# The impact of warm up intensity and duration on sprint performance

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## Abstract

A traditional warm-up (WU) for track sprinters usually includes a general WU, a series of mobility drills and some short sprint strides lasting 30-60 min in total. A WU of this duration might cause significant fatigue and impair sprint performance.

**Aim:** To test the hypothesis that a traditional high intense warm-up of long duration would elicit fatigue and impair sprint performance.

**Methods:** Five highly trained males competitive in endurance sports performed three different WU protocols on separate days in their postseason period. Their mean ± SD age, body mass and height were 24.2 ± 1.6 years, 78.4 ± 7.8 kg, 179.6 ± 8.8 cm. The study participants performed a timed 60 meter sprint on an indoor track. The traditional warm-up (LONG), started with 10 min of easy running; then 7 min of mobility drills followed by five sprints performed with 3-min break in between. The total duration of LONG was 35 minutes. The experimental warm-up (SHORT) was shorter and less intense; 10 min of easy running was followed by just one sprint. Both warm-up protocols were followed by 10 min of recovery, where participants were not allowed to sit down. A third test occasion served as control (CON), where participants did not conduct physical activity prior to the time trial, only 10 min of recovery. Participants also rated the satisfaction of their performance on a 10 point scale.

**Results:** The results of 60 m time trial performance showed no significant differences among the different WU protocols ($P = 0.20$). The 60 m performance was better for SHORT (8.02 ± 0.10 sec) than for LONG (8.08 ± 0.16 sec) and CON (8.20 ± 0.21 sec). 4 of 5 participants experienced their fastest time trial following SHORT. It appeared that participants were significantly faster following SHORT (7.99 ± 0.22 $ms^{-1}$) compared to LONG (7.77 ± 0.33 $ms^{-1}$) in the final 10 m of the time trial ($P = 0.05$).

The satisfaction after SHORT scored highest (6.9), followed by LONG (5.9) and CON (4.5).

**Conclusions:** There is no significant difference between a traditional WU compared to a WU of shorter duration and lower intensity. The traditional WU showed a significant decline in running speed in the final stage of the time trial, which might be caused by fatigue.

**Keywords:** warm-up, muscle fatigue, sprint performance, 60-m sprint, no warm-up

## Contents

## Tables and figures

# 1 Introduction

Warm-up (WU) is a common pre-competition routine in almost all athletic sport. Even for races of very short duration such as sprinting events, a long time is spent on WU (Balilionis, Nepocatych, Ellis, Richardson, Neggers & Bishop, 2012; Mujika, de Txabarri, Maldonado-Martín & Pyne, 2012). Since it is a very common procedure one might think that the scientific evidence for WU is clear. This appears not to be the case. Between scientists there are many divergent arguments for the benefits of WU. As suggested by the name, one of the main purposes of WU is to warm up the body. Therefore, most of the studies that have been done have evaluated body temperature-related mechanisms.

# 2 Background

## *2.1 Muscle temperature*

The body can be warmed up in two different ways. Passive WU involves raising muscle- or core temperature by external heat whereas with an active WU, heat is produced by muscular activity. One potential benefit caused by increased muscular temperature is decreased resistance of muscles and joints. Studies have shown that an increase in temperature can significantly increase range of motion. The passive resistance of the human metacarpal joint decreases by 20% (Wright & Johns, 1961), and hip extension increases after 15 minutes of warm-up (Stewart & Sleivert, 1998). However, flexibility has not been correlated with injuries in Australian footballers (Orchard, Marsden, Lord & Garlick, 1997).

There is also another reason as to why exercise reduces muscle stiffness. A resting muscle develops stable bonds between actin and myosin filaments and the stiffness of the muscle increases (Enoka, 1994). With physical activity many of the bonds are broken, and muscle stiffness decreases (Proske, Morgan & Gregory, 1993). However, the stiffness again increases as the body temperature decreases during inactivity following exercise (Lakie & Robson, 1988; Galazoulas, Tzimou, Karamousalidis & Mougios, 2012). But on the other hand, static stretching has been shown to decrease sprinting properties (Nelson, Driscoll, Landin, Young & Schexnayder, 2005).

Additionally, increased muscle temperature is known to increase nerve conduction rate by increasing the transmission speed of nervous impulses (Karvonen, 1992). Elevated muscle temperature has also been shown to stimulate vasodilation of blood vessels and increased muscle blood flow (Barcroft & Edholm, 1943). The increase in oxygen delivery to muscles has been connected to the properties of hemoglobin. Oxygen dissociates twice as rapidly from hemoglobin at 41°C compared to 36°C in rabbits (Barcroft & King, 1909). While an increase in temperature should increase oxygen delivery to the muscles; this will not enhance aerobic energy production if the oxygen supply is sufficient. Despite this, active WU has not been reported to speed up phase II $VO_2$ kinetics during exercise in healthy adults at any intensity (Burnley, Jones, Carter & Doust, 2000). The phase II is known as the fundamental component in the $VO_2$ kinetics. The phase II response reflects the body's ability to adapt to an altered exercise load by the time the body uses to adapt to the new $VO_2$ demands towards a steady-state value (Manns, Tomczak, Jelani & Haennel, 2010).

Additionally, there is a limit to how much heat the human body can store. The heat produced by exercising muscles raises the body core temperature (Saltin, Gagge & Stolwijk, 1968). Long-term performance in hot environments appears to be limited by a critical core temperature (Kozłowski, Brzezińska, Kruk, Kaciuba-Uściłko, Greenleaf & Nazar, 1985). The muscle temperature at 40 mm depth ($T_{m40}$) is at rest about 35 °C (Saltin, Gagge & Stolwijk, 1968; Bishop, 2003a; Sargeant, 1987). Within 5 - 10 minutes of exercise the $T_{m40}$ rises, while the rectal temperature is constant at 37 °C (Bishop, 2003a). Rectal temperature is a good indicator of body core temperature (Saltin & Hermansen, 1966). First when $T_{m40}$ exceeds the rectal temperature it causes an increase in rectal temperature, thereby increasing the core temperature (Bishop, 2003a). Adding additional heat by extensive WU in hot environments may be crucial to performance up until an upper critical rectal temperature is reached (Nadel, 1987). Sargeant (1987) have evaluated leg extension force at different muscle temperatures at $T_{m40}$ and found an optimum at around 39 °C. There was an ~11 % increase in maximal peak force and power as well as the maximal mean power during 20-s of maximal sprint effort compared to resting temperature - 35 °C (Sargeant, 1987).

However, the effects of WU don't last for very long. Galazoulas et al. (2012) have shown that sprint performance in basketball players declines after only 10 minutes of inactivity and gradually declines until 40 minutes. Additionally 15 min of inactivity during halftime in a soccer game, decreased sprinting performance with 2.4% whereas an active break where the participants performed 7 minutes of relaxation followed by 7 minutes of running at 70% of maximum heart rate, kept sprinting performance unchanged (Mohr, Krustrup & Bangsbo, 2005).

## 2.2 Energy sources

The cells in the human body get their energy by breaking the molecular bonds in the adenosine triphosphate (ATP) molecule. During times of sufficient oxygen supply, during exercise below the anaerobic threshold, most of the ATP is produced by the breakdown of glycogen. However in very short explosive events such as 100 meter running a process that is more rapidly initiated is dominating. This process utilizes phosphocreatine (PCr) stored in the muscles (Söderlund & Hultman, 1991). The amount of PCr stored in the muscles is very limited and provides enough energy for about 5 seconds of maximal sprinting (Newsholme, 1986). However, when examining PCr concentration following a single 6 s bout of maximal exercise, muscle PCr concentration decreased by only 57% in healthy males (Gaitanos, Williams, Boobis & Brooks, 1993). This is explained by considerable contribution of anaerobic glycolysis and aerobic metabolism to the total ATP supply during short-duration maximal-sprint exercise (Medbø, Gramvik & Jebens, 1999). PCr degradation and anaerobic glycolysis are activated simultaneously during the initiation of maximal exercise (Hultman & Sjöholm, 1983). Therefore, the PCr stores will not be depleted until about 8-10 seconds (Gaitanos et. al. 1993). PCr depletion has also been related to training status of subjects (Hirvonen, Rehunen, Rusko & Härkönen, 1987). Hirvonen et al. (1987) demonstrated that PCr degradation was greater in a group of national level 100 m track sprinters who possessed a high maximal speed compared with sprinters with a lower maximal speed.

The resynthesis of PCr is an oxygen dependent process and can be restored in the muscle within 5-10 minutes with adequate recovery in both fast- and slow twitch muscle fibers (Harris, Edwards, Hultman, Nordesjö, Nylind & Sahlin, 1976). Studies have shown that further recovery can potentially lead to PCr levels above the resting levels prior to exercise (Tomaras & MacIntosh, 2011; Söderlund & Hultman, 1991; Zoladz, Korzeniewski, Kulinowski, Zapart-Bukowska, Majerczak & Jasiński, 2010). This PCr overshoot is thought to be associated with muscle acidification and a decrease in phosphorylation potential (Söderlund & Hultman, 1991; Zoladz et. al. 2010). However the ATP content has been shown to be lower in both fast- and slow twitch fibers after 15 minutes of recovery following intense muscle stimulation compared with resting levels (Söderlund & Hultman, 1991).

Even though PCr is predominantly used as an energy source in sprinting events, depletion of muscle glycogen can occur during short time of maximal exercise (Gaitanos et. al. 1993; Esbjörnsson-Liljedahl, Sundberg, Norman & Jansson, 1999). Glycogen concentration in muscles of the thigh fell 14% after a single 6 s bout of all-out cycle exercise (Gaitanos et. al.

1993), and a 30 s cycling sprint can reduce muscle glycogen by up to 27% (Esbjörnsson-Liljedahl et. al. 1999). During one single 6 s bout of all-out cycling 53 % of the energy consumption can be contributed from glycolysis (Boobis, Williams & Wooton, 1982). Depletion of glycogen in fast twitch fibers could play a role in fatigue during high intensity sprint exercise (Walberg-Rankin, 2000; Jensen, Rustad, Kolnes & Lai, 2011). Research conducted on Danish soccer players have shown that fewer maximal sprints in the end of the match were performed when their muscle glycogen levels were low (Krustrup, Mohr, Steensberg, Bencke, Kjaer & Bangsbo, 2006). Low glycogen levels were a better indicator of fatigue rather than $H^+$ and lactate (Krustrup et. al. 2006).

## *2.3 Muscle fibers*

The human muscles fiber types can be divided into two main categories; slow twitch (ST) and fast twitch (FT) fibers or simply type I and type II. The fibers can though be further classified (Andersen, Schjerling & Saltin, 2000). The type of myosin present in the fiber in addition to the degree of oxidative phosphorylation that the fiber undergoes determines contraction time for the muscle. The ST fibers solely rely on oxidative metabolism to generate ATP, while FT fibers can be both oxidative and glycolytic. Energy from oxidative metabolism is very energy efficient, but cannot contract as quickly as FT fibers. One the other hand FT fibers use energy less efficiently, but contract up to ten times faster than ST fibers. Both muscle fiber types contract with about the same amount of force (Andersen, Schjerling & Saltin, 2000).
As mention earlier energy is released by breaking the molecular bonds in ATP into ADP and free inorganic phosphate and resynthesized back into ATP. The different types of muscle fibers have at rest been shown to have different levels of especially the metabolites; PCr, free inorganic phosphate (Pi) and total creatine (Kushmerick, Moerland & Wiseman, 1992; Tesch, Thorsson & Fujitsuka, 1989). In muscles with a high fraction of FT fibers, Pi content is low and PCr and ATP contents are high. In muscles with a large fraction of type ST fibers, Pi content is high and PCr and ATP contents are low (Kushmerick, Moerland & Wiseman, 1992).
It has been hypothesized that it might be a difference in the recovery pattern of ATP and PCr in human single fibers (Söderlund & Hultman, 1991; Kushmerick, Moerland & Wiseman, 1992). Studies that have looked on PCr kinetics in isolated muscle fiber types have revealed that the recovery pattern of PCr following anaerobic exercise is fiber dependent. During the initial recovery period, when the oxygen stores are replenished, the ST fibers show a more

rapid resynthesis of PCr, probably due to a higher mitochondrial density and capillary supply (Söderlund & Hultman, 1991; Kushmerick, Moerland & Wiseman, 1992). Biopsies taken immediately after intermittent electrical stimulation and after 20 s, 60 s, 5 min, and 15 min of recovery showed significant differences in PCr and ATP recovery. After exercise, PCr was depleted in both fiber types. After the 60 s of recovery the PCr content in ST fibers was significantly higher compared with FT fibers, but, after 5 min of oxidative recovery, the PCr levels were equal in the two fiber types. Fifteen minutes post-exercise, FT fibers demonstrated a significantly higher content compared with its resting value. However, after 15 min of recovery, ATP was resynthesized to 95 and 76% in ST and FT fibers, respectively. The contents of lactate, and glucose were both still higher in mixed muscle tissue after 15 min of recovery compared with resting contents (Söderlund & Hultman, 1991).

## *2.4 Postactivation potentiation*

The definition of postactivation potentiation (PAP) is that previous muscle contractions influence the mechanical performance of subsequent muscle performance (Robbins, 2005). After any exercise, muscle contractile response can be decreased by fatigue or enhanced by PAP. PAP has the greatest potential in muscle with high proportion of FT fibers (Grange, Vandenboom, Houston, 1993). The phenomenon is typically induced from maximum voluntary contractions (MVC), but has also been induced by submaximal contractions (Mitchell & Sale, 2011). PAP is thought to be a consequence of regulatory light chain phosphorylation increasing neuromuscular activation by making actin-myosin more sensitive to calcium (Moore & Stull, 1984). WU with a high intensity component of MVC, such as sprinting, may cause PAP (Tomaras & MacIntosh, 2011; Young, Jenner & Griffiths, 1998). The time from MVC to the performing event seems to be a crucial factor as to whether PAP will enhance the performance or not (Tomaras & MacIntosh, 2011; Young, Jenner & Griffiths, 1998; Hamada, Sale, MacDougall & Tarnopolsky, 2000).

The sport track and field is pretty unique by having a mandatory call room prior to individual events. In the call room competition equipment and uniforms (e.g. bib numbers, shoes and spikes) are controlled to meet prescribed measurements and regulations. Athletes who fail to appear on time in the call room without a valid reason are usually excluded from participating. Once the call room procedures have been completed, a judge escorts the athletes to their event.

## *2.5 Injuries*

An injury can be defined as a physical problem severe enough to force a reduction in training. The beliefs that running speed, running surface, and body weight are closely related to the risk of injury are deep-rooted in the running community. However, these beliefs lack scientific evidence (van Mechelen, 1992). A Research (Marti, Vader, Minder & Abelin, 1988) with 4,358 male joggers, occurrence of jogging injuries was associated with higher weekly mileage, history of previous running injuries, and competitive training motivation, rather than running speed, surface etc. During the 1 year study period, 45.8% had sustained jogging injuries and 14.2% had required medical care. Higher mileage was also associated with more frequent medical consultations caused entirely by jogging-related injuries (Marti et. al. 1988; Walter, Hart, McIntosh & Sutton, 1989). Additionally the effects of better knowledge about standardized warm-up, cool-down, and stretching exercises among 326 male recreational endurance runners have been investigated (van Mechelen, Hlobil, Kemper, Voorn & de Jongh, 1993). They were matched for age, weekly running distance, and general knowledge of preventing sports injuries and were randomly split into an intervention group and a control group. The intervention group was educated on prevention of running injuries while the control group did not. During the 16-week study, injury incidence for control and intervention subjects was 4.9 and 5.5 running injuries per 1000 hours, respectively. The intervention was not effective in reducing the number of running injuries, but was significantly effective in improving specific knowledge of warm-up and cool-down techniques in the intervention group (van Mechelen et. al. 1993). Studies that have recorded injuries among recreational runners during a 12-month period show that about 50 % of the runners experienced at least one injury, but almost half of the injuries were recurrences of previous problems. Runners who were injured in the previous year had approximately a 50% higher risk for a new injury the following year (Walter et. al. 1989; Macera, Pate, Powell, Jackson, Kendrick & Craven, 1989; van Mechelen, 1992). This means that standard therapeutic approaches to running injuries (e.g., rest, icing, and anti-inflammatory medications) are effective over the short but not the long term. Scientific support for strength training as an injury preventer is well documented (Henja, Rosenberg, Buturusis, Krieger, 1982). Many injuries are caused by weak muscles which simply are not ready to handle the specific demands of the sport. Research carried out with tennis players reveal that athletes who do not carry out regular resistance training have a much higher incidence of common injuries such as “tennis elbow” (Gruchow & Pelletier, 1979). Additionally, competitors who undergo a preventative resistance training program after developing tennis elbow have only about a 30% re-occurrence of symptoms, compared to 41% in those who did not strength train. Hamstring muscle strain is the most prevalent injury in track sprinters. Orchard et. al. (1997) demonstrated in Australian Footballers that injured hamstring muscles were all weaker than in the opposite leg, in terms of absolute values and hamstring-to-quadriceps muscle ratios. Muscle weakness has also been reported to play an important role in shoulder injuries in elite volleyball players (Wang & Cochrane, 2001), swimmers (Hawkins & Kennedy, 1980), as well as hip pain in recreational runners (Niemuth, Johnson, Myers & Thieman, 2005). Therefore muscle imbalance screening is being used as an injury-prevention strategy in some sports (Kemp, 2000).

## *2.6 Literature review*

Studies evaluating different types of WU have been done on quite different sports, both anaerobic as well as aerobic. Athletes competing in track cycling events traditionally perform a WU with duration up to 50 min of high intensity prior to a 200 m sprint (Tomaras & MacIntosh, 2011). Tomaras and MacIntosh (2011) designed with guidance of coaches an experimental WU protocol with much lower intensity, fewer maximal sprints and a total duration of 17 min. Following WU, competitive athletes recruited from the Calgary Track Cycling League then performed a highly anaerobic 30 s Wingate test. There was a 12.5-min rest period between the WU's and the Wingate test.

The results showed higher mean power, higher total work done and higher peak power output during the Wingate test after the experimental WU of shorter duration compared to the traditional WU. Mean skin temperature was not significantly different between the two WU protocols. However the mean peak active torque following experimental- and traditional WU, actually showed a lower value compared to resting levels prior to WU. The change in blood lactate concentration during the Wingate test was somewhat greater after the experimental WU, suggesting a greater anaerobic contribution to power production in the early stages of the Wingate compared to the traditional WU.

Balilionis et. al. (2012) evaluated three different types of WU protocols prior to a 50 yd (45.72 m) maximal effort swimming time trial in freestyle technique. The subjects (n=16) were competitive swimmers at a high level. The first WU protocol was no activity at all, only rest for 3 min. The second WU protocol was swimming 100 yd at increasing intensity up to 90% of their maximal effort. The third WU protocol was the athletes own pre-competition swim WU with an average length just over 20 min. There was a 3 min resting period between the WU's and the 50 yd time trial. The group mean 50 yd time trial was significantly faster after regular WU compared with the short WU. However, individual data indicated that 19% of the participants swam their best 50 yd time after a short WU, 37% after no WU, and 44% after regular WU. Which means more than half of the swimmer swam faster with a less intense WU protocol than their own pre-competition WU routine. No significant differences were found for reaction time between WU and lack of WU (Balilionis et. al. 2012).

In young football players, 40 m sprint performance has been evaluated following three different WU protocols (Ismail, Mazaulan, Hasan & Raja, 2010). Twenty five football players aged 15.6 ± 0.70 yrs completed in randomized order three WU protocols; no warm-up, 15 min of static warm-up or 10 min of dynamic warm-up. There was a 3 min resting period between the WU and the sprint measurements. Post Hoc comparisons revealed that participants' sprint performances were significantly faster following no warm-up (5.39 ± 0.14 sec) compared to static warm-up (5.57 ± 0.21 sec) and dynamic warm-up (5.54 ± 0.21 sec).

It seems that there are possible benefits of WU, but the unavoidable delay between WU and the performing event may be crucial. And what if the achievement of all these possible beneficial mechanisms also leads to fatigue? Earlier studies evaluating different WU protocols have shown large individual variation in responses (Balilionis et. al. 2012). Highly trained athletes have been shown to perform better with WU of a low intensity or without any WU in the initial stage of an event (Balilionis et. al. 2012; Ingham, Fudge, Pringle & Jones, 2013; Mujika et. al. 2012). Tomaras and MacIntosh (2011) showed on sprint track cyclists, a greater cycling power output following a shorter WU with lower intensity compared with a regular WU of high intensity. Therefore it is possible that some athletes might benefit from refraining from high intensity exercise in the form of WU prior to an event with very short duration.

# 3 Aim

Despite the potential benefits, most warm-up procedures used by athletes and coaches are based on practical experience and tradition rather than scientific evidence, and little is known about the best warm-up practices for specific sports (Bishop, 2003b). There is always a fine line between fatigue and enhanced performance following WU. Therefore, the aim of this study was to develop an optimized warm-up procedure for competitive sprint athletes. With previous studies in mind, this study investigated whether a shorter and less intense WU protocol could be beneficial for short time trials such as 60 m running.

In addition to a traditional high-intensity WU protocol (LONG), a low-intensity WU protocol (SHORT) was designed with shorter duration and lower intensity with elements from LONG to prevent any degree of fatigue and keep the ATP and PCr levels in the FT fibers at a higher level throughout the WU. To see whether WU had an effect on sprint performance at all, a maximal effort time trial with no prior physical activity was used as control (CON). The hypothesis was that the athletic performance would be better following SHORT, and a lesser degree of fatigue compared to LONG.

# 4 Methods

## *4.1 Participants*

Five (5 male) highly trained athletes recruited from *Dala Sports Academy* volunteered to participate in the study which had received ethical approval from the Research Ethics Committee at Dalarna University. All procedures in the study were performed according to the Declaration of Helsinki. The participants were not competitive track runners, but cross country skiers at national level and familiarized with track running. Their normal competition time, range from 2-40 min. The study participants were chosen because the test location was situated adjacent to their training facility. Participants' physical characteristics are presented in Table 1. The study took place when the participants had finished their competitive season. Participants were informed that the purpose of the investigation was to compare the effects of different warm-up procedures, but not aware of the study hypothesis. The participants were instructed to avoid strenuous exercise for 48 h prior to each testing session. Participants were asked to arrive into the laboratory adequately hydrated and having refrained from consuming alcoholic beverages for 24 h and food or caffeine for 3 h before each test. No other limitations were given to their diet as long as they tried to eat the same before the test occasions. The participants were free to stretch as they liked as long as it was done equally on all test occasions. Changing of stretching routine has been shown to increase the rate of injury by 40% (Pereles, Clanton & Kaeding, 2007). Participants were excluded from the study if an acute injury occurred or the participant had had any type of surgery or injury that may have resulted in an increased risk of exercise participation. All the recruited study participants completed the study.

Table 1 – Participants' Physical Characteristics

| Characteristics | Male (n=5), Means ± SD |
|---|---|
| Age | 24.2 ± 1.6 years |
| Height (cm) | 179.6 ± 8.8 cm |
| Weight (kg) | 78.4 ± 7.8 kg |

### 4.2 Study design

The study had a randomized, crossover design. Three different WU protocols were performed on three different occasions. The three test occasions was separated by at least 48 hrs. For each participant, all 3 tests were completed within 7 days. The study participants performed a maximal effort 60 meter sprint on an indoor synthetic track following three different WU protocols. Testing conditions were constant at 20°C. It would have been appropriate to measure muscle temperature and muscle metabolites, but is not possible without taking biopsies. This study did not have the funding or opportunity to take biopsies.

Prior to the testing sessions, study design and procedures were explained, participants' height and weight were recorded. The study participants were asked to wear heart rate monitors at all time to easily control the intensity during WU. Participants' maximum heart rate was self-reported. The participants were followed by personnel during the WU's to make sure everything was done correctly.

The traditional high-intensity WU protocol (LONG) was designed with guidance of elite level coaches to make it relevant to a common WU procedure for competitive athletes. However, some common WU drills were excluded to make it manageable for study participants without an extraordinary range of motion. The experimental WU protocol (SHORT) was designed with elements of LONG, but with shorter duration and fewer sprints. The recovery period between the WU and the start signal in sporting events is most likely to be much larger because of waiting in call rooms and transportation to the competition site (Ingham et. al. 2013). Since studies have shown that sprinting performance rapidly decreases during inactivity (Galazoulas et. al. 2012; Mohr, Krustrup, Bangsbo, 2005), one of the important objectives for SHORT was to shorten the time of inactivity. The recovery times after the WU protocols were set to have equal length to avoid the recovery duration as a determining factor of the outcome. During the recovery period the participants were not allowed to sit or lay down, but had to stand up or stroll inside a designated area. The subjects put on warm clothes to prevent any heat loss during the recovery period. The participants were free to use the recovery period for mental preparation (e.g., listen to music and visualize the event) as long as it was done equally at all test occasions.

The three WU protocols are described in details in Tables 2-4 and briefly described below. LONG consisted of 10 min easy running followed by a series of mobility drills. Then 5 sprints were performed at 90-95% of maximal effort with 3 min break in between before the participants had 10 min of preparation before the time trial. SHORT consisted of 10 min easy running followed by one sprint at 90-95% of maximal effort before the participants had 10 min of preparation before the time trial. In the CON group the participants only did mental preparation for 10 min before the time trial.

Table 2. Traditional warm-up protocol

| Time, min:s | Classification | Description |
|---|---|---|
| 0-10 min | General warm-up | Running at 65-75% of $Hr_{max}$, with increasing intensity |
| 10-17 min | Mobility drills | Standing on one leg, while moving the opposite leg back and forth, 15 times on each leg, repeated 2 times<br>running with high knees, less than 90° knee angle, 10 times on each leg, repeated 3 times<br>running with quick, short steps in rings, 15 rings, repeated 3 times. |
| 18 min | Sprint | 40-50 m sprint, 90-95% of maximal effort |
| 19-22 min | Recovery | Walking or easy jog |
| 22 min | Sprint | 40-50 m sprint, 90-95% of maximal effort |
| 23-26 min | Recovery | Walking or easy jog |
| 26 min | Sprint | 40-50 m sprint, 90-95% of maximal effort |
| 27-30 min | Recovery | Walking or easy jog |
| 30 min | Sprint | 40-50 m sprint, 90-95% of maximal effort |
| 31-34 min | Recovery | Walking or easy jog |
| 34 min | Sprint | 40-50 m sprint, 90-95% of maximal effort |
| 35-45 min | Recovery | Standing or strolling inside a designated area |

Table 3. Experimental warm-up protocol

| Time, min:s | Classification | Description |
|---|---|---|
| 0-10 min | General warm-up | Running at 65-75% of $Hr_{max}$, with increasing intensity |
| 10 min | Sprint | 40-50 m sprint, 90-95% of maximal effort |
| 11-21 min | Recovery | Standing or strolling inside a designated area |

Table 4. Control protocol

| Time, min:s | Classification | Description |
|---|---|---|
| 0-10 min | Recovery | Standing or strolling inside a designated area |

## *4.3 Time trial performance*

The maximal effort time trial measured how fast each participant completed 60 m of track running on a 60 m indoor track. A longer time trial such as 100-200 m would have been more appropriate since the PCr storage would have been completely depleted which means the performance is depending even more on the levels of glycogen in the FT fibers. However, such time trial was not possible indoor because of the test location and time of year. Additionally, an indoor track is preferable because the results are not influenced by wind or other weather conditions as compared to an outdoor track. Exercise tests were conducted at the same time of the day ± 2 h for each subject.

IVAR timing system (SH Sport & Fitness, Mora, Sweden) was used to time the maximal effort time trials. The timing system consists of photocells. The clock starts and stops when the light beam is broken by the participants at start and finish. At the start, the participants were given the verbal command “ready” and two clapping hands functioned as the start signal. The clock started when the subjects passed the first photo cell which was placed 1 meter after the starting line so variations in the reaction time would not affect the results. However, reaction time has not been affected by WU procedures in highly trained swimmers (Balilionis et. al. 2012). Photocells were also placed at 30 m and 50 m to measure split times during the time trial. Ideally, splits should have measured every 10 m section to be able to measure every phase of the time trial, but with the photocells and equipment available it was unfortunately not manageable. Running speed was calculated from recorded time between the photo cells. The participants were free to use starting blocks as long as they used it on all test occasions. The stride rate was counted in the 60 m time trial. The study participants did not get any encouragement from the testing personnel during the maximal effort time trials. The test location was quiet and free from disturbances on all test occasions. The participants did not get to know their test results before all tests were completed.

### *4.4 Performance rating*

The study participants rated how satisfied they were with their time trial performance without knowing their time, on a scale designed for this specific study. The scale ranged from 1-10 where 1 is the lowest and 10 is the highest satisfaction. The participants also rated how satisfied they were with the warm-up as preparation for the time trial on the same 10-point scale. Since WU is deep-rooted in the sport society, it was important to investigate whether the running performances corresponded to participants' sensation of the time trial and the WU protocols. The performance rating would hopefully also give answer to what WU protocol participants favored the most.

### *4.5 Ethical considerations*

It is well accepted that activity of increasing intensity prior to maximal effort exercise prevents injuries. However, studies evaluating injuries in competitive sports are divergent on warm-up as injury prevention (Fradkin, Gabbe & Cameron, 2006). A review by Fradkin, Gabbe and Cameron (2006) suggests that there is insufficient evidence that WU will reduce the risk of exercise-related injury. The muscle temperature was thought to be approximately the same following the two WU protocols including prior physical activity. Athletes in explosive sports such as 60 meter sprint will always have the risk of injuries including straining and pulling muscles. However, since long time is spent on recovery between the WU and the performing event (Ingham et. al. 2013), the muscle temperature may not be of high importance. Therefore the risk of severe injuries was considered as very low.
Scientists have recently revealed that if warm-up stretches are part of the WU routine, one should not stop immediately. They found that runners who changed their stretching routine had a 40% higher rate of injury (Pereles, Clanton & Kaeding, 2007). Even though there is no reason to believe stretching prevents injuries itself, one should rather slowly taper down the

amount of stretching as the part of WU than stop immediately. The testing facility is provided with common first aid equipment in case of an acute injury.

Another possible benefit of WU is the psychological aspect. Without a proper or regular WU protocol the athletes are used to, they might not be mentally ready. This time trial was of very short duration and did not include any complex movements or possibly dangerous situations, and was considered safe at any mental stage.

All study participants was provided informed written consent to participate in the experimental procedure in advance. The results were coded so that it was not identifiable to an individual and was stored in a secure manner. Each participant was referred to as a number in the study. No names of the participants were published.

## *4.6 Statistical analysis*

All statistical analyses were performed on a commercially available statistical platform (SSPS Version.16, Illinois, Chicago, USA). The running performances were tested statistically with student's paired t-tests and one-way ANOVA. Values of $P < 0.05$ were considered significant. Data were reported as means and standard deviations (SD). To estimate the sample size needed to measure significant differences between the WU protocols, a two-tailed statistical power test (80%) was used. With the observed differences, the sample size needed to be significant was estimated to be 45 with the .80 convention (SD 0.1). And with the sample size of five, the effect size was estimated to be 0.18 sec.

# 5 Results

All of the study participants were highly motivated throughout the testing period. None of the study participants chose to incorporate stretching in their WU or the use of starting blocks in their maximal performance time trials. Results for the one-way repeated measures ANOVA showed no significant differences among the different WU protocols (P = 0.20) in 60 m performance. The counted stride rate was not significantly different (P = 0.73) between the WU protocols.

The mean running speeds calculated from the split times of the time trials are shown in Figure 1. The split times indicated that the participants progressively lost time following CON compared to the other two WU protocols. At half the time trial distance (30 m), the mean speed of LONG (6.75 ± 0.09 $ms^{-1}$) and SHORT (6.76 ± 0.05 $ms^{-1}$) were almost identical with no significant differences between any of the WU protocols (P = 0.31). It appeared that participants were significantly faster following SHORT (7.99 ± 0.22 $ms^{-1}$) compared to LONG (7.77 ± 0.33 $ms^{-1}$) in the final 10 m of the time trial (P = 0.05).

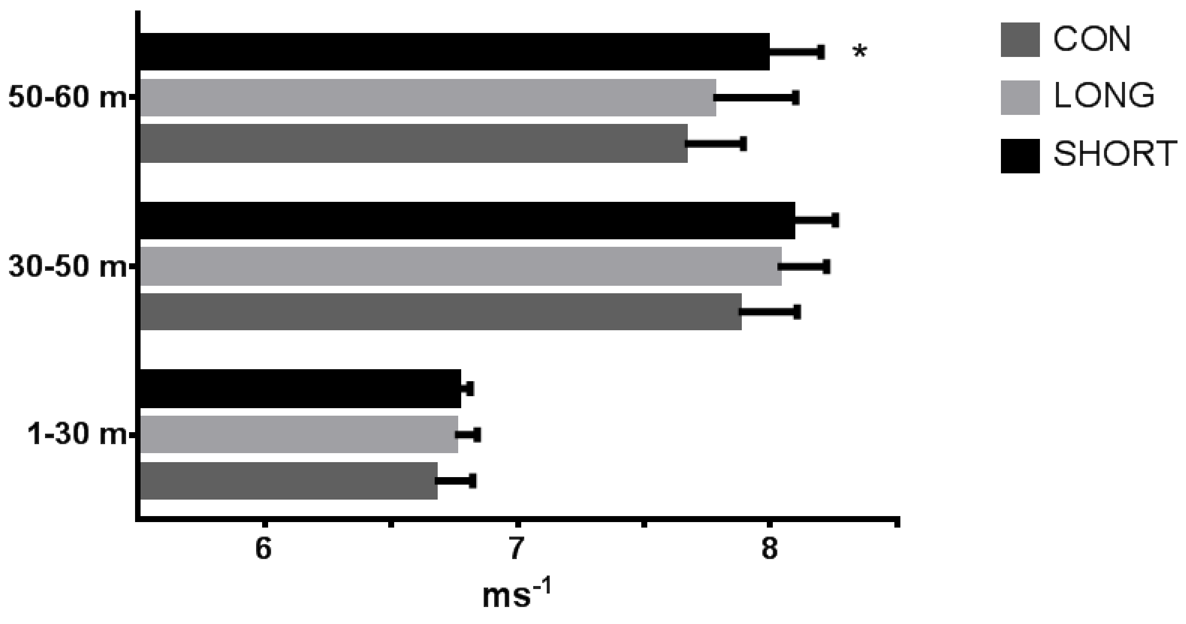


**Figure 1** – The mean running speed separated into three sections of the time trial. *Significant difference between traditional and experimental WU (P < 0.05).

Individual results of the 60 m time trial for two of the subjects along with group mean are shown in figure 2. Subject 1 experienced a lot slower time after CON (8.56 s) compared to LONG (8.10 s) and SHORT (8.01 s). Subject 2 performed the slowest time after LONG (8.19 s) and showed similar times between CON (8.06 s) and SHORT (8.04 s). The mean 60 m running times were faster for SHORT (8.02 ± 0.10 sec) than for LONG (8.08 ± 0.16 sec) and CON (8.20 ± 0.21 sec). 4 of 5 participants experienced their fastest time trial following SHORT. On average, study participants were 1% faster following SHORT compared to LONG and 2.2% compared to CON. However, no significant differences were found between CON and LONG (P = 0.32), CON and SHORT (P = 0.14) or between SHORT and LONG (P = 0.17) on 60 m sprint performance.

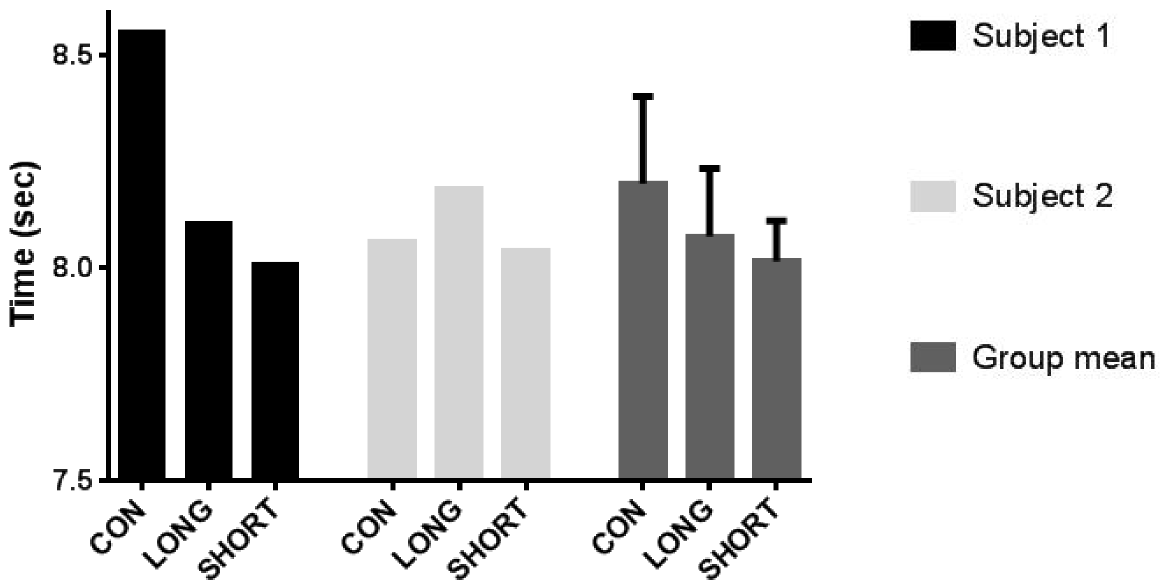


**Figure 2** – Individual results of the 60-m time trial for two of the subjects.

Individual results for all of the study participants are presented in Table 5. Next to the times of the different time trials, their own performance ratings are also presented. There is a strong correlation between time trial performance and self-reported performance rating, however, not always. Subject 2 and 5 performed almost identical results following CON and SHORT, but have rated their performance for CON lower compared to SHORT.

Table 5. Individual results of the 60 m time trial along with participants' performance rating.

| | CON | rating | LONG | rating | SHORT | rating |
|---|---|---|---|---|---|---|
| Subject 1 | 8.56 | 2 | 8.10 | 4.5 | 8.01 | 6 |
| Subject 2 | 8.06 | 5 | 8.19 | 6 | 8.04 | 6 |
| Subject 3 | 8.08 | 5 | 7.81 | 6 | 7.86 | 7.5 |
| Subject 4 | 8.20 | 4.5 | 8.08 | 7 | 8.07 | 7.5 |
| Subject 5 | 8.10 | 6 | 8.21 | 6 | 8.10 | 7.5 |
| Group Mean | 8.20 | 4.5 | 8.08 | 5.9 | 8.02 | 6.9 |

Figure 3 shows the results of the combined scores of the participants rating of their own time trial satisfaction and the evaluation of the warm-up as a performance enhancer. The score result from the participants warm-up evaluation were not significantly different from their time trial satisfaction ($P = 0.59$). The combined scores were significantly different ($P < 0.02$) following the different warm-up protocols. The study participants scored CON lowest (4.5), followed by LONG (5.9) and SHORT (6.9).

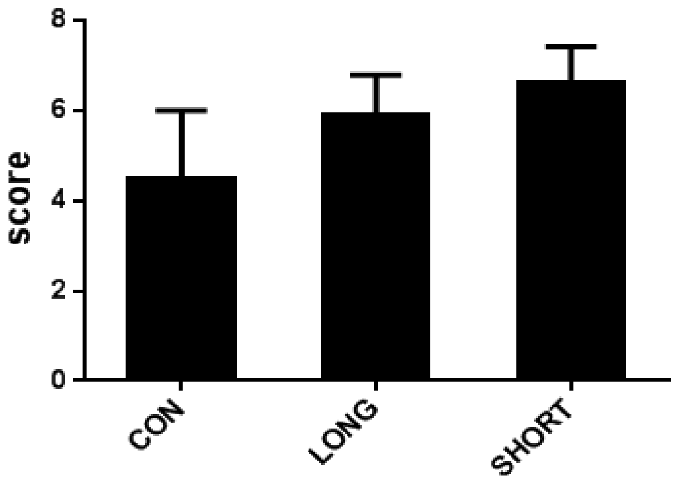


**Figure 3** – The study participants' self-reported performance rating. The combined scores of the participants' evaluation of the warm-up as a performance enhancer and satisfaction of their own 60 m time trial performance on a 10 point scale.

# 6 Discussion

## *6.1 Time trial performance*

The intent of this study was to investigate the effects of three different warm-up protocols (no warm-up, short warm-up and traditional warm-up) on 60 meter running performance.

Active warm-up has been reported to increase muscle and core temperature within five minutes (Bishop, 2003a&b). With WU, we would expect to see faster times in the maximal effort time trials due to breakage of myosin bonds, decreased muscle stiffness (Proske, Morgan & Gregory, 1993) and increased range of motion (Wright & Johns, 1961; Stewart & Sleivert, 1998). Additionally, an increase in muscle temperature can potentially increase the transmission speed of nervous impulses (Karvonen, 1992) and stimulate vasodilation of blood vessels and thereby increase muscle blood flow (Barcroft & Edholm, 1943).

The results of maximal effort time trial with no prior physical activity that served as control (CON), did not show a significant difference compared to the WU protocols with prior physical activity ($P = 0.20$). This might be due to a small sample size ($n = 5$) and a large standard deviation, since 4 of 5 study participants performed their slowest time trial without any prior activity. Thereby 80% of the participants performed better with prior physical activity compared to the control group. Even though the same amount of time was spent on mental preparation between WU and the 60 m time trial, previous research has shown that WU increases preparedness and provides time to concentrate before an event (Bishop, 2003a). This might be one explanation why most of the participants ran slower in their time trail without any WU. Another explanation can be lack of PCr overshoot in the control group compared to the other two WU protocols.

Since both LONG and SHORT included sustained activity for more than five minutes, we would expect muscle temperature after both WU protocols to have reached temperature optimum (Saltin, Gagge & Stolwijk, 1968). The mean times of the maximal effort time trial are presented in Figure 1. The results indicate that both LONG and SHORT WU protocols led to better time trial performance than the control group. 4 of 5 study participants performed their fastest time trial following SHORT WU. This might indicate that fatigue after LONG WU. The running times following SHORT had a smaller standard deviation compared to LONG, making the WU protocol more predictable to individual responses.

All WU protocols included 10 minutes of recovery between WU and the maximal effort time trial. This resting period was to simulate a call room at a competitive event. Galazoulas et al.

(2012) have revealed that there is a relatively fast decline in muscle temperature thus jumping and running performance when basketball players remained inactive after warm-up. Already 10 minutes after WU, the players sprinting properties were significantly decreased and gradually continued to decrease up until 40 min after WU completion. Therefore, the recovery period between the WU and the performing event might have a big impact on the sprint performance. Additionally, the holding of athletes at a competitive sprinting event usually is much longer, up to 20-40 min, during which time supplementary preparation is limited (Ingham et. al. 2013).

## *6.2 Final stage of time trial*

Highly trained athletes have been shown to perform better with WU of a low intensity or without any WU in the initial stage of an event (Balilionis et. al. 2012; Ingham et. al. 2013; Mujika et. al. 2012). This somewhat interfere with the theory of breakage of myosin bonds, decreased muscle stiffness, increased range of motion etc. However, the results of this study, shown in Figure 1, suggest otherwise. There are no significant differences in running speed between the WU protocols in the initial part of the 60 m time trials. The split times indicated that the participants progressively lost time following CON compared to the other two WU protocols. Interestingly, the significant differences in running speeds were found in the final 10 m of the time trial ($P = 0.05$). Participants running time trial following LONG, lost on average 0.04 sec the final 10 m compared to SHORT. This may not sound like a lot, but when taken into consideration that the mean difference of the entire time trial was only 0.06 sec, the time loss during the final 10 m accounts for 67% of the loss in time trial performance following LONG. If the time trial was to be 100 m and not 60 m, one might hypothesize that the gap would have been larger. Hypothetically, 0.20 sec, if the study participants had continued in the same speed as in the final part of the 60 m time trial. However, the participants had a decline in running speed in the final 10 m following all the three WU protocols. The reason for this might be mental circumstances. The participants see the finish line and slow down before crossing it.

The reason why the participants experienced a greater decline in running speed in the final part of the time trial following LONG compared to the other WU protocols is unclear. One likely possibility is that the muscles were fatigued following the intense LONG WU. Depletion of glycogen in fast twitch fibers can play a role in fatigue during high intensity sprint exercise (Walberg-Rankin, 2000; Jensen et. al. 2011). There is a big risk that muscle glycogen can be depleted following a high intensity WU (Gaitanos et. al. 1993). Another possibility is that the PCr levels in the muscles were not fully restored before the time trial. Fully restored muscles, get depleted within 8-10 seconds (Gaitanos et. al. 1993) due to considerable contribution of anaerobic glycolysis and aerobic metabolism to the total ATP supply during maximal-sprint exercise (Medbø, Gramvik & Jebens, 1999). In a research with 100 m sprinters, a decline in running speed after 5-7 sec in a 100 m maximal effort time trial was explained by reduced energy supply from high-energy phosphate Hirvonen et al. (1987). This corresponds well to the decline in running speed in the final 10 m following LONG in our study. There are strong reasons to believe the depressed results following LONG were caused by muscular fatigue. Lactate levels were not measured in this study since $H^+$ and lactate levels are not a good indicator of fatigue (Krustrup et. al. 2006).

## *6.3 Individual responses*

Earlier studies evaluating different WU protocols have shown large individual variation in responses (Balilionis et. al. 2012). This study is no exception. Figure 2 illustrates individual data of two of the study participants as well as group mean. Even though 80% of the participants performed their fastest time trial following SHORT WU, two of the participants showed no improvement in time trial performance following a physical active WU compared with CON with no prior physical activity at all. This reveals that mental preparation might be of higher importance than the actual WU. As mentioned, WU has been reported to increase preparedness before an event (Bishop, 2003a). There is likely to be individual differences in the study participants' abilities to concentrate on the time trial without prior WU. In other words competitive athletes must customize their WU procedures for optimal performance. Competitive athletes should therefore explore whether their current WU provide optimal preparation for competition.

## *6.4 Performance satisfaction*

The study participants were asked immediately after completion of the maximal effort time trial about their satisfaction of their time trial performance and how well the WU functioned as performance enhancement. The mean results of the combined score are shown in Figure 3. The mean scores were significantly different ($P < 0.02$) following the different warm-ups and were very much related to the mean results of the time trial performance. Not surprisingly the scores showed that when the participants were satisfied with their time trial performance, they were convinced that the WU had a positive impact on their time trial performance as well. The study participants did not get to know results of their time trial performance before the study period was completed. The purpose of the self-reported performance rating was to investigate whether the participants had a negative attitude to some of the WU protocols. Individual data shows that participants' satisfaction did not always correspond with their time trial performance. The participants tended to give low scores on their best time trial performance compared to the two other time trials. However, the overall mean performance ratings corresponded well with the time trial performances. Even though the study participant were competitive athletes, it is not always easy to rate the performance before looking at the time especially when one is not used to the duration of the event. To investigate individual responses to warm-up is thereby even more important to optimize individual sprint performance.

## *6.5 Recovery period*

Some of the study participants also commented that they felt the recovery period was too long. The recruited study participants were competitive in fairly aerobic sports, which mean they most likely have a high percentage of slow twitch muscle fibers. ST fibers have a more rapid resynthesis of PCr, due to a higher mitochondrial density and capillary supply (Söderlund & Hultman, 1991; Kushmerick, Moerland & Wiseman, 1992).
PCr overshoot is thought to occur within 5-10 minutes with adequate recovery and oxygen availability (Harris et. al. 1976). This PCr overshoot is thought to be associated with muscle acidification and a decrease in phosphorylation potential (Söderlund & Hultman, 1991; Zoladz et. al. 2010). As mentioned the recovery time between WU and the performing event for competitive sprint athletes is much larger (Ingham et. al. 2013). Not only is this a possible explanation to why CON were slower than the other two groups, but a longer recovery period following WU might diminish the positive effects of PCr overshoot on sprint performance. The recovery period is likely to equalize the differences in time trial performance between the WU protocols. It is interestingly since many of the study participants meant 10 min of recovery was too much. If a theoretically optimal WU procedure is not possible because of mandatory call rooms were little physical activity is possible, the structure of the sport is far from perfect. Some track and field events actually have closure of the call room 70 minutes prior to start of their event (Athletics Canada, 2013). And since muscle temperature and sprinting ability reach resting levels after only 40 min of inactivity (Galazoulas et al. 2012), it is easy to understand the procedures of call rooms do not support maximum performance.

## *6.6 Limitations*

In this study male cross country skiers were used as study participants. The reason why track sprinters were not chosen as subjects, was simply because no one wanted to participate and risking having injuries in their specific competition preparation period. However, it would have been preferable to use competitive track sprinters as they are more used to the running surface, time trial distance, more likely to have higher percentage of fast twitch muscle fibers and capable of greater PCr degradation (Hirvonen et al. 1987).

The sample size of this study was only five (N=5) which was not sufficient to achieve a significant result even though there was between 1-2.2% differences in running times following the different warm-up protocols. It would have taken 45 study participants with the current results to conclude with 95% certainty. With the standard deviation in the experimental group (0.1) the effect size needed for a significant result was estimated to be 0.18 sec. With large individual responses to some of the WU protocols, the effect size would have to be even larger for a significant result with the current sample size. Even though the results were not significant, the small standard deviation in the experimental group and 1% difference in running times between LONG and SHORT makes the results highly relevant to competitive athletes.

Split times were only recorded at two points in the time trial. With only three split times from the time trials, important investigations of the running speed might have been left out. Perhaps the distance for the acceleration phase was too long. With continuous measurements of speed it would have been possible to determine at what point the running speed was at the highest level and at what point the running speed started to decline.

Because the time trials were performed on nonconsecutive days it was necessary to set up and take down the photo cells after every test occasion. The photo cells were placed on marked spots on the running track, but minor variations in the set-up might have happened. Even though tiny differences in the running times might have happened, it is unlikely the outcome of the study was affected. With the mean running speed the participants had with the experimental warm-up in the last 10 m, they ran the last 0.5 m in 0.06 sec. With the traditional warm-up protocol the participants were on average 0.06 sec slower compared to the experimental warm-up protocol. This means that when the group mean finished the time trial following the experimental warm-up, the group mean still had 50 cm to run following the traditional warm-up.

# 7 Conclusions

Without being able to measure many variables related to sprint performance, it is difficult to determine the outcome the study. The shorter less intense warm-up protocol produced, on average, faster mean 60 m times than the other two WU protocols with a significant difference in the final 10 m (P = 0.05). Additionally, prior physical activity produced faster 60 m times compared to the control group. On the basis of the observed decline in running speed following the traditional warm-up protocol, we conclude from this study that a shorter, less intense WU can possibly benefit athletes competing in sprint running events. Previous studies evaluating different WU protocols have mainly focused on events with duration longer than 20 sec (Balilionis et. al. 2012; Ingham et. al. 2013; Mujika et. al. 2012; Tomaras & MacIntosh, 2011). This study confirms that a shorter less intense WU might have a positive impact on sprint performance in events <10 sec as well. There was big individual variation in responses to WU and further research needs to be done on WU protocols in sprinting events to optimize WU for individual athletes.

## References

Andersen, JL, Schjerling, P, Saltin, B. (2000). Muscle, Genes and Athletic Performance, *Scientific American*, vol. 283(3), pp. 48-55.

Athletics Canada, *2013 Canadian Track and Field Championships*, http://moncton2013.com/documents/2013_Moncton_Technical_Manual.pdf, [2013-05-02]

Balilionis, G, Nepocatych, S, Ellis, CM, Richardson, MT, Neggers, YH, Bishop, PA. (2012). Effects of different types of warm-up on swimming performance, reaction time, and dive distance, *J Strength Cond Res*, vol. 26(12), pp. 3297-3303.

Barcroft, J, King, WOR. (1909). The effect of temperature on the dissociation curve of blood, *J Physiol*, vol. 39(5), pp. 374-384.

Barcroft, H, Edholm, OG. (1943). The effect of temperature on blood flow and deep temperature in the human forearm, *J Physiol*, vol. 102(1), pp. 5-20.

Bishop, D. (2003a). Warm Up I. Potential Mechanisms and the Effects of Passive Warm Up on Exercise Performance, *Sports Med*, vol. 33(6), pp. 439-454.

Bishop, D. (2003b). Warm up II: performance changes following active warm up and how to structure the warm up, *Sports Med*, vol. 33(7), pp. 483–498.

Boobis, L, Williams, C, Wooton, SA. (1982). Human muscle metabolism during brief maximal exercise in man, *J Physiol*, vol. 338, pp. 21-22P.

Burnley, M, Jones, AM, Carter, H, Doust, JH. (2000). Effects of prior heavy exercise on phase II pulmonary oxygen uptake kinetics during heavy exercise, *J Appl Physiol*, vol. 89(4), pp. 1387-1396.

Enoka, RM. (1994). Acute adaptations, In: Enoka R.M, editor, *Neuromechanical basis of kinesiology*, 2nd ed. Champaign (IL): Human Kinetics, pp. 271-302.

Esbjörnsson-Liljedahl, M, Sundberg, CJ, Norman, B, Jansson, E. (1999). Metabolic response in type I and type II muscle fibers during a 30-s cycle sprint in men and women, *J Appl Physiol*, vol. 87(4), pp. 1326-1332.

Fradkin, AJ, Gabbe, BJ, Cameron, PA. (2006). Does warming up prevent injury in sport? The evidence from randomised controlled trials? *J of Sci and Med in Sport*, vol. 9(3), pp. 214-220.

Gaitanos, GC, Williams, C, Boobis, LH, Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise, *J Appl Physiol*, vol. 75(2), pp. 712-719.

Galazoulas, C, Tzimou, A, Karamousalidis, G, Mougios, V. (2012). Gradual decline in performance and changes in biochemical parameters of basketball players while resting after warm-up, *Eur J Appl Physiol*, vol. 112(9), pp. 3327-3334.

Grange RW, Vandenboom R, Houston ME. (1993). Physiological significance of myosin phosphorylation in skeletal muscle, *Can J Appl Physiol*, vol. 18(3), pp. 229-242.

Gruchow, HW, Pelletier, D. (1979). An epidemiologic study of tennis elbow. Incidence, recurrence, and effectiveness of prevention strategies, *Am J Sports Med*, vol. 7(4), pp. 234-238.

Hamada, T, Sale, DG, MacDougall, JD, Tarnopolsky, MA. (2000). Postactivation potentiation, fibre type and twitch contraction time in human knee extensor muscles, *J Appl Physiol*, vol. 88(6), pp. 2131-2137.

Harris, RC, Edwards, RH, Hultman, E, Nordesjö, LO, Nylind, B, Sahlin, K. (1976). The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man, *Pflugers Arch*, vol. 367(2), pp. 137-142.

Hawkins, RJ, Kennedy, JC. (1980). Impingement syndrome in athletes, *Am J Sports Med*, vol. 8(3), pp. 151-158.

Henja WF, Rosenberg A, Buturusis DJ, Krieger A. (1982). The prevention of sports injuries in High school students through strength training, *Strength and Conditioning Journ*, vol. 4(1).

Hirvonen J, Rehunen S, Rusko H, Härkönen M. (1987). Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. *Eur J Appl Physiol Occup Physiol*, vol. 56(3), pp. 253-259.

Hultman E, Sjöholm H. (1983). *Substrate availability*. Champaign (IL): Human Kinetics, pp. 63-75.

Ingham, SA, Fudge, BW, Pringle, JS, Jones, AM. (2013). Improvement of 800-m running performance with prior high-intensity exercise. *Int J Sports Physiol Perform*, vol. 8(1), pp. 77-83.

Ismail, H, Mazaulan, M, Hasan, H, Raja, MF. (2010). Effects of different warm-up protocols and no warm up on speed performance among football players, *CSSR*, pp. 1137-1142.

Jensen, J, Rustad, PI, Kolnes, AJ, Lai, Y-C. (2011). The Role of Skeletal Muscle Glycogen Breakdown for Regulation of Insulin Sensitivity by Exercise, *Front Physiol*, vol. 2, pp. 112.

Karvonen, J. (1992). Importance of warm up and cool down on exercise performance. In: Karvonen J, Lemon PWR, Iliev I, editors, *Medicine and sports training and coaching*, Basel: Karger, pp. 190-213.

Kemp, S. (2000). *Why detecting muscle imbalance is an essential part of an injury prevention strategy*. http://www.pponline.co.uk/encyc/using-muscle-imbalance-screening-to-reduce-injury-465 [2013-04-03].

Kozłowski, S, Brzezińska, Z, Kruk, B, Kaciuba-Uściłko, H, Greenleaf, JE, Nazar, K. (1985). Exercise hyperthermia as a factor limiting physical performance: temperature effect on muscle metabolism, *J Appl Physiol*, vol. 59(3), pp. 766-773.

Krustrup, P, Mohr, M, Steensberg, A, Bencke, J, Kjaer, M, Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance, *Med Sci Sports Exerc*, vol. 38(6), pp. 1165-1174.

Kushmerick, MJ, Moerland, TS, Wiseman, RW. (1992). Mammalian skeletal muscle fibers distinguished by contents of phosphocreatine, ATP, and Pi, *Proc Natl Acad Sci U S A*, vol. 89(16), pp. 7521–7525.

Lakie, M, Robson, LG. (1988). Thixotropic changes in human muscle stiffness and the effects of fatigue, *Q J Exp Physiol*, vol. 73(4), pp. 487-500.

Lorenz D. (2011). Postactivation Potentiation: an introduction, *Int J Sports Phys Ther*, vol. 6(3), pp. 234-240.

Macera, CA, Pate, RR, Powell, KE, Jackson, KL, Kendrick, JS, Craven, TE. (1989). Predicting lower-extremity injuries among habitual runners, *Arch Intern Med*, vol. 149(11), pp. 2565-2568.

Manns, PJ, Tomczak, CR, Jelani, A, Haennel, RG. (2010). Oxygen uptake kinetics: associations with ambulatory activity and physical functional performance in stroke survivors, *J Rehabil Med*, vol. 42(3), pp. 259-264.

Marti, B, Vader, JP, Minder, CE, Abelin, T. (1988). On the epidemiology of running injuries. The 1984 Bern Grand-Prix study, *Am J Sports Med*, vol. 16(3), pp. 285-294.

van Mechelen, W. (1992). Running injuries. A review of the epidemiological literature, *Sports Med*, vol. 14(5), pp. 320-335.

van Mechelen, W, Hlobil, H, Kemper, HC, Voorn, WJ, de Jongh, HR. (1993). Prevention of running injuries by warm-up, cool-down, and stretching exercises, *Am J Sports Med*, vol. 21(5), pp. 711-719.

Medbø JI, Gramvik P, Jebens E. (1999). Aerobic and anaerobic energy release during 10 and 30 s bicycle sprints. *Acta Kinesiol Univ Tartuensis*, vol 4, pp. 122-146

Mitchell CJ, Sale DG. (2011). Enhancement of jump performance after a 5-RM squat is associated with postactivation potentiation, *Eur J Appl Physiol*, vol. 111(8), pp. 1957-1963.

Mohr, M, Krustrup, P, Bangsbo, J. (2005). Fatigue in soccer: a brief review, *J Sports Sci*, vol. 23(6), pp. 593-599.

Moore, RL, Stull, JT. (1984). Myosin light chain phosphorylation in fast and slow skeletal muscles in situ, *Am J Physiol*, vol. 247(5 Pt 1), pp. C462-471.

Mujika, I, de Txabarri, RG, Maldonado-Martín, S, Pyne, DB. (2012). Warm-up intensity and duration's effect on traditional rowing time-trial performance, *Int J Sports Physiol Perform*, vol. 7(2), pp. 186-188.

Nadel, ER. (1987). Prolonged exercise and high and low ambient temperatures, *Can J Sport Sci*, vol. 12(3 Suppl. 1), pp. 140S-142S.

Nelson, A, Driscoll, NM, Landin, DK, Young, MA, Schexnayder, IC. (2005). Acute effects of passive muscle stretching on sprint performance, *J Sports Sci*, vol. 23(5), pp. 449-454.

Newsholme EA. (1986). Application of principles of metabolic control to the problem of metabolic limitations in sprinting, middle distance, and marathon running. *Int J Sports Med*, vol. 7, pp. 66-70.

Niemuth, PE, Johnson, RJ, Myers, MJ, Thieman, TJ. (2005). Hip muscle weakness and overuse injuries in recreational runners, *Clin J Sport Med*, vol. 15(1), pp. 14-21.

Orchard, J, Marsden, J, Lord, S, Garlick, D. (1997). Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers, *Am J Sports Med*, vol. 25(1), pp. 81-85.

Pereles, D, Clanton, TO, Kaeding, CC. (2007). USATF press release. *The impact of a pre-run stretch on the risk of injury in runners*. http://www.usatf.org/stretchStudy/index.asp [2012-11-03].

Proske, V, Morgan, DL, Gregory, JE. (1993). Thixotropy in skeletal muscle spindles: a review, *Prog Neurobiol*, vol. 41(6), pp. 705-721.

Robbins DW. (2005). Postactivation potentiation and its practical applicability: a brief review, *J Strength Cond Res*, vol. 19(2), pp. 453-458.

Saltin, B, Hermansen, L. (1966). Esophageal, rectal, and muscle temperature during exercise, *J Appl Physiol*, vol. 21(6), pp. 1757-1762.

Saltin, B, Gagge, AP, Stolwijk, JAJ. (1968). Muscle temperature during submaximal exercise in man, *J Appl Physiol*, vol. 25(6), pp. 679-688.

Sargeant, AJ. (1987). Effect of muscle temperature on leg extension force and short-term power output in humans, *Eur J Appl Physiol*, vol. 56(6), pp. 693-698.

Stewart, IB, Sleivert, GG. (1998). The effect of warm-up intensity on range of motion and anaerobic performance, *J Orthop Sports Phys Ther*, vol. 27(2), pp. 154-61.

Söderlund, K, Hultman, E. (1991). ATP and phosphocreatine changes in single human muscle fibers after intense electrical stimulation, *Am J Physiol Endocrinol Metab*, vol. 261(6 Pt 1), pp. E737-E741.

Tesch, PA, Thorsson, A, Fujitsuka, N. (1989). Creatine phosphate in fiber types of skeletal muscle before and after exhaustive exercise, *J Appl Physiol*, vol. 66(4), pp. 1756-1759.

Tomaras, EK, MacIntosh, BR. (2011). Less is more: standard warm-up causes fatigue and less warm-up permits greater cycling power output, *J Appl Physiol*, vol. 111(1), pp. 228-235.

Walberg-Rankin, J. (2000). Dietary Carbohydrate & Performance of Brief, Intense Exercise, *Sports Science Exchange*, vol. 13(4), pp. 79.

Walter, SD, Hart, LE, McIntosh, JM, Sutton, JR. (1989). The Ontario Cohort Study of Running-Related Injuries, *Arch Intern Med*, vol. 149(11), pp. 2561-2564.

Wang, HK, Cochrane, T. (2001). Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes, *J Sports Med Phys*

*Fitness*, vol. 41(3), pp. 403-410.

Wright, V, Johns, RJ. (1961). Quantitative and qualitative analysis of joint stiffness in normal subjects and in patients with connective tissue disease, *Ann Rheum Dis*, vol. 20(1), pp. 36-46.

Young, WB, Jenner, A, Griffiths, K. (1998). Acute enhancement of power performance from heavy load squats, *J Strength Cond Res*, vol. 12(2), pp. 82-84.

Zoladz, JA, Korzeniewski, B, Kulinowski, P, Zapart-Bukowska, J, Majerczak, J, Jasiński, A. (2010). Phosphocreatine recovery overshoot after high intensity exercise in human skeletal muscle is associated with extensive muscle acidification and a significant decrease in phosphorylation potential, *J Physiol Sci*, vol. 60(5), pp. 331-341.

## Appendix 1 – Informed Consent

**Consent to participate in a study evaluating different warm-up protocols.**

The tests are part of a Master thesis conducted by a student at The Swedish School of Sport and Health Science (GiH). The study is conducted at Dalarna University with Michail Tonkonogi (mtn@du.se) as supervisor.

The study will contain three test occasions, all at LIVI in Falun. The test occasions will take plae in week 17. You will perform a timed 60 meter all-out running sprint on an indoor track following two different warm-up protocols. At the third test occasion you will perform the 60 m all-out sprint without prior physical activity. You will wear a heart rate monitor during the entire test. As a study participant you will be asked to refrain from any hard training above aerobic threshold or maximum strength for 48 hrs prior to each testing session. Consumption of caffeine for 3 h and alcoholic beverages for 24 h prior to the test will not be allowed.
We would like you to participate in all three tests. If you have problems with some of the test dates, contact us and we will find other times for the tests.

Athletes in explosive sports such as 60 meter sprint will always have the risk of injuries including straining and pulling muscles. Since studies evaluating injuries in competitive sports are very divergent on warm up as injury prevention, the risk of severe injuries in this study is considered as very low. The tesing facility is provided with common first aid equipement in case of an acute injury.

The data will be encoded so that it is not identifiable to an individual and stored in a secure manner. Each participant will be referred to as a number in the study. No names will be published. The study is research ethically reviewed by the Research Ethics Board at Dalarna University. At the end of the study period you will get your results from the test so you can use them to evaluate your own training and competition preparations.

With my signature I consent to participate in the study, but I am aware of my right to withdraw at any time without any reason. I have read the above information, received a copy of the informed consent.

______________________________ ____________________
Signature Date

If you have further questions please contact:
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## Appendix 2 – Literature search

**Aim and questions:** The aim of this study was investigate whether a shorter and less intense WU protocol could be beneficial for short time trials such as 60 m running.

### Words used in the literature search

*warm up*
*fatigue*
*injury*
*prevent injuries*
*stretching*
*benefits*
*muscle temperature*
*call room*
*track and field*
*basketball players*
*decline performance*
*track cycling*
*glycogen depletion*
*sprinting*
*weak muscles,*
*sprint*
*long warm up,*
*rowing*
*muscle fiber types*
*swimming*
*PCr overshoot*
*Phillip Bishop*
*Pereles*
*higher rate*

### Databases used

*Google + Google Schoolar,*
*PubMed*

### Relevant search strings

*Google + Google Schoolar; warm up fatigue, warm up injury, muscle temperature warm up, injuries weak muscles, sprint long warm up, muscle fiber human types, glycogen depletion sprinting, PCr overshoot warm up*
*PubMed; basketball players decline performance, track cycling warm up, rowing warm up, Phillip Bishop swimming warm up*

## Comments

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| *Relevant articles were easily found through Google and Google Schoolar* |