ABSTRACT

Purpose: The purpose was to investigate whether 20 min cool-down exercise performed on an ergometer cycle immediately after eccentric exercise of knee extensors would reduce delayed onset of muscle soreness and maximal isometric force loss.

Methods: Twenty-four volunteers, (14 woman and 10 men) were randomly assigned into two groups: a “cool- down” group and a “control” group, i.e., each group consisted of 12 volunteers (7 woman and 5 men). Maximal voluntary isometric contraction force (MVC) in knee extensors, pressure pain threshold (PPT) along the rectus femoris muscle and subjective rating of pain intensity in thigh muscles were obtained before eccentric exercise (baseline), and 24 and 48 hours after eccentric exercise. Subjects in the cool-down group completed 20 min exercise on an ergometer cycle (60-70% of HRmax) immediately after the eccentric exercise. Subjects in the control group did not receive any interventions.

Results: A significant group by time interaction from baseline to 48 hours after the eccentric exercise were found for PPT in the distal portion of rectus femoris (P = .047). For both groups, PPT at the distal part of the muscle decreased from day 1 to day 3; however, the reduction was substantially higher for the control group (23.3 %) compared to the cool-down group (9.6 %). A tendency for a group by time interaction from baseline to both 24 and 48 hours after eccentric exercise was found for MVC (P = .06). For both groups the mean force was lower on day 2 and 3 compared to baseline; however, the reduction in force for both comparisons was higher for the control group (22.5 %, 20.4 %) compared to the cool-down group (9.7 %, 8.2 %). The pattern of change in PPT at the central part of the muscle belly over the time period was not different between the groups. No significant difference in pain intensity rating (VAS) was found between the control and cool-down group at 24 and 48 hours after eccentric exercise.

Conclusions: The result suggest that 20 min of cycling at moderate intensity performed immediately after eccentric exercise may have a preventive effect on the development of delayed onset of muscle soreness and strength loss after eccentric exercise.

INTRODUCTION

Delayed onset of muscle soreness (DOMS) is an exercise-induced phenomenon that is among the most common and recurrent forms of sport injury (Cheung et al 2003). DOMS is the perception of discomfort and pain in the muscles in the days following unaccustomed physical activity, especially when eccentric contractions are involved (Proske and Morgan 2001). Muscle pain related to DOMS is evident throughout the muscle belly as well as at muscle-tendon junctions (Cleak and Eston 1992; Friden and Lieber 2001), and is experienced during contraction, stretching, or palpation of the muscle (Proske and Allen 2005). A greater manifestation of DOMS has been demonstrated near the muscle-tendon junction of quadriceps muscle, compared to the muscle belly (Cleak and Eston 1992; Hedayatpour et al 2008). DOMS is usually not present until 8-24 hours after exercise (Newham et al 1983) and peaks between 24 and 48 hours (Newham et al 1987; Bowers et al 2004; Prasartwuth et al 2005). The symptoms then gradually disappears 5-7 days post exercise (Ebbing and Clarkson 1989; Howell et al 1993). In addition to muscle soreness and pain, a decrease in maximal force is evident immediately post exercise and in the days following unaccustomed eccentric exercise (Newham et al 1987; Chapman et al 2008).

Several studies have shown that eccentric exercise produce muscle damage (Friden et al 1981, 1983; Newham et al 1983a; Hortobagyi et al 1998), and it is no longer a controversy that unaccustomed eccentric exercise causes temporary muscle fiber damage (Proske and Morgan 2001). Despite substantial research, there are still controversies regarding the exact mechanisms of muscle damage. However, it is generally agreed that overstretched sarcomeres and damage to the excitation-contraction coupling are two prominent signs of muscle damage immediately after a series of eccentric contractions, and it appears that these changes are the main contributors to the immediate force loss (Morgan and Allan 1999; Proske and Morgan 2001). It has been demonstrated that the immediate mechanical events initiating muscle fiber damage is followed by inflammation of the injured tissue (MacIntyre et al 1996). It has been suggested that both immediate mechanical disruption of muscle fibers and the accompanying inflammatory response is contributing to the force decline in the days following eccentric exercise (Sayers and Clarkson 2001). However the precise pathology of DOMS and mechanisms responsible for the reduced muscle function after eccentric exercise is indefinite.

Muscle soreness and strength loss may affect athletic performance, clinical exericse treatment and function in daily life. Any form for practice that reduce the severity of muscle damage or hastens recovery would be of interest to regular exercisers, athletes, coaches, and therapists. Because DOMS and mechanisms responsible for the reduced muscle function are only vaguely understood, a wide range of different strategies to reduce DOMS and enhance recovery from damaging exercise have been examined. Intervention strategies such as warm-up (Law and Herbert 2007), massage (Hilbert et al 2003), immobilization (Sayers et al 2000), anti-inflammatory medication (Gulick et al 1996), and exercise (i.e. active recovery) (Sayers et al 2000; Dannecker et al 2002; Zainuddin et al 2006; Chen et al 2008;), has been examined, but few have firm scientific support (Connolly et al 2003). Cool-down exercise (e.g. cycling), may be an alternative method because it improves blood circulation in working muscles (Pirnay et al 1972), prevents blood accumulation (McArdle et al 1986), and increases lactate consumption in muscles and other tissue (Gladden 2008). Research investigating the effect of exercise on DOMS has mainly examined the role of exercise as a treatment strategy, i.e., treating DOMS after it has occurred (Dannecker 2002; Chen et al 2008). A number of investigators have detected short term temporary analgesic effects of exercise on DOMS (Zainuddin et al 2006), but few studies have found any long-term effect of exercise on DOMS and muscle function (Hasson et al 1989; Sayers et al 2000). A few studies have investigated the effect of cool-down exercise immediately after eccentric exercise with an attempt to prevent (i.e. carry out an intervention before the onset of DOMS) symptoms related to DOMS and loss of muscle function (Gulick et al 1996; Law and Herbert 2007; Takahashi et al 2006; Isabell et al 1992); however, findings have been inconsistent. This inconsistency may be due to differences in exercise intensity and length, type of muscle work, length of follow-up period and specificity of the exercise performed. Takahashi and co-workers (2006) reported that 30 min pool exercise had a preventive effect on muscle power. Exercise in water almost exclusively includes concentric contractions. Cycling includes mainly concentric muscle contractions (Ericson et al 1986; Bijker et al 2002), and may thus show similar effect as pool exercise.

The purpose of this experiment was to further assess the preventative effect of cool-down exercise on DOMS and muscle function. This study investigated whether 20 min on an ergometer cycle at moderate intensity performed immediately after eccentric exercise of knee extensors would reduce delayed onset of muscle soreness and maximal isometric force loss. Also differences in pain perception from different parts of rectus femoris muscle were examined. This paper is a part of a larger randomized controlled study, with two intervention groups (cool-down and warm-up group) and one control group (no intervention). This study only concerns the effect of cool-down compared to the control group. The effect of warm-up is addressed in another paper.

METHODS

Participants

Twenty-four volunteers (14 women, 10 men) participated in the study. The subjects were randomly assigned into two groups: a “cool-down” group, and a “control” group. The allocation of participants to each of the groups was performed by random draw, men and woman being assigned to each group separately, so that each group consisted of 7 woman and 5 men. Background subject characteristics are presented in table 1. The subjects met the following criteria: 1) had not performed resistance training on the lower body, particularly squats and lunges, on a regular basis during the previous 3 months, 2) were not experiencing injuries/problems in the back, hips or knees currently or during the last year, and 3) were not pregnant. The subjects were asked to refrain from physical activity/training during the experimental period. Each participant was given the information that they could withdraw their consent to participate in the study at any time. The subjects were informed of the procedures and possible disadvantages involved in the study, and each of them gave their written informed consent. The study was approved by the Regional committee for ethics in medical research. The study was carried out according to the Declaration of Helsinki.

Table 1. Subjects characteristics

Group	Cool-down	Control	*P*-value
Age (years)	23±3	22±3	0.684
Height (m)	1.69±0.1	1.76±0.1	0.046
Weight (kg)	69±8	75±19	0.329
BMI (kg/m^2)	23.8±.1.9	24.0±4.8	0.932

Values are means ± SD

Study design

Figure 1 summarizes the experimental design of this study. The experimental period for each subject consisted of measurements on three consecutive days. On day 1, measure of DOMS symptoms and maximal voluntary isometric contraction force (MVC) was collected for the dominant knee extensors. A visual analog scale (VAS) for pain intensity assessment and pressure pain threshold (PPT) was used to provide a measure of DOMS symptoms. The measurements were carried out in following order VAS, PPT and MVC. Just after MVC measurements the cool-down group completed a bout of eccentric exercise, and then performed the bicycle session. The control group performed the same bout of eccentric exercise just after the MVC measurements, but did not receive any interventions. Recordings of VAS, PPT, and MVC were repeated at the second and third day in both groups, with testing times kept as consistent as possible between days for each subject (within 2 h difference).

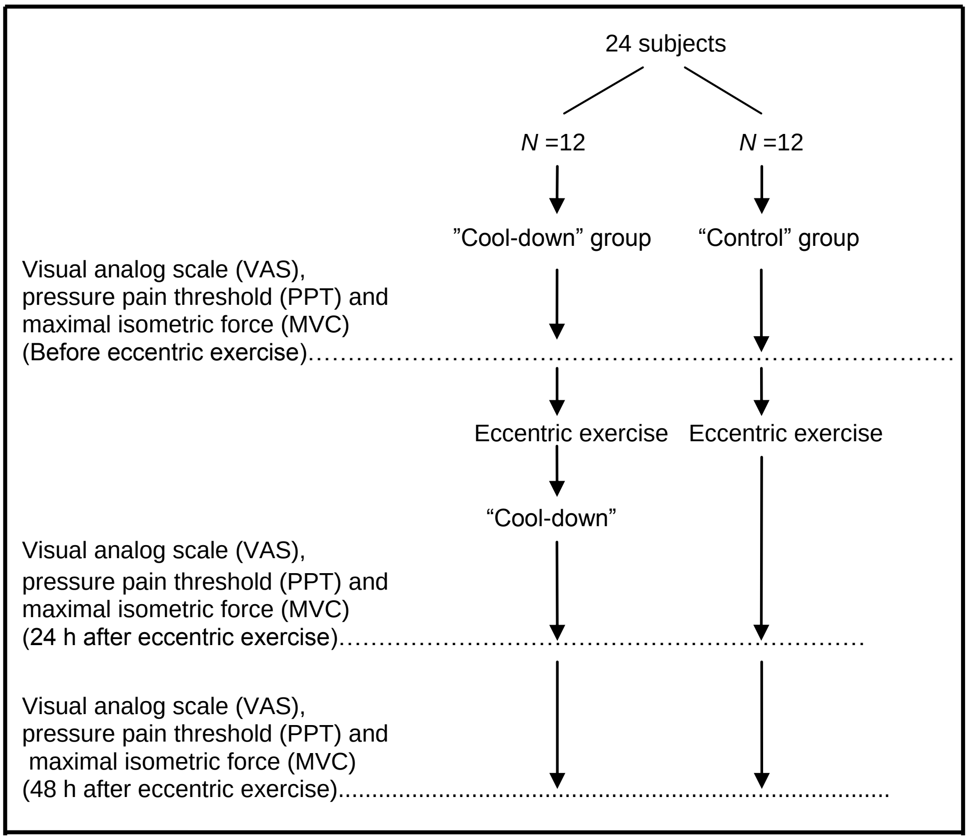

Figure 1. Illustration of the study design. Subjects were randomized into two groups: a "cool-down" group and a "control" group. Maximal isometric force (MVC) and symptoms of muscle soreness in knee-extensors, was recorded before eccentric exercise, 24 hours after eccentric exercise and 48 hours after eccentric exercise.

Assessment of muscle soreness

VAS consisted of a 100 mm line with end points; "no pain at all" (0 mm), and "worst pain imaginable" (100 mm). Subjects were asked to rate their perception of pain intensity in front of the thigh in the exercised dominant leg during walking a distance of about 10 meters.

PPT was defined as the minimum pressure (kPa) that induced pain, and was estimated using a hand held electronic pressure algometry (Somedic Algometer Type II, Sweden). PPT was estimated at six locations along the rectus femoris muscle in the dominant leg. The locations corresponded to 10, 20, 30, 40, 50, and 60% of the distance from the superior border of patella to the anterior superior iliac spine (ASIS) (figure 2). The locations were marked using a permanent marker to ensure that PPT was recorded at the same locations on all three days. Both location marking and PPT recordings was conducted in a seated position with 90° in the hip and knee joint. PPT measurements were performed twice at each of the marked points, starting with the distal points and ending with the proximal points in both recordings. The PPT recordings were performed by the same investigator throughout the test period. The algometry was applied perpendicular to the skin at each of the marked locations with an application rate of 40 kPa/s, so that the entire probe (1-cm^2) on the algometry was in contact with the muscle. The subjects were holding a handle with a stop button connected to the algometry, and they were told to press down the button when the sensation of pressure changed to one of pain. Pressing down the button instantly froze the readings, a sound was produced indicating that a measurement had been taken, and the downward pressure was then immediately ceased. The amount of force applied was recorded, and the mean of the two measurements at each point was used as the PPT for further data analysis. If the subject did not push the stop button before reaching a pressure of ≥ 1700 kPa, the recording was automatically ended. The pressure algometry was calibrated according to the user manual before testing began, for each test day.

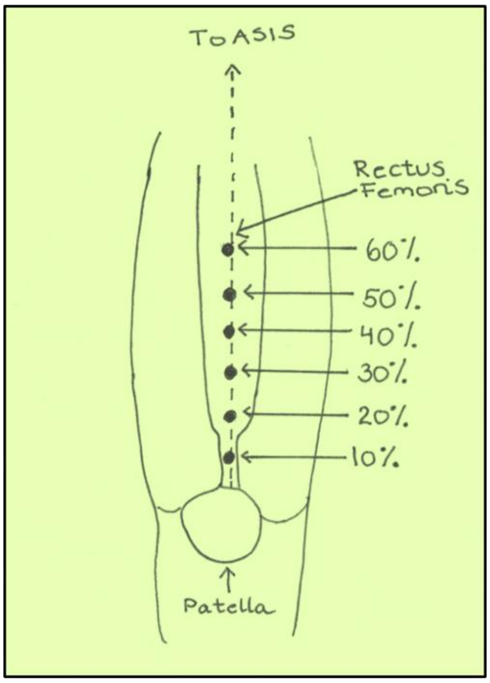

Figure 2. Illustration of the marked locations on rectus femoris for PPT recordings

Strength measurement

Maximal voluntary isometric contraction force (MVC) in knee extension was measured three times for 5 sec in the exercised dominant leg with 1 min rest between measurements. Force measurements were carried out using a force transducer (SM-2000N) and the force signal outcome was provided by utilizing Delsys bagnoli-16 EMG system. The force signal was further analyzes using Acqwin (Jacobus systems, UK). The force signal was digitally low-pass filtered (Butterworth, low- pass 10 Hz, 6th order) before further analysis. The force transducer was embedded in a belt strap which was fixed around the subject's ankle enclosing their lateral malleolus and secured to the base of an adjustable chair. The measurements was carried out in seated position in an adjustable chair with belts strapped around hip and active limb at an knee and hip angel of 90˚. The subjects held their hands on handles attached to the chair as they conducted the contractions. Visual feedback of force was provided on a screen in front of the subject. Subjects were instructed to give maximum effort for each repetition. The average of the three contractions was determined as the MVC and used for further analysis.

Eccentric exercise

Each subject performed a bout of front lunges, which impose eccentric lengthening of the quadriceps when breaking the ground forces. Precise and consistent description about the exercise was given to each subject regarding performance technique. The exercise was standardized, by marking the stride length in bottom position of the lunge, when each subject had 90˚ in the knee and hip joint and a strait torso. In addition, each subject was instructed to follow the pace of a metronome (44 beats/min) which provided timing clicks to assist subject to perform each lengthening and shortening contraction. The exercise consisted of a series of 5 sets of 10 repetitions with 30 sec rest between each set. The load was set to 40 and 50 % of the bodyweight for woman and men, respectively. Six subjects did not manage to carry out the exercise with desirable load, in those cases the load was reduced such that each subject completed 5 sets of 10 repetitions. Each subject practiced on the exercise technique a couple of times both with and without the timing clicks. In addition, the subjects tried to do a few front lunges with the desirable load before performing the exercise.

Cool-down

The cool-down group performed 20 min exercise on an ergometercycle (Monark 939E, Vansbro, Sweden) immediately after the eccentric exercise. The bike was adjusted to each individual. The first 5 min was used to adjust the work load corresponding ~ 65% of estimated maximum heart rate (HRmax; HRmax adjusted for age; 220-age for subjects * 0.65). The last 15 min was performed with a work load at 60-70% of HRmax with a cadence between 65-75 rpm. The HR measurement was done with a standard heart rate monitor (Polar RS800, Kempele, Finland). The average work load (watt) the last 15 min was calculated and registered for each subject.

Statistics

To assess differences between groups in subjective characteristics and baseline MVC, PPT and VAS, a one-way ANOVA was used. To assess changes due to treatments, a mixed design ANOVA (2 x 3) was conducted to determine changes in both MVC and PPT. Three different PPT variables was defined; the average of 10, 20, 30, 40, 50 and 60% locations ($PPT_{\text{muscle distal + central}}$), 50 and 60% locations ($PPT_{\text{muscle central}}$), and 10 and 20 % locations ($PPT_{\text{muscle distal}}$). The analysis included one between-group variable, *group*, with two levels (cool-down group and control group) and one within-subject variable, *time*, with three levels; before, 24 hours and 48 hours after eccentric exercise**.** The effect of group, the effect of time, and group by time interactions was tested. When the effect of time, and group by time interaction was significant, a pairwise comparison were performed using a Bonferroni post hoc test to look at combinations of the repeated measures and the between subjects factors.

For all three PPT variables, *P* values of logarithmic transformed data were used due to lack of normally distribution of some of the actual measures (positively skewed). After log transforming the data, each value was normally distributed except for one value that was close to be non-significant ($P = .046$). When the assumption of sphericity was violated, significance was adjusted using the Greenhouse-Geisser method.

Pain intensity ratings (VAS) were analyzed using non-parametric tests due to non-normal distribution (negatively skewed). A Mann-Whitney test was used to evaluate group differences for each day separately, and a Wilcoxon signed-rank test was performed to compare pain intensity within the groups before exercise with 24 and 48 hours after the eccentric exercise. Effect size estimate were calculated by converting *Z*-scores into Pearsons correlation coefficients. Cohen (1992) suggests that *r*'s > 0.5 indicate large effect, 0.3-0.5 medium effect, and < 0.3 small effect. Statistical significance was accepted at $p < .05$ for all comparisons. The statistics were performed with SPSS (17.0) software.

RESULTS

Subject characteristics

There was no significant differences in age, weight, BMI or load during the eccentric exercise between the groups ($P > .05$); however, the control group was significantly taller (7.0 cm) than the cool-down group ($P = .049$); table 1. There were no significant differences between groups in baseline (day 1) MVC, PPT or VAS ($P > .05$). Baseline values are presented as 100 % indicated by dotted horizontal line.

Maximal voluntary force

Figure 3 presents the pattern of change in force (A), PPT $_{\text{muscle central + distal}}$ (B), PPT $_{\text{muscle central}}$ (C), and PPT $_{\text{muscle distal}}$ (D) for the control and cool-down group on day 1-3.

For force there was a significant main effect of time (F [1.45, 27.56] = 25.86, $P < .001$). A bonferroni post hoc test showed that the main effect reflected significantly lower force on both day 2 and 3 compared to day 1, $P < .001$. No significant difference was found between day 2 and 3 ($P = .742$). Although there was no significant group effect (F [1, 19] = 2.21, $P = .15$), there was a tendency for a group by time interaction, (F [1.45, 27.56] = 3.51, $P = .06$), suggesting that the pattern of change tended to be different among the groups during the time period (day 1, 2 and 3). A bonferroni post hoc test revealed that this tendency was related to the different pattern of changes from day 1 to day 2 and from day 1 to day 3 (for both comparisons). For both groups the mean force was lower on day 2 and 3 compared to day 1; however the average reduction in force for both comparisons was higher for the control group compared to the cool-down group. MVC decreased by 22.5 % in the control group and 9.7 % in the cool-down group 24 hours after the eccentric exercise. At 48 hours, MVC force was only slightly recovered and it was still 20.4 % (control group) and 8.2 % (cool-down group) lower than the MVC force before the eccentric exercise. For the control group the reduction in force on both day 2 and 3 from day 1 was significant ($P < .001$); however no significant difference was observed between day 2 and 3 ($P = 1.000$). For the cool-down group no significant reduction was observed between day 1 and 2 ($P = .054$), between day 1 and 3 ($P = .14$), nor between day 2 and 3 ($P = 1.000$). This indicates that the overall pattern of change in force decline between day 1 and 2 and between day 1 and 3 tended to be different for the cool-down and control group.

Pain pressure threshold (PPT)

There was a significant main effect of time, for both PPT $_{\text{muscle central + distal}}$ (F [1.42, 31.33] = 28.01, P < .001), PPT $_{\text{muscle central}}$ (F [1.47, 32.36] = 25.15, P < .001) and PPT $_{\text{muscle distal}}$ (F [1.51, 33.32] = 23.73, P < .001). A bonferroni post hoc test showed that each of the three PPT variables on both day 2 and 3 was significantly lower than day 1, P < .003. No significant differences was found between day 2 and 3 for PPT $_{\text{muscle central + distal}}$ (P = .10) nor PPT $_{\text{muscle distal}}$ (P = .55). PPT $_{\text{muscle central}}$ was significant higher on day 3 compared to day 2 (P = .02).

There was no significant group by time interaction for PPT $_{\text{muscle central}}$ (F [1.47, 32.36] = 1.55, P = .33), a significant group by time interaction for PPT $_{\text{muscle distal}}$ (F [1.51, 33.32] = 3.93, P = .047), and a tendency for a group by time interaction for PPT $_{\text{muscle central + distal}}$ (F [1.42, 31.33] = 3.60, P = .08), suggesting that the pattern of change for PPT $_{\text{muscle cental + distal}}$ and PPT $_{\text{muscle distal}}$ was different among the groups during the time period. A bonferroni post hoc test showed that the observed interaction for PPT $_{\text{muscle distal}}$ and the tendency for an interaction for PPT $_{\text{muscle central + distal}}$ were linked to the different patterns of change from day 1 to day 3. For both groups PPT $_{\text{muscle distal}}$ and PPT $_{\text{muscle central + distal}}$ decreased from day 1 to day 3; however the reduction was substantially higher for the control group compared to the cool-down group. PPT decreased by 23.3 % and 21.1 % in the control group and 9.6 % and 9.3 % in the cool-down group 48 hours after the eccentric exercise for PPT $_{\text{muscle distal}}$ and PPT $_{\text{muscle distal + central}}$, respectively. For the control group the reduction in PPT from day 1 to day 3 for both PPT $_{\text{muscle central + distal}}$ and PPT $_{\text{muscle distal}}$ was significant (P < .001). For the cool-down-group the PPT reduction was not significant for PPT $_{\text{muscle central + distal}}$ (P = .22), nor PPT $_{\text{muscle distal}}$ (P = .13).

A bonferroni post hoc test revealed that there was no different pattern of change for PPT between groups from day 1 to day 2, neither from day 2 to day 3. Reduction in PPT from day 1 to day 2 for each PPT variable was significant for both control group (P < .002) and cool-down group (P = .02). Moreover, no significant reduction in PPT from day 2 to day 3 was found for neither control group; PPT $_{\text{muscle central + distal}}$ (P = .84), PPT $_{\text{muscle central}}$ (P = .34), PPT $_{\text{muscle distal}}$ (P = 1.000), nor cool-down group; PPT $_{\text{muscle central + distal}}$ (P = .14), PPT $_{\text{muscle central}}$ (P = .06), for PPT $_{\text{muscle distal}}$ (P = .35).

Finally, there was no significant effect of group, neither for PPT $_{\text{muscle central + distal}}$ (F [1, 22] = 0.246, P = .84), PPT $_{\text{muscle central}}$ (F [1, 22] = 0.516, P = .77) nor PPT $_{\text{muscle distal}}$ (F [1, 22] = 0.11, P = .88), indicating that the overall PPT was similar for the two groups.

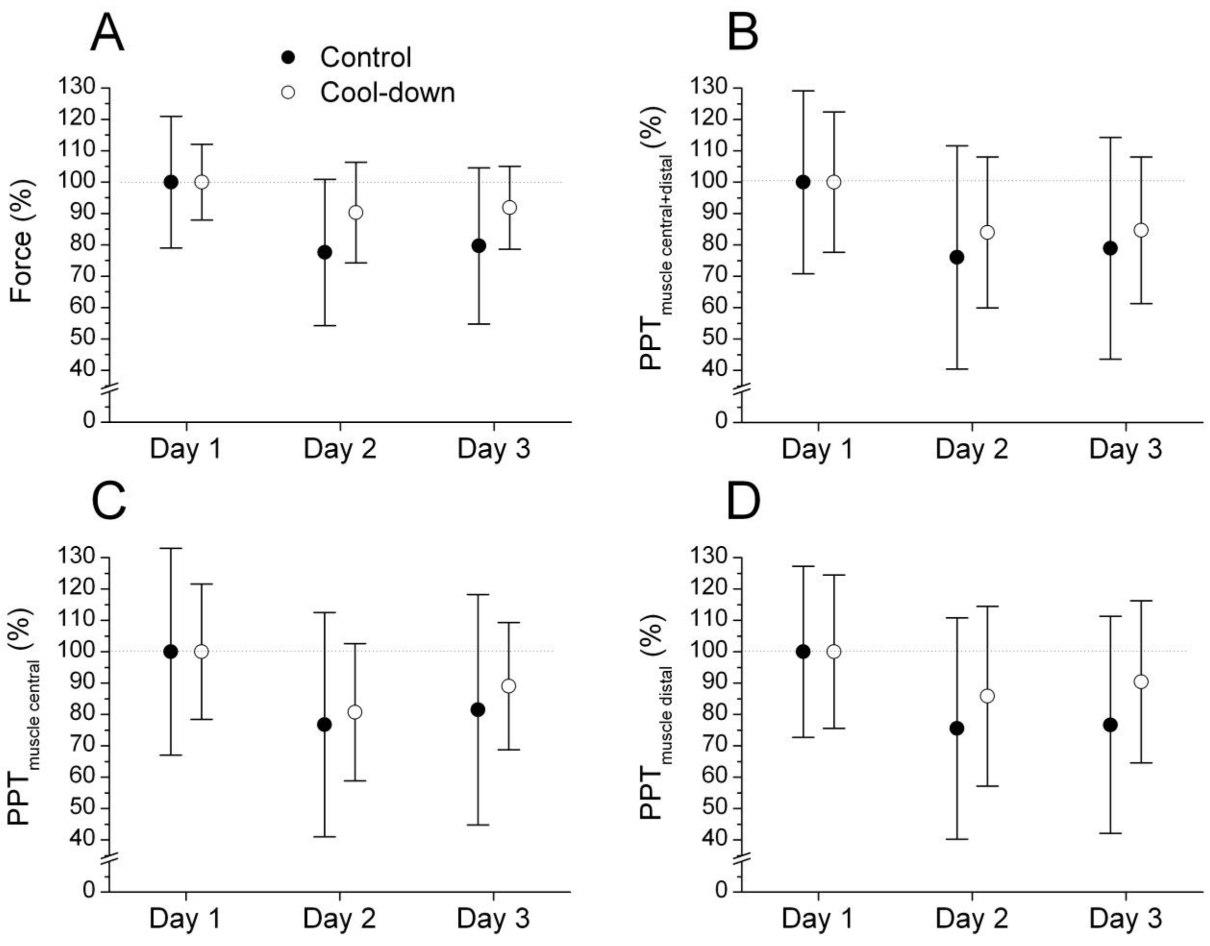

Figure 3. Force (A), PPT $_{\text{muscle central + distal}}$ (B), PPT $_{\text{muscle central}}$ (C), and PPT $_{\text{muscle distal}}$ (D) on day 1-3 for control group and cool-down group. Baseline (day 1) values are presented as 100 % indicated by the horizontal dotted line. Error bars indicate 95% CI of mean.

Pain intensity rating (VAS)

The cool-down group (*mdn* = 7.00) did not seem to differ in pain intensity ratings from the control group (*mdn* = 14.00) 24 hours after the eccentric exercise (W = 145.5, P > .05, r = .05). This was also the case when comparing the cool-down (*mdn* = 7.50) and control group (*mdn* = 13.50) 48 hours after the eccentric exercise (W = 137.0, P > .05, r = .15). For the participants in the cool-down group, pain intensity ratings were higher on both day 2 (*mdn* = 7.00) and day 3 (*mdn* = 7.50) compared to day 1 (*mdn* = 0), T = 0, P=.005, r = .47. This was also the case for the control group, with higher pain intensity ratings day 2 (*mdn* = 14.00) than day 1, T = 0, P = .007, r = .45 and day 3 (*mdn* = 13.50) than day 1, T = 0, P = .005, r = .47.

DISCUSSION

This study investigated the preventive effect of 20 min of cycling at 60-70% of maximal HF performed immediately after eccentric exercise on development of symptoms related to DOMS and decline in isometric muscle strength. A significant reduction in MVC and PPT, and also a significant increase in pain intensity rating (VAS) were observed both 24 and 48 hours post-eccentric exercise in the control group, indicating that the protocol used in this study effectively produced muscle soreness and strength loss. Reduced strength and increased muscle soreness assessed with PPT and VAS 24 and 48 hours after eccentric exercise, has been documented previously (Cleak and Eston 1992). Although outside the level of accepted significance, a tendency for a larger decrease in PPT was found for the control group compared to the cool-down group when all PPT locations were averaged ($PPT_{\text{muscle central + distal}}$) 48 hours after eccentric exercise. The pattern of change in PPT at muscle belly ($PPT_{\text{muscle central}}$) over the time period was not different between the groups. However, a larger decrease in PPT was observed in the control group compared to the cool-down group in the most distal portion of the muscle ($PPT_{\text{muscle distal}}$) 48 hours after the eccentric exercise. Therefore, the trend observed for the $PPT_{\text{muscle central + distal}}$ was linked to the significant interaction effect in the distal portion of the muscle. A trend for a larger decline in MVC was observed in the control group compared to the cool-down group both 24 and 48 hours after the eccentric exercise. No significant difference in pain intensity rating (VAS) was found between the control and cool-down group 24 and 48 hours after eccentric exercise.

For both the cool-down and control group MVC and PPT reductions was highest 24 hours after eccentric exercise with a slight recovery, although not significant, 48 hour after eccentric exercise. Also the percentage reduction in MVC and PPT was approximately the same, for both groups 24 and 48 hours after eccentric exercise.

Muscle soreness

A site specific effect of cool-down on PPT change after eccentric exercise was observed in this study. A larger decrease in PPT was found in the control group compared to the cool-down group in the most distal portion of the muscle 48 hours after the eccentric exercise. However, no preventive effect of exercise on PPT was observed in the central part of the muscle. The lack of group differences in pain intensity (VAS) was not in accordance with a smaller reduction in PPT observed for the cool-down group in the distal portion of the rectus femoris muscle. However, the pattern of change in PPT at the central part of the muscle belly was not different for the groups at any time, which coincides with the lack of group differences in pain intensity ratings (VAS) both 24 and 48 hours after the eccentric exercise. The method used to assess pain intensity (VAS) did not differentiate between locations within the quadriceps muscle which may explanation this discrepancy. It is also possible that slow speed walking did not produce a large enough contraction or stretch of the rectus femoris muscle for pain receptors to be stimulated significantly. Nosaka and co-workers (2002) found significantly smaller peak soreness when flexing compared to palpation and extension of the elbow flexors after eccentric exercise. Thus, level of muscle soreness assessed with VAS may depend on the "size" of the stimuli. It is also possibility that local pressure assessed with pressure algometry stimulates pain receptors to a larger extent than light contraction/stretching of the muscle, e.g. like during walking.

Only a few studies have investigated the preventive effect of exercise on development of DOMS symptoms following a bout of eccentric exercise. Gulick and co-workers (1996) demonstrated that high velocity concentric muscle contractions on an upper extremity ergometer for 10 min immediately after 15 sets of 15 repetitions of eccentric wrist extension, had no preventive effect on muscle soreness assessed with VAS and PPT. The results of the latter study was in line with the findings of Law and Herbert (2007), reporting that 10 min of forward uphill walking on an inclined treadmill performed immediately after backward downhill walking on an inclined treadmill for 30 min, was not effective in reducing DOMS assessed with PPT and VAS. However the latter study only measured PPT 10 minutes and 48 hours post-exercise and no comparisons between control and cool-down group regarding pattern of change over time for PPT was examined. The exact onset of DOMS is hard to establish, however it has been reported that DOMS is not apparent until 8 hours post exercise (Newham et al 1983b). Thus, tenderness measured after 10 minutes in the study of Law and Herbert (2007) would most likely be a measure of muscle fatigue. Although, the results from the present study coincide with the result from both Gulick and co-workers (1996) and Law and Herbert (2007) for VAS assessment, only PPT in the central part of the muscle coincided with PPT from those latter studies. Gulick and co-workers (1996) measured PPT at 10 sites that spanned the length and width of the lower arm wrist extensor musculature and used the average of those 10 sites in the analysis, while Law and Herbert (2007) measured PPT at the central part of the gastrocnemius muscle. However, neither Gulick and co-workers (1996), nor Law and Herbert (2007) measured PPT only at the distal part of the muscle, where the present study found the most pronounced preventive effect of exercise on PPT. Thus, it is possible that the effect of exercise on DOMS is dependent on the site of stimulation.

Potential mechanisms as to why a smaller reduction in PPT occurred in the cool-down group, and possible explanations to why this reductions are most evident in the most distal locations of the rectus femoris, are currently unknown. Moreover, the literature offers some suggestions that should be considered. Blood flow increases in the working muscle during exercise (Pirnay et al 1972). Increased blood flow to the rectus femoris muscle immediately after the damaging exercise might attenuate muscle soreness by interfering with the events following the initial damage before DOMS occur. It has been documented that the immediate muscle and/or connective tissue damage after unaccustomed eccentric exercise is followed by an inflammatory response of the injured tissue (MacIntyre et al 1996; MacIntyre et al 2001; Raastad et al 2003; Paulsen et al 2010). Whether the inflammation response is responsible for the occurrence of DOMS is indefinite. Several investigators have examined the relation between time course of leukocyte accumulation and muscle soreness in eccentric exercised human muscles. Although previous finding (Paulsen et al 2010) has reported no association between muscle inflammation and DOMS after eccentric exercise, MacIntyre and co-workers (1996) reported gradually increased leukocyte concentration in the muscle up to 20-24 hours after eccentric exercise which coincided with the highest degree of muscle soreness 24 hours after the eccentric exercise. The latter finding may indicate that DOMS is related to an acute inflammation response. It has been proposed that products from the inflammation, such as prostaglandins and histamine, may sensitize muscle nociceptors served by group III and IV afferents, resulting in muscle soreness (Proske and Morgan 2001). Thus, in light of this assumption, increased blood circulation immediately after damaging exercise might have affected the production of pain generating inflammatory products from the injured tissue, and be responsible for the reduced sensitivity to local pressure, and hence reduced the sensation of muscle soreness.

An interesting question is why increased blood flow may reduce the sensation of muscle soreness in the distal portion of muscle near the muscle/tendon junction, and not in central part of the muscle. This may have been due to site-specific muscle damage. In this present study a larger decline in PPT for the control group was observed in the most distal location compared to more proximal locations of the rectus femoris muscle following eccentric exercise. These results were in line with previous study examining site specific sensitivity to pressure after eccentric exercise in quadriceps muscle (Hedayatpour et al 2008). Also, Cleak and Eston (1992) reported most tenderness around the distal muscle-tendon junctions of the elbow flexor after eccentric exercise. These findings may indicate that the distal area of the quadriceps muscle is more susceptible to exercise-induced muscle damage.

It has been demonstrated that the architecture of rectus femoris are different for different sites within the muscle, with decreasing pennation angles in the distal portion of the muscle compared to more central regions (Blazevich et al 2006). The angle of the muscle fascicles affects the magnitude of fibers that can be placed in parallel (i.e. physiological cross sectional area; CSA). Reduced fascicle angles, and derby reduced physiological CSA in the distal region of the rectus femoris muscle compared to more central regions, may result in larger damage distally due to higher mechanical strain per muscle unit. Another possible explanation for site specific damage is proposed by MacIntyre and co-workers (1996), suggesting that muscles are susceptible to injury in the distal part due to biomechanical stresses at the muscle-tendon junction. Regardless of mechanisms of any site specific damage, if larger muscle damage in the distal part of the muscle was evident, a more extensive production of inflammation products would most likely have occurred at that site compared to more central regions of the muscle. If there is a possibility that increased blood circulation might limit the production of pain generating inflammatory products, the increased blood circulation would most likely be most critical for the portion of the muscle with the largest muscle damage, and most extensive inflammatory response.

Maximal voluntary force

Although lack of significant evidence, a tendency for a larger decline in MVC force was observed in the control group compared to the cool-down group both 24 and 48 hours after the eccentric exercise. This tendency was evident because the reduction in force on both day 2 and 3 was significant for the control group, however for the cool-down group there was no significant decline in force production over the time period. These results are in accordance with the findings of Takahashi and co-workers (2006) investigating the effect of 30 min pool exercise on recovery of lower limb muscles after 3 sets of 5 min downhill running. The latter study reported that muscle power was significantly reduced only in the control group the day after performing eccentric exercise with no significant change in the group performing pool exercise. Contrary to this, Gulick and co-workers (1996) did not report any different pattern of change in maximal isometric force between control and exercise group in the days following eccentric exercise. The similar result from Takahashi and co-workers (2006) and the results in the present study may be due to that both studies was using exercise that is assumed to only produce concentric contractions. However, the exercise intervention of the study of Gulick and co-workers (1996) consisted of high velocity concentric contraction on an upper extremity ergometer, which also is considered as an activity of concentric contractions.

This latter study only performed 10 min of cool-down exercise, which is substantial shorter than the length of the cool-down exercise period used in this present study and in the study of Takahashi and co-workers (2006). Thus, it is possible that the preventive effect of exercise on force decline is dependent of the length of the exercise period.

Studies examining strength recovery after eccentric exercise has mainly performed measurements immediately after the exercise and in the following days after the exercise (Cleak and Eston 1992; Newham et al 1987). Typically findings from these studies are a more pronounced decline in force immediately after exercise with recovery 24 hours after and in following days (Newham et al 1987; Chapman et al 2007). However, several studies have collected data at more frequent intervals, and found a biphasic recovery pattern of maximal force with a second force loss occurring 9-24 hours after the damaging exercise (Faulkner et al 1993; MacIntyre et al 1996; Raastad and Hallen 2000; Raastad et al 2003). It is suggested that the initial decline in force is a result of mechanical injury and fatigue (Proske and Allen 2005; McIntyre et al 1996). The second force decline has been attributed to secondary muscle damage at the site of the initial muscle damage due to an inflammatory response (MacIntyre et al 1996; Raastad et al 2000; Paulsen et al 2010). Therefore, it is possible that the force loss seen in this study is not only due to the initial mechanical damage, but also as a result of a second damage and inflammatory response. Although it seem unlikely that cycling reversed the mechanical damage and reduced the magnitude of the initial strength loss, increased blood circulation may have limited the inflammatory response, and thus the delayed muscle damage, resulting in the smaller force decline observed in the cool-down group after eccentric exercise.

In this present study, limitation of the inflammatory response due to increased blood circulation in the injured tissue was suggested as a potential mechanism for the positive effect of cool-down on muscle soreness and muscle strength. No direct measure of inflammation was performed in this study. Therefore, it is not known whether the magnitude of DOMS and strength loss was related to the inflammatory response. Future studies should attempt to examine how cool-down affect the inflammatory response caused by eccentric exercise.

Limitations

This study has some limitations. MVC was only measured before, 24 and 48 hours after eccentric exercise. No measurement was performed immediately following the eccentric bout before the cycling bout. Therefore, the effect of the eccentric exercise bout for the two groups is not known. Large inter-subject variability has been reported for changes in both muscle soreness and MVC after eccentric exercise (Chapman et al 2008), and may have been a possible confounding factor in this study. Similarity in the amount of force loss between the groups immediately after eccentric exercise would have reinforced that the smaller force decline observed in the cool-down group were due to the cycling bout and not attributed to the possibility that the eccentric exercise protocol was more stressful for the control group. However, force decline measured immediately after a series of eccentric contractions is likely caused by both metabolic fatigue and muscle damage (Proske and Allan 2005) and may not have been a valid measure of muscle damage caused by eccentric exercise.

Because pain is a subjective and individual phenomenon, difficulties exist when trying to quantify muscle soreness with measurement tools such as VAS and pressure algometry.

However, both VAS and pressure algometry are widely used to measure exercise induced muscle soreness (Hedayatpour et al 2008). Although reliability has been reported for PPT measures with a pressure algometry (Nussbaum and Downes 1998) and VAS (Price et al 1983), it cannot be excluded that subjects under-or overestimated muscle soreness in this present study. It is also possible that the examiners application technique of the algometry may have been variable from time to time. Also limited ability to provide consistent indication of muscle soreness from day to day might have biased the data. However, only one examiner performed the pressure algometry measurements, and the examiner practiced in the use of the pressure algometry prior to the study on several subjects not participating in this study. Those initiatives may have limited the potential variability in the PPT data.

This present study measured muscle soreness and strength only on two days following eccentric exercise. It might have been interesting to follow a more detailed time course of the influence of exercise on DOMS and muscle strength. Collecting data at more frequent intervals both before 24 hours and at time points after 48 hours, may have revealed different pattern of change between cool-down and control group that might not have been revealed in this present study. Another limitation of this study was the sample size. With a larger sample size, the differences between groups may have revealed statistically significance.

The muscle selected for this investigation was rectus femoris. It was suspected that the marked PPT locations on the skin corresponded to the underlying rectus femoris muscle. However, the exact measurement point on the muscle is not known. It was assumed that the two most distal points lay near the muscle-tendon junction, and that the two most proximal points was on the central muscle belly. It is possible that muscle soreness in vastus medialis or vastus lateralis have been measured.

CONCLUTION

The findings in the current study indicate that 20 min of cycling at moderate intensity performed immediately following eccentric exercise may be beneficial in reducing symptoms of DOMS. Despite non significant results, the pattern of change in the data might indicate that this intervention strategy may to some extent, reduce maximal isometric force decline in knee extensors. However, more studies with larger sample size are needed to assess the effectiveness of this intervention strategy to reduce DOMS and force decline.

Acknowledgement

I sincerely thank my supervisor Paul Jarle Mork at the Human Movement Science Program at NTNU for guidance and support. I also thank Olav Olsen for his collaboration, inspiration and useful insights. Grateful tanks also to the participants involved in this study.

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