rest. On another occasion, participants followed an identical protocol, but instead the cuff was inflated to 20 mmHg (without affecting arterial inflow). The latter procedure represented the SHAM-intervention, whilst the order of days was counterbalanced.

**Blood lactate accumulation (Aim 2a):** A discontinuous incremental test was used to assess accumulation of blood lactate. The test commenced following a five-minute warm-up ranging between 6-10 km/h (this was standardised for all tests). Five cycles of three-minute submaximal stages (10-14 km/h) were performed, interspersed with 30 sec of passive recovery to obtain lactate measurements (5). During the test, breath-by-breath expired gases were continuously monitored (Oxycon IV, Jaeger, Germany) for oxygen consumption ($\text{VO}_2 \text{ ml·kg}^{-1}\text{·min}^{-1}$), ventilation ($\text{VE} \text{ L·min}^{-1}$) and respiratory exchange ratio (RER) and were averaged over the last 15 sec of each stage. Heart rate was measured continuously with a chest strap and monitor (RS800, Polar, Finland), whilst ratings of perceived exertion (RPE) were measured at the end of each stage using Borg’s 6-20 scale. A 2.5 ml venous blood sample was collected via a forearm cannula at rest and after each submaximal stage. Upon collection, each sample was immediately placed on ice and spun in a refrigerated centrifuge. Plasma was stored at -80°C and were later analysed for lactate concentration (Daytona, Ireland). Blood lactate concentration (in mMol$^{-1}$) was plotted against workload (intensity) during the incremental running test. The absolute increase in blood lactate was plotted against time and compared between both conditions. The onset of blood lactate accumulation (OBLA) was analysed as the point (km/h) that was associated with a lactate level that first exceeded the 4 mMol$^{-1}$ threshold. OBLA represents a marker of endurance capacity which is frequently used to predict endurance ability and performance. The reproducibility of the OBLA at a given intensity has been reported as high ($r=0.88$) and is able to detect meaningful changes in training status.

**5km time trial (Aim 1):** Upon completion of the running test to assess the OBLA, a 45 min rest period in the supine position followed, then a 5km running time trial was performed on a
motorised treadmill (Pulsar 4.0, H/P Cosmos, Germany). Participants were instructed to run five kilometres as quickly as possible. The running time and running speed were blinded to the participant. The speed of the treadmill was set at 8 km/h, and once the participant was ready the time trial was started. Throughout the time trial, participants were allowed to alter running speed, but were kept blinded for running speed and running time. The only information available to the participants during each time trial was total distance covered (m) as to adjust work-output to pace towards the known endpoint\(^1\). No further information or encouragements were provided. Heart rate was monitored continuously, with RPE was recorded at the end of each 1000m. All trials were performed with a fan placed 0.5m in front of the treadmill to provide air circulation and cooling to the participant to match field conditions. The 5km time trial has previously shown to have a greater absolute reliability, compared to time-to-exhaustion tests of the same relative intensity\(^33\). Before the beginning of the experimental trials participants received at least three supervised familiarisation trials. The 5km time trial revealed a coefficient of variation (CV) of 2.2% test-retest in participants after familiarisation. This finding is in line with previous studies\(^24,33\).

**Brachial artery endothelial function (Aim 2b):** Brachial artery endothelial function was measured using the flow-mediated dilation (FMD) technique\(^48\). This method provides an index of vascular function of the brachial artery. This measure was performed before and after the IPC/SHAM-intervention to examine the potential immediate effect, but also after the 5km time trial to examine whether IPC can prevent the decline in FMD after strenuous exercise. For this purpose, participants were instructed to abstain from strenuous exercise for 24 hrs and from caffeine and alcohol ingestion for 18 hrs before attending the laboratory. Measurements were performed in the supine position. Baseline assessment was performed after resting for 20 minutes, followed by assessment of heart rate and blood pressure using an automated sphygmomanometer (GE Pro 300V2, Dinamap, Tampa, FL). This was followed by assessment of brachial artery diameter and velocity.

To examine brachial artery FMD, the arm was extended and positioned at an angle of ~80° from the torso. A rapid inflation and deflation pneumatic cuff (D.E. Hokanson, Bellevue, WA) was positioned on the forearm, immediately distal to the olecranon process to provide a stimulus to forearm ischemia. A 10MHz multi-frequency linear array probes, attached to a high-resolution ultrasound machine (T3000; Terson, Burlington, MA) was then used to image the brachial artery in the distal 1/3rd of the upper arm. Continuous Doppler velocity assessments were obtained using the ultrasound and were collected using the lowest possible isonation angle (always <60°). Following baseline assessments, the forearm cuff was inflated (>200 mmHg) for five minutes. Diameter and flow recordings resumed 30 sec prior to cuff deflation and continued for three minutes thereafter, in accordance with recent technical specifications\(^6,50\). Post-test analysis was performed using custom-designed edge-detection and wall-tracking software, which is largely independent of investigator bias\(^6,50\). From synchronised diameter and velocity data, blood flow (the product of lumen cross-sectional area and Doppler velocity) and shear rate (four times mean blood velocity/vessel diameter) were calculated at 30Hz. Reproducibility of diameter measurements using this semi-automated software is significantly better than manual methods\(^50\).

**Statistics**

Statistical analyses were performed using SPSS 17.0 (SPSS, Chicago, IL) software. All data are reported as means (±SD), and statistical significance assumed at \(P<0.05\). For all analyses, trial order (IPC or C first) was entered into the statistical model as a between subjects factor. According to recent advice, the least significant difference (LSD) test was used for pair-wise multiple comparisons\(^44,47\).
For Aim 1 (‘performance’), a Students’ paired t-test was used to compare 5km time trial performance (IPC versus C). In addition, a 2-factor repeated measures GLM (trial x time) was also used to examine differences in parameters during the 5km time trial (RPE, running speed and heart rate).

For Aim 2a (‘mechanism: lactate’), a 2-factor (trial x time) repeated measures GLM with 95% confidence intervals was used to assess differences in parameters (blood lactate levels, oxygen consumption and heart rate) during the five stages of the incremental test to examine our primary hypothesis. Also, a one-factor repeated measures GLM was used to compare OBLA (IPC versus C).

For Aim 2b (‘mechanism: vascular’), we deemed it important to control for the influence of moderators of FMD (shear rate and baseline diameter). We therefore analysed the effects of trial and time on logarithmically-transformed diameter changes using a Generalised Estimating Equation (GEE) which incorporated baseline diameter and shear rate as covariates. Mean and 95% confidence intervals (95% CI) for the effect magnitudes of brachial artery FMD are cited.

RESULTS

5km time trial (Aim 1)

Mean time trial performance significantly improved following the IPC-intervention (34±49 sec, 95% CI five to 64 sec, \( P = 0.027 \)) (Figure 4). Running speed and heart rate gradually increased during the 5km time trial, but these increases were similar between conditions (Table 1). Post-hoc analysis showed that the RPE was significantly lower during the first 1000m of the 5km time trial after IPC compared to the control intervention, but this difference disappeared when continuing exercise (Table 1).

Blood lactate accumulation (Aim 2a)

Heart rate, oxygen consumption, ventilation and ratings of perceived exertion increased across the five incremental stages, but these increases were of similar magnitude in both conditions (Table 2). Resting blood lactate levels were similar between both tests (Figure 5).

Figure 4: Aim 1: Performance (Individual and mean (error bars represent SD) data on 5km time trial performance after IPC and control interventions in healthy young men (n=13) (* denotes a significant treatment effect of IPC, \( P = 0.027 \)).
Table 1: Exercise characteristics during the 5km time trial in healthy subjects (n=13)

<table>
<thead>
<tr>
<th></th>
<th>1000m</th>
<th>2000m</th>
<th>3000m</th>
<th>4000m</th>
<th>5000m</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (b·min⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>167±8</td>
<td>173±7</td>
<td>176±5</td>
<td>177±5</td>
<td>185±6</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>166±11</td>
<td>172±6</td>
<td>177±8</td>
<td>179±5</td>
<td>189±7</td>
<td>IPC: 0.159</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Time*IPC: 0.180</td>
</tr>
<tr>
<td>RPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>14±3</td>
<td>15±2</td>
<td>16±1</td>
<td>17±1</td>
<td>19±1</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>13±3*</td>
<td>15±2</td>
<td>16±1</td>
<td>17±1</td>
<td>19±1</td>
<td>IPC: 0.136</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time*IPC: 0.030</td>
</tr>
<tr>
<td>Running speed (km·h⁻¹)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>12.8±1.5</td>
<td>13±1.5</td>
<td>13.2±1.5</td>
<td>13.7±1.6</td>
<td>14.3±2.2</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>13±1.0</td>
<td>13.5±1.2</td>
<td>14.1±1.3</td>
<td>14±1.5</td>
<td>14.7±1.6</td>
<td>IPC: 0.371</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Time*IPC: 0.387</td>
</tr>
</tbody>
</table>

*Significantly different between IPC and C at P<0.05. RPE; ratings of perceived exertion.

Blood lactate concentration increased over time in both conditions (P<0.001). When exercise was preceded with IPC, a smaller increase in blood lactate was observed, resulting in a difference between both tests of 1.07±0.11 mMol⁻¹ at 14 km/h (Figure 5). A later OBLA was evident when exercise was preceded with IPC, but did not reach statistical significance (13.1±1.9 and 14.6±1.4 km/h, mean difference 1.5-km/h, 95% CI -0.18 to 3.87, P=0.071).

Figure 5: Aim 2a: lactate (Blood lactate levels at rest at all five submaximal stages during the incremental running tests. Exercise preceded by IPC shown with solid circles and exercise preceded by control intervention shown with open circles. Error bars represent SE. *Post hoc significantly different between C and IPC.)
### Table 2: Exercise characteristics during incremental stages during running test in healthy subjects (n=13)

<table>
<thead>
<tr>
<th></th>
<th>10 km/h</th>
<th>11 km/h</th>
<th>12 km/h</th>
<th>13 km/h</th>
<th>14 km/h</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VO₂(mLO₂·kg⁻¹·min⁻¹)</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>34.1±2.58</td>
<td>36.5±2.2</td>
<td>39.4±2.5</td>
<td>42.1±2.4</td>
<td>45.3±2.8</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>34.4±1.2</td>
<td>36.6±1.2</td>
<td>39.5±1.8</td>
<td>41.9±2.3</td>
<td>45.0±2.8</td>
<td>IPC: 0.971, TimeIPC: 0.796</td>
</tr>
<tr>
<td><strong>VE (L·min⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>65±9</td>
<td>72±11</td>
<td>81±15</td>
<td>94±18</td>
<td>107±19</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>65±9</td>
<td>73±10</td>
<td>81±13</td>
<td>94±19</td>
<td>106±18</td>
<td>IPC: 0.88, TimeIPC: 0.630</td>
</tr>
<tr>
<td><strong>RER</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.84±0.03</td>
<td>0.88±0.14</td>
<td>0.91±0.03</td>
<td>0.94±0.05</td>
<td>0.99±0.04</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>0.83±0.03</td>
<td>0.86±0.04</td>
<td>0.91±0.03</td>
<td>0.94±0.07</td>
<td>0.98±0.03</td>
<td>IPC: 0.378, TimeIPC: 0.521</td>
</tr>
<tr>
<td><strong>Heart rate (b·min⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>136±12</td>
<td>152±14</td>
<td>166±8</td>
<td>175±7</td>
<td>181±12</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>136±13</td>
<td>150±12</td>
<td>166±11</td>
<td>176±5</td>
<td>182±14</td>
<td>IPC: 0.761, TimeIPC: 0.540</td>
</tr>
<tr>
<td><strong>RPE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>10±2</td>
<td>12±2</td>
<td>13±2</td>
<td>14±1</td>
<td>16±1</td>
<td>Time: &lt;0.001</td>
</tr>
<tr>
<td>IPC</td>
<td>10±2</td>
<td>12±2</td>
<td>13±2</td>
<td>14±2</td>
<td>16±2</td>
<td>IPC: 0.357, TimeIPC: 0.841</td>
</tr>
</tbody>
</table>

RPE; ratings of perceived exertion, VE; ventilation, RER; respiratory exchange ratio

**Brachial artery endothelial function (Aim 2b)**

No differences in baseline diameter and SRₐᵤₐₚ were found at baseline between testing days or after the IPC- or SHAM-intervention (all P>0.05). At baseline, differences in FMD were negligible and non-significant between the SHAM [5.3% (4.5-6)] and IPC [4.8 (3.6-5.9)] trials (P>0.05). FMD changed by less than 0.6% immediately after both the IPC and SHAM interventions (P>0.30, Table 3). In the SHAM trial, FMD decreased following the 5km time trial (P=0.02). However, in the IPC trial FMD was similar post-IPC and post-5km time trial, with an FMD of 5.4% (4.4-6.4) and 5.7% (4.6-6.8) (P=0.60; Figure 6), respectively. IPC had no effect on the change in baseline diameter and SRₐᵤₐₚ (Table 3).
Figure 6: Aim 2b: vascular (Brachial artery flow-mediated dilation (FMD) before (pre) and after (post) the intervention (IPC or SHAM) as well as post 5km time trial in health, volunteers (n=11, two participants were not included due to technical problems) during the SAHM- (solid squares) and IPC-intervention (open squares). Error bars represent 95% CI. Data from the GEE were included in the figure.)

Table 3: Brachial artery FMD before (pre) and after (post) the IPC or SHAM intervention as well as after the 5km time trial (TT) in healthy volunteers (n=11, one subject was missing because of technical problems) (Data is presented as mean (95% Confidence Intervals). P-values refer to a Generalised Estimating Equation (effect of ‘time’, ‘IPC’ and ‘time*IPC’).)

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Post 5km TT</th>
<th>P-values</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>pre</td>
<td>Post</td>
</tr>
<tr>
<td><strong>D_{rest} (mm)</strong></td>
<td></td>
<td></td>
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<tr>
<td>SHAM</td>
<td>0.41(0.38-0.44)</td>
<td>0.41(0.39-0.43)</td>
</tr>
<tr>
<td>IPC</td>
<td>0.41(0.39-0.44)</td>
<td>0.41(0.38-0.43)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>SR_{AUC} (s, 10^3)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHAM</td>
<td>15.7 (12.4-19.0)</td>
<td>16.3 (12.8-19.7)</td>
</tr>
<tr>
<td>IPC</td>
<td>11.4 (7.8-15.1)</td>
<td>13.8 (11.5-16.1)</td>
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Post-hoc significantly at P<0.05 different from *pre-intervention or #SHAM
**Discussion**

The general aim of this study was to examine the potential of IPC to enhance exercise performance and to elucidate potential underlying mechanisms for this effect. First, our study is the first to demonstrate that IPC can improve running exercise performance. Moreover, we provided the first insight into potential mechanisms, providing strong evidence that IPC is associated with a reduction in blood lactate accumulation during submaximal running exercise. In addition, IPC was associated with the prevention of impaired vascular function that is typically observed after strenuous exercise. Therefore, our results may have important consequences for athletes to improve exercise performance.

**Impact of IPC on mechanisms: lactate**

Oxygen uptake at the lactate threshold represents the strongest predictor for maximal oxygen uptake \(^{12,39}\). Lower blood lactate concentrations at a given workload are therefore associated with improved exercise economy, including in highly trained athletes \(^{36,39}\). Interestingly, data in our study indicates that IPC attenuates the accumulation of blood lactate during an incremental running test, a finding that is supported by the trend for a later onset of blood lactate accumulation. More specifically, we found significantly lower blood lactate levels after IPC at submaximal running speed of 14 km/h, which may relate to the improved exercise performance during the 5km time trial (performed at average speed of 13.7 km/h after IPC, compared to 13.1 km/h after SHAM).

It is important to note that the attenuated accumulation of lactate during exercise is not explained by differences in absolute or relative exercise intensity level between tests (Table 2). Moreover, due to our randomisation procedure and statistical analysis, familiarisation or order-effects are unlikely explain our findings. A potential explanation for the altered lactate levels may relate to a faster removal and/or lower production of lactate during exercise. For example, IPC may work through improvements in vascular function, which regulates blood flow to remove blood lactate, but also enhances blood flow to ensure sufficient O\(_2\) supply (resulting in dominance of aerobic glycolysis and less lactic acid production). Also, increases in mitochondrial capacity importantly contribute to endurance performance \(^{25}\). Previous studies in animals and humans indicate that IPC enhances mitochondrial capacity, most likely via ATP-sensitive potassium channels located on the inner membrane \(^{46}\). An alternative but not mutually exclusive explanation could relate to a reduction in muscle lactate production after IPC. Animal studies have shown previously that IPC can enhance muscle efficiency in ATP-usage via ATP-sparing, augmented function of the mitochondrion or increased efficiency in the excitation-contraction coupling \(^{27,34,43}\).
Nevertheless, within the bounds of our current data we can only speculate about the mechanisms underlying the lower blood lactate levels at submaximal workload with IPC.

**Impact of IPC on mechanisms: vascular**

Based on the importance of blood flow control during exercise, changes in performance after IPC may also relate to the vasculature. First, we confirmed findings from previous studies\(^\text{16, 23, 35}\) that brachial artery endothelial function (i.e., vascular function) is reduced after strenuous running exercise. More importantly, a unique and novel finding in our study is that the decrease in vascular function was abolished when exercise was preceded by IPC. Several previous studies have established that IPC can prevent vascular injury after prolonged periods of ischemia\(^\text{30, 37, 38}\) or prevent cardiac damage in clinical groups, as evidenced by smaller increments in ischemic biomarkers and infarct size\(^\text{7, 10}\). In line with these observations, we add the novel observation that IPC also protects against the acute decrease in vascular function observed after strenuous exercise. Our findings may have clinical consequences, as an attenuated vascular function is associated with an impaired exercise-induced blood flow\(^\text{9}\). Although speculative, prevention of the impaired vascular function and blood flow response during strenuous exercise by IPC may contribute to the enhanced exercise performance.

Our findings that application of IPC to the lower limbs prevents a decrease in upper limb brachial artery vascular function indicate that the effects of IPC are systemic rather than localised. Strenuous exercise in humans is associated with increased levels of oxidative stress, which may be linked to the development of vascular dysfunction after exercise\(^\text{20}\). Interestingly, previous studies provided evidence that IPC upregulates cellular antioxidant defence mechanisms, thereby preventing tissue damage\(^\text{13, 40}\). In addition, IPC has well-established effects on vasodilators, such as adenosine and bradykinin, which may contribute to the protective effects of IPC against cellular damage and increase blood supply to the exercising muscles during strenuous exercise\(^\text{46}\). Although the underlying mechanisms are not fully understood, prevention of vascular damage after strenuous exercise may contribute to the effect of IPC on sport performance and/or recovery from exercise.

**What are limitations of our study?**

A potential limitation of this study is that we provided limited insight into the practical application of IPC in athletes to enhance performance level. Little is known about optimising the protocol for IPC (number of ischaemic events + duration of ischaemia for an optimal benefit on exercise performance). Based on the findings presented in this series of experiments, logical follow-up studies include the assessment of different (timing of) IPC-protocols. Such knowledge will further improve the practical implication of this technique in daily routine for athletes to enhance sport performance.

**Clinical relevance: who will benefit?**

An obvious question that arises from our data is whether all athletes benefit from IPC to enhance performance. In a recent study, we examined the impact of IPC during a repeated anaerobic sprint test and repeated cycling sprints in elite rugby players\(^\text{3}\). Interestingly, we found a moderate to strong effect size for IPC to enhance power output during high-intensity cycling exercise and attenuate running time and cycling sprint output during repeated sprint exercise. This observation confirms findings from a recent study, which found improved performance of 0.7 sec during the 100m freestyle in elite swimmers after IPC of the upper limbs\(^\text{15}\). In addition to running exercise, evidence (including from our laboratory) supports a potential for IPC to improve cycling performance\(^\text{14, 18}\), and swimming times\(^\text{27}\). Finally, the beneficial effects of IPC on exercise performance seems to relate to sprinting\(^\text{1}\), short-term exercise (1-2 minutes)\(^\text{27}\), moderate-term exercise\(^\text{14, 18}\), and to endurance exercise (i.e., 5km time trial). Taken together, our introduction of IPC as a potential strategy to improve exercise may apply to all athletes, which is unique as most interventions are specific for a single sport event only.
Conclusions and Recommendations

In conclusion, we have established the potential of IPC to improve running exercise performance in healthy men. In addition to the remarkable effect on exercise performance, we provided novel mechanistic insight into the potential mechanisms that may explain this effect. First, we found that IPC attenuates blood lactate accumulation during submaximal exercise. Second, IPC prevented impairment in vascular function that is typically associated with strenuous running exercise. The lower blood lactate accumulation and improved vascular function by IPC may contribute to an enhanced exercise performance. Thus, the series of experiments performed in our laboratory have introduced IPC as a novel, cheap, easy applicable and non-invasive strategy to improve exercise performance in humans.

Technical advances have demonstrated value in the history of sport. However, development takes a long time, has problems with implementation (disqualification in the worst case scenario), is associated with high costs, and is always restricted to a single sports event. We have provided strong evidence that a novel, low cost, and easy applicable tool (i.e. repeated cuff inflation during warm-up) can enhance sport performance. Recommendation for application of this novel method in athletes is very broad:

1. IPC has a large potential for most Olympic athletes and is not restricted to a single event.
2. IPC can be applied acutely (short term) and therefore is clinically relevant.
3. IPC can be applied at all levels (moderate versus elite athletes, Paralympics versus Olympics).
4. IPC is a legal, simple, easy accessible and a low cost intervention that can easily be applied.
5. IPC can be applied without interference with the athlete’s training programme, development of sport-specific techniques or competition tactics.

Whilst the focus of this report is on (elite) athletes, we believe that IPC may benefit various groups. A logical follow-up from this project will be the application of IPC in various patient groups. These groups experience important limitations to perform exercise and benefit from exercise training (such as cardiovascular disease, diabetes mellitus, COPD). Application of IPC may enable these groups to improve their performance and benefit to exercise training. Currently, we are performing the first studies in spinal cord-injured individuals and heart failure patients to examine the potential of IPC. Such interventions could lead to a larger benefit of exercise training for patient groups. *This also marks the potential of IPC to lead to clinically meaningful improvements in health for various patient groups.*

Taken together, the studies performed in our laboratory have resulted in the first description of the potential of IPC to improve performance. The follow-up studies, partly described in this report, consolidate the practical benefit of IPC to improve performance in various groups, whilst we have produced the first mechanistic insight to understand these remarkable effects of ‘ischaemic preconditioning’. Therefore, our introduction of IPC represents a large step forward for (applied) exercise physiology and the athlete’s benefit. More importantly, our series of experiments have introduced a cheap, non-invasive, legal, easy to apply manner that are suitable for all types (endurance-sprint), levels (moderate vs elite, paralympics vs olympics) and modes (cycling vs running) of exercise to enhance performance which can be implemented immediately.

**Please send all correspondence to:**

*Prof Dick Thijssen*
*Dick.Thijssen@radboudumc.nl*
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Applied Research

Monitoring Skin Thermal Response to Training with Infrared Thermography
by Ismael Fernández de la Cuevas, Manuel Sillero de la Quintana, Miguel Angel Garcia de la Concepcion, Juan Ribot de la Serrano, Pedro Gomez de la Carmona and Joao CB Marins
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by Ismael Fernández de la Cuevas, Manuel Sillero de la Quintana, Miguel Angel Garcia de la Concepcion, Juan Ribot de la Serrano, Pedro Gomez de la Carmona, Joao CB Marins

ABSTRACT

There is no doubt that core or central temperature has a direct relationship with exercise intensity. However, local temperature responses, specifically the acute temperature effects of workouts on joints and muscles, and the temperature changes that take place during the recovery process, have not yet been well described. Infrared thermography (IRT) is a safe, non-invasive and low-cost technique that makes it possible to measure specific local thermal responses to exercise. The authors used IRT to observe changes in skin temperature related to muscle and joint activity of both the upper and lower limbs during, immediately after and up to eight hours after strength and aerobic training. They found that the use of IRT may provide important information on local metabolic activity generated by training and adaptations related to the reestablishment of initial skin temperature post training, which can indicate whether the athlete has recovered enough to be able to effectively train or compete again. If this finding can be confirmed, IRT would be a practical tool for monitoring athletes’ training.

AUTHORS

Ismael Fernandez de la Cuevas, PhD, is a post-doctoral student at INEF, the Polytechnic University of Madrid, Spain.

Manuel Sillero de la Quintana, PhD, is a professor in the Faculty of Physical Activity and Sport Sciences at INEF, the Polytechnic University of Madrid, Spain.

Miguel Angel Garcia de la Concepcion, is a PhD student currently working at the Aspetar Orthopaedic and Sports Medicine Hospital in Qatar.

Juan Ribot de la Serrano is a post-graduate student at at INEF, the Polytechnic University of Madrid, Spain.

Pedro Gomez de la Carmona, PhD, is a physical conditioning coach for the Real Betis Balompié football club in Seville, Spain.

Joao CB Marins, PhD, is a professor at the Universidade Federal de Viçosa, Brazil.
Monitoring Skin Thermal Response to Training with Infrared Thermography

Introduction

The physiological effects of training are reasonably well established in terms of hormonal1,2, morphological3, bone4, neural5, or cardiovascular6 responses, or with regard to the type of training7. However, local temperature responses, specifically the acute effects of workouts on joints and muscles, and the changes that take place during the recovery process, have not yet been well described.

There is no doubt that core or central temperature has a direct relationship with exercise intensity8,9. Some studies have focused on measuring central thermal response by using gastrointestinal capsules (ingestible sensors) or by taking rectal, oesophageal or tympanic temperature during and after exercise9-13. These have reported different temperature responses in certain regions of the body, such as the joints, compared to the central temperature14 caused by redistribution of blood flow via hypothalamic thermal control15. The temperature response from each part of the body can also vary in the recovery period, as the trained muscular regions and joints involved in the movement have a higher metabolic activity with faster energetic and tissue recovery facilitated by increased blood supply2,16.

Infrared Thermography (IRT)17 is a safe, non-invasive and low-cost technique that makes it possible to rapidly record the irradiated energy released from the body18. It has recently been proved that a high-resolution thermal image can provide interesting information about the complex thermoregulation system of the body19. The development of fast and easy IRT monitoring tools allows us to obtain general and local thermal profiles of humans, including their main body regions of interest (ROI), and to provide interesting information on physiological responses after exercise.

The influence of physical activity on skin temperature (Tsk)20 and the validity of the assessment of Tsk distributions by thermography19 are well known, but there is a lack of studies about the long-term evolution of Tsk after moderate intensity strength or aerobic training. Therefore, it seems quite interesting to study the long-term thermal behavior of the skin after exercise as a reflection of the responses of the structures underneath it. Moreover, analysis of local thermal response may provide the technical team (practitioners, physical therapist and coaches) with important information on the recovery status of the athlete and his/her capacity to continue training at a given level of intensity.

It is well-known that core temperature gradually decreases after conclusion of an extended period of exercise8,25. However, to our knowledge, there is no research about local and specific thermal responses of joints and muscles temperatures just after exercise and during the recovery process.

Therefore, the purpose of the study is to use IRT to determine the evolution of Tsk for muscles and joints after aerobic and strength training in order to understand better the impact of physical activity on the thermoregulatory system and metabolism. We hypothesize that the temperature response of the skin over eight hours post workout will be different in the joints than in the muscles, and different for aerobic training and strength training.

Methods

Subjects

A total of fifteen physically active university students from the Technical University of Madrid (Age: 21.44 ± 2.64 years; Height: 1.78 ± 0.04m; Weight: 73.2 ± 7.6kg; BMI: 23.05 ± 1.56) reporting that they exercise at least three times per week volunteered for this study. The participants reported no physical limitations or diseases, and declared no consumption of medicines, drugs, alcohol or tobacco. They were asked to refrain from a list of activities 24 hours prior to the test.

The Ethics Committee of the Technical University of Madrid approved the study plan,
following the principles outlined by the Word Medical Assembly Declaration of Helsinki.

**Training and establishment of working load intensity parameters**

The participants chosen for the study signed a consent form informing them about the aims, procedures and risks involved in the investigation. They also answered questions pertaining to a history of their injuries, strength training experience, and other personal details. Measurements for height (m) and weight (kg) as well as their capacity and limitations with the assigned exercises were recorded. Participants were familiarised with the appropriate technique of the exercises (rhythm and coordination) as well as the thermography machine (IRT).

During the morning of the study, participants recorded their individual resting heart rate (RHR). This value was used to calculate their maximal heart rate (MHR) with use of the Whaley formula\(^26\). Based on the formula, 60% and 75% of their MHR-RHR was calculated, establishing the heart rate limits for the study. With the limits established, participants performed a trial run for 45 minutes on the treadmill, familiarising them with the aerobic portion of the study.

With regards to the strength training component, two exercises for major muscle groups - bench press (BP) and crossed pulleys (CP) for the chest; leg press (LP) and leg extension (LE) for the thigh - were chosen. All participants completed a one repetition maximum (1RM) test for each exercise in two separate sessions. The 1RM test, was measured based on the principles described by BAECHLE & EARLE\(^27\). Each participant warmed up for five minutes on a cycle ergometer. The 1RM protocol consisted of a warm-up phase followed by five progressive lifts, with the work load increased systematically until only one repetition with the proper technique and a rhythm of 2:2 (2 seconds eccentric and 2 seconds concentric) could be performed. To prevent muscular fatigue, a maximum of five sets were used to determine 1 RM\(^28\). Table 1 summarises the maximal strength values achieved.

**Strength training session protocol**

After the familiarisation process, the strength training portion of the study was started. Participants performed a five-minute warm-up on the bicycle followed by five minutes of general stretching targeting the muscles involved in the selected exercises. Before each lift, six to ten repetitions with a light weight were performed to establish proper technique and rhythm of execution (cadence 2:2). All participants performed four sets of ten repetitions at 70% of 1RM, with a rest period of 90 seconds between sets and three minutes between exercises.

Monitoring during the exercise provided real-time feedback about the speed and range of movement of each exercise. Participants performed two main exercises (BP and LP), followed by two ancillary exercises (CP and LE). Upon the completion of the last exercise, thermogram measurements were conducted two minutes post, followed by a ten-minute passive stretching session of the muscles used in the exercises.

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<thead>
<tr>
<th></th>
<th>1RM</th>
<th>1RM/kg</th>
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<tr>
<td>BP: Bench press (session 1)</td>
<td>76.36±9.44</td>
<td>0.79±0.10</td>
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<tr>
<td>CP: Crossed pulleys (session 2)</td>
<td>26.07±6.01</td>
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<td>LE: Leg extension (session 1)</td>
<td>107.86±14.24</td>
<td>1.11±0.15</td>
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<tr>
<td>LP: Leg Press (session 2)</td>
<td>180.57±28.25</td>
<td>1.86±0.29</td>
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</table>

Table 1: Averaged maximal strength results
Resistance training session protocol

Similarly to the strength portion of the study, participants warmed up for five minutes prior to a 45-minute treadmill run at a moderate intensity (60-75% HR). The intensity of the exercise was measured using the Borg scale of perceived exertion (from 6 to 20).

Before and after each run, participants were weighed to establish a dehydration level. A calculation of the measured loss was performed giving a value for the amount of water needed to be consumed post exercise. With regards to ingestion of food, participants were allowed their normal daily intake during the supervised eight-hour period post-exercise. Water consumption was calculated to at least 150% of the weight lost due to dehydration.

General and thermographic protocol

Participants were asked to maintain normal eating and resting habits, but were instructed to desist from any exercise for at least 24 hours before the trial. Each trial session began between 08:30 and 11:30. Participants were requested to remain in their underwear for a minimum of 15 minutes in order to achieve a thermal balance with their surroundings, before baseline skin temperatures were recorded. The average temperature for the room was maintained at 20.6 ± 0.7°C with a humidity reading of 44.0 ± 3.2%.

During the workouts participants wore shorts, T-shirt and training shoes. They were instructed to consume the minimal amount of water during and immediately after exercise. With the room temperature kept at a constant temperature (18.5°C and 21.0°C), participants were monitored for eight hours post-trial. They were asked to abstain from having a shower, but were allowed to wear comfortable clothing. During the monitoring period they remained seated, partaking in passive activities (i.e. reading, studying or playing computer games). The only time they were allowed to leave the room was to eat between 13:30 and 15:30.

Ten series of four thermograms (Anterior and Posterior of the Upper and Lower body: AU, AL, PU, PL) were registered before the exercise (BE), immediately after exercise (IAE) and once an hour post-workout (“A+1” to “A+8”). Temperature data from the selected regions of interest (ROI) were obtained from 72 anatomical regions based on criteria set out by GOMEZ CARMONA et al. Temperature data from the selected regions of interest (ROI) were obtained from 72 anatomical regions based on criteria set out by GOMEZ CARMONA et al. (see Figure 1). The selected ROI were: pectoral (PEC), dorsal (DOR) deltoids (DEL), biceps brachii (BIB), triceps brachii (TRB), quadriceps (QUA) and Hamstring (HAM) muscles and 2) the elbow (ELB) and knee (KNE) joints bilaterally (left and right), when applicable, in the frontal (F) and dorsal (D) views. In addition, during the resistance training, the abdominal (ABD) region was considered. Tympanic temperature readings were taken twice during each thermal assessment.

The thermographic protocol for this study was in agreement with the guidelines of the European Association of Thermology concerning the participants, camera and environmental conditions, ensuring the recording of images of the highest quality.

Equipment

Thermograms were recorded using the 335 FLIR infrared camera (FLIR Systems, Sweden), with data extracted by Termotrackor software (Pemagroup, Spain). Tympanic temperature was recorded with a ThermoScan® PRO-4000 (BRAUN, Germany). The environmental conditions were controlled by a BAR-908-HG portable weather station (Oregon Scientific, USA).

The machines used for the strength training protocol were: leg extension (X Pression - Panatta, Italy); leg press (Free Weight); Smith machine (X Pression - Panatta, Italy); cable station with bar (X Pression - Panatta, Italy). For the initial assessment, experimental trial and the aerobic training test, the Runner Advance “E” (Panatta, Italy) treadmill and the RS400 heart rate monitor (Polar, Finland) were used.

Statistical analyses

Average and standard deviations for the Tsk of the selected ROI were derived from the thermograms using the Termotrackor software.
Results

Effects of strength training on skin temperature

A summary of the averaged Tsk and the standard deviations for each muscle ROI in the ten conditions: baseline before exercise (BE), immediately after the strength training (IAE) and during the eight hours of recovery ("A1" to "A8") is presented in Table 2. Additionally, significant differences for the multivariate analysis of repeated measures test for Tsk by data collection moment and the results of the post hoc Tukey analysis among different moments during recording of Tsk are also presented. Furthermore, Table 3 shows the relation of Tsk to the articular regions and tympanic temperatures.

From Table 2 we concluded that the Tsk_{IAE} is lower or similar than Tsk_{BE} in all the muscle ROIs. In turn, differences regarding thermal responses related to muscle activity in the selected exercises (agonist, synergist or antagonist) for both the upper and lower limbs are shown.

The thermal response of the skin of the articular regions (elbows and knee) was also different when considering either the upper or lower limbs (Table 3). In the upper limb, the strength exercises affected the anterior differently from the posterior part of the elbow with regards to Tsk. However, the Tsk response of the knee to the strength training exercise did not reflect a significant decrement in most areas.
Table 2: Averaged temperatures (±) standard deviations and repeated measurements multivariable analysis for each considered muscular ROI along the data collection process. (STRENGTH TRAINING)

<table>
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<th>A+n = Number of hours after training; (X) = Codes for significant differences in the post hoc Tukey test during resting.</th>
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**ROI:** Regions of Interest; **F:** Forehead; **D:** Dorsal; **R:** Right; **L:** Left; **BE:** Before exercise; **AE:** Immediately After Exercises; **VT:** Variance Test; **A+n:** Number of hours after training; **(X):** Codes for significant differences in the post hoc Tukey test during resting.
### Table 3: Averaged temperatures (±) standard deviations and repeated measurements multivariable analysis for each considered articular ROI and tympanic temperature along the data collection process. (STRENGTH TRAINING)

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<tr>
<td>F R</td>
<td>31.82</td>
<td>+ 0.71</td>
<td>31.86</td>
<td>+ 0.52</td>
<td>+ 0.57</td>
<td>+ 0.87</td>
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<tr>
<td>D R</td>
<td>28.95</td>
<td>+ 0.80</td>
<td>29.61</td>
<td>+ 0.69</td>
<td>+ 0.75</td>
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<td>+ 0.81</td>
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<td>+ 0.74</td>
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<td>F R</td>
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<td>+ 0.76</td>
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<td>+ 0.36</td>
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</table>

**Post hoc Tukey**

- **Post** BE - IAE (only p<0.05)
- **Diff** BE - IAE (only p<0.05)

**ROI = Regions of Interest; F = Frontal; D = Dorsal; R = Right; L = Left; BE = Before exercise; IAE= Immediately After Exercise; A+n = Number of hours after training; (X) = Codes for significant differences in the post hoc Tukey test during resting. (*p=0.06)**
Effects of resistance training on skin temperature.

Similarly to the strength training data, Tables 4 and 5 present a summary of the muscle, joint Tsk and tympanic temperature at rest (BE), immediately after aerobic exercise (IAE) and during the eight-hour recovery period (“A1” to “A8”). Multivariate analysis of repeated measures test and post hoc Tukey analysis for the Tsk among the different recording moments are presented in these tables. In most of the selected ROIs, the upper limb $Tsk_{IAE}$ is lower than the $Tsk_{BE}$ with significance being achieved only in the anterior part of the deltoids (See Table 4). In contrast, the triceps brachii $Tsk_{IAE}$ is higher than the $Tsk_{BE}$. Concerning the lower limb muscles, the IAE temperature remained constant or showed a slight increase but was of no significance.

The results for the joints were heterogeneous (Table 5) with significant increments of Tsk shown in the posterior part of the elbows and anterior part of the knees. However, non-significant measures of Tsk were recorded IAE compared with the BE baselines. Within Table 5, an increase in IAE of the tympanic temperatures are shown but were not significant. With regards to the abdominal area there was a sharp decrease in temperature IAE.

Discussion

Thermographic recordings present a complex physiological response of the skin to different training load, involving the skeletal muscle (metabolism), the cardiovascular system (blood flow), neural system (central and local) and adrenergic system. In this study, thermographic data indicated that the skin response was specific for the muscle group and selected joints evaluated over time for different training loads.

Short-term effects of training on skin temperature.

Among the 16 evaluated muscle ROIs, a reduction of Tsk occurred in 75% of cases immediately after strength training, ranging from 0.1°C to 1.6°C. Significance ($p<0.05$) was demonstrated only in the posterior deltoid (R & L), pectoral (R), dorsal (R & L) and hamstring (R & L) (see Table 2). Comparing strength to aerobic training (Table 4), there was a reduction of the Tsk in 63% of the analysed ROIs post 45-minute run. The change in range was from 0.3°C to 0.8°C. However, a significant difference ($p<0.05$) was only observed in the right anterior shoulder.

The thermal response to strength training was heterogenic in the joints (Table 3) with a significant rise ($p<0.05$) in the back part of the elbow (R & L) and a reduction in the knee joint. Significance was observed in the left anterior and both the left and right posterior part ($p<0.05$), with an average decrease of up to 2.0°C. The response to aerobic versus strength training in the joints was different with a slight and non-significant decrease on the anterior and posterior regions of the elbow and knee joints, respectively. The temperature change was between 0.3°C and 0.5°C, with a heightened and significant increase on the posterior region of the elbow and the anterior region of the knee ($p<0.05$), ranging between 1.2°C and 2.7°C.

From the data collected the muscle areas of Tsk were lower than the initial IAE temperature with a pronounced decrease in the strength training protocol. With regards to the elbow or knee joints, a greater decrease in temperature was observed in the knee post strength training. The mean difference was approximately 2.0°C in the posterior. However, after aerobic training the temperature was reduced between 0.4°C – 0.5°C with the higher readings recorded in IAE of the posterior region of the elbow (between 1.0°C – 2.7°C) and anterior part of the knee (between 1.2°C – 1.5°C).

Skin cooling has been shown to occur during both running and exercise with a cycle ergometer. However, the reduction of temperature after strength training has yet to be investigated. Using IRT, Merla et al. showed...
### Table 4: Averaged temperatures (\(\pm\)) standard deviations and repeated measurements multivariable analysis for each considered muscular ROI along the data collection process (RESISTANCE TRAINING)

<table>
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<tr>
<th>ROI</th>
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**Notes:**
- \(\pm\) = Standard deviation
- \(P < 0.05\) = Significant difference
- \(\uparrow\) = Significant difference
- ROI = Region of Interest
- BE = Before exercise
- A+n = Number of hours after training
- (X) = Codes for significant differences in the post hoc Tukey test during resting.
Table 5: Averaged temperatures (±) standard deviations and repeated measurements multivariable analysis for each considered articular ROI and tympanic temperature along the data collection process (RESISTANCE TRAINING)

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ROI = Regions of Interest; F = Frontal; D = Dorsal; R = Right; L = Left; BE = Before exercise; IAE= Immediately After Exercise; A+n = Number of hours after training; (X) = Codes for significant differences in the post hoc Tukey test during resting.

Monitoring Skin Thermal Response to Training with Infrared Thermography
a reduction in Tsk in response to a gradual increase of running intensity over 12 minutes in the forearms (5.2°C), the trunk (3.0°C), and the quadriceps (4.6°C). The two training protocols of this study produced similar results, but with less magnitude in the case of the strength training. At this point we have to consider that the characteristics of the efforts were quite different. In our study, the duration of the exercises exceeded 30 minutes versus 12 minutes in the studies of MERLA et al21. The observed acute Tsk reduction IAE may be partially compensated by heat conduction mechanisms: the sweat created, as a result of blood flowing from the muscle to the skin, releases excess heat from the muscle.

The thermal gradient between the skin and blood accounts for evaporation of sweat. This mechanism cools the blood, maintaining the internal temperature at an acceptable level14,32. The tympanic temperature measurements of this study validated this argument as they were significantly higher than the skin temperature IAE.

The internal temperature of the body can be influenced by exercise intensity8,9. Regulation of blood temperature, pressure and metabolic activity by the hypothalamus protects the body from dangerous increases in core temperature. Active central and peripheral vasoconstriction and vasodilation mechanisms in the body ensure that blood flows from the muscle to the skin. Under extreme conditions, six to eight l/min of blood may flow32 in an attempt to cool the skin. In addition, the stimulation of sweat glands and the reduction of the temperature of blood by convection, the relationship of ambient air temperature to the skin19,36 ensures that temperature of the body is maintained at a safe and constant level. The radiated skin temperature in response to the aforementioned mechanisms can be captured by IRT19, 36.

The displacement of blood flow from the skin to regions of active muscle assists in the reduction of body temperature obtained IAE, during short-term exercise21. During moderate intense running, blood flows from the abdominal region to other muscles providing nutrients and a cooling effect. The measurement for Tsk in the abdominal region indicates a decrease in blood flow when analysed.

Interval strength training promotes a specific local thermal adjustment in contrast to a continuous run, with running imposing a neural vasodilation reflex in the skin32. The redistribution of blood from the skin to the active muscle region is inhibited by an increased need for internal heat loss. This inhibition is caused by thermal stress in response to extremely high air temperatures, or by a large internal heat production for a prolonged period of high-intensity exercise. Nonetheless, these phenomena were not seen in this study.

Tympanic temperature is an indicator of internal body temperature. A study by MEIR et al13 indicated that tympanic temperature accounted for a significant increase of 0.34°C compared to the resting condition at the end of a rugby match. This rise was greater than the value for strength training (0.11°C), but similar to the data after aerobic training (0.29°C), in the present study. In turn, the data collected in this study indicates a direct relationship between the increment of internal temperature with the intensity and duration of exercise.

**Skin temperature during recovery**

Changes of Tsk during recovery in the ROI for both strength and aerobic training increased when compared to the initial temperature BE and IAE (Tables 2 and 4). However, Tsk increases for the joints did not present with any significant changes. Though a sharp temperature increase in the anterior region of the knee post aerobic training was seen, this value was similar to the rest value two hours post 40-minute run (Tables 3 and 4). The use of IRT in research evaluating Tsk response during recovery post strength training is sparse. This limitation prevents the comparison of our data to other material. However, the rise in Tsk in several regions of the body post running has been shown by MERLA et al35.
Monitoring Skin Thermal Response to Training with Infrared Thermography

In general, the highest recorded temperatures occurred four to six hours and six to nine hours post strength and aerobic training, respectively. An interesting response was noticed concerning maximal Tsk values recorded IAE and two hours post training for the anterior part of the knee and posterior part of the elbow. The values obtained in these areas were quite similar to the resting conditions.

After the exercise there is a new metabolic condition, demanding specific thermal adjustments including a redistribution of blood flow. Furthermore, it is known that during the recovery period the internal oesophageal temperature remains elevated indicating an increased metabolic activity. After the completion of the exercise, activation of the mechanisms for releasing the metabolic and mechanica heat produced during the training period and their long term effects is still necessary. Kenny et al established that 53% of heat stored during 60 minutes of cycling at 70 W was lost in 60 minutes of recovery. Therefore, the increase in skin temperatures during the recovery period may be attributed to the activation of the above mentioned mechanism.

Exercise produces an increase of nitric oxide (NO) in the blood, an important vasodilator of the cutaneous arteriole. Given the need for a local metabolic heat loss, NO promotes the vasodilatation in the exercised regions through a mechanism called the prolonged plateau nitric oxide vasodilation mechanism. The result is an increase in blood supply causing an elevation of local temperature, which can be measured by thermal imagers.

Increases in Tsk during the recovery of the joints and muscle, may be influenced by other mechanisms such as glycogen resynthesis or adaptive mechanisms of hypertrophy. The heat generated by these mechanisms occurs in the anatomical structures just under the skin.

The thermal profile obtained during the eight-hour recovery period can be influenced by environmental conditions, creating a thermal gradient between the skin and environment. In cases of extremely hot environmental conditions (≈ 38°C and ≈ 70% RH in tropical areas) it is possible that this response would be different.

It is difficult to establish the effect of circadian variation of temperature on the results of this study. A study by ARNETT indicated that swim training in the morning eliminated the effect of daily variation in body temperature, with MORRIS et al concluding that Tsk during recovery after exercise (70% VO2 max for 30 min) did not vary significantly. However, it is interesting to note that in this study, the highest temperature recorded for the ROI was approximately six hours post-exercise, which is similar to peak temperatures recorded by circadian rhythm studies.

In this study, the thermal measurements recorded for the 24 ROI in relation to Tsk were different before, during and after both strength and aerobic training. The results were influenced by the type of training (strength vs aerobic), the characteristics of the collected samples as well as the environmental conditions (room temperature). The constant monitoring of the body with regards to the aforementioned influences, is a very complex endeavour involving the synergy between the hypothalamus and other multiple sensors. This feedback loop provides a constant monitoring of the internal temperature, maintaining a safe range for the proper function of the body. Factors that may influence this “safe” temperature range are: age, gender, level of fitness, hydration, clothing, circadian rhythm, type of training, as well as environmental conditions.

The specificity of local thermal responses to exercise requires further study to enhance the basic knowledge, particularly in high-performance competitive sport, where the athlete’s recovery actions and the assimilation of training loads, are essential for the intervention of physical therapists and trainers.
Recommendations

Use of thermography may prove to be a valuable tool for trainers. By evaluating the local metabolic activity generated by the workout, and the subsequent return to baseline Tsk, a decision can be made when the athlete can resume training. In addition, therapists may use thermography as a tool for monitoring individual effects of techniques on their patients. In turn, the absence of differences in temperature between paired ROIs may indicate a balanced condition thereby minimising the possibility of injury.

The use of thermography on a regular basis during the training will create a thermal profile of the athlete, with special attention given to regions (muscle and joint) exposed to a higher training load or greater risk of injury. Increments of Tsk in these regions may be a strong indicator of an incomplete recovery. This information may help trainers control, decrease or abandon the training until Tsk returns to baseline levels.

Please send all correspondence to:
Ismael Fernandez de la Cuevas
ismael.fernandez@upm.es

Conclusions

Considering the ROI, Tsk presents specific responses in relation to strength and aerobic training. The main changes in Tsk observed in muscle (chest and thigh) were a reduction in temperature immediately post exercise versus the initial values, and a progressive increase during the eight hour recovery period with Tsk peaking approximately six hours post exercise. This value during the recovery period was never higher than 1°C compared to the initial resting values. The impact of exercise on Tsk with regards to the joints (knee and elbow) was lower and more heterogeneous with the local temperatures increasing or decreasing moderately in the ROI after strength training. However, the effects were more relevant after aerobic training in both the anterior part of the knee and posterior part of the elbow; with the recovery lasting only one or two hours. Therefore, use of IRT may provide important information on local adaptations in response to re-establishing the initial skin temperature post training. This may indicate whether the athlete has recovered enough to effectively train or compete again. If this theory is proven, IRT would be a practical and easy tool for monitoring the athletes’ training.
REFERENCES


Coaching

contents

Shot Put With Lighter Implements
by Basil Grammaticos
Shot Put With Lighter Implements

by Basil Grammaticos

ABSTRACT

Following a competition in 2012, a group of the world’s top shot putters were invited to compete using a 5kg implement. The results were somewhat surprising in that the distances achieved were not as long as might be expected, based on the assumption that the length of a throw is inversely proportional to the mass of the shot. The aim of this paper is to provide an intuitive, physics-based interpretation of the results of the aforementioned competition and set a frame for the description of shot putting with implements of non-standard weights. The model, combined with the classical kinematics results for a projectile motion under the influence of gravity (and neglecting air resistance), allows the derivation of a simple expression for the dependence of the length of throw on the implement mass. This result is compared to existing performances and the limitations of the model when too heavy or too light implements are used are discussed. It is hoped that the results can assist coaches by providing a tool for interpreting the capability of athletes based on their results with different weight shots.

AUTHOR

Basil Grammaticos, Ph.D., is a Director of Research at the National Scientific Research Centre (CNRS) in Paris and is currently head of the modelling team of the joint University of Paris VII – University of Paris XI Laboratory for Imaging and Modelling for Neurobiology and Cancer Studies (IMNC).

Introduction

This paper has been motivated by the results of a 2012 competition, where top-class shot putters were invited, after the normal competition, to vie for the longest put of the year. Thus, after having completed an event using the regulation weight, 7.257kg shot, the athletes returned to the circle in order to compete with a lighter, 5kg implement. The results with the normal implement were the following:

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</tbody>
</table>
the most salient features, which, we believe, are the ones determining the length of the throw as a function of the mass of the implement.

In our model we distinguish two phases, which are fundamentally different. The first is what we call the acceleration phase. The thrower starts from a position where his velocity is zero and, using one of the two customary techniques, glide or spin, moves from the back to the front edge of the circle accelerating all the way. In the glide technique, there is a substantial vertical acceleration, while in the spin technique a centrifugal acceleration is perceived in the athlete’s frame, but these details are not expected to play a crucial role and thus we shall not delve further on these points. The net result of the acceleration phase is to bring the hand of the thrower holding the shot to some velocity \( v_0 \). Since the thrower is much more massive than the shot (typically 100kg compared to 4-7kg) a small difference in the mass of the shot will not make any difference when it comes to the value \( v_0 \) of the velocity attained. Thus as a first approximation we can assume that the acceleration phase leads to a velocity \( v_0 \) independently of the mass \( m \) of the implement.

The second phase is that of the throw itself, during which the thrower pushes the shot and, expending a quantity of energy \( E \), which we take to be always the same, increases the kinetic energy of the shot from

\[
\frac{1}{2}mv_0^2 \quad \text{to} \quad \frac{1}{2}mv^2
\]

where \( v \) is the velocity at which the shot leaves the thrower’s fingers. We have thus

\[
E = \frac{1}{2}m(v^2 - v_0^2) \quad (1)
\]

It is clear from this expression that the final velocity of the shot depends crucially on its mass. The separation of the throwing process in two phases is quite a natural one and, in fact, common to all throws. In his book on throwing events, SILVESTER distinguishes precisely these two phases in his discussion of the bio-

### Shot Put With Lighter Implements

With the lighter one, the order did not change a lot and the throw distances were:

<table>
<thead>
<tr>
<th>Name of Athlete</th>
<th>Distance with 5kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffa</td>
<td>25.20m</td>
</tr>
<tr>
<td>Rodhe</td>
<td>24.68m</td>
</tr>
<tr>
<td>Majewski</td>
<td>24.54m</td>
</tr>
<tr>
<td>Armstrong</td>
<td>24.36m</td>
</tr>
<tr>
<td>Giza</td>
<td>21.34m</td>
</tr>
<tr>
<td>Zbroszczyk</td>
<td>20.50m</td>
</tr>
</tbody>
</table>

Now, at first sight, these results may appear astonishing. The naive assumption that the length of the throw is inversely proportional to the mass of the shot would have one expect much longer throws with the lighter implement. However, the collected data disputes this proportionality argument forcing one to seek a better understanding of the situation. Therefore, the aim of this paper is to provide an intuitive, physics-based, interpretation of the results of the aforementioned competition and set a frame for the description of shot putting with implements of non-standard weight. In fact, contrary to what is alluded to in the title, our approach is valid also in the case where a heavier implement is used (more on this in the Discussion).

In what follows we start by presenting our model and then analyse the kinematics of the shot after it has left the thrower’s hand. We combine these two items in order to make a prediction on the dependence of the throw length to the mass of the implement and compare it to existing data. Finally, we discuss the results obtained, pointing out limitations to their domain of validity and propose a somewhat better model.

### The Model

It is beyond the scope of the present paper to present a biomechanically accurate model of the shot put. On the contrary, we shall over-simplify the shot putting process in order to isolate
mechanics of throwing techniques\textsuperscript{2}. Indeed, the corresponding chapter deals with the processes of “developing momentum in the run-up area” (a most restrictive one in the case of shot put) and of “transmitting energy from the body to the implement”, corresponding to the acceleration and push phases of our model.

**The Kinematics of Shot Putting**

Once the shot leaves the hand of the athlete, its trajectory is subject to the usual laws of ballistics. The trajectory of a projectile released at height ($h$), with velocity ($v$) and at an angle ($\theta$) with respect to the horizontal is given, as a function of time ($t$) by the equations

\[ x = v \cos \theta t \]  
\[ y = h + v \sin \theta t - \frac{1}{2} gt^2 \]  

where $x$, $y$ give the position of the (centre of mass of the) shot, measured along the horizontal and vertical axes and where $g$ is the gravitational acceleration. These equations can be found in any elementary physics textbook. They are derived by neglecting the effect of air resistance on the moving body. In the case of the shot put, this is perfectly justified as shown by LICHTENBERG & WILLS\textsuperscript{3}. The length ($L$) of the throw is given by the value of $x$ when $y = 0$. Eliminating $t$ between the two equations of (2a & b) we find that $L$ is given by

\[ gL^2 - 2v^2 \cos \theta (\sin \theta L + h \cos \theta) = 0 \]  

At this point it is advantageous to introduce non-dimensional quantities

\[ S = \frac{L}{h} \quad \text{and} \quad d = \frac{v^2}{2gh} \]

Using typical values for $v = 14\text{m/s}$, $h = 2\text{m}$, and given that $g = 9.8\text{m/s}^2$, we find for $d$ the value $d = 5$: in the same spirit, a throw of $L = 20\text{m}$ gives an $S$ of 10.

The standard textbook answer as to the optimal angle in ballistics is $\theta = 45^\circ$. However this is valid only for throws from zero height. Since in our case the release height is not negligible with respect to the other parameters, we expect the optimal angle to be smaller than $45^\circ$. Still, in order to simplify our argument let us at first neglect this effect and assume $\theta = 45^\circ$. We find that the throw length is given by

\[ S = d + \sqrt{d^2 + 2d} \]  
this can further be approximated by

\[ S = 2d + 1 \] 

(the first correction being $-\frac{1}{2d}$, of the order of 1\% given the typical value of $d$).

We can now go back to the full angle dependence. The optimisation of the angle gives a solution around $\theta = 41^\circ$ (using our standard values of $v$ and $h$). This is in agreement with previous results\textsuperscript{5,6} but with slight disagreement with measurements based on competition data\textsuperscript{4,7,8}, which give angles around $37^\circ$-$38^\circ$. The explanation of this discrepancy is given in an elegant way by LENZ & RAPPL\textsuperscript{9} who considered the correlation between the velocity of the shot and the release angle. Still, for the case at hand, given the small deviation of the optimal value of the angle from $45^\circ$ and the fact that we use an approximation for $S$, equation (5), we can safely neglect the angle effect and work just with the expression $S = 2d + 1$.

**The Dependence of Throw Length on Implement Mass**

Starting from equation (5) we revert to quantities with dimensions and find for the throw length

\[ L = \frac{v^2}{g} + h \]  

Next we use equation (1) and obtain $v^2$

\[ v^2 = v_0^2 + \frac{2E}{m} \]  

we substitute into (6) and find

\[ L = \frac{v_0^2}{g} + h + \frac{2E}{mg} \]  

which we represent schematically as

\[ L = a + \frac{b}{m} \]
Equation (9) gives the dependence of the throw length on the mass of the implement. Roughly stated, a large value of $a$ would indicate a good acceleration in the circle, while a large value of $b$ indicates a strong push. Validating equation (9) is far from an easy task. While elite throwers may train with heavier or lighter implements the precise data are not available. When competitions like the one that spurred this study are held, one has just the results for two different shot weights, which only allow to fix the parameters of (9). If we analyse the results of the introduction using (9) we find the following set of parameters for the athletes:

<table>
<thead>
<tr>
<th>Name of Athlete</th>
<th>$a$ (m)</th>
<th>$b$ (kgm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffa</td>
<td>14.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Majewski</td>
<td>12.7</td>
<td>59.6</td>
</tr>
<tr>
<td>Armstrong</td>
<td>12.4</td>
<td>60.0</td>
</tr>
<tr>
<td>Rodhe</td>
<td>11.6</td>
<td>65.2</td>
</tr>
<tr>
<td>Giza</td>
<td>12.9</td>
<td>42.2</td>
</tr>
<tr>
<td>Zbroszczyk</td>
<td>13.1</td>
<td>37.2</td>
</tr>
</tbody>
</table>

In addition to drawing comparisons on elite athletes, application of this model can be used with junior male throwers provided the existence of useful data. Even though competitions are held with lighter implements, the elite junior throwers do also train with the heavier ones and often participate at senior events. Unfortunately the data is scarce and only one complete set of performances was found, that of the new prodigy thrower Jacko Gill (NZL). His personal records, all of them from 2011, are 20.38m with a 7.25kg, 22.31m with a 6kg, and 24.45m with the 5kg shot. Using the two heavier implements and equation (9) we obtain the following values for $a = 11.1$m and $b = 67.2$kgm. With these values one is able to extrapolate a performance of 24.54m with a 5kg shot. This value is in agreement with the value obtained for the actual throw (24.45m). It is interesting to note that this athlete also trains with a heavier shot (8kg), and there exists one testimonial of a 18.20m throw. Our expression (9) predicts a throw around 19.5m, which would not have been impossible for the athlete if that weight were used in competition. Another junior athlete for whom some results exist is for Krzysztof Brzozowski (POL). His best performance records in 2012 were 19.63m with a 7.25kg shot, 21.78m with a 6kg while with the 5kg shot his personal best was 23.23m dating back to 2010.

We start by obtaining the parameters $a$ and $b$ from the 2012 performances and find $a = 9.3$m and $b = 74.8$kgm. With use of equation (9) for a 5kg shot we find a distance of 24.3m perfectly compatible with the one meter shorter result recorded when the athlete was younger, since a junior thrower is expected to improve substantially in two years. Finally we examined the case of the two time world champion David Storl (GER) who as a junior in 2009, recorded 20.43m with a 7.25kg shot, and 22.73m with a 6kg one. No performance with the 5kg shot appears to be known past 2007 but the use of (9) and the fitted parameters ($a = 9.4$m and $b = 80.0$ kgm) give a prediction of 25.4m, which is not at all unreasonable, given the excellence of this athlete.

Discussion

While based on quite reasonable hypotheses, the equation relating the length of a throw to the mass of the shot is blatantly wrong to the eyes of a physicist. Given an expression like (9) one is naturally led to the question of what happens at the limits $m \to \infty$ and $m \to 0$. The answers obtained through use of equation (9) at both limits are wrong. For $m \to \infty$ equation (9) predicts $L = a$ (i.e. a non-zero result), while for $m \to 0$ it predicts an infinitely long throw. Does this mean that our model is wrong? Not at all, for the absurd results obtained at the two limits are possibly due to the fact that some basic assumptions are violated.

Let us examine first the $m \to \infty$ case. The tacit hypothesis in our model is that the thrower accelerates always to the same final velocity $v$, independently of the shot’s mass. This can only be true as long as this mass is small compared to the body mass of the thrower, let’s
say up to 10%. As the weight of the implement becomes substantial the hypothesis breaks down. In any case, given the constraints of the material world, the heaviest shot we could expect to have at our disposal without exceeding the 11-13cm diameter is one at around 20kg. Still it is expected that even so far from the $m \to \infty$ limit, a 20kg shot would alter significantly the dynamics of the acceleration phase.

Referring now to the $m \to 0$ limit, the tacit hypothesis here is that the limit to the velocity imparted to the shot is solely due to the inertia of the shot itself. However when the mass of the latter becomes very small the inertia of the body parts (essentially the arm and the hand) becomes far from negligible. Another complication stems from the fact that for light, fast-moving implements, the resistance of the air cannot be neglected anymore and the study must be redone afresh, including this effect. All in all we expect equation (9) to be certainly valid for 4kg shots and perhaps still valid down to 3kg while it will most probably break down at the 2kg level.

Having discussed the limitations of equation (9) as to the mass of the implement, it is now possible to present a better model, which has the merit of possessing correct $m \to \infty$ and $m \to 0$ limits, at the expense of only a moderate complication. First, we take into account the mass of the implement during the acceleration phase. This leads to an expression for $v_0$ given by

$$v_0^2 = \frac{2E_0}{m + m_0}$$  \hspace{1cm} (10)

where $m_0$ is the mass of the athlete. Second, we introduce the arm inertia of the athlete during the push phase, whereupon expression (7) becomes

$$v^2 = v_0^2 + \frac{2E}{m + f}$$  \hspace{1cm} (11)

Combining (10) and (11) we find an expression for $d$ of the form

$$d = \frac{1}{gh} \left( \frac{E_0}{m + m_0} + \frac{E}{m + f} \right)$$  \hspace{1cm} (12)

which can be written schematically

$$d = \frac{p}{m + m_0} + \frac{q}{m + f}$$  \hspace{1cm} (13)

However, in order to compute the throw length $L$ we must use the full expression (4), since $d$ is not guaranteed to be a large quantity anymore. We remark here that a new parameter $f$ has made its appearance. While we expect its value to be of the order of a few kg there is no easy way to fit it precisely, in particular in view of the paucity of results on which to make a fit. Still, an upper limit can be obtained by asking that the value of $p$ be positive. This results in an $f$ value being smaller than 6kg. Based on this assumption thus we decided to pursue our calculations by fixing $f$ at 5kg. Fitting the performances of Gill for $m = 7.25$kg and 6kg we found the values $p = 113$kgm and $q = 100$kgm. These values lead to a prediction of 24.1m for a 5kg shot while for a 8kg the result is 19.4m. On an anecdotal level we may mention the 37m throw of Gill with a 1kg shot, a result very far from the prediction of equation (9), which turns out to be in nice agreement with the value of $L$, predicted for the set of $p$ and $q$ just obtained, which is 37.6m.

While the use of equation (4) leads to a somewhat complicated expression linking $L$ to $m$, it is quite easy to visualize this dependence graphically (see Figure 1, next page). This graph is based on using the parameters for Gill.

Moreover once the graph is obtained it is easy to introduce a simple expression fitting the curve. We find

$$L = \frac{l}{m + k}$$  \hspace{1cm} (14)

with $l = 286$kgm and $k = 6.5$kg. One interesting result of this fit is that the elite throwers should be able to throw an osmium shot of the same diameter as the regulation one but of a weight slightly over 20kg at a distance of over 10m (Of course we do not think that anyone would stage a competition with such a precious implement).
low. If we assume a more realistic value of $k = 4$kg we find, using the performance of 21.24m for a 4kg shot, $l = 170$ kgm. Based on these values we can now predict that Adams should be able to throw the 5kg shot at 18.90m and the 7.25kg at just over 15m. This would be a respectable performance, coveted by many a male throwers at a regional level. Let us hope that such a test fits in the preparation of this athlete under the guidance of her coach and that some new data will be available in the near future confirming the present approach.

**Conclusion**

This paper provides a model of predicting the results of throwing a shot put with lighter, regulation and heavier shots. It is hoped that this model will provide coaches with another tool to aid in the training of their athletes. The prediction based on their current characteristics may provide a target for the athletes to aim for.
Acknowledgment

I am indebted to Jean Pierre Egger who kindly answered my questions, providing me with data on Valerie Adams but also offering a most useful insight on the coaching of throwers.

Please send all correspondence to:
Basil Grammaticos grammati@paris7.jussieu.fr

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Development

Contents

Competition of Sports
by Helmut Digel
Competition of Sports

by Helmut Digel

Claiming that the various sports are competing against each other might be surprising at first sight. Biathlon or athletics can only be found once, which is likewise true for handball or table tennis. As soon as a certain sport shows a specific organization, it is a monopolist for a specific branch of sport. This monopoly position is guaranteed to each sport by the legislative body, which is why in e.g. the German umbrella organization, the DOSB (Deutscher Olympischer Sportbund - German Olympic Sports Confederation) there can only be one member association for each sport.

The same is true on the level of the IOC (International Olympic Committee) where there is only one single contact in respect to each sport. Hence the Olympic sports are generally not subject to any internal competition, as they are played according to codified rules. The survival of a sport is secured as long as there are enough people willing to comply to the respective rules of that particular sport.

Some sports are subject to internal competition in so far as they comprise different events, which can be of varying attractiveness. In swimming various individual strokes - breaststroke, backstroke crawl or butterfly - are in a sense competing against each other. In athletics there 47 events, all of which respectively strive to ensure attention and new blood for themselves. Running is more successful than the throws. The jumps seem consistently attractive to the public, whereas some events, e.g. race walking, seem less so.

This competitive situation can be quite different from nation to nation. Hence there are athletics nations in which the technical events are very popular, e.g. Hungary, Czech Republic and Germany; there are regions, in which race walking is very attractive, e.g. in the Russian republics of Mordovia and Chevashia; countries where middle and long distance events dominate, e.g. Kenya and Ethiopia; and countries where the sprints are most attractive, e.g. Jamaica, the Bahamas, Nigeria and the USA.

Setting national priorities in respect to the Olympic sports not only happens within the respective sports, but also in respect to some sports in general. Badminton is extremely popular in Indonesia and Malaysia. Wrestling however is a popular national sport in many African and Asian countries.
These observations reflect the actual competition situation within and between the Olympic sports, as it has developed over the last decades. The success of a sport depends primarily on how accomplished it is at recruiting athletes, drawing spectators and media audiences to competitions and generally in presenting itself as an attractive sport of interest to the mass media and commercial partners.

Apart from the competition of the Olympic sports amongst each other, there has been a competition between the non-Olympic sports and the Olympic sports long. But also the non-Olympic sports are in an increasingly fierce competition amongst each other. In this context, the big question is which of the non-Olympic sports will become eligible to move up to the privileged Olympic group.

Meanwhile a competitive situation has arisen between the non-Olympic sports and the Olympic sports in respect to the partnership between the economy and sports, as well as concerning the reception of these sports in the media, which is carried out in all its severity. Winter sports are fighting against summer sports, and basically everybody is fighting against everybody else.

On a world-wide scale, football (soccer) takes an exceptional position. No other sport can similarly tie spectators, sponsors and mass media down to it, as is the case in football. Without any doubt this dominance creates a disadvantage for all remaining sports, and it is not surprising that an increasing number of sport organisations have initiated discussions on the consequences of this dominance. Nowadays it seems to be inevitable for each sport to be precisely aware of its own market position in the respective international competition.

The market positions of the sports can be defined very exactly. By measuring the volume of sponsorship that an association achieves through selling licenses, one can know the economic value of a sport. The market share can be measured very accurately, just as the number of spectators, that can be reached at broadcasts of a competition, as well as the audience present at the competition, willing to pay for a ticket. If these calculations are carried out and one looks at these statistics over a longer period of time, one can watch the rise and fall of the market positions of both the Olympic sports and of the non-Olympic sports within the sport market.

Some Olympic sports seem to have become nearly totally dependent on the Olympic Games. Their international market position is extremely weak judged by the sport calendar excepting the Olympic Games, and the bulk of their financial resources come from their share of the Olympic income. This applies to archery, curling, modern pentathlon, synchronised swimming, skeleton and eventing in equestrian. Others, however, are marked by a rising tendency. Some non-Olympic sports show more spectators, sponsoring revenues and television viewers than some Olympic sports are capable of achieving. One simply has to think of sports like dragon boat racing, karate and billiard. In the World Games sports like water skiing, (in-line) speed skating and sport climbing have to be called spectacular.

Trying to evaluate the international competitive quality of a sport, exact and hence reliable data is desirable in respect to spectators per year, sponsoring volume and television viewers per year for each and every sport. However, such data is only available for a few countries and regions. Following expert-ratings concerning these indicators, football (soccer) leads the ranking of sports, except in North America. Leading positions are being taken by sports like baseball, basketball, volleyball and handball. Ice hockey dominates winter sport, followed by skiing and biathlon. Generally team sports bind the most spectators to themselves throughout the year and therefore are also attractive to sponsors. In this competitive situation only a few individual sports can stand their ground, e.g. athletics and swimming. In terms of the afore mentioned indicators, sports like modern pentathlon, curling and mountain biking show only little success.
One also has to take into consideration that national rankings can vary profoundly from international evaluations. This is true when comparing continents to each other, but within one continent one can also observe vast differences. In Europe, England shows e.g. the following ranking momentarily: football, rugby, cricket, cycling, athletics. In France, football and rugby take the top positions, like in England, but then basketball, handball and cycling follow, whereas in Germany football is followed by handball, skiing, basketball and Formula 1.

Some rankings change nearly every year, others have remained constant throughout several decades. Regardless of this situation, marketing experts and sport executives of TV stations and online media are making their decisions about the cooperation with one sport on the basis of the currently valid rankings in the respective nations.

If a sport wants to survive in this aggressive competition, a self-critical examination of its own attractiveness is absolutely inevitable. Is the presentation of its competitions still up-to-date? Which target groups are reached with the competitions? Which ones are not reached? How many paying spectators are there in the events of the national championships? Which sponsoring volume can the association achieve with its events? What would in this context be realistic goals for the future? Which cooperation is there with the mass media? Is there sufficient news coverage on television?

Such questions are to be answered soberly. Consequently sensible goals have to be set to make the sport competitive in the future. Each sport has a realistic chance to increase its share in the competitive market of sports, but only if it takes a systematic and professional approach and is open to the necessary changes.

Pleases send all correspondence to:
Prof. Dr. Helmut Digel
helmut.digel@uni-tuebingen.de
Introduction

The traditional opinion among athletes and coaches is that time spent on warming up will improve an athlete’s level of performance. As a result the coach must encourage the athlete to regard the warm-up as an essential part of both the training session and competition itself. An appropriate warm-up will result in:

1. Activating the body’s circulatory system by enhancing blood flow, which will improve the body’s ability to utilize oxygen and remove waste product. Blood vessels open up increasing blood flow and thereby maintaining muscle temperature.

2. Engaging the musculoskeletal system, which will further warm up muscles to reduce muscle stiffness, to provide a more forceful contraction and to help prevent injuries.

3. Exciting the neuromuscular system, which allows the brain to coordinate the nervous system’s ability to fire muscles effectively and efficiently. It will also increase speed of contraction and relaxation of warmed muscles.

Failure to properly warm up, on the other hand, can lead to discomfort, poor performance and possibly injury.

The following bibliography, which is the first in NSA dealing exclusively with different aspects of the warm-up: It contains 83 articles from the year 2000 to 2013.

One of the most discussed issues in connection with the warm-up is the question of whether static stretching is a useful part of the warm-up procedure or whether it can even have detrimental effects on the subsequent performance. At least 27 articles in this bibliography address this issue.

Of these, the one by Wiemann & Klee (2004) deserves particular attention. The authors draw on new knowledge about the anatomy of muscle fibres, as well as research that has examined the role of stretching in preparing to participate in vigorous physical activity. The important conclusion that comes from muscle structure research is that the amount of passive tension the elastic elements of the muscle have to bear is by no means smaller during extreme stretching than during active tension in voluntary maximal isometric contractions. Indeed, the passive tension from stretching can be much higher. Consequently, the forces applied during contractions and stretching in training should have the same or similar effects. In the discussion on the effects of stretching, the authors emphasize the distinction between short-term and long-term stretch training programs. The authors are concerned only with the short-term programmes. The distinction between intensive stretching (e.g. stretching to the maximal tolerable tension) and light, submaximal stretching is made. The benefits of stretching on the range of motion at the joints (movement amplitude) are not ques-
Concerning the current status of research on this topic, the article by Ückert and Joch can be taken as an example. In their study, twenty subjects performed two laboratory endurance tests in conditions of high ambient temperature and relative humidity. One test followed a 20-minute warm-up and the other a 20-minute pre-cooling procedure. The comparison of results showed that pre-cooling significantly extends the time to exhaustion and slows the increase in both body core temperature and heart rate. Therefore, it seems that pre-cooling optimises thermoregulatory processes before physical effort in warm conditions and has a positive influence on performance.

Other questions addressed concern for example the relevance of the warm-up to:

- The quality of the subsequent performance in general (15 articles).
- Injury prevention in particular (5 articles).
- The organisation and duration of the warm-up (12 articles).

This bibliography, which does not acclaim to be complete, has been compiled by using
- SPOLIT, the sports literature database of the Federal Institute of Sport Science (BISp) in Cologne, Germany (www.bisp-datenbanken.de, free access),
- SPORTdiscus, the database of the Sport Research and Information Centre in Ottawa, Canada (www.sirc.ca, no free access).

In addition, many articles were found by “free search” in the Central Library of Sports Science of the German Sports University in Cologne and some stem from the private library of the author.

Readers interested in obtaining one or more articles from this bibliography should contact Dr. Jürgen Schiffer j.schiffer@dshs-koeln.de.
Research suggests that static stretching can negatively influence muscle strength and power and may result in decreased functional performance. The dynamic warm-up (DWU) is a common alternative to static stretching before physical activity, but there is limited research investigating the effects of a DWU. The purpose of this study was to compare the acute effects of a DWU and static stretching warm-up (SWU) on muscle flexibility, strength, and vertical jump using a randomized controlled trial design. Forty-five volunteers were randomly assigned into a control (CON), SWU, or DWU group. All participants rode a stationary bicycle for 5 minutes and completed a 10-minute warm-up protocol. During this protocol, the DWU group performed dynamic stretching and running, the SWU group performed static stretching, and the CON group rested. Dependent variables were measured immediately before and after the warm-up protocol. A digital inclinometer measured flexibility (degrees) for the hamstrings, quadriceps, and hip flexor muscles. An isokinetic dynamometer measured concentric and eccentric peak torque (N•m/kg) for the hamstrings and quadriceps. A force plate was used to measure vertical jump height (meters) and power (watts). In the DWU group, there was a significant increase in hamstring flexibility (pretest: 26.4 ± 13.5°, posttest: 16.9 ± 9.4°; p < .0001) and eccentric quadriceps peak torque (pretest: 2.49 ± 0.83 N•m/kg, posttest: 2.78 ± 0.69 N•m/kg; p = 0.04). The CON and SWU did not significantly affect any flexibility, strength, or vertical jump measures (p > 0.05). The DWU significantly improved eccentric quadriceps strength and hamstrings flexibility, whereas the SWU did not facilitate any positive or negative changes in muscle flexibility, strength, power, or vertical jump. Therefore, the DWU may be a better preactivity warm-up choice than an SWU.


Sports massage provided before an activity is called pre-event massage. The hypothesized effects of pre-event massage include injury pre-
Nine were highly trained, 13 were moderately trained, and 8 were sedentary. Subjects participated in both treatments, which were randomly assigned and were 48-72 hours apart. In one treatment, subjects warmed-up first by walking on a treadmill for 5 minutes at approximately 50% of their age-predicted maximum heart rate, and then performed 3 static stretches: quadriceps, hamstrings, and calf muscles. Each stretch was held 3 times, 15 seconds each. Next, flexibility measurements were determined for the hip, hamstrings, and ankle using a goniometer. The other treatment consisted of performing 20 minutes of walking or jogging at a moderate intensity, then the same stretching exercises were performed and the same flexibility measurements were taken. Reliability coefficients ranged from 0.90-0.96. There were no significant differences in any of the flexibility measurements except for hip flexibility, which approached significance (p = 0.06) and therefore favored stretching after the workout. The placement of stretching, before or after a workout, does not make a difference in its effect on flexibility.

Beedle, B. B.; Leydig, S. N.; Carnucci, J. M.  
No difference in pre- and postexercise stretching on flexibility  

According to the American College of Sports Medicine (1), there is limited information about when to stretch during an exercise session. The purpose of this study was to determine if the placement of static stretching, either before or after a workout, would affect flexibility in the hip, knee, and ankle. Thirty college-age men (n = 12) and women (n = 18) volunteered to participate. Nine were highly trained, 13 were moderately trained, and 8 were sedentary. Subjects participated in both treatments, which were randomly assigned and were 48-72 hours apart. In one treatment, subjects warmed-up first by walking on a treadmill for 5 minutes at approximately 50% of their age-predicted maximum heart rate, and then performed 3 static stretches: quadriceps, hamstrings, and calf muscles. Each stretch was held 3 times, 15 seconds each. Next, flexibility measurements were determined for the hip, hamstrings, and ankle using a goniometer. The other treatment consisted of performing 20 minutes of walking or jogging at a moderate intensity, then the same stretching exercises were performed and the same flexibility measurements were taken. Reliability coefficients ranged from 0.90-0.96. There were no significant differences in any of the flexibility measurements except for hip flexibility, which approached significance (p = 0.06) and therefore favored stretching after the workout. The placement of stretching, before or after a workout, does not make a difference in its effect on flexibility.

Beedle, B. B.; Mann, C. L.  
A comparison of two warm-ups on joint range of motion  

The purpose of this study was to compare a 5-minute treadmill activity at 70% maximum heart rate (MHR) and 5 to 6 minutes of ballistic stretching to a 5-minute treadmill activity at 60% of MHR and 5 to 6 minutes of static stretching. Thirty healthy college students, 7 men and 23 women, volunteered. Most volunteers were moderately active. All participants signed an informed consent. Participants received the aforementioned warm-ups in random order with 48 to 72 hours between warm-ups. The stretching exercises were a back stretch, a quadriceps stretch, and a hamstring stretch. Three trials for 30 seconds each were given. After each warm-up the participants performed the modified-modified Schober test for low back flexibility, active knee extension test for hamstring flexibility, and plantar flexion for ankle flexibility. There were no significant differences on any of the 3 range of motion (ROM) tests although the ankle ROM test was almost significantly greater (68.8[degrees]) after the
warm-up with static stretching compared with 65.9 [degrees] after the warm-up with ballistic stretching. A more intense cardiovascular activity and ballistic stretching were similar to a less intense cardiovascular activity and static stretching on flexibility. If athletes perform a warm-up and static or ballistic stretching before their workouts, then they should continue to perform the warm-up and the stretching routine with which they are most familiar and comfortable.

Bien, D. P.
Rationale and implementation of anterior cruciate ligament injury prevention warm-up programs in female athletes

The sex disparity in anterior cruciate ligament (ACL) injury risk and the subsequent adverse effects on knee joint health, psychosocial well-being, and financial costs incurred have produced a surge in research on risk factors and interventions designed to decrease this disparity and overall incidence. Biomechanical and neuromuscular differences have been identified throughout the trunk and lower extremity that may increase noncontact ACL injury risk in female athletes. Evidence demonstrates that many risk factors are modifiable with intervention programs and that athletic performance measures can be enhanced. No universally accepted ACL injury prevention program currently exists, and injury prevention programs are diverse. Anterior cruciate ligament injury prevention programs introduced in a warm-up format offer multiple benefits, primarily, improved compliance based on improved practicality of implementation. However, drawbacks of warm-up style formats also exist, most notably that a lack of equipment and resources may preclude measurable improvements in athletic performance that foster improved compliance among participants. The purpose of this review is to analyze the current literature researching possible biomechanical and neuromuscular risk factors in noncontact ACL injury in female athletes and the most effective means of implementing critical elements of a program to decrease ACL injury risk in female athletes while improving athletic performance. Hip and hamstring training, core stabilization, plyometrics, balance, agility, neuromuscular training with video and verbal feedback to modify technique, and stretching appear to be essential components of these programs. Further research is critical to determine ideal training program volume, intensity, duration, and frequency.

Effect of a prior intermittent run at vVO2max on oxygen kinetics during an all-out severe run in humans
The Journal of sports medicine and physical fitness, Turin, 40, (2000), 3, pp. 185-194

Background: The purpose of this study was to examine the influence of prior intermittent running at VO2max on oxygen kinetics during a continuous severe intensity run and the time spent at VO2max. Methods: Eight long-distance runners performed three maximal tests on a synthetic track (400 m) whilst breathing through the COSMED K4 portable telemetric metabolic analyser: i) an incremental test which determined velocity at the lactate threshold (vLT), VO2max and velocity associated with VO2max (vVO2max), ii) a continuous severe intensity run at vLT+50% (v-delta50) of the difference between vLT and vVO2max (91.3±1.6% vVO2max) preceded by a light continuous 20 minute run at 50% of vVO2max (light warm-up), iii) the same continuous severe intensity run at v-delta50 with a prior interval training exercise (hard warm-up) of repeated hard running bouts performed at 100% of VO2max and light running at 50% of vVO2max (of 30 seconds each) performed until exhaustion (on average 19±5 min with 19±5 interval repetitions). This hard warm-up speeded the VO2 kinetics: the time constant was reduced by 45% (28±7 sec vs 51±37 sec) and the slow component of VO2 (deltaVO2 6-3 min) was deleted (-143±271 ml/min vs 291±153 ml/min). In conclusion, despite a significantly lower total run time at v-delta50 (6 min 19 ± 0 min 17 vs 8 min 20 ± 1 min 45, p=0.02) after the intermittent warm-up at VO2max, the time spent specifically at VO2max in the severe continuous run at v-delta50 was not significantly different.

Bird, S. P.; Stuart, W.
Integrating balance and postural stability exercises into the functional warm-up for youth athletes

The goal of the functional warm-up is to stimulate sensory and motor components related to preparatory (feed-forward) and reactive (feed-back) systems through functionally integrated movement patterns. This article presents balance and postural stability exercises that are easily implemented into the functional warm-up as a movement preparation strategy for youth athletes.

Bishop, D.; Maxwell, N. S.
Effects of active warm up on thermoregulation and intermittent-sprint performance in hot conditions
Journal of Science and Medicine in Sport, Belconnen, 12, (2009), 1, pp. 196-204

This study examined the effects of active warm-up on thermoregulatory responses and intermittent-sprint cycle performance in hot conditions (35.5 ± 0.6 °C, RH 48.7 ± 3.4%). Eight trained males performed a 36-min, intermittent-sprint test (IST) after no (WUP 0), 10-min (WUP 10) or 20-min warm-up (WUP 20). The IST contained 2-min blocks consisting of a 4-s sprint, 100 s active recovery and 20 s passive rest. Twice during the IST, there was a repeated-sprint bout (RSB) comprising five, 2-s sprints separated by not, vert, similar 20 s. There were no significant differences between trials for mean work (3870 ± 757 versus 4028 ± 562 versus 3804 ± 494 J sprint−1), peak power (W) or work decrement (%). However, mean work was significantly less in RSB2 than RSB1 for WUP 20 only (P < 0.05). Plasma lactate was significantly higher after active warm-up (WUP 20 = WUP 10 > WUP 0; P < 0.05), but not significantly different between conditions following either RSB. Rectal temperature (Tre) was significantly higher after active warm-up (WUP 20 = WUP 10 > WUP 0; P < 0.05), but not significantly different between conditions following either RSB. Rectal temperature (Tre) was significantly higher after active warm-up (37.0 ± 0.3 versus 37.3 ± 0.3 versus 37.7 ± 0.1 °C for WUP0, WUP10 and WUP20, respectively) and throughout the IST. The longer active warm-up resulted in a greater increase in Tre and was associated with a decrease in short-term repeated-sprint ability (with incomplete recovery), but not prolonged, intermittent-sprint performance in the heat. As active warm-up did not improve performance (<40 min), team-sport athletes may minimise changes in Tre (and the likelihood of heat illness) by avoiding excessive warm-up when competing in the heat.

Brown, P. I.; Hughes, M. G.; Tong, R. J.
The effect of warm-up on high-intensity, intermittent running using non-motorized treadmill ergometry

The aim of this study was to investigate the effect of previous warming on high-intensity intermittent running using nonmotorized treadmill ergometry. Ten male soccer players completed a repeated sprint test (10 x 6-second sprints with 34-second recovery) on a nonmotorized treadmill preceded by an active warm-up (10 minutes of running) (70% VO2max; mean core temperature (Tc) 37.8 ± 0.2[degrees]C), a passive warm-up (hot water submersion: 40.1 ± 0.2[degrees]C until Tc reached that of the active warm-up; 10 minutes ± 23 seconds), or no warm-up (control). All warm-up conditions were followed by a 10-minute static recovery period with no stretching permitted. After the 10-minute rest period, Tc was higher before exercise in the active trial (38.0 ± 0.2[degrees]C) compared to the passive (37.7 ± 0.4[degrees]C) and control trials (37.2 ± 0.2[degrees]C; p < 0.05). There were no differences in pre-exercise oxygen consumption and blood lactate concentration; however, heart rate was greater in the active trial (p < 0.05). The peak mean 1-second maximum speed (MxSP) and group mean MxSP were not different in the active and passive trials (7.28 ± 0.12 and 7.16 ± 0.10 m/s, respectively, and 7.07 ± 0.33 and 7.02 ± 0.24 m/s, respectively; p > 0.05), although both were greater than the control. The percentage of decrement in performance fatigue was similar between all conditions (active, 3.4 ± 1.3%; passive, 4.0 ± 2.0%; and control, 3.7 ± 2.4%). We conclude that there is no difference in high-intensity intermittent running performance when preceded by an active or passive warm-up when matched for post-warm-up Tc. However, repeated sprinting ability is significantly improved after both active and passive warm-ups compared to no warm-up.

Brunner-Ziegler, S.; Strasser, B.; Haber, P.
Comparison of metabolic and biomechanic responses to active vs. passive warm-up procedures before physical exercise
Active warm-up before physical exercise is a widely accepted practice to enhance physical performance, whereas data on modalities to passively raise tissue temperature are rare. The study compared the effect of active vs. passive warm-up procedures before exercise on energy supply and muscle strength performance. Twenty young, male volunteers performed 3 spiroergometer-test series without prior warm-up and after either an active or passive warm-up procedure. Oxygen uptake (VO$_2$), heart rate (HR), pH value, and lactate were determined at 80% of individual VO$_2$max values and during recovery. Comparing no prior warm-up with passive warm-up, pH values were lower at the fourth test minute (p < 0.004), and lactate values were higher at the sixth and third minutes of recovery (p < 0.01 and p < 0.010, respectively), after no prior warm-up. Comparing active with passive warm-up, HR was lower, and VO$_2$ values were higher at the fourth and sixth test minutes (p < 0.033 and p < 0.011, respectively, and p < 0.015 and p < 0.022, respectively) after active warm-up. Differentiation between active and passive warm-up was more pronounced than between either warm-up or no warm-up. Conditions that may promote improved performance were more present after active vs. passive warm-up. Thus, athletes may reach the metabolic steady state faster after active warm-up.

Carvalho, F. L. P.; Carvalho, M. C. G. A.; Simão, R.; Gomes, T. M.; Costa, P. B.; Neto, L. B.; Carvalho, R. L. P.; Dantas, E. H. M.

**Acute effects of a warm-up including active, passive, and dynamic stretching on vertical jump performance**

*Journal of Strength and Conditioning Research, Colorado Springs, 26, (2012), 9, pp. 2447-2452*

The purpose of this study was to examine the acute effects of 3 different stretching methods combined with a warm-up protocol on vertical jump performance. Sixteen young tennis players (14.5 ± 2.8 years; 175 ± 5.6 cm; 64.0 ± 11.1 kg) were randomly assigned to 4 different experimental conditions on 4 successive days. Each session consisted of a general and specific warm-up, with 5 minutes of running followed by 10 jumps, accompanied by one of the subsequent conditions: (a) Control Condition (CC) – 5 minutes of passive rest; (b) Passive Stretching Condition (PSC) – 5 minutes of passive static stretching; (c) Active Stretching Condition (ASC) – 5 minutes of active static stretching; and (d) Dynamic Stretching Condition (DC) – 5 minutes of dynamic stretching. After each intervention, the subjects performed 3 squat jumps (SJs) and 3 countermovement jumps (CMJs), which were measured electronically. For the SJ, 1-way repeated measures analysis of variance (CC x PSC x ASC x DC) revealed significant decreases for ASC (28.7 ± 4.7 cm; p = 0.01) and PSC (28.7 ± 4.3 cm; p = 0.02) conditions when compared with CC (29.9 ± 5.0 cm). For CMJs, there were no significant decreases (p > 0.05) when all stretching conditions were compared with the CC. Significant increases in SJ performance were observed when comparing the DC (29.6 ± 4.9 cm; p = 0.02) with PSC (28.7 ± 4.3 cm). Significant increases in CMJ performance were observed when comparing the conditions ASC (34.0 ± 6.0 cm; p = 0.04) and DC (33.7 ± 5.5 cm; p = 0.03) with PSC (32.6 ± 5.5 cm). A dynamic stretching intervention appears to be more suitable for use as part of a warm-up in young athletes.

Cè, E.; Margonato, V.; Casasco, M.; Veicsteinas, A.

**Effects of stretching on maximal anaerobic power: the roles of active and passive warm-ups**


The purpose of the study was to provide practical suggestions on the effect of stretching on the maximal anaerobic power preceded by active or passive warm-up. To this aim, 15 relatively fit male subjects (age 23 ± 0.2 years, height 177 ± 2 cm, body mass 74 ± 2 kg; [mean ± SE]) randomly performed a series of squat jumps (SJ) and countermovement jumps (CMJ). Jumps were preceded alternatively by: i) passive stretching of lower limbs muscles; ii) active warm-up (AWU); iii) passive warm-up (PWU); and iv) the joining of stretching with either active warm-up (AWU+S) or passive warm-up (PWU+S). In control conditions (C) only jumps were required. For the 2 jumps the flight time (Fi), the peak force (Pf), and the maximal power (Latin capital letter W with dot above)max were calculated. It resulted that Fi, Pf, and [Latin capital letter W with dot above]max values were significantly higher: i) after AWU than
after PWU and PWU+S in CMJ; and ii) in AWU as compared to those of other protocols of SJ. Stretching did not negatively affect the maximal anaerobic power, per se, but seems to inhibit the effect of AWU. The results suggested that AWU seemed to increase vertical jump performance when compared to PWU, presumably due to an increase in metabolic activity as a consequence of AWU, which did not occur in PWU, despite the same skin temperature. Passive stretching alone seemed not to negatively influence vertical jump performance, whereas, if added after AWU, could reduce the power output.

Chaouachi, A.; Castagna, C.; Chtara, M.; Brughelli, M.; Turki, O.; Galy, O.; Chamari, K.; Behm, D. G.
Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in trained individuals
The objective of the present study was to investigate the effects of static and dynamic stretching alone and in combination on subsequent agility, sprinting, and jump performance. Eight different stretching protocols: (a) static stretch (SS) to point of discomfort (POD); (b) SS less than POD (SS<POD); (c) dynamic stretching (DS); (d) SS POD combined with DS (SS POD + DS); (v) SS<POD combined with DS (SS<POD + DS); (vi) DS combined with SS POD (DS + SS POD); (vii) DS combined with SS<POD (DS + SS<POD); and (viii) a control warm-up condition without stretching were implemented with a prior aerobic warm-up and followed by dynamic activities. Dependent variables included a 30-m sprint, agility run, and jump tests. The control condition (4.2 ± 0.15 seconds) showed significant differences (p = 0.05) for faster times than the DS + SS<POD (4.28s ± 0.17) condition in the 30-m (1.9%) sprint. There were no other significant differences. The lack of stretch-induced impairments may be attributed to the trained state of the participants or the amount of time used after stretching before the performance. Participants were either professional or national level elite athletes who trained 6-8 times a week with each session lasting approximately 90 minutes. Based on these findings and the literature, trained individuals who wish to implement static stretching should include an adequate warm-up and dynamic sport-specific activities with at least 5 or more minutes of recovery before their sport activity.

Chattong, C.; Brown, L. E.; Coburn, J. W.; Nof- fal, G. J.
Effect of a dynamic loaded warm-up on vertical jump performance
Considering the importance of the vertical jump in several sports, an optimal warm-up protocol may help athletes perform at their maximum level. The purpose of this study was to investigate the potentiating effects of different levels of external resistance (weighted vest) during box jumps on vertical jump performance. Twenty resistance trained men (age 22.45 ± 1.73 years, height 176.83 ± 6.67 cm, mass 76.98 ± 8.56 kg) participated in this study. Subjects performed 5 jumps onto a box equivalent in height to their lateral femoral condyle. After a 2-minute rest period, subjects performed 3 vertical jumps with the greatest height being recorded. On day 1, each subject performed a control condition with no external resistance to establish a baseline vertical jump height. On the following days, they performed 4 random jump conditions with a weight vest equivalent to 5, 10, 15, or 20% of their body weight then rested for 2 minutes before performing 3 posttest vertical jumps. Results demonstrated no significant interaction of condition by time for vertical jump height. However, there was a significant main effect for time (p < 0.05) with posttest jump height (22.99 ± 3.35 in.) being greater than pretest jump height (22.69 ± 3.37 in.). Performing an active dynamic warm-up with or without a weighted vest produced significantly greater posttest vertical jump performance. A dynamic warm-up may improve vertical jump performance, albeit to a very small increment.

Church, J. B.; Wiggins, M. S.; Moode, F. M.; Crist, R.
Effect of warm-up and flexibility treatments on vertical jump performance
Although different warm-up and flexibility routines are often prescribed before physical activity, little research has been conducted to deter-
mine what effects these routines have on athletic performance in activities. The purpose of this investigation was to determine to what degree different warm-up routines affect performance in the vertical jump test. The 40 female participants were asked to perform a general warm-up only, a general warm-up and static stretching, and a general warm-up and proprioceptive neuromuscular facilitation (PNF) on 3 nonconsecutive days. Each of the treatments was followed by a vertical jump test. A 1-way repeated-measures analysis of variance revealed a significant difference in vertical jump performance. A post hoc analysis revealed decreased vertical jump performances for the PNF treatment group. Based on the results of this study, performing PNF before a vertical jump test would be detrimental to performance.

Cochrane, D.  
The sports performance application of vibration exercise for warm-up, flexibility and sprint speed  

Since the turn of the 21st century, there has been a resurgence of vibration technology to enhance sport science especially for power and force development. However, vibration exercise has been trialled in other areas that are central to athlete performance such as warm-up, flexibility and sprint speed. Therefore, the aim of this review was to attempt to gain a better understanding of how acute and short-term vibration exercise may impact on warm-up, flexibility and sprint speed. The importance of warming up for sporting performance has been well documented and vibration exercise has the capability to be included or used as a standalone warm-up modality to increase intramuscular temperature at a faster rate compared to other conventional warm-up modalities. However, vibration exercise does not provide any additional neurogenic benefits compared to conventional dynamic and passive warm-up interventions. Vibration exercise appears to be a safe modality that does not produce any adverse affects causing injury or harm and could be used during interval and substitution breaks, as it would incur a low metabolic cost and be time-efficient compared to conventional warm-up modalities. Acute or short-term vibration exercise can enhance flexibility and range of motion without having a detri-mental effect on muscle power, however it is less clear which mechanisms may be responsible for this enhancement. It appears that vibration exercise is not capable of improving sprint speed performance; this could be due to the complex and dynamic nature of sprinting where the purported increase in muscle power from vibration exercise is probably lost on repeated actions of high force generation. Vibration exercise is a safe modality that produces no adverse side effects for injury or harm. It has the time-efficient capability of providing coaches, trainers, and exercise specialists with an alternative modality that can be implemented for warm-up and flexibility either in isolation or in conjunction with other conventional training methods.

DeRenne, C.  
Effects of postactivation potentiation warm-up in male and female sport performances: a brief review  

A proper precompetitive warm-up during sprint competition with explosive athletes will elicit a postactivation potentiation (PAP). This article will review the effects of heavy preload warm-up protocols eliciting (PAP with explosive male and female athletes, resulting in enhanced performances and provide strength coaches with practical applications.

The impact of cold-water immersion on power production in the vertical jump and the benefits of a dynamic exercise warm-up  

The purpose of this study was to examine the influence of a cold treatment and a dynamic warm-up on lower body power in the form of a counter-movement vertical jump (CMVJ). Nine physically active men, who were either current or ex-National Collegiate Athletic Association (NCAA) Division 1 athletes, consented to participate in the study.
Using a balanced, randomized presentation and a within-subject design, each subject performed 4 environmental and warm-up protocols (i.e., ambient temperature without warm-up, ambient temperature with warm-up, cold without warm-up, or cold with warm-up). Two sets of 3 maximal effort CMVJs were performed on a force plate at each testing time point. For each protocol, the subjects completed a pretest set of CMVJ (pretreatment [PRE]), were then exposed to 1 of the 2 temperature treatments, completed another set of CMVJ (initial [IT]), then either went through a 15-minute warm-up, or were asked to sit in place. Then a final set of CMVJs was completed (posttreatment [PT]). The primary finding in this study was that warm-up was effective in offsetting the negative effects of cold exposure on CMVJ power. There was a significant main effect for Time (PRE > PT > IT), and there was a significant (p ≤ 0.05) main effect for Trial (AMB = AMBWU > COLDWU > COLD). Because athletic competitions happen in various colder climates, it is important to make sure that a proper warm-up be completed to maximize the athlete’s power output. The results of this study demonstrate that when athletes are exposed to cold conditions, it is recommended that before practice or play, a dynamic warm-up be employed to optimize performance.

Duffield, R.; Steinbacher, G.; Fairchild, T. J. The use of mixed-method, part-body pre-cooling procedures for team-sport athletes training in the heat

The current study investigated the effects of a pre-cooling intervention on physiological and performance responses to team-sport training in the heat. Seven male lacrosse players performed a familiarization session and 2 randomized, counterbalanced sessions consisting of a 30-minute intermittent-sprint conditioning session. Prior to the sessions, players performed a 20-minute mixed-method, part-body cooling intervention (consisting of cooling vests, cold towels to the neck, and ice packs to the quadriceps) or no cooling intervention. Performance was determined from collection of 1 Hz global positioning system (GPS) data and analyzed for distance and speed. Prior to, during, and following the sessions, core temperature, heart rate, rating of perceived exertion (RPE), and thermal sensation scale (TSS) were measured; additionally, a venous blood sample was collected before and after each session for measurement of interleukin-6 (IL-6), insulin-like growth factor (IGF-1), and insulin-like growth factor-binding protein3 (IGF-BP3). Results indicated that a greater distance was covered during the pre-cooling condition (3.35 ± 0.20 vs. 3.11 ± 0.13 km; p = 0.05). Further, most of this improvement was evident from a greater distance covered during moderate intensities of 7 to 14 km/h (2.28 ± 0.18 vs. 2.00 ± 0.24 km; p = 0.05). Peak speeds and very-high-intensity efforts (20 km/h ±) were not different between conditions (p > 0.05). The increase in core temperature was blunted following cooling, with a lower core temperature throughout the cooling session (38.8 ± 0.3 vs. 39.3 ± 0.4[degrees]C; p < 0.05). However, there were no differences in heart rate, RPE, TSS, IL-6, IGF-1, or IGF-BP3 between conditions (p > 0.05). Accordingly, the use of a mixed-method, part-body cooling intervention prior to an intermittent-sprint training session in the heat can assist in reducing thermoregulatory load and improve aspects of training performance for team sports.

Faigenbaum, A. D.; Bellucci, M.; Bernieri, A.; Bakker, B.; Hoorens, K. Acute effects of different warm-up protocols on fitness performance in children
Journal of Strength and Conditioning Research, Colorado Springs, 19, (2005), 2, pp. 376-381

The purpose of this study was to compare the acute effects on youth fitness of 3 different warm-up protocols utilizing static stretching or dynamic exercise performance. Sixty children (mean age 11.3 ± 0.7 years) performed 3 different warm-up routines in random order on nonconsecutive days. The warm-up protocols consisted of 5 minutes of walking and 5 minutes of static stretching (SS), 10 minutes of dynamic exercise (DY), or 10 minutes of dynamic exercise plus 3 drop jumps from 15-cm boxes (DYJ). Following each warm-up session, subjects were tested on the vertical jump, long jump, shuttle run, and v-sit flexibility. Analysis of the data revealed that vertical-jump and shuttle-run performance declined significantly following SS as compared to DY and DYJ, and long-jump performance was significantly reduced following SS as compared to DYJ (p < 0.05). There were
no significant differences in flexibility following the 3 warm-up treatments. The results of this study suggest that it may be desirable for children to perform moderate-to-high-intensity dynamic exercises prior to the performance of activities that require a high power output.

Faigenbaum, A. D.; McFarland, J. E.; Schwertman, J. A.; Ratamess, N. A.; Kang, J.; Hoffman, J. R. Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes

Context: Recent authors have not found substantial evidence to support the use of static stretching for improving performance, so interest in dynamic warm-up procedures has risen. Our findings may improve the understanding of the acute effects of different types of pre-exercise protocols on performance and may help clinicians develop effective warm-up protocols for sports practice and competition. Objective: To examine the acute effects of 4 warm-up protocols with and without a weighted vest on anaerobic performance in female high school athletes. Design: Randomized, counterbalanced, repeated-measures design. Setting: High school fitness center. Patients or Other Participants: Eighteen healthy high school female athletes (age = 15.3 ± 1.2 years, height = 166.3 ± 9.1 cm, mass = 61.6 ± 10.4 kg). Intervention(s): After 5 minutes of jogging, subjects performed 4 randomly ordered warm-up protocols: (1) Five static stretches (2 × 30 seconds) (SS), (2) nine moderate-intensity to high-intensity dynamic exercises (DY), (3) the same 9 dynamic exercises performed with a vest weighted with 2% of body mass (DY2), and (4) the same 9 dynamic exercises performed with a vest weighted with 6% of body mass (DY6). Main Outcome Measure(s): Vertical jump, long jump, seated medicine ball toss, and 10-yard sprint. Results: Vertical jump performance was significantly greater after DY (41.3 ± 5.4 cm) and DY2 (42.1 ± 5.2 cm) compared with SS (37.1 ± 5.1 cm), and long jump performance was significantly greater after DY2 (180.5 ± 20.3 cm) compared with SS (160.4 ± 20.8 cm) (P ≤ .05). No significant differences between trials were observed for the seated medicine ball toss or 10-yard sprint. Conclusions: A dynamic warm-up performed with a vest weighted with 2% of body mass may be the most effective warm-up protocol for enhancing jumping performance in high school female athletes.

Favero, J.-P.; Midgley, A. W.; Bentley, D. J. Effects of an acute bout of static stretching on 40 m sprint performance: influence of baseline flexibility
Research in Sports Medicine, Philadelphia (Penns.), 17, (2009), 1, pp. 50-60

This study investigated the effect of stretching on sprint performance. Ten trained male subjects (age 22 ± 2.3 yrs; body mass 77.1 ± 6.9 kg; height 179 ± 5.5 cm) were randomly assigned to “Rest” and “Stretch” conditions. A low intensity 5 min running warm-up was followed by either 12 min of inactivity (Rest) or lower-limb stretches (Stretch). Subjects walked for 60s before completing three maximal effort 40m sprint trials. There were no statistically significant differences in measures of sprint performance between conditions (p>0.05); however, there was a significant correlation between baseline sit-and-reach scores and mean change in mean velocity between conditions (r=-0.68; p=0.03). There was a tendency for stretching to negatively effect sprint performance in subjects with comparatively high baseline flexibility. An acute bout of stretching did not exert a significant effect on sprint performance under prescribed conditions.

Fletcher, I. M. An investigation into the effect of a pre-performance strategy on jump performance

The aim of this study was to explore the effect that different components, making up a commonly used pre-performance preparation strategy, have on jump height performance. Sixteen male collegiate athletes (age, 21.38 ± 0.52 years; height, 1.79 ± 0.07 m; and body mass, 75.1 ± 5.26 kg) performed a preparation strategy involving a cycle ergometer warm-up, followed by a dynamic stretch component, and finishing with heavy back squats. This intervention was re-
peated to test countermovement, squat or drop jump performance after each component of the preparation strategy, with electromyographic activity measured during each jump test. Significant increases (p < 0.05) in jump height and electromyographic activity were noted, with a stepwise increase in performance from pre- to post-warm-up, increased further by the dynamic stretch component and again increased after the back squat. It was also noted that the increases in performance, attributed to the stretch and lift components, were significantly greater (p < 0.05) than the increases in jump height associated with the active warm-up. It seems likely that the initial active warm-up raised core temperature, helping to increase the jump performance. The specific movements employed in the stretch and lift interventions seemed to potentiate the agonistic muscles involved in jumping, shown by increases in electromyographic activity in the prime movers for the jumps explored. This could be an example of postactivation potentiation, where muscles are primed to increase performance beyond changes linked to an active warm-up.


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


The practice of warming up prior to exercise is advocated in injury prevention programs, but this is based on limited clinical evidence. It is hypothesised that warming up will reduce the number of injuries sustained during physical activity. A systematic review was undertaken. Relevant studies were identified by searching Medline (1966–April 2005), SPORTDiscus (1966–April 2005) and PubMed (1966–April 2005). This review included randomised controlled trials that investigated the effects of warming up on injury risk. Studies were included only if the subjects were human, and only if they utilised other activities than simply stretching. Studies reported in languages other than English were not included. The quality of included studies was assessed independently by two assessors. Five studies, all of high quality (7–9 (mean=8) out of 11) reported sufficient data (quality score >7) on the effects of warming up on reducing injury risk in humans. Three of the studies found that performing a warm-up prior to performance significantly reduced the injury risk, and the other two studies found that warming up was not effective in significantly reducing the number of injuries. There is insufficient evidence to endorse or discontinue routine warm-up prior to physical activity to prevent injury among sports participants. However, the weight of evidence is in favour of a decreased risk of injury. Further
well-conducted randomised controlled trials are needed to determine the role of warming up prior to exercise in relation to injury prevention.

The value of warming-up is a worthy research problem because it is not known whether warming-up benefits, harms, or has no effect on individuals. The purpose of this study was to review the evidence relating to performance improvement using a warm-up. A systematic review and meta-analysis were undertaken. Relevant studies were identified by searching Medline, SPORTDiscus, and PubMed (1966-April 2008). Studies investigating the effects of warming-up on performance improvement in physical activities were included. Studies were included only if the subjects were human and only if the warm-up included activities other than stretching. The quality of included studies was assessed independently by 2 assessors using the Physiotherapy Evidence Database scale. Thirty-two studies, all of high quality (6.5-9 [mean = 7.6] of 10) reported sufficient data (quality score >6) on the effects of warming-up on performance improvement. Warm-up was shown to improve performance in 79% of the criterions examined. This analysis has shown that performance improvements can be demonstrated after completion of adequate warm-up activities, and there is little evidence to suggest that warming-up is detrimental to sports participants. Because there were few well-conducted, randomized, controlled trials undertaken, more of these are needed to further determine the role of warming-up in relation to performance improvement.

Frantz, T. L.; Ruiz, M. D. Effects of dynamic warm-up on lower body explosiveness among collegiate baseball players
Debate exists between the benefits and effectiveness of a dynamic warm-up vs. a static warm-up. This study was conducted to compare dynamic and static warm-ups on lower body explosiveness as measured by stationary vertical jump (VJ) and standing long jump (LJ) among collegiate baseball players. Participants (n = 17; age = 19.59 ± 1.37 years) progressed through 3 different warm-ups on weekly testing dates over a 7-week period. After the warm-up routines, participants were measured for VJ height and LJ distance in centimeters. The mean jump heights for VJ were 66.49 ± 8.28 cm for dynamic, 61.42 ± 7.51 cm for static, and 62.72 ± 7.84 cm for the control condition. The mean jump distances for LJ were 231.99 ± 20.69 cm for dynamic, 219.69 ± 20.96 cm for static, and 226.46 ± 20.60 cm for the control. Results indicated that the participants jumped significantly higher in both experimental conditions while under the influence of the dynamic warm-up (VJ-F = 22.08; df = 1.33, 21.345; p < 0.00 and LJ-F = 32.20; df = 2, 32; p < 0.01). Additional LJ analysis determined that individuals jumped significantly further after no warm-up compared to after a static warm-up (-6.78, p < 0.05). Lower body explosiveness is critical in baseball and many other sports as well. The results show that dynamic warm-ups increases both VJ height and LJ distance. Specifically, these findings indicate that athletes could gain nearly 2 in. on his or her vertical jump by simply switching from a static warm-up routine to a dynamic routine.

Gelen, E. Acute effects of different warm-up methods on jump performance in children
The aim of this study was to determine the acute effects of static stretching and dynamic warm-up exercises on vertical jump performance. Sixty-four children (mean age 13.3 ± 0.5 years) were assigned randomly to 3 different warm-up routines on non-consecutive days. The warm-up methods used were 5 minutes of jogging and 5 minutes of static stretching (SS), 5 minutes of jogging and 10 minutes of dynamic exercises (DYN), and finally only 5 minutes of jogging as the control (NS). After each warm-up session, all the children were made to undertake a vertical jump test. Data were analysed using repeated measures analyses of variance (ANOVA), and a statistically significant difference between the NS, SS and DYN groups with regards to vertical jump perfor-
mance was established (p<0.05). Based on these results, static stretching performed after aerobic exercises of mild intensity was found to hinder vertical jump performance, while dynamic warm-up was found to have a positive effect.

Gray, S.; Nimmo, M. Effects of active, passive or no warm-up on metabolism and performance during high-intensity exercise
The aim of this study was to determine the influence of type of warm-up on metabolism and performance during high-intensity exercise. Eight males performed 30 s of intense exercise at 120% of their maximal power output followed, 1 min later, by a performance cycle to exhaustion, again at 120% of maximal power output. Exercise was preceded by active, passive or no warm-up (control). Muscle temperature, immediately before exercise, was significantly elevated after active and passive warm-ups compared to the control condition (36.9 ± 0.18°C, 36.8 ± 0.18°C and 33.6 ± 0.25°C respectively; mean ± sx ) ( P < 0.05). Total oxygen consumption during the 30 s exercise bout was significantly greater in the active and passive warm-up trials than in the control trial (1017 ± 22, 943 ± 53 and 838 ± 45 ml O 2 respectively). Active warm-up resulted in a blunted blood lactate response during high-intensity exercise compared to the passive and control trials (change = 5.53 ± 0.52, 8.09 ± 0.57 and 7.90 ± 0.38 mmol/l respectively) ( P < 0.05). There was no difference in exercise time to exhaustion between the active, passive and control trials (43.9 ± 4.1, 48.3 ± 2.7 and 46.9 ± 6.2 s respectively) ( P = 0.69). These results indicate that, although the mechanism by which muscle temperature is elevated influences certain metabolic responses during subsequent high-intensity exercise, cycling performance is not significantly affected.

Hayes, P. R.; Walker, A. Pre-exercise stretching does not impact upon running economy
Pre-exercise stretching has been widely reported to reduce performance in tasks requiring maximal or near-maximal force or torque. The purpose of this study was to compare the effects of 3 different pre-exercise stretching routines on running economy. Seven competitive male middle and long-distance runners (mean ± SD) age: 32.5 ± 7.7 years; height: 175.0 ± 8.8 cm; mass: 67.8 ± 8.6 kg; [Latin small letter v with dot above]O2max: 66.8 ± 7.0 ml[middle dot]kg-1[middle dot]min-1 volunteered to participate in this study. Each participant completed 4 different pre-exercise conditions: (a) a control condition, (b) static stretching, (c) progressive static stretching, and (d) dynamic stretching. Each stretching routine consisted of 2 - 30-second stretches for each of 5 exercises. Dependent variables measured were sit and reach test before and after each pre-exercise routine, running economy [ml[middle dot]kg-1[middle dot]min-1].
and steady-state oxygen uptake (mL[km⁻¹][kg⁻¹][min⁻¹]), which were measured during the final 3 minutes of a 10-minute run below lactate threshold. All 3 stretching routines resulted in an increase in the range of movement (p = 0.008). There was no change in either running economy (p = 0.915) or steady-state \(v\)O₂ (p = 0.943). The lack of change in running economy was most likely because it was assessed after a period of submaximal running, which may have masked any effects from the stretching protocols. Previously reported reductions in performance have been attributed to reduced motor unit activation, presumably IIx. In this study, these motor units were likely not to have been recruited; this may explain the unimpaired performance. This study suggests that pre-exercise stretching has no impact upon running economy or submaximal exercise oxygen cost.

Holdeman, J.  
Minimizing injury and maximizing performance in fast running: Warming up and warming down

*Track coach, Mountain View, (2004), 167, pp. 5336-5341*

Speed and sprint work are essential ingredients to any well-balanced training recipe for runners, irrespective of event distance. Prior to engaging in speed or sprint training, most runners tend to follow the same basic routine just prior to rolling out their repeat: 1. They run easily for a couple of miles to warm up. 2. Next, they stretch out. 3. Then, if they have them, they lace on the spikes or flats and do a few strides. Once the up-tempo portion of the session is over, the majority of athletes tend to engage in an abbreviated period of jogging and perhaps a few light stretches before jumping in the car to head home. But, in order to maximize performance and minimize injury, is this the best path to follow? Stretching, specifically, and flexibility training, generally, have long been part of athletic warm-up routines. The use of stretching as part of the warm-up comes from the belief that stretching will aid in subsequent performance and help to prevent injury. However, recent studies show that stretching is not the best way to prepare one’s muscles for the demands of fast running. So, how should one warm up before a session on the track or a race? Fast running is an explosive activity. Like Olympic-style weight lifting, shooting a pullup jumper, or throwing the javelin, you are asking your muscles to contract very fast and generate a lot of power. The interesting thing about this is that a short, tight muscle contains a lot of potential energy: your visual here should be of your muscles as big elastic bands. But, like elastic bands, muscles have an optimum length and strength that is developed (or allowed to atrophy) over time. To consider the extremes of this example, think of putting a rubber band in the freezer for a few hours. When you pull it out and try to stretch it very quickly, what do you think happens? It will break after only a short stretch cycle, as its fibers are not very elastic when cold. What about the converse? Think of putting a rubber band in a 200-degree (not so hot that it melts) oven for a while. When you pull it out and try to stretch it very quickly, what happens now? It will stretch like crazy; but, will have virtually no potential energy because the fibers are all lax and long, unable to provide that “pop” we associate with a rubber band. When you’re doing speed work, you need that pop! That pop is what gets you quickly off the line and sprinting. Therefore, in order to optimize your pre-workout and prerace routines, I recommend you do what many strength/power athletes (including elite weightlifters, powerlifters, track and field throwers, etc.) do: stretch dynamically before activity and statically after. Here’s what to do before a workout or race: 1. Jog easily for 10-20 minutes to get your muscles and limbs nice and lubricated – the temperature of your training environment will influence the length of this warm-up period. A good rule of thumb is that if you’ve broken a good sweat, you’re warm. 2. Change into whatever footwear you’ll be using to conduct the workout, so that when the warm-up has concluded, you will be ready to immediately begin the session. Note: after each of the next 8 exercises, stride out 50-60m, making each one progressively faster as you go along. This will provide your body with additional neuromuscular stimulation necessary to prepare for the bout of intense exercise to follow. 3. Conduct 30m of walking forward lunges. Make sure your forward shin is perpendicular to the ground when you reach the lowest point in the lunge: this will optimize the stretch and keep you from putting unwanted pressure on the con-
nective tissues of the knee. 4. Conduct 30m of backward lunges. As above, just realize these will be more awkward and will take longer, as there are balance considerations to make. 5. Do 30m of side sweeps. Turn sideways and crouch slightly; then, take a long step out to the right with your right foot, keeping your hips low and your weight on the left foot. Slide your butt low and slow to the right and come to a full standing Position. Repeat for the full 30m. Then, face the other direction and repeat while leading with the left foot. 6. Perform 30m of side shuffles. Just like they sound, simply turn sideways (lead with your right foot) and quickly shuffle your feet from side-to-side over the course of the 30m distance. Pause briefly and return, this time, leading with your left foot. 7. Do 30m of high knees. Just as it sounds, you jog along very springily, driving your knees up as you go. Keep your up- per torso upright with a slight forward lean. 8. Do 30m of butt kick-throughs. Unlike the “traditional” butt-kick, which tends to emphasize a more vertical flicking of the heels, this more functional version requires that you maintain a slightly forward lean in the up- per torso with an emphasis on a more horizontal “driving” of the heels past the butt and along the upper part of the hamstring. This encourages higher knee lift and better forward ex- tension of the lower leg, which produces a much more functional movement. 9. Do 30m of skipping striving to achieve a mix between horizontal and vertical movement. 10. Do 30m of straight- leg running. Again, just as it sounds, run with no bend in your knees, leaning slightly forward, extending your feet out as far in front of you as you can manage gracefully. 11. End your warm-up session with a couple of 100m accelerations: accelerate up to high speed over the first 40m, maintain that speed for 40m, then decelerate for 20m. Minimize the time between the end of the warm-up and the actual workout. You will want to preserve the neural stimulus created during the warm-up to optimize the effect of your workout.


Traditionally, stretching has been practiced as a means of preparing the body for activity. A variety of stretching methods and techniques have been advocated for eliciting improvements in flexibility and performance in addition to reducing injury risk during training and competition. Although the scientific literature surrounding the effects of stretching is quite meagre, there have been an increasing number of reports in recent years. This article considers current knowledge of the effects of stretching in light of its importance in the warm-up. Specifically, the efficacy of stretching regimes in the context of flexibility, performance, and injury prevention is considered. Simple, practical key points are illuminated for the coach. The authors arrive at the following conclusion: Coaches should critically evaluate the stretching practices of their athletes to ensure their efforts are worthwhile. Just as training methods must be specific to the physical demands of the event stretching, should also be contextualised rather than simply being ‘attached’ to a training session. It may be that stretching immediately prior to activity has little impact on injury risk and a potentially negative impact on performance, however, routines that improve flexibility over time, whether undertaken during a warm-up or otherwise, may indirectly exert their influence on injury risk and performance.


Throwing is a complex motion that involves the entire body and often puts an inordinate amount of stress on the shoulder and the arm. Warm-up prepares the body for work and can enhance performance. Sling-based exercise (SE) has been theorized to activate muscles, particularly the stabilizers, in a manner beneficial for preac- tivity warm-up, yet this hypothesis has not been tested. Our purpose was to determine if a warm-up using SE would increase throwing velocity and accuracy compared to a traditional, thrower’s 10 warm-up program. Division I baseball players (nonpitchers) (16 men, age: 19.6 ± 1.3, height: 184.2 ± 6.2 cm, mass: 76.9 ± 19.2 kg) volunteered to participate in this crossover study. All subjects underwent both a warm-up routine us- ing a traditional method (Thrower’s 10 exercises)
and a warm-up routine using closed kinetic chain SE methods (RedCord) on different days separated by 72 hours. Ball velocity and accuracy measures were obtained on 10 throws after either the traditional and SE warm-up regimens. Velocity was recorded using a standard Juggs radar gun (JUGS; Tualatin, OR, USA). Accuracy was recorded using a custom accuracy target. An Analysis of covariance was performed, with the number of throws recorded before the testing was used as a covariate and p < 0.05 was set a priori. There were no statistical differences between the SE warm-up and Thrower’s 10 warm-up for throwing velocity (SE: 74.7 ± 7.5 mph, Thrower’s 10: 74.6 ± 7.3 mph p = 0.874) or accuracy (SE: 115.6 ± 53.7 cm, Thrower’s 10: 91.8 ± 55 cm, p = 0.136). Warming up with SE produced equivalent throwing velocity and accuracy compared to the Thrower’s 10 warm-up method. Thus, SE provides an alternative to traditional warm-up.


Context: Athletes running in a hot, humid environment may have an increased risk of heat illness. In the 2004 Olympic Games, American and Australian athletes were provided with ice vests designed to cool their bodies before performance. The vest appeared to be effective in keeping body temperatures down and improving the performance of the marathoners. However, body temperatures have not been reported when the vest was used before an actual competition. Objective: To determine if wearing the Nike Ice-Vest decreased core temperature (Tc) before and during athletic performance in warm (26°C to 27°C), humid (relative humidity = 50% to 75%) conditions. Design: A 2 × 3 mixed-model design was used to compare groups (ice vest, no ice vest) across changes in temperature from baseline (10 minutes and 1 minute before the race and immediately after the race). Setting: 2005 Big Wave Invitational 4-km race in Hawaii and 2005 Great American 5-km race in North Carolina. Patients or Other Participants: Eighteen women from a National Collegiate Athletic Association Division I cross-country team who participated in either the Big Wave Invitational or the Great American Race. Intervention(s): Four hours before the start of the race, the athletes ingested radiotelemetry temperature sensors. One hour before the start of the race, Tc was recorded, and half of the athletes donned a Nike Ice-Vest, which was removed immediately before the race. Main Outcome Measure(s): Additional Tc readings were taken at 10 minutes and 1 minute before the start of the race and immediately after the race. Results: Ten minutes before the start of the race, Tc was elevated by 0.84°C ± 0.37°C in the no-vest group, compared with 0.29°C ± 0.56°C in the ice-vest group (P < .01). This difference in Tc persisted at 1 minute before the start. Immediately after the finish, the increase in Tc averaged 2.75°C ± 0.62°C in the no-vest group and 2.12°C ± 0.62°C in the ice-vest group (P < .01). Conclusions: Wearing an ice vest before cross-country performance in warm, humid conditions allowed athletes to start and finish the competition with a lower Tc than did those who did not wear a vest.


Preactivity warm-up and stretching recommendations are well established in the research literature, but many coaches do not use them. Although certification programs exist to guide coaches through the wide variety of available knowledge to help them develop evidence-based practices, questions remain as to what extent certification actually impacts coaching practices.


Collegiate and high school strength and conditioning coaches throughout the nation often use a 1 repetition maximum (1 RM) back squat to test lower extremity strength. Three scientifically supported warm-up variations are discussed for the professional strength coach to consider when planning for their athletes 1RM squat warm-up.
Kallerud, H.; Gleeson, N.
**Effects of stretching on performances involving stretch-shortening cycles**
*Sports medicine, Auckland, 43, (2013), 8, pp. 733-750*

Background: Alongside its role in athletic conditioning, stretching has commonly been integrated in warm-up routines prior to athletic performance. Numerous studies have reported detrimental acute effects on strength following stretching. Consequently, athletes have been recommended to discontinue stretching as part of warm-ups. In contrast, studies indicate that chronic stretching performed as a separate bout from training or competition may enhance performance. However, the influence of stretching on complex performances has received relatively little attention. Objective: The purpose of this study was to review both the acute and chronic effects of stretching on performances involving the stretch-shortening cycle (SSC). Methods: A systematic search for literature was undertaken (January 2006–December 2012) in which only randomized controlled trials (RCTs) or studies with repeated measures designs were included. The Physiotherapy Evidence Database (PEDro) rating scale was used for quality assessment of the evidence. Results: The review included 43 studies, from which conflicting evidence emerged. Approximately half of the studies assessing the acute effect of static stretching reported a detrimental effect on performance, while the remainder found no effect. In contrast, dynamic stretching showed no negative effects and improved performance in half of the trials. The effect size associated with static and dynamic stretching interventions was commonly low to moderate, indicating that the effect on performance might be limited in practice. Factors were identified that might have contributed to the conflicting results reported across studies, such as type of SSC performance and carrying out dynamic activity between the stretching bout and performance. Few studies since 2006 have addressed the chronic effect of stretching on functional and sports performance. Although negative effects were not reported, robust evidence of the overall beneficial effects within current bibliographic databases remains elusive. Plausible mechanisms for the observed effects from stretching are discussed, as well as possible factors that may have contributed to contradictory findings between studies. Limitations: Considerable heterogeneity in study design and methods makes comparison between studies challenging. No regression analysis of the contribution of different predictors to variation between trials had previously been performed. Hence, predictors had to be selected on the basis of a qualitative analysis of the predictors that seemed most influential, as well as being identified in previous narrative reviews. Conclusion: Different types of stretching have differential acute effects on SSC performances. The recommended volume of static stretching required to increase flexibility might induce a negative acute effect on performances involving rapid SSCs, but the effect sizes of these decrements are commonly low, indicating that the acute effect on performance might be limited in practice. No negative acute effects of dynamic stretching were reported. For athletes that require great range of motion (ROM) and speed in their sport, long-term stretching successfully enhances flexibility without negatively affecting performance. Acute dynamic stretching may also be effective in inducing smaller gains in ROM prior to performance without any negative effects being observed.

Kistler, B. M.; Walsh, M. S.; Horn, T. S.; Cox, R. H.
**The acute effects of static stretching on the sprint performance of collegiate men in the 60- and 100-m dash after a dynamic warm-up**
*Journal of Strength and Conditioning Research, Colorado Springs, 24, (2010), 9, pp. 2280-2284*

Previous research has shown that static stretching has an inhibitory effect on sprinting performances up to 50 m. The purpose of this study was to see what would happen to these effects at longer distances such as those seen in competition. This study used a within-subjects design to investigate the effects of passive static stretching vs. no stretching on the 60- and 100-m sprint performance of college track athletes after a dynamic warm-up. Eighteen male subjects completed both the static stretching and the no stretching conditions in counterbalanced order across 2 days of testing. On each day, all subjects first completed a generalized dynamic warm-up routine that included a self-paced 800-
m run, followed by a series of dynamic movements, sprint, and hurdle drills. At the end of this generalized warm-up, athletes were assigned to either a static stretching or a no-stretching condition. They then immediately performed 2 100-m trials with timing gates set up at 20, 40, 60, and 100 m. Results revealed a significant slowing in performance with static stretching ($p < 0.039$) in the second 20 (20-40) m of the sprint trials. After the first 40 m, static stretching exhibited no additional inhibition of performance in a 100-m sprint. However, although there was no additional time loss, athletes never gained back the time that was originally lost in the first portion of the trials. Therefore, in strict terms of performance, it seems harmful to include static stretching in the warm-up protocol of collegiate male sprinters in distances up to 100 m.

Koch, A. J.; O’Bryant, H. S.; Stone, M. E.; Sanborn, K.; Proulx, C.; Hruby, J.; Shannonhouse, E.; Boros, R.; Stone, M. H.  
**Effect of warm-up on the standing broad jump in trained and untrained men and women**  

The effect of 3 warm-up routines on standing broad jump (SBJ) performance was investigated. Thirty-two men and women participated as subjects. Following the determination of 1-repetition maximum (1RM) squat, subjects completed warm-up routines and broad jumps on 4 occasions in a randomized order. Subjects performed SBJ immediately (POST) and 15 min following (POST15) the given warm-up routine. The routines were high force, consisting of high % 1RM, low repetition squats; high power, consisting of low % 1RM, low repetition speed squats; stretching, consisting of static stretches; and no activity, a control condition. Repeated measures analysis of covariance (ANCOVA) revealed no differences among broad jump performance following any of the warm-up routines ($p = 0.157$). A strong correlation ($R = 0.805$) was found between 1RM squat and SBJ. These data indicate that warm-up of any type has little effect on jump performance and that maximum strength is strongly related to jumping ability.

Kof, B.; Strojnik, V.  
**The effect of two warm-up protocols on some biomechanical parameters of the neuromuscular system of middle distance runners**  
*Journal of Strength and Conditioning Research, Colorado Springs, 21, (2007), 2, 394-399*

The objective of this study was to determine the effect of 2 different warm-up protocols on the neuromuscular system of well-trained middle distance runners. Seven runners performed 2 different warm-up protocols, one of which included slow running, stretching, and bounding and sprinting exercises, while the other consisted of slow running and stretching only. Before and after warm-up, contractile properties of the vastus lateralis and quadriceps femoris were monitored with a single twitch test, maximal torque, and the level of muscle activation during maximal voluntary extension. The 2 types of warm-up protocols showed statistically significant differences in the increase of peak knee extension torque and muscle activation level. After warm-up 1 maximal twitch torque was increased and twitch contraction time (CT) was shortened. Both maximal torque and the level of activation were increased. Parameter changes after warm-up 2 were similar to those after warm-up 1 but not statistically significant. Sprinting and bounding as part of athletes’ warm-up improve muscle activation.

Kwon, Y. S.; Robergs, R. A.; Schneider, S. M.  
**Effect of local cooling on short-term, intense exercise**  

The widespread belief that local cooling impairs short-term, strenuous exercise performance is controversial. Eighteen original investigations involving cooling before and intermittent cooling during short-term, intense exercise are summarized in this review. Previous literature examining short-term intensive exercise and local cooling primarily has been limited to the effects on muscle performance immediately or within minutes following cold application. Most previous cooling studies used equal and longer than 10 minutes of pre-cooling, and found that cooling reduced strength, performance and endurance. Because short duration, high intensity exercise requires adequate warm-up to prepare for optimal per-
formance, prolonged pre-cooling is not an effective method to prepare for this type of exercise. The literature related to the effect of acute local cooling immediately before short duration, high intensity isotonic exercise such as weight lifting is limited. However, local intermittent cooling during short-term, high intense exercise may provide possible beneficial effects; first, by pain reduction, caused by an “irritation effect” from hand thermal receptors which block pain sensation, or second, by a cooling effect, whereby stimulation of hand thermal receptors or a slight lowering of blood temperature might alter central fatigue.

Marquez, G. J.; Mon, J.; Acero, R. M.; Sanchez, J. A.; Fernandez-del-Olmo, M. Low-intensity cycling affects the muscle activation pattern of consequent countermovement jumps
Players (eg, basketball, soccer, and football) often use a static bicycle during a game to maintain warming. However, the effectiveness of this procedure has not been addressed in the literature. Thus, it remains unknown whether low-intensity cycling movement can affect explosive movement performance. In this study, 10 male subjects performed countermovement jumps before and after a 15-minutes cycling bout at 35% of their maximal power output. Three sessions were tested for 3 different cadences of cycling: freely chosen cadence, 20% lower than freely chosen cadence (FCC-20%), and 20% higher than freely chosen cadence (FCC+20%). Jump height, kinematics, and electromyogram were recorded simultaneously during the countermovement jumps. The results showed a significant decreasing in the height of countermovement jump after cycling at freely chosen cadence and FCC-20% (p = 0.03 and p = 0.04, respectively), but not for FCC+20% cadences. The electromyographic parameters suggest that changes in the countermovement jump after cycling can be attributed to alteration of the pattern of activation and may be modulated by the preceding cycling cadence. Our study indicates that to avoid a possible negative effect of the cycling in the subsequent explosive movements, a cadence 20% higher than the preferred cadence must be used.

Matthews, M. J.; Matthews, H. P.; Snook, B. The acute effects of a resistance training warmup on sprint performance
Research in Sports Medicine, Philadelphia (Penns.), 12, (2004), 2, pp. 151-159
Twenty male rugby union players were tested to determine the acute effect of a resistance training warmup on subsequent 20-m sprint performance. The study consisted of a repeated measures design with two experimental conditions. During the control (C) condition, the participants performed a 20-m sprint, rested for 10min, and then repeated the 20-m sprint. During the experimental (E) condition, the second sprint was preceded by five repetitions of a back-squat with a load equal to each participant’s five repetition maximum (5RM). Sprint times were recorded using New Test digital recording equipment. The results showed a mean improvement of 0.098s (p<0.0001) when the second sprint was preceded by the back squats. This amounted to a 3.3%improvement on the precondition time. During the control condition, no improvement was observed between the first and second sprint. The improved sprint times observed during the E condition probably were due to a temporary increase in the efficiency of neuromuscular activation following the performance of heavy-load back squats.

McHugh, M. P.; Cosgrave, C. H. To stretch or not to stretch: the role of stretching in injury prevention and performance
Stretching is commonly practiced before sports participation; however, effects on subsequent performance and injury prevention are not well understood. There is an abundance of literature demonstrating that a single bout of stretching acutely impairs muscle strength, with a lesser effect on power. The extent to which these effects are apparent when stretching is combined with other aspects of a pre-participation warm-up, such as practice drills and low intensity dynamic exercises, is not known. With respect to the effect of pre-participation stretching on injury prevention a limited number of studies of varying
quality have shown mixed results. A general consensus is that stretching in addition to warm-up does not affect the incidence of overuse injuries. There is evidence that pre-participation stretching reduces the incidence of muscle strains but there is clearly a need for further work. Future prospective randomized studies should use stretching interventions that are effective at decreasing passive resistance to stretch and assess effects on subsequent injury incidence in sports with a high prevalence of muscle strains.

McMillian, D. J.; Moore, J. H.; Hatler, B. S.; Taylor, D. C.  
**Dynamic vs. static-stretching warm up: the effect on power and agility performance**  
The purpose of this study was to compare the effect of a dynamic warm-up (DWU) with a static-stretching warm-up (SWU) on selected measures of power and agility. Thirty cadets at the United States Military Academy completed the study (14 women and 16 men, ages 18-24 years). On 3 consecutive days, subjects performed 1 of the 2 warm-up routines (DWU or SWU) or performed no warm-up (NWU). The 3 warm-up protocols lasted 10 minutes each and were counterbalanced to avoid carryover effects. After 1-2 minutes of recovery, subjects performed 3 tests of power or agility. The order of the performance tests (T-shuttle run, underhand medicine ball throw for distance, and 5-step jump) also was counterbalanced. Repeated measures analysis of variance revealed better performance scores after the DWU for all 3 performance tests (p < 0.01), relative to the SWU and NWU. There were no significant differences between the SWU and NWU for the medicine ball throw and the T-shuttle run, but the SWU was associated with better scores on the 5-step jump (p < 0.01). Because the results of this study indicate a relative performance enhancement with the DWU, the utility of warm-up routines that use static stretching as a stand-alone activity should be reassessed.

Naperalsky, M. E.; Anderson, J.-H.  
**An upper extremity active dynamic warm-up for sport participation**  
*Strength and Conditioning Journal, Colorado Springs, 34, (2012), 1, pp. 51-54*  
The use of active dynamic warm-ups (ADWUs) before exercise has become increasingly popular for athletes and coaches before sport activity. Dynamic warm-ups prepare the body for exercise and have been shown to help prevent injury and improve performance. Many warm-ups, however, neglect the extensive use of the upper body and trunk that are inherent to many sports. This article explains the importance of including upper-body warm-up exercises and proposes an upper extremity ADWU protocol for individuals before sport participation.

Nelson, A. G.; Driscoll, N. M.; Landin, D. K.; Schexnayder, I. C.; Young, M. A.  
**Acute effects of passive muscle stretching on sprint performance**  
The results of previous research have shown that passive muscle stretching can diminish the peak force output of subsequent maximal isometric, concentric and stretch-shortening contractions. The aim of this study was to establish whether the deleterious effects of passive stretching seen in laboratory settings would be manifest in a performance setting. Sixteen members (11 males, 5 females) of a Division I NCAA track athletics team performed electronically timed 20 m sprints with and without prior stretching of the legs. The experiment was done as part of each athlete’s Monday work-out programme. Four different stretch protocols were used, with each protocol completed on a different day. Hence, the test period lasted 4 weeks. The four stretching protocols were no-stretch of either leg (NS), both legs stretched (BS), forward leg in the starting position stretched (FS) and rear leg in the starting position stretched (RS). Three stretching exercises (hamstring stretch, quadriceps stretch, calf stretch) were used for the BS, FS and RS protocols. Each stretching exercise was performed four times, and each time the stretch was maintained for 30s. The BS, FS and RS protocols induced a significant (P <0.05) increase (0.04 s) in the 20 m time. Thus, it appears that pre-event stretching might negatively impact the performance of high-power short-term exercise.

Nunn-Cearns, G.  
**Question of the continuous warm up**
In the past it was advised for athletes to firstly raise their body temperature with 5-10 minutes of gentle cardiovascular work. Slow paced running is, after all, a very specific way to warm up your muscles for faster paced efforts. It is possible to incorporate many of the drills listed into a type of seamless warm-up – ie by interspersing them with periods of jogging. But it is probably best to move gradually towards this goal over time – especially if you have always used the traditional warm-up approach. In saying there are many coaches who practice a continuous warm-up (ie a 20-30 minutes uninterrupted exercise program), it is essential that the athletes correctly perform exercises to ensure injury does not result. There are a few laws of training essential when undertaking this form of warm-up: 1. Specificity – exercises need to focus on the joints involved and demands of training. 2. Overload – Improvements in flexibility will occur when existing range of movements are regularly reached and extended. 3. Reversibility – as in all training – you don’t use it, you lose it! Should the athlete not continue to undertake flexibility work, levels will decrease. The ‘new’ theory about warm-ups is that we should replace the old generalist approach with a much more dynamic, focused routine, specifically tailored to our chosen sport. The various drills employed need to warm up our muscles specifically for the movements that will be required of them in the activity to follow. In this way specific neuromuscular patterning will be switched on and specific, functional range of movement developed. The continuous warm-up can vary during the year whether the athlete is in general, specific or competition season. The continuous movement (jogging) along with the kinetic flexibility exercises allows the body to adjust mentally and physically for the session they are preparing for. The warm-up should vary from between 20-30 minutes depending on the weather and specific part of the preparation. Research work by McNair (2000) (1) and Knudson (2001) (2) suggests that the use of dynamic stretches - movements through the full range of motion - are the most appropriate exercises for the warm-up. By contrast, static stretches are more appropriate for the cool-down where the athlete can take time and go through range of motion. 

Ogura, Y.; Miyahara, Y.; Naito, H.; Katamoto, S.; Aoki, J. 
Duration of static stretching influences muscle force production in hamstring muscles 
The purpose of the present study was to investigate whether duration of static stretching could affect the maximal voluntary contraction (MVC). Volunteer male subjects (n = 10) underwent 2 different durations of static stretching of their hamstring muscles in the dominant leg: 30 and 60 seconds. No static stretching condition was used as a control condition. Before and after each stretching trial, hamstring flexibility was measured by a sit and reach test. MVC was then measured using the maximal effort of knee flexion. The hamstring flexibility was significantly increased by 30 and 60 seconds of static stretching (control: 0.5 ± 1.1 cm; 30 seconds: 2.1 ± 1.8 cm; 60 seconds: 3.0 ± 1.6 cm); however, there was no significant difference between 30 and 60 seconds of static stretching conditions. The MVC was significantly lowered with 60 seconds of static stretching compared to the control and 30 seconds of the stretching conditions (control: 287.6 ± 24.0 N; 30 seconds: 281.8 ± 24.2 N; 60 seconds: 262.4 ± 36.2 N). However, there was no significant difference between control and 30 seconds of static stretching conditions. Therefore, it was concluded that the short duration (30 seconds) of static stretching did not have a negative effect on the muscle force production. 

Pope, R. P.; Herbert, R. D.; Kirwan, J. D.; Graham, B. J. 
A randomized trial of preexercise stretching for prevention of lower-limb injury 
Purpose: This study investigated the effect of muscle stretching during warm-up on the risk of exercise-related injury. Methods: 1538 male army recruits were randomly allocated to stretch or control groups. During the ensuing 12 wk of training, both groups performed active warm-up exercises before physical training sessions. In addition, the stretch group performed one 20-s static stretch under supervision for each of six major leg muscle groups during every warm-
The control group did not stretch. Results: 333 lower-limb injuries were recorded during the training period, including 214 soft-tissue injuries. There were 158 injuries in the stretch group and 175 in the control group. There was no significant effect of preexercise stretching on all-injuries risk (hazard ratio (HR) = 0.95, 95%CI 0.77-1.18), soft-tissue injury risk (HR = 0.83, 95%CI 0.63-1.09), or bone injury risk (HR = 1.22, 95%CI 0.86-1.76). Fitness (20-m progressive shuttle run test score), age, and enlistment date all significantly predicted injury risk (P<0.01 for each), but height, weight, and body mass index did not. Conclusion: A typical muscle stretching protocol performed during preexercise warm-ups does not produce clinically meaningful reductions in risk of exercise-related injury in army recruits. Fitness may be an important, modifiable risk factor.

Reiman, M. P.; Peintner, A. M.; Boehner, A. L.; Cameron, C. N.; Murphy, J. R.; Carter, J. W. Effects of dynamic warm-up with and without a weighted vest on lower extremity power performance of high school male athletes Journal of Strength and Conditioning Research, Colorado Springs, 24, (2010), 12, pp. 3387-3395

This study examined lower extremity power performance, using the Margaria-Kalamen Power Test, after a dynamic warm-up with (resisted) and without (nonresisted) a weighted vest. Sixteen (n = 16) high school male football players, ages 14-18 years, participated in 2 randomly ordered testing sessions. One session involved performing the team’s standard dynamic warm-up while wearing a vest weighted at 5% of the individual athlete’s body weight before performing 3 trials of the Margaria-Kalamen Power Test. The second session involved performing the same dynamic warm-up without wearing a weighted vest before performing 3 trials of the Margaria-Kalamen Power Test. The warm-up performed by the athletes consisted of various lower extremity dynamic movements over a 5-minute period. No significant difference was found in power performance between the resisted and nonresisted dynamic warm-up protocols (p > 0.05). The use of a dynamic warm-up with a vest weighted at 5% of the athlete’s body weight was not advantageous for increasing lower extremity power output in this study. The results of this study suggest that resisted dynamic warm-up protocols may not augment the production of power performance in high school football players.


Context: Research into the effects of ice on neuromuscular performance is limited, and the results sometimes conflict. Objective: To examine the effects of ice bag application to the anterior thigh and active warm-up on 3 maximal functional performance tests. Design: A 2 × 2 repeated-measures design with 4 randomly assigned treatment conditions: (1) no ice/no warm-up, (2) ice/ no warm-up, (3) no ice/warm-up, and (4) ice/warm-up. Setting: Gymnasium with a wooden floor. Patients or Other Participants: Twenty-four active, uninjured men, 18 to 24 years of age. Intervention(s): For the ice application, we applied an ice bag with compression to the anterior thigh for 20 minutes. Warm-up (6.5 minutes) consisted of 3 minutes of jogging, 3 minutes of stretching, and ten 2-legged vertical jumps. Main Outcome Measure(s): Maximal performance of 3 functional fitness tests: single-leg vertical jump height, shuttle run time, and 40-yd (36.58-m) sprint time. Results: Significant main effects were noted for both ice and warm-up for all functional tests, with a significant interaction (ice × warm-up) for the 40-yd sprint test. Ice bag application negatively affected performance on all 3 functional tests; warm-up significantly improved posticing performance. High-intensity maximal performance after ice bag application almost returned to the no ice/no warm-up pretreatment levels with the addition of active warm-up and time. Conclusions: Ice bag application negatively affected performance of maximal high-intensity functional tests. Active warm-up and time for muscle warming after ice bag application decreased the detrimental effects of icing on functional performance.

Rønnestad, B. R.; Ellefsen, S. The effects of adding different whole-body vibration frequencies to preconditioning exercise on subsequent sprint performance

New Studies in Athletics • no. 1,2014 113
The phenomenon postactivation potentiation can possibly be used to acutely improve sprint performance. The purpose of this study was to investigate the effect of adding whole-body vibration (WBV) to body-loaded half-squats, performed as preconditioning activity to the 40-m sprint test. Nine male amateur soccer players performed 1 familiarization session and 6 separate test sessions. Each session included a standardized warm-up followed by 1 of the after preconditioning exercises: 30-seconds of half-squats with WBV at either 50 or 30 Hz or half-squats without WBV. The 40-m sprint was performed 1 minute after the preconditioning exercise. For each subject, each of the 3 protocols was repeated twice on separate days in a randomized order. Mean values were used in the statistical analysis. Performing the preconditioning exercise with WBV at a frequency of 50 Hz resulted in a superior 40-m sprint performance compared to preconditioning exercise without WBV (5.48 ± 0.19 vs. 5.52 ± 0.21 seconds, respectively, p < 0.05). There was no difference between preconditioning exercise with WBV at a frequency of 30 Hz and the no-WBV condition. In conclusion, preconditioning exercise performed with WBV at 50 Hz seems to enhance 40-m sprint performance in recreationally trained soccer players. The present findings suggest that coaches can incorporate such exercise into the warm-up to improve sprint performance or the quality of the sprint training.

Sander, A.; Keiner, M.; Schlumberger, A.; Wirth, K.; Schmidtbleicher, D.

Effects of functional exercises in the warm-up on sprint performances


The process of warming up prepares athletes for subsequent stress and increases their level of performance. Functional exercises are often included in warm-up programs for power sports, although a positive effect of functional exercises has not been confirmed. The aim of this study was to measure a possible effect of functional exercises on sprint performance included in a warm-up program. A total of 121 elite youth soccer players between 13 and 18 years of age participated in this study and performed 2 different warm-up programs. The first program (NWP) consisted of 5 minutes of nonspecific running, coordination exercises, stretching, and acceleration runs. The second program (WPS) was the same with additional functional exercises. The subjects were tested performing linear sprints of approximately 30 m and change-of-direction sprints of approximately 10 m. The t-test for dependent samples showed significant differences between the groups for each segment of the linear sprint (p < 0.01 for 5 m; p < 0.001 for 10, 15, 20, 25, and 30 m); however, the effect sizes are small. Also, in the change-of-direction sprint, the...
Many athletes and coaches also believe that light aerobic exercise augments the results of stretching. There is little empirical evidence that shows that warming up by light exercise (i.e., jogging) before stretching will significantly increase flexibility. The purpose of this paper is to examine the research considering the acute performance effects of stretching.

Schilling, B. K.
**Stretching: acute effects on strength and power performance**

Stretching (flexibility training) has long been part of the warm-up routine for athletes. The use of stretching as part of the warm-up comes from the belief that stretching will aid in subsequent performance and help prevent injury. The type and degree of stretching used as part of a warm-up routine varies among sports. Our observations of many strength/power athletes (including elite weightlifters, powerlifters, track and field throwers, etc.) suggest that many of these athletes do little in the way of general stretching (especially the agonist muscle groups) or general warm-up. The pre-event and prepractice routines of these athletes consist more of sport-specific exercises done with light resistance and/or low velocity, slowly building up to full effort. This contradicts the suggestions of Arnheim, who states, "general warm-up procedures should consist of jogging or easy running, gradual stretching, and general exercises. These procedures should mobilize the body for action and make it supple and free."

Schipani, D.
**Inside moves. To avoid injury on chilly outdoor runs, warm up indoor first**
*Runner’s World, Emmaus, 48*, (2013), 2, pp. 46

Starting a run at cold outside temperatures with cold and stiff muscles can lead to injuries. Warming-up before the run increases the heart rate, the core temperature, and the muscle blood flow. This in turn reduces the strain on the organism during hard work under unfavourable environmental conditions. Ideally, the warm-up should take place indoors, for example in the form of ten minutes of dynamic Yoga exercises. Six of these exercises are presented in this article.

Sekir, U.; Arabaci, R.; Akova, B.; Kadagan, S. M.
**Acute effects of static and dynamic stretching on leg flexor and extensor isokinetic strength in elite women athletes**

The aim of this study was to explore the effects of static and dynamic stretching of the leg flexors and extensors on concentric and eccentric peak torque (PT) and electromyography (EMG) amplitude of the leg extensors and flexors in women athletes. Ten elite women athletes completed the following intervention protocol in a randomized order on separate days: (a) non-stretching (control), (b) static stretching, and (c) dynamic stretching. Stretched muscles were the quadriceps and hamstring muscles. Before and after the stretching or control intervention, concentric and eccentric isokinetic PT and EMG activity of the leg extensors and flexors were measured at 60 and 180°/s. Concentric and eccentric quadriceps and hamstring muscle strength at both test speeds displayed a significant decrease following static stretching (P < 0.01–0.001). In contrast, a significant increase was observed after dynamic stretching for these strength parameters (P <
compromised when static stretching is conducted after dynamic activities and immediately prior to performance (D-S).

Skurvydas, A.; Kamandulis, S.; Stanislovaiteis, A.; Streckis, V.; Mamkus, G.; Drazdaskaas, A. Leg immersion in warm water, stretch-shortening exercise, and exercise-induced muscle damage


Context: Whether muscle warming protects against exercise-induced muscle damage is unknown. Objective: To determine the effect of leg immersion in warm water before stretch-shortening exercise on the time course of indirect markers of exercise-induced muscle damage.

Design: Crossover trial. Setting: Human kinetics laboratory. Patients or Other Participants: Eleven healthy, untrained men (age = 21.5 ± 1.7 years).

Intervention(s): Participants' legs were immersed in a water bath at 44 ± 1°C for 45 minutes. Main Outcome Measure(s): Creatine kinase changes in the blood, muscle soreness, prolonged (within 72 hours) impairment in maximal voluntary contraction force and height of drop jump, and electrically evoked muscle force at low and high stimulation frequencies at short and long muscle lengths.

Results: Leg immersion in warm water before stretch-shortening exercise reduced most of the indirect markers of exercise-induced muscle damage, including creatine kinase activity in the blood, muscle soreness, maximal voluntary contraction force, and jump height. The values for maximal voluntary contraction force and jump height, however, were higher during prewarming than for the control condition at 48 hours after stretch-shortening exercise, but this difference was only minor at other time points. Muscle prewarming did not bring about any changes in the dynamics of low-frequency fatigue, registered at either short or long muscle lengths, within 72 hours of stretch-shortening exercise.

Conclusions: Leg immersion in warm water before stretch-shortening exercise reduced most of the indirect markers of exercise-induced muscle damage. However, the clinical application of muscle prewarming may be limited, because decreasing muscle damage did not necessarily lead to improved voluntary performance.

Sim, A. Y.; Dawson, B. T.; Guelfi, K. J.; Wallman, K. E.; Young, W. B. Effects of static stretching in warm-up on repeated sprint performance


The aim of this study was to examine the effects of static stretching during warm-up on repeated sprint performance and also to assess any influence of the order in which dynamic activities (i.e., run-throughs and drills) and static stretching are conducted. Thirteen male team sport players completed a repeated sprint ability test consisting of three sets of maximal 6 x 20-m sprints (going every 25 seconds) after performing one of three different warm-up protocols in a within-subjects counterbalanced design. Each warm-up protocol involved an initial 1000-m jog, followed by either dynamic activities only (D), static stretching followed by dynamic activities (S-D), or dynamic activities followed by static stretching (D-S). First (FST), best (BST) and total (TST) 20-m sprint times were determined for each individual set of the repeated sprint ability test and overall (3 sets combined). Although consistent significant differences were not observed between trials for TST, BST, and FST, the mean values for TST in all individual sets and overall were generally slowest in the D-S condition (D = 60.264 ± 1.127 seconds; S-D = 60.347 ± 1.774 seconds; D-S = 60.830 ± 1.786 seconds). This trend was supported by moderate to large effect sizes and qualitative indications of "possible" or "likely" benefits for TST, BST, and FST for the D and S-D warm-ups compared to D-S. No significant differences or large effect sizes were noted between D and S-D, indicating similar repeated sprint ability performance. Overall, these results suggest that 20-m repeated sprint ability may be compromised when static stretching is conducted after dynamic activities and immediately prior to performance (D-S).
During the warm-up of the experimental TTs, runners wore either a t-shirt (control [C]) or a cooling vest (V), the order of which was randomized. No differences were found between the C and V conditions for the 10-km TT times (2,533 ± 144 and 2,543 ± 149 seconds, respectively) (p = 0.746) or any of the 2-km split times. Heart rate (HR) at the start of the TT equaled 90 ± 17 b•min⁻¹ for C and 94 ± 16 b•min⁻¹ for V. The HR peaked at 184 ± 20 b•min⁻¹ in C and 181 ± 19 b•min⁻¹ in V. At the start of the TT Tc was 37.65 ± .72°C in C and 37.29 ± .73°C in V (p = 0.067). In C, Tc gradually increased until 39.34 ± 0.43°C while in V is reached 39.18 ± 0.72°C (p = 0.621). Although rating of perceived exertion (RPE) and Thermal sensation (TS) increased during both experimental TTs, there were no differences between V and C. Findings suggest wearing a cooling vest during a warm-up does not improve 10-km performance. The use of cooling vests during the warm-up did not produce any physiological (HR and Tc) or psychological (RPE and TS) benefit, perhaps accounting for the lack of improvement.

Stewart, M.; Adams, R.; Alonso, A.; Koesveld, B. van; Campbell, S.
Warm-up or stretch as preparation for sprint performance?
Journal of Science and Medicine in Sport, Beccles, 10, (2007), 6, pp. 403-410
Warm-up and stretching are widely used as techniques in preparation for intense physical activity, yet there is little information available to compare their effectiveness in relation to athletic performance. Fourteen elite Under-19 year old rugby league footballers undertook each of four preparation protocols (no preparation, stretching only, warm-up only, warm-up and stretching) in four successive testing sessions. Protocols were randomly allocated to players in a counterbalanced design so that each type of preparation occurred equally on each day of testing. During each session, athletes performed three solo sprint trials at maximum speed. Sprints were of 40-m distance and were electronically timed with wind speed and direction recorded. Preparation involving warm-up resulted in significantly faster sprint times compared to preparations having no warm-up, with a diminishing effect over the three trials. On the first trial, warm-up resulted in a mean advantage of 0.97 m over 40 m. Stretching resulted in a mean

Stannard, A. B.; Brandenburg, J. P.; Pitney, W. A.; Lukaszuk, J. M.
Effects of wearing a cooling vest during the warm-up on 10-km run performance
The purpose of this study was to examine whether wearing a cooling vest during an active warm-up would improve the 10-km time trial (TT) performance of endurance runners. Seven male runners completed 3 10-km TTs (1 familiarization and 2 experimental) on a treadmill after a 30-minute warm-up. During the warm-up of the experimental TTs, runners wore either a t-shirt (control [C]) or a cooling vest (V), the order of which was randomized. No differences were found between the C and V conditions for the 10-km TT times (2,533 ± 144 and 2,543 ± 149 seconds, respectively) (p = 0.746) or any of the 2-km split times. Heart rate (HR) at the start of the TT equaled 90 ± 17 b•min⁻¹ for C and 94 ± 16 b•min⁻¹ for V. The HR peaked at 184 ± 20 b•min⁻¹ in C and 181 ± 19 b•min⁻¹ in V. At the start of the TT Tc was 37.65 ± .72°C in C and 37.29 ± .73°C in V (p = 0.067). In C, Tc gradually increased until 39.34 ± 0.43°C while in V is reached 39.18 ± 0.72°C (p = 0.621). Although rating of perceived exertion (RPE) and Thermal sensation (TS) increased during both experimental TTs, there were no differences between V and C. Findings suggest wearing a cooling vest during a warm-up does not improve 10-km performance. The use of cooling vests during the warm-up did not produce any physiological (HR and Tc) or psychological (RPE and TS) benefit, perhaps accounting for the lack of improvement.

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disadvantage of 0.18 m on the first trial, and no significant effect overall despite significant wind assistance. Warm-up was effective at improving immediate sprint performance, whereas an equivalent duration of lower limb stretching had no effect.

Takizawa, K.; Ishii, K.

**The effects of different warm-up loads [routines] at equal total workload for high intensity exercise performance**


It is well known that warm-up (W-up) routines improve exercise performance and that the duration and intensity of W-up affects high intensity aerobic exercise performance. Previous studies have suggested that intensity and/or duration of W-up affect high intensity aerobic exercise performance, but the total workloads used in those studies were different. In this study, the effects of W-ups of different intensities upon the equal total workloads of high intensity aerobic exercise performance were investigated. Subjects performed three exercise tests under differing W-up conditions. These conditions were firstly W-up at lactate threshold (LT), secondly at 50%LT and thirdly, at the onset of blood lactate accumulation (OBLA). The total workload of each W-up was the equal as 15 minutes at LT. Following a 5-min rest period after completion of W-up, each subject performed a cycling exercise test at 100% Vo2peak until experiencing exhaustion. The duration of the exercise test was used as an index of exercise performance. Vastus lateralis and rectal temperatures of each subject were measured. No significant differences were observed at vastus lateralis (50%LT: 36.8 ± 0.4 ºC, LT: 37.2 ± 0.5 ºC, OBLA: 37.4 ± 0.3 ºC, p>0.05) or rectal (50%LT: 37.0 ± 0.3 ºC, LT: 37.2 ± 0.4 ºC, OBLA: 37.4 ± 0.4 ºC, p>0.05) temperatures after performing W-up at any of the three different intensities. Similarly, significant differences were observed at exercise test duration between W-up conditions (50%LT: 214.1 ± 84.4 sec, LT: 306.7 ± 125.5 sec, OBLA: 274.4 ± 118.0 sec, p>0.05). These results suggest that if total workloads are the equal and rises in body temperature are similar, W-ups of different intensities have the same effect on high intensity aerobic exercise performance.


**Effect of warm-up exercise on delayed-onset muscle soreness**

*European Journal of Sport Science, Abingdon, 12, (2012), 6, pp. 455-461*

In this study, we wished to determine whether a warm-up exercise consisting of 100 submaximal concentric contractions would attenuate delayed-onset muscle soreness and decreases in muscle strength associated with eccentric exercise-induced muscle damage. Ten male students performed two bouts of an elbow flexor exercise consisting of 12 maximal eccentric contractions with a warm-up exercise for one arm (warm-up) and without warm-up for the other arm (control) in a randomized, counterbalanced order separated by 4 weeks. Muscle temperature of the biceps brachii prior to the exercise was compared between the arms, and muscle activity of the biceps brachii during the exercise was assessed by surface integral electromyogram (iEMG). Changes in visual analogue scale for muscle soreness and maximal voluntary isometric contraction strength (MVC) of the elbow flexors were assessed before, immediately after, and every 24 h for 5 days following exercise, and compared between the warm-up and control conditions by a two-way repeated-measures analysis of variance. The pre-exercise biceps brachii muscle temperature was significantly (P < 0.01) higher for the warm-up (35.8±0.2°C) than the control condition (34.4±0.2°C), but no significant differences in iEMG and torque produced during exercise were evident between conditions. Changes in muscle soreness and MVC were not significantly different between conditions, although these variables showed significant (P < 0.05) changes over time. It was concluded that the warm-up exercise was not effective in mitigating delayed-onset muscle soreness and loss of muscle strength following maximal eccentric exercise.

Taylor, J. M.; Weston, M.; Portas, M. D.

**The effect of a short practical warm-up protocol on repeated sprint performance**


The aim of our study was to investigate the effect of a short, practical, 2-phase warm-up on repeated sprint performance when compared
with more traditional warm-up protocols that contain stretching activities. Eleven subelite male soccer players completed a warm-up protocol that commenced with 5 minutes jogging at approximately 65% of maximal heart rate, followed by no stretching, static stretching, or dynamic stretching and finishing with a task-specific high-intensity activity. Using a crossover design, the 3 warm-up protocols were performed in a counterbalanced order with at least 48 hours between sessions. Repeated sprint performance was measured using a repeated sprint test that consisted of 6 × 40-m maximal sprints interspersed with a 20-second recovery. There were trivial differences in mean sprint time (0.2%) and posttest blood lactate (3.1%) between the 2-phase warm-up and the 3-phase warm-up that included dynamic stretching, whereas the short warm-up had a possibly detrimental effect on fastest sprint time (0.7%). Fastest (−1.1%) and mean (−1.2%) sprint times were quicker and posttest blood lactates were higher (13.2%) after the 2-phase warm-up when compared with the 3-phase warm-up that included static stretching. Although it is not harmful to complete a traditional 3-phase warm-up that includes dynamic stretching, it appears practical for athletes preparing for activities dependent on repeated sprint ability to complete a 2-phase warm-up consisting of a cardiovascular and specific high-intensity activity.

Taylor, K.-L.; Sheppard, J. M.; Lee, H.; Plummer, N. 
Negative effect of static stretching restored when combined with a sport specific warm-up component 
Journal of Science and Medicine in Sport, Belconnen, 12, (2009), 6, pp. 657-661

There is substantial evidence that static stretching may inhibit performance in strength and power activities. However, most of this research has involved stretching routines dissimilar to those practiced by athletes. The purpose of this study was to evaluate whether the decline in performance normally associated with static stretching pervades when the static stretching is conducted prior to a sport specific warm-up. Thirteen netball players completed two experimental warm-up conditions. Day 1 warm-up involved a submaximal run followed by 15 min of static stretching and a netball specific skill warm-up. Day 2 followed the same design; however, the static stretching was replaced with a 15 min dynamic warm-up routine to allow for a direct comparison between the static stretching and dynamic warm-up effects. Participants performed a countermovement vertical jump and 20 m sprint after the first warm-up intervention (static or dynamic) and also after the netball specific skill warm-up. The static stretching condition resulted in significantly worse performance than the dynamic warm-up in vertical jump height (−4.2%, 0.40 ES) and 20 m sprint time (1.4%, 0.34 ES) (p < 0.05). However, no significant differences in either performance variable were evident when the skill-based warm-up was preceded by static stretching or a dynamic warm-up routine. This suggests that the practice of a subsequent high-intensity skill based warm-up restored the differences between the two warm-up interventions. Hence, if static stretching is to be included in the warm-up period, it is recommended that a period of high-intensity sport-specific skills based activity is included prior to the on-court/field performance.

Terzis, G.; Karampatsos, G.; Kyriazis, T.; Kavouras, S. A.; Georgiadis, G. 
Acute effects of countermovement jumping and sprinting on shot put performance 

The purpose of this study was to investigate the acute effects of countermovement jumping and sprinting on shot put performance in experienced shot putters. Ten shot putters (best performance 13.16-20.36 m) participated in the study. After a standard warm-up including jogging, stretching, and 4-6 submaximal puts, they performed 3 shot put attempts with maximum effort, separated with a 1.5-minute interval. Three minutes later, they performed 3 maximal consecutive countermovement jumps (CMJs). Immediately after jumping, they performed 3 maximal consecutive countermovement jumps (CMJs). Immediately after jumping, they performed 3 shot put attempts with maximum effort, separated with 1.5-minute interval. Three minutes later, they performed 3 maximal consecutive countermovement jumps (CMJs). Immediately after jumping, they performed 3 shot put attempts with maximum effort, separated with a 1.5-minute interval. One week later, they carried out a similar protocol, at similar external conditions, but they performed a bout of 20-m sprinting instead of the CMJs, to potentiate shot put performance. Muscular strength (1 repetition maximum in squat, snatch, bench press, incline bench press) and body composition (dual x-ray absorptiometry) were measured during the same training period (±10 days from the
jumping and sprinting protocols). Shot put performance was significantly increased after the CMJs (15.45 ± 2.36 vs. 15.85 ± 2.41 m, p = 0.0003). Similarly, shot put performance was significantly increased after sprinting (15.34 ± 2.41 vs. 15.90 ± 2.46 m, p = 0.0007). The increase in performance after sprinting was significantly higher compared with the increase after jumping (2.64 ± 1.59 vs. 3.74 ± 1.88%, p = 0.02). In conclusion, the results of this study indicate that a standard warm-up protocol followed by 3 maximal bouts of shot put and either 3 consecutive countermovement jumps or a bout of 20-m sprinting induce an acute increase in shot put performance in experienced shot putters.

Thomas, M.
The functional warm-up


The warm-up is generally designed to prepare the cardiorespiratory and musculoskeletal systems to meet the demands of exercise. It also mentally prepares the individual for the activity that he or she is about to perform. When most people think about warming up, there are 3 ideas that typically come to mind: stretching, the basic warm-up, and the specific warm-up.

Thompson, A. G.; Kackley, T.; Palumbo, M. A.; Faigenbaum, A. D.
Acute effects of different warm-up protocols with and without a weighted vest on jumping performance in athletic women


The purpose of this study was to examine the acute effects of 3 different warm-up protocols with and without a weighted vest on vertical jump (VJ) and long jump (LJ) performance in athletic women. Sixteen subjects (19.7 ± 1.4 years, 67.0 ± 10.7 kg, 165.7 ± 11.4 cm) participated in 3 testing sessions in random order on 3 nonconsecutive days. Prior to the testing of the VJ and LJ, the subjects performed 1 of the following 10-minute warm-up protocols: (a) low- to moderate-intensity stationary cycling followed by 4 lower-body static stretches (SS) (3 x 20 seconds); (b) 12 moderate- to high-intensity dynamic exercises (DY); and (c) the same 12 dynamic exercises with a weighted vest (10% of body mass) worn for the last 4 exercises (DYV). Analysis of the data revealed that VJ performance was significantly greater (p < 0.05) following DYV (43.9 ± 6.7 cm) and DY (43.6 ± 6.5 cm) as compared to SS (41.7 ± 6.0 cm). Long jump performance was significantly greater (p < 0.05) following DYV (186.8 ± 19.5 cm) as compared to DY (182.2 ± 19.1 cm), which in turn was significantly greater (p < 0.05) than performance following SS (177.2 ± 18.8 cm). Warm-up protocols that include dynamic exercise may be a viable method of enhancing jumping performance in athletic women as compared to stationary cycling and static stretching. In addition, these data suggest that it may be desirable for athletic women to perform dynamic exercises with a weighted vest on some movements prior to the performance of the long jump.

Tsolakis, C.; Bogdanis, G. C.
Acute effects of two different warm-up protocols on flexibility and lower limb explosive performance in male and female high level athletes


This study examined the effects of two different warm-up protocols on lower limb power and flexibility in high level athletes. Twenty international level fencers (10 males and 10 females) performed two warm-up protocols that included 5-min light jogging and either short (15s) or long (45s) static stretching exercises for each of the main leg muscle groups (quadriceps, hamstrings and triceps surae), followed by either 3 sets of 3 (short stretching treatment), or 3 sets of 5 tuck jumps (long stretching treatment), in a randomized crossover design with one week between treatments. Hip joint flexion was measured with a Lafayette goniometer before and after the 5-min warm-up, after stretching and 8 min after the tuck jumps, while counter movement jump (CMJ) performance was evaluated by an Ergojump contact platform, before and after the stretching treatment, as well as immediately after and 8 minutes after the tuck jumps. Three way ANOVA (condition, time, gender) revealed significant time (p < 0.001) and gender (p < 0.001) main effects for hip joint flexion, with no interaction between factors. Flexibility increased by 6.8 ± 1.1% (p < 0.01) after warm-up and by another 5.8 ± 1.6% (p < 0.01) af-
The effects of warm-up and pre-cooling on endurance performance in highly trained male athletes


Recently, athletes have transitioned from traditional static stretching during warm-ups to incorporating dynamic stretching routines. However, the optimal volume of dynamic drills is yet to be identified. The aim of this repeated-measures study was to examine varying volumes (1, 2, and 3 sets) of active dynamic stretching (ADS) in a warm-up on 10- and 20-m sprint performance. With a within-subject design, 16 highly trained male participants (age: 20.9 ± 1.3 years; height: 179.7 ± 5.7 cm; body mass: 72.7 ± 7.9 kg; % body fat: 10.9 ± 2.4) completed a 5-minute general running warm-up before performing 3 preintervention measures of 10- to 20-m sprint. The interventions included 1, 2, and 3 sets of active dynamic stretches of the lower-body musculature (gastrocnemius, gluteals, hamstrings, quadriceps, and hip flexors) performed approximately 14 times for each exercise while walking (ADS1, ADS2, and ADS3). The active dynamic warm-ups were randomly allocated before performing a sprint-specific warm-up. Five minutes separated the end of the warm-up and the 3 postintervention measures of 10- to 20-m sprints. There were no significant time, condition, and interaction effects over the 10-m sprint time. For the 0- to 20-m sprint time, a significant main effect for the pre-post measurement (F = 10.81; p < 0.002), the dynamic stretching condition (F = 6.23; p = 0.004) and an interaction effect (F = 41.19; p = 0.0001) were observed. A significant decrease in sprint time (improvement in sprint performance) post-ADS1 (2.56%, p = 0.001) and post-ADS2 (2.61%, p = 0.001) was observed. Conversely, the results indicated a significant increase in sprint time (sprint performance impairment) post-ADS3 condition (2.58%, p = 0.001). Data indicate that performing 1–2 sets of 20 m of active dynamic stretches in a warm-up can enhance 20-m sprint performance. The results delineated that 3 sets of ADS repetitions could induce acute fatigue and impair sprint performance within 5 minutes of the warm-up.

Ückert, S.; Joch, W. The effects of warm-ups incorporating different volumes of dynamic stretching on 10- and 20-m sprint performance in highly trained male athletes


It is well established that warm conditions have a detrimental effect an endurance performance. If skin temperature is exceeded by the ambient temperature, heat dissipation is impaired and heat storage is likely to occur. A warm-up, which by definition entails increasing body temperature, is generally considered a vital part of the preparation for competition – including endurance performances in hot weather. On this understanding, the question arises if cooling prior to competition (pre-cooling) might be a better alternative. Twenty subjects performed two laboratory endurance tests in conditions of high ambient temperature and relative humidity. One test followed a 20-minute warm-up and the other a 20-minute pre-cooling procedure. The comparison of results shows that pre-cooling significantly extends the time to exhaustion and slows the increase in both body core temperature and heart rate. The authors conclude that pre-cooling, as opposed to warm-up, optimises thermoregulatory processes before physical effort in warm conditions.
known about the potential mechanisms of WU on performance and on the lactate distribution in the blood compartment. The purpose of the present study was to investigate whether different WU procedures affect performance and lactate distribution between plasma and red blood cells (RBCs) after maximal exercise. At three different occasions eleven subjects performed one 30 s maximal effort exercise on a cycle ergometer. Before each exercise, subjects warmed up at different intensities: 1. no WU (NWU); 2. extensive WU (EWU); 3. intensive WU (IWU). Blood samples were taken under resting conditions, after WU, and in 1 minute intervals during recovery to determine lactate concentrations [LA] in whole blood ([LA]WB), plasma ([LA]plasma) and erythrocytes ([LA]RBC). Mean power output was +58 Watt (EWU) and +60 Watt (IWU) higher compared to NWU. For each WU condition [LA]plasma and [LA]RBC differed significantly at any time point, showing greater [LA]plasma compared to [LA]RBC. The maximal effort exercise caused a rapid decrease of the [LA]RBC/[LA]plasma ratio. [LA]RBC reached the peak 3-5 minutes later than [LA]plasma depending on the WU condition. The initial increments in [LA]RBC were 10-16% lower after IWU compared to NWU and EWU. The lower increment of [LA]RBC after IWU might be due to a "higher preloading" with lactate before exercise, causing a smaller initial [LA] gradient between plasma and RBCs. It seems that the influx decreases with increasing intracellular [LA]. Another possibility one could speculate about is, that the extracellular increase in [LA] inhibits the outflux of lactate produced by the RBC itself. This inhibited export of lactate from RBCs may lead to an intracellular lactate accumulation. But the relatively fast increase in [LA]RBC and other investigations partly contradicts this possibility.

Wahl, P.; Zinner, C.; Yue, Z.; Bloch, W.; Mester, J. Warming-up affects performance and lactate distribution between plasma and red blood cells

Warming-up (WU) is a widely used preparation for training and competition. However, little is
petition takes a long time stretching his thigh muscles. When doing some warm-up jumps he feels some muscle stiffness in his left quadriceps (assume the right leg is his take-off leg). Fearing he may not have stretched intensely enough, and thinking of the advice from both his coach, and physiotherapist of how to get rid of muscle stiffness, he does additional stretching for the quadriceps, in order to be well prepared for his first competition jump. However, during the take-off phase of his first competition jump disaster strikes. As he swings his left leg up, the athlete feels a sharp pain in his left quad, which forces him to abandon the jump and the competition.

The authors then describe in great detail the effects of stretching, and the cause/s of injuries similar to that described above. In reaching their conclusions, they draw on new knowledge about the anatomy of muscle fibers, as well as research that has examined the role of stretching in preparing to participate in vigorous physical activity. The important conclusion that comes from muscle structure research is that the amount of passive tension the elastic elements of the muscle have to bear is by no means smaller during extreme stretching than during active tension in voluntary maximal isometric contractions. Indeed, the passive tension from stretching can be much higher. Consequently, the forces applied during contractions and stretching in training should have the same or similar effects. In the discussion on the effects of stretching, the authors emphasize the distinction between short-term and long-term stretch training programs. A short-term stretch training program consists of 10-20 minutes stretching with 3-5 sets of 3-10 repetitions, as it is often employed in the warm-up or cool-down of a training session, or in the warm-up to a competition. Five light, but dynamic, stretches are sufficient to prepare the body for action.

The significance of stretching in the warm up before maximum performance

According to the authors, the perceived benefits of intense static stretching before a maximum performance have not been proven. On the contrary, intense static stretching prior to vigorous physical activity is responsible for a reduced performance in addition to producing a higher risk of injury. This is not to say that regular stretch training will not improve performance by an increase in joint flexibility. The issue is when to participate in static stretching sessions. The authors argue that static stretching should be performed in separate training sessions. In the warm-up phase immediately before maximal performances only submaximal stretching should be used. Five light, but dynamic, stretches are sufficient to prepare the body for action.

The significance of stretching in the warm up before maximum performance

In the introduction, the authors describe the following fictitious but familiar scenario: An athlete (e.g. a long jumper), in his warm-up for a competition takes a long time stretching his thigh muscles. When doing some warm-up jumps he feels some muscle stiffness in his left quadriceps (assume the right leg is his take-off leg). Fearing he may not have stretched intensely enough, and thinking of the advice from both his coach, and physiotherapist of how to get rid of muscle stiffness, he does additional stretching for the quadriceps, in order to be well prepared for his first competition jump. However, during the take-off phase of his first competition jump disaster strikes. As he swings his left leg up, the athlete feels a sharp pain in his left quad, which forces him to abandon the jump and the competition.

The authors then describe in great detail the effects of stretching, and the cause/s of injuries similar to that described above. In reaching their conclusions, they draw on new knowledge about the anatomy of muscle fibers, as well as research that has examined the role of stretching in preparing to participate in vigorous physical activity. The important conclusion that comes from muscle structure research is that the amount of passive tension the elastic elements of the muscle have to bear is by no means smaller during extreme stretching than during active tension in voluntary maximal isometric contractions. Indeed, the passive tension from stretching can be much higher. Consequently, the forces applied during contractions and stretching in training should have the same or similar effects. In the discussion on the effects of stretching, the authors emphasize the distinction between short-term and long-term stretch training programs. A short-term stretch training program consists of 10-20 minutes stretching with 3-5 sets of 3-10 repetitions, as it is often employed in the warm-up or cool-down of a training session, or in the warm-up to a competition. A long-term stretch training program on the other hand is a series of short-term stretching programs carried out several times a week over a period of several weeks or months. The authors are concerned only with the short-term programs. The distinction between intensive stretching (e.g. stretching to the maximal tolerable tension) and light, submaximal stretching is made. The benefits of stretching on the range of motion at the joints (movement amplitude) are not questioned. Short-term stretching has been found to increase the amplitude by at least 8%. The authors refer to a review on stretching research...
conducted by Wydra (1997) who found that the conventional rhythmical-ballistic stretching (out of vogue for some time) has at least the same, and in some cases a superior effect on joint amplitude compared with that of static stretching. What is interesting is that the most gains in movement amplitude are reached in the first 3-5 repetitions, with only slight increases with additional repetitions. In a short-term stretch training session the tension on the passive structures of the muscles fibers increase. In stretching the muscle, the athlete becomes accustomed to the stretch pain, which allows an increased tolerance of higher movement amplitudes. Consequently, the athlete can reach or exceed the load limit of the passive structures of the muscle fibers without knowing it. To date it is not known which of the passive structures are the weakest links. The adaptations occur at a neural (central-nervous system) level, and subsequently a higher psychological stress might increase the pain adaptation further. This may occur before competitions where an athlete through stretching exceeds the limits of the passive structures of the muscles causing micro-trauma. The authors return to the fictitious long jumper and explain his injury as follows: The athlete may have over-stretched in the warm-up, which caused micro-trauma in his rectus femoris. At the moment the right leg plants on the take-off board the rectus femoris of the take-off leg is in an extremely stretched position, which produces high passive tension. What follows is a high active tension as the leg swings up, adding to the passive tension and causing the injury. The authors conclude that the perceived benefits of intense static stretching before a maximum performance have not been proven. On the contrary, intense static stretching prior to vigorous physical activity is responsible for a reduced performance in addition to producing a higher risk of injury. This is not to say that regular stretch training will not improve performance by an increase in joint flexibility. The issue is when to participate in static stretching sessions. The authors argue that static stretching should be performed in separate training sessions. In the warm-up phase immediately before maximal performances only submaximal stretching should be used. Five light, but dynamic, stretches are sufficient to prepare the body for action.

Winchester, J. B.; Nelson, A. G.; Kokkonen, J.
A single 30-s stretch is sufficient to inhibit maximal voluntary strength
Research quarterly for exercise and sport, Philadelphia (Penns.), 80, (2009), 2, pp. 257-261
While it has been well established that an acute stretching program can inhibit maximal muscle performance, the amount of stretching needed to produce the deleterious response is unknown. Therefore this study examined the dose-response relationship between acute stretching and strength inhibition. Eighteen college students performed a one repetition maximum (1-RM) test of knee-flexion following 0, 1, 2, 3, 4, 5, or 6 30-s bouts of hamstring stretching held at the limit of toleration. All seven dose variations were done by each subject, with each variation done on a separate day. One week separated each test, and the order of the stretch variations was balanced across the seven testing days. Stretching significantly (p<.05) reduced 1-RM after one 30-s stretch (5.4 percent), and continued to decrease 1-RM up to and including six 30-s stretches (12.4 percent). A single 30-s stretch, if held at the limit of toleration, is sufficient to cause an inhibition in a person's 1-RM. Additional bouts of stretching will further decrease the 1-RM, suggesting that multiple mechanisms may be involved in stretch-induced strength inhibition.

Wittekind, A. L.; Beneke, R.
Effect of warm-up on run time to exhaustion
Journal of Science and Medicine in Sport, Belconnen, 12, (2009), 4, pp. 480-484
It is not known whether warm-up protocols typically employed by athletes are beneficial to performance. The aim of this study was to investigate the effect of warm-up on a perimaximal run to exhaustion, VO2 kinetics, energy metabolism and running economy. Nine male distance runners ran to exhaustion at a speed corresponding to 105% maximal oxygen uptake (VO2max) after each of three different warm-up protocols: no warm-up (NW), jog warm-up (WM), or jog with strides (WH). Warm-up did not affect pre-run blood lactate concentration (BLC), BLC-increase (ΔBLC), net oxygen consumption, or running economy. WH increased the amplitude of the primary VO2 response (mean (confidence intervals of difference); 4083 ml min−1 vs. 3763 ml min−1 (−638, −2)), with no change in the time constant;
Yaicharoen, P.; Wallman, K.; Morton, A.; Bishop, D.
The effect of warm-up on intermittent sprint performance and selected thermo-regulatory parameters
Journal of Science and Medicine in Sport, Belconnen, 15, (2012), 5, pp. 451-456
Objectives: To investigate the effect of various warm-up intensities based upon individual lactate thresholds on subsequent intermittent sprint performance, as well as to determine which temperature (muscle; T_{mu}, rectal; T_{re} or body; T_{b}) best correlated with performance (total work, work and power output of the first sprint, and % work decrement). Design: Nine male team-sport participants performed five 10-min warm-up protocols consisting of different exercise intensities on five separate occasions, separated by a week. Methods: Each warm-up protocol was followed by a 6×4-s intermittent sprint test performed on a cycle ergometer with 21-s of recovery between sprints. T_{mu}, T_{re} and T_{b} were monitored throughout the test. Results: There were no differences between warm-up conditions for total work (J kg\(^{-1}\); \(P=0.442\)), first sprint work (J kg\(^{-1}\); \(P=0.769\)), power output of the first sprint (W kg\(^{-1}\); \(P=0.189\)), or % work decrement (\(P=0.136\)), respectively. Moderate to large effect sizes (\(>0.5\); Cohen's d) suggested a tendency for improvement in every performance variable assessed following a warm-up performed at an intensity midway between lactate inflection and lactate threshold. While T_{mu}, T_{re}, and T_{b} increased significantly during the exercise protocols (\(P<0.05\)), there were no significant correlations between T_{mu}, T_{re}, and T_{b} assessed immediately after each warm-up condition and any performance variable assessed. Conclusions: Warm-up performed at an intensity midway between lactate inflection and lactate threshold resulted in optimal intermittent sprint performance. Significant increases in T_{mu}, T_{re} and T_{b} during the sprint test did not affect exercise performance between warm-up conditions.

Yaicharoen, P.; Wallman, K.; Bishop, D.; Morton, A.
The effect of warm-up on single and intermittent sprint performance
Lack of benefit of warm-up on prolonged intermittent-sprint performance has been proposed to be due to use of a pacing strategy by participants. To investigate this, twelve participants performed four cycle trials that consisted of either prolonged intermittent-sprint performance (80 min) or single-sprint performance (4 s), with or without a warm-up. The first-sprint of intermittent-sprint performance was also assessed. No interaction effects (\(P>0.05\)) were found between trials for intermittent-sprint performance for total work, or percentage work and power decrement. Work done during the first-sprint of intermittent-sprint performance (no warm-up) was less (\(P=0.001\)) than the first-sprint of intermittent-sprint performance (warm-up; effect size (ES)=0.59) and both single-sprint trials (warm-up and no warm-up; ES=0.91, 0.75, respectively). Peak power for single-sprint (warm-up) was greater (\(P=0.05\)) than single-sprint (no warm-up), and the first-sprint of intermittent-sprint performance (warm-up and no warm-up). Warm-up improved single-sprint performance and the first sprint of intermittent-sprint performance. Use of a pacing strategy probably resulted in similar intermittent-sprint performance between trials. These results suggest that team-sport players should perform a warm-up at the start of a game or before substitution during a game.
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