Warm-up reduces delayed-onset muscle soreness but cool-down does not: a randomised controlled trial

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Question: Does warm-up or cool-down (also called warm-down) reduce delayed-onset muscle soreness? **Design**: Randomised controlled trial of factorial design with concealed allocation and intention-to-treat analysis. **Participants**: Fifty-two healthy adults (23 men and 29 women aged 17 to 40 years). **Intervention**: Four equally-sized groups received either warm-up and cool-down, warm-up only, cool-down only, or neither warm-up nor cool-down. All participants performed exercise to induce delayed-onset muscle soreness, which involved walking backwards downhill on an inclined treadmill for 30 minutes. The warm-up and cool-down exercise involved walking forwards uphill on an inclined treadmill for 10 minutes. **Outcome measure**: Muscle soreness, measured on a 100-mm visual analogue scale. **Results**: Warm-up reduced perceived muscle soreness 48 hours after exercise on the visual analogue scale (mean effect of 13 mm, 95% CI 2 to 24 mm). However cool-down had no apparent effect (mean effect of 0 mm, 95% CI –11 to 11 mm). **Conclusion**: Warm-up performed immediately prior to unaccustomed eccentric exercise produces small reductions in delayed-onset muscle soreness but cool-down performed after exercise does not. **[Law RYW, Herbert RD (2007) Warm-up reduces delayed-onset muscle soreness but cool-down does not: a randomised controlled trial. Australian Journal of Physiotherapy 53: 91–95]**

Key words: Exercise, Physical Activity, Sports, Prevention and Control, Muscles, Pain

Introduction

Most people experience muscle soreness following unaccustomed eccentric exercise. The eccentric muscle contractions cause damage to muscle fibres (Friden and Lieber 2001, Morgan 1990, Morgan and Allen 1999, Proske and Morgan 2001) triggering a chain of events that produce delayed-onset muscle soreness (Armstrong 1984), swelling (Cleak and Eston 1992), loss of range of motion (Cleak and Eston 1992), and loss of strength (Cleak and Eston 1992, Sayers et al 2000). Many interventions have been used in an attempt to prevent delayed-onset muscle soreness. They include stretching, massage, cryotherapy, electrical stimulation, ultrasound, pharmacological agents, and warm-up and cool-down (Cheung et al 2003, Connolly et al 2003). Some of these interventions are self-administered and some are administered by physiotherapists or other health professionals.

Warm-up (gentle exercise preceding vigorous physical activity) is said to reduce muscle strain injuries by increasing muscle temperatures, and hence muscle compliance (Safran et al 1989, Shellock 1983, Shellock and Prentice 1985). It is thought that the compliant muscle can be stretched further before it is damaged (Lehmann et al 1970, Noonan et al 1993, Safran et al 1988). Good evidence from a well-designed trial suggests that warm-up can reduce the risk of injury, at least in competitive handball (Olsen et al 2005). However, direct evidence of effects of warm-up on delayed-onset muscle soreness is inconclusive. High and colleagues (1989) randomised 30 subjects to groups who performed quadriceps stretches and warm-up, or quadriceps stretches only, prior to soreness-inducing step-up exercise. The warm-up involved 10 minutes of gentle step-up exercise. The authors concluded that stretching and warm-up prior to eccentric exercise did not produce statistically significant reductions in delayed-onset muscle soreness. The effect of stretching was small (less than 0.2 points on a 10-point scale at 24 hours) but insufficient data were reported to definitively exclude clinically-worthwhile effects. In contrast, Rodenburg and colleagues (1994) reported that an intervention involving warm-up (15 minutes of arm cycling), stretching and massage produced a statistically significant reduction in one of two measures of muscle soreness (by ~1 point on a 6-point scale at 48 hours) following an exercise protocol that involved intense eccentric contractions of the elbow flexor muscles. The Rodenburg study investigated the effects of a combination of interventions (warm-up, stretching, and massage), so it could not provide an estimate of the specific effect of the warm-up component.

Cool-down (gentle exercise after vigorous physical activity; also called warm-down) has been recommended because it has been observed that cool-down aids in the removal of lactic acid (Bale and James 1991, Dodd et al 1984, Stamford et al 1981, Weltman et al 1979). The relevance of this observation is questionable, as delayed-onset muscle soreness is now known not to be due to an accumulation of lactic acid (Schwane et al 1983). Nonetheless cool-down is still performed routinely by many people in the belief that it may reduce delayed-onset muscle soreness. A very small cross-over study by Bale and James (1991) (n = 9) compared effects on perceived muscle stiffness of passive rest, massage and cool-down after a treadmill run, but in this study perceived muscle stiffness was measured 20 minutes after exercise, before delayed-onset muscle soreness would have developed.

As the existing studies of the effects of warm-up and cool-down on delayed-onset muscle soreness were inconclusive, we conducted a randomised study. The research questions were:

1. Does a 10-minute warm-up reduce delayed-onset muscle soreness and tenderness over 3 days following eccentric exercise?
2. Does a 10-minute cool-down reduce delayed-onset muscle soreness and tenderness over 3 days following eccentric exercise?

Method

Design: The study utilised a 2 × 2 factorial design. The two factors were warm-up and cool-down. The purpose of employing a factorial design was to enable simultaneous investigation of the two factors, not to examine the interaction between the two factors (Montgomery et al 2003). Healthy adults were allocated randomly to one of four groups using a blocked procedure (13 participants per group). The allocation sequence was generated by computer and concealed from both the person recruiting participants and potential participants by using opaque envelopes. Each participant was allocated to one of four groups: a warm-up and cool-down group, a warm-up only group, a cool-down only group, or a neither warm-up nor cool-down group. Initially, all participants rested in a seated position for 10 minutes. Subsequently, participants in the two warm-up groups performed the 10-minute warm-up. Participants in the two groups that did not warm up remained resting for a further 10 minutes. Then all participants performed 30 minutes of eccentric exercise to induce muscle soreness. Immediately after the exercise, participants in the two groups that cooled down performed the 10-minute cool-down. Participants in the two groups that did not cool down rested in sitting for a further 10 minutes. Participants were instructed to refrain from strenuous physical activities for three days after the exercise in this study. Muscle soreness in the gastrocnemius muscle of the right leg was assessed 10 minutes after the exercise, and then at 24-hour intervals over the three days following the exercise. Since the outcome measures were all self-reports, the measurers were not blinded. The University of Sydney Human Research Ethics Committee granted approval for the study and written informed consent was provided by all participants.

Participants: Healthy adults were included if they were aged 17 to 40 years and answered 'No' to all questions on the Physical Activity Readiness Questionnaire (Whaley et al 2000). They were excluded prior to randomisation if they were experiencing delayed-onset muscle soreness or did not consider themselves capable of performing the treadmill exercise for 30 minutes.

Intervention: Muscle soreness was induced using unaccustomed eccentric exercise. The exercise was designed to induce muscle soreness in the gastrocnemius muscle of the right leg and involved walking backwards downhill on a treadmill inclined at 13 degrees, for 30 minutes at 35 steps per minute, leading with the right leg. Participants were instructed to take large backward steps with the right leg and to strike the treadmill with the toe of the right foot and with the right knee extended. This protocol induces muscle soreness in most people (Weerakkody et al 2001, Whitehead et al 2001).

Both warm-up and cool-down exercise consisted of walking forwards uphill on a gently inclined treadmill (3 degrees inclination) for 10 minutes at 4.5 to 5 kph. Walking at this speed and on this inclination consumes energy at an estimated average rate of approximately 3.1 to 3.4 metabolic equivalents (95% CI 11.0 to 11.8 ml/kg/min) (Whaley et al 2000). Walking was used to warm-up and cool-down because, like the activities used in many warm-up and cool-down protocols, this activity involves similar though not identical muscle groups and muscle actions to those involved in the activity which subsequently induced the muscle soreness.

Outcome measures: Soreness was rated on two scales: a 100-mm visual analogue scale anchored at 'no pain' and 'most severe pain', and a 10-point numerical rating scale anchored at 'no pain' and 'most severe pain'. Tenderness was measured 10 minutes and 48 hours after exercise by applying a force transducer with a 1 cm^2 head to the calf over the belly of the most tender part of the gastrocnemius muscle with progressively increasing force (Fischer 1987, Weerakkody et al 2001, Wessel and Wan 1994). Participants reported when they first felt discomfort and the force was recorded. Low forces are associated with high levels of tenderness.

Data analysis: The sample size of 52 participants was determined prior to the conduct of the study. This sample size was sufficient to provide a better than 90% probability of detecting an effect of 20 mm on visual analogue scale soreness at 48 hours for either warm-up or cool-down, assuming within-cell standard deviations of 20 mm.

Effects of warm-up and cool-down were estimated with factorial analysis of variance using a regression approach. A separate analysis was conducted for each follow-up time (10 minutes and 24, 48, and 72 hours). The two factors in the regression model were warm-up and cool-down (both dummy coded as 0 and 1). For the primary analysis, the dependent variable, nominated *a priori*, was the visual analogue scale measure of soreness at 48 hours. The initial model included a term for the interaction between warm-up and cool-down, but where the interaction was not significant ($p > 0.05$) the analysis was repeated without the interaction term in the model. The effects of warm-up and cool-down were expressed as means (on the original metric of mm on a 100 mm scale) and their 95% confidence intervals. Secondary analyses were conducted on the other measures of soreness and tenderness at 10 minutes, 24 hours, 48 hours and 72 hours post-exercise. All analyses were by intention-to-treat.

Results

Flow of participants through the trial: Participants were 23 men and 29 women with a mean age of 21 years (SD 4, range 17 to 40). All 52 participants completed the study. There were no dropouts or withdrawals during the course of the study, and there were no missing data.

Effect of intervention: Group data for the four measurement times are presented in Table 1 and Figure 1 and individual data for the four measurement times are presented in Table 2 (see Table 2 on eAddenda for the complete dataset). The interaction between warm-up and cool-down was not statistically significant so it was dropped from the statistical model. Estimates of the effects of warm-up and cool-down from the final model are given in Table 3. The Table shows the coefficients for the warm-up factor, which quantify the

Table 1. Mean (SD) score for all outcomes for the four groups.

	Warm-up and cool-down	Warm-up only	Cool-down only	No warm-up or cool-down
Soreness				
VAS *(0 to 100)*				
10 minutes	0 (1)	1 (2)	2 (6)	0 (1)
24 hours	24 (19)	31 (25)	39 (22)	33 (18)
48 hours	27 (16)	32 (27)	45 (18)	40 (19)
72 hours	17 (12)	24 (24)	27 (24)	25 (17)
NRS *(0 to 10)*				
10 minutes	0.0 (0.0)	0.2 (0.40)	0.4 (1.0)	0.1 (0.3)
24 hours	2.9 (2.1)	3.5 (2.4)	4.0 (1.9)	3.5 (1.9)
48 hours	3.2 (1.7)	3.5 (2.7)	4.7 (1.7)	4.3 (1.9)
72 hours	2.1 (1.4)	2.5 (2.4)	3.0 (2.1)	2.7 (1.6)
Tenderness *(N)*				
10 minutes	22 (8)	25 (8)	23 (9)	19 (8)
48 hours	19 (7)	25 (11)	16 (7)	14 (9)

VAS = visual analogue scale, NRS = numerical rating scale

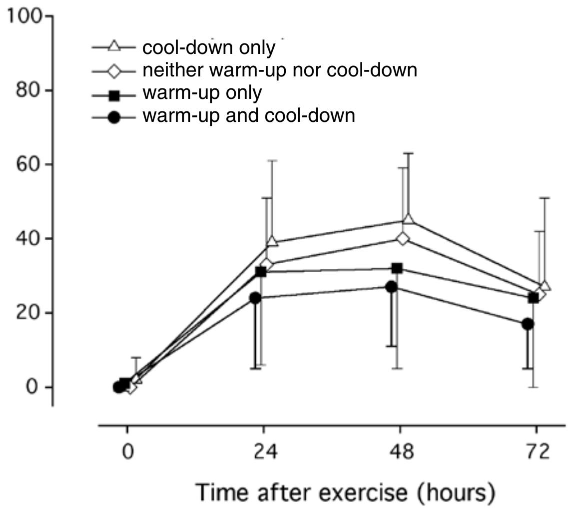

Figure 1. Mean (SD) muscle soreness measured on a visual analogue scale. For all four groups, soreness was measured 10 minutes, 24 hours, 48 hours, and 72 hours after exercise, but times have been slightly offset in this figure for clarity.

difference in the outcomes of participants who did and did not perform warm-up, and the coefficients for the cool-down factor, which quantify the difference in outcomes of participants who did and did not perform cool-down. Forty-eight hours after exercise, warm-up reduced muscle soreness by a mean of 13 mm on a 100 mm scale (95% CI 2 to 24, $p = 0.03$). In contrast, cool-down had no effect on muscle soreness at 48 hours (mean effect 0 mm, 95% CI –11 to 11, $p = 0.99$).

In addition to the effect of warm-up on visual analogue scale soreness at 48 hours, there was a tendency for warm-up to reduce visual analogue scale soreness at 24 and 72 hours, and to reduce numerical rating scale soreness at 24, 48, and 72 hours. The effect was statistically significant only for the numerical rating scale at 48 hours, and then only marginally (mean effect 1.1, 95% CI 0.0 to 2.3, $p = 0.049$). There was a significant tendency for warm-up to reduce tenderness at 48 hours (mean effect 6.8 N, 95% CI 2.0 to 11.6, $p = 0.007$).

There was no evidence of an effect of cool-down on either measure of soreness or tenderness. All point estimates were very close to zero, and none approached statistical significance ($p > 0.05$).

Discussion

The aim of this study was to determine the effects of warm-up and cool-down on muscle soreness following eccentric exercise. Our results showed that warm-up produced a small reduction in muscle soreness that was most apparent 48 hours after exercise. Cool-down did not reduce muscle soreness.

We believe the findings of this study are robust. The study involved comparison of randomised groups, randomisation was concealed, there was an adequate sample size (n = 52), there were no missing data, and a single primary outcome was specified *a priori*.

A potential threat to the validity of the findings is that participants could not be blinded. In the absence of blinding it is possible that the observed effect could be due to placebo, or could result from participants anticipating the experimenters' expectations and mis-reporting soreness. However, the observation that warm-up but not cool-down reduced muscle soreness suggests these types of bias did not occur, because it seems unlikely that warm-up would be associated with a greater placebo effect or a greater anticipation of experimenter expectations than cool-down.

Warm-up: Delayed-onset muscle soreness is thought to be due to damage of stretched myofibrils (Friden and Lieber 2001, Morgan 1990, Morgan and Allen 1999, Proske and Morgan 2001). This suggests a mechanism by which warm-up could reduce delayed-onset muscle soreness: the increase in muscle temperature associated with warm-up (of the order of 3 degrees C) (Gray and Nimmo 2001) could increase the compliance of structures in series with myofibrils. This would reduce the degree of stretch experienced by myofibrils, which could decrease the myofibrillar damage that occurs with unaccustomed exercise and the resulting muscle soreness.

The duration of the warm-up exercise used in this study is comparable to that in previous studies (High et al 1989, Rodenburg et al 1994). Ten minutes of warm-up produced small reductions in muscle soreness. However, as has been suggested previously (High et al 1989), a longer warm-up could provide greater protection against muscle damage and may result in a greater reduction in soreness. The effect of duration of warm-up on muscle soreness warrants investigation.

The intensity of warm-up in the present study was at a moderate level (3.1 to 3.4 metabolic equivalents). High et al (1989) used a lower warm-up intensity (2.7 metabolic equivalents) in the belief that high intensity warm-up might itself result in soreness. The authors speculated that the intensity of warm-up in their study may have been insufficient to prevent muscle soreness. Rodenburg et al (1994) used a higher intensity of warm-up (5.0 metabolic equivalents) and it is possible that this is why, unlike High et al, Rodenburg et al found their mixed intervention reduced muscle soreness.

Cool-down: Many people cool-down after exercise because they believe that cool-down will reduce delayed-onset muscle soreness. This study demonstrated that cool-down performed immediately following eccentric exercise does not reduce delayed-onset muscle soreness.

Cool-down is performed after the events that initiate eccentric exercise-induced muscle damage. Thus the only way that cool-down could reduce muscle soreness is by interfering with the cascade of events that follow the initial damage. The present study demonstrates that cool-down has no appreciable effect on muscle soreness, and it suggests that cool-down has little effect on soreness-inducing events that follow the initial damage. The similarity of mean soreness ratings of participants who cooled down and those who did not cool down indicates that cool-down neither exacerbates nor protects against muscle damage.

Clinical implications: This study shows that warm-up can reduce delayed-onset muscle soreness. However, the reduction in muscle soreness is only small (13 mm on a 100 mm scale). Some athletes may consider this effect too small to justify warm-up but, because warm-up exercises are convenient and easily performed, others are likely to consider effects of this magnitude make warm-up worthwhile.

Our warm-up protocol involved an exercise that was specific to the subsequent activity and muscles utilised. The exercise was performed at a moderate intensity (3.1 to 3.4 metabolic equivalents) for 10 minutes. Until systematic investigations are carried out to investigate the optimal way of preventing delayed-onset muscle soreness, this may be a sensible protocol to use.

Table 3. Mean (95% CI) effect of warm-up and cool-down.

	Warm–up*	Cool–down*
Soreness		
VAS *(0 to 100)*		
10 minutes	1 (–1 to 3)	1 (–1 to 3)
24 hours	9 (–3 to 20)	0 (–11 to 12)
48 hours	13 (2 to 24)	0 (–11 to 11)
72 hours	6 (–5 to 17)	2 (–9 to 13)
NRS *(0 to 10)*		
10 minutes	0.1 (–0.2 to 0.4)	0.0 (–0.3 to 0.3)
24 hours	0.5 (–0.6 to 1.7)	0.1 (–1.1 to 1.2)
48 hours	1.1 (0.0 to 2.3)	0.0 (–1.1 to 1.1)
72 hours	0.5 (–0.5 to 1.6)	0.0 (–1.0 to 1.1)
Tenderness *(N)*		
10 minutes	2.5 (–2.3 to 7.3)	0.3 (–4.5 to 5.1)
48 hours	6.8 (2.0 to 11.6)	–1.6 (–6.4 to 3.2)

* = Effects are estimated coefficients of warm-up and cool-down factors from the linear model. VAS = visual analogue scale, NRS = numerical rating scale. Shaded row = soreness measured on the VAS at 48 hours is the primary outcome

In conclusion, warm-up performed immediately prior to unaccustomed eccentric exercise produces small reductions in delayed-onset muscle soreness, but cool-down performed after intense exercise does not.

eAddenda: Table 2 available at www.physiotherapy.asn.au/AJP

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