Effects of Varying Post-Warm-Up Recovery Time on 200-m Time-Trial Swim Performance

Thomas Zochowski, Elizabeth Johnson, and Gordon G. Sleivert

**Context:** Warm-up before athletic competition might enhance performance by affecting various physiological parameters. There are few quantitative data available on physiological responses to the warm-up, and the data that have been reported are inconclusive. Similarly, it has been suggested that varying the recovery period after a standardized warm-up might affect subsequent performance.

**Purpose:** To determine the effects of varying post-warm-up recovery time on a subsequent 200-m swimming time trial.

**Methods:** Ten national-caliber swimmers (5 male, 5 female) each swam a 1500-m warm-up and performed a 200-m time trial of their specialty stroke after either 10 or 45 min of passive recovery. Subjects completed 1 time trial in each condition separated by 1 wk in a counterbalanced order. Blood lactate and heart rate were measured immediately after warm-up and 3 min before, immediately after, and 3 min after the time trial. Rating of perceived exertion was measured immediately after the warm-up and time trial.

**Results:** Time-trial performance was significantly improved after 10 min as opposed to 45 min recovery (136.80 ± 20.38 s vs 138.69 ± 20.32 s, \( P < .05 \)). There were no significant differences between conditions for heart rate and blood lactate after the warm-up. Pre-time-trial heart rate, however, was higher in the 10-min than in the 45-min rest condition (109 ± 14 beats/min vs 94 ± 21 beats/min, \( P < .05 \)).

**Conclusions:** A post-warm-up recovery time of 10 min rather than 45 min is more beneficial to 200-m swimming time-trial performance.

**Key Words:** athletic training, swimming, sport physiology, exercise performance, coaching

A warm-up is designed to prepare an athlete for ensuing performance. It has been proposed that warm-up helps athletes prepare physiologically. Warm-up can enhance performance through increasing muscle temperature and concomitantly enhancing muscle power, altering the sensitivity of muscle to calcium (postactivation potentiation), and reducing the oxygen deficit, among other things. There are few quantitative data available on physiological responses to the warm-up, and the data
that have been reported are inconclusive. Early studies were poorly controlled, omitted statistical analysis, and had large variations in warm-up protocol (continuous vs intermittent, intensity, duration, and time before competition). These variations both in the literature and in practice make it difficult to draw any firm conclusions or guidelines on the best protocol for warming up.

Warm-up protocols can be classified into 2 approaches. The first, passive warm-up, involves raising muscle or core temperature by an external means, and the second, active warm-up, uses exercise. This study concentrated on athletes' responses after active warm-up.

It is understood that a higher temperature in a working organism facilitates the performance of work. It has been proposed that temperature might improve performance by causing a decrease in the viscous resistance of muscle, a speeding of the rate-limiting oxidative reactions, or an increase in oxygen delivery to muscles. It is difficult, however, to compare thermoregulatory results across studies because results are presented as either rectal temperature or muscle temperature or the muscle temperature has been taken at different depths. Furthermore, increased thermoregulatory strain has the potential to adversely affect performance. An increase in muscle temperature can affect performance as a result of a decrease in the viscous resistance of muscles and joints. Mild warming has been reported to reduce passive resistance of the metacarpal joint. Similarly, muscle-fiber stiffness has been reported to decrease during contraction as temperature increases. Even though there were small increases in dynamic shortening of muscle, however, there was very little extra tension developed.

Enhanced performance has been associated with vasodilation of muscle blood vessels and the associated rightward shift of the oxyhemoglobin-dissociation curve after warm-up. Hemoglobin gives up almost twice as much oxygen at 41°C as at 36°C, and oxygen dissociates twice as rapidly. A similar effect is shown on the dissociation curve of myoglobin. In addition, increased temperature causes vasodilation, which increases muscle blood flow. Research has demonstrated that an increase in muscle temperature increases muscle glycogenolysis, glycolysis, and high-energy phosphate degradation during exercise. Muscle temperature might also contribute to improved performance by escalating the function of the nervous system. Increased muscle temperature improves central-nervous-system function and increases the transmission speed of nerve impulses. Increased nervous-system function can be especially critical for activities that require rapid reactions and complex body movements.

Although warm-up does not increase VO\textsubscript{2} kinetics, it can allow subsequent tasks to begin with an elevated baseline VO\textsubscript{2}. As a result, less of the initial work is completed anaerobically. This leaves more anaerobic capacity for later in the task. An elevated VO\textsubscript{2} is only likely to result in initial sparing of anaerobic capacity, however, if the period between warm-up and competition does not allow VO\textsubscript{2} to return to baseline. After a moderate warm-up VO\textsubscript{2} can return close to resting value within approximately 5 minutes.

Performance of skeletal muscle is affected by its contractile history. Postactivation potentiation acts to improve performance. This potentiation is attributed to phosphorylation of myosin-regulatory light chains and elevation of Ca\textsuperscript{2+} in the cytosol. It is possible that active high-intensity warm-up including maximum voluntary contractions might improve certain types of performance. Some studies have shown
that there is a fatiguing effect associated with a high-intensity active warm-up.\textsuperscript{10} One such study used only a 15-second recovery interval, however, between maximum voluntary contraction and dynamic contraction during dynamic knee extension. On the other hand, using longer recovery intervals of 3 to 5 minutes was shown to be adequate time to recover from fatigue while maintaining postactivation potentiation during loaded squats.\textsuperscript{11} Therefore, with appropriate rest intervals it seems that an active warm-up that includes maximum voluntary contraction might be able to increase twitch potentiation and improve strength and power performance.

With inactivity, the number of actin and myosin bonds increases, leading to muscle stiffness. One of the benefits of active warm-up is that it minimizes muscle stiffness. This reduction in stiffness is transient, however, and muscles tend to return to a stiffer state after only a short period of time.\textsuperscript{12}

Warm-up protocols vary between sports in duration, intensity, and design. In swimming, warm-up is typically ceased ~45 minutes before competition. This is contrary to the physiological rationale supporting warm-up. Although there have been several studies that detailed the effect of warm-up on swimming performance,\textsuperscript{13,14} they used only 5-minute rest intervals between the end of warm-up and the beginning of the performance repetition. Heart-rate and blood-lactate measures were used in these studies to track physiological characteristics of a time-trial performance. The purpose of this study was to determine the effects of varying the time between warm-up and a subsequent race on optimizing performance in a 200-m swimming time trial. We hypothesized that the 10-minute rest interval would elicit a substantially faster time-trial performance than the 45-minute rest interval after the active warm-up.

**Methods**

**Subjects**

Five male and 5 female national-level swimmers from the Victoria Amateur Swim Club participated in the study. They were informed of any risks and discomforts associated with the study before giving written consent. Subjects had experience with varying time between warm-up and competition.

The physical characteristics of the male participants were age 17.0 ± 1.2 years, height 184.1 ± 6.7 cm, and body mass 73.2 ± 6.0 kg, and of the female participants, age 16.0 ± 1.0 years, height 168.8 ± 2.6 cm, and body mass 63.4 ± 2.1 kg. Participants were all national-team level, with a minimum of 7 years competitive experience.

**Experimental Design**

The experiment followed a repeated-measures design. A time course of events is illustrated in Figure 1. On 2 separate occasions separated by 2 days subjects performed a standard swimming warm-up followed by a time-trial performance over 200 m using their specialty stroke. All tests were performed in a 25-m swimming pool. Of the 5 male participants, 4 swam front crawl and 1 swam backstroke. Of the 5 female participants, 3 swam breaststroke and 2 swam front crawl. The warm-up protocol was designed by a collaboration of swim coaches from the Victoria
Amateur Swim Club and the PacificSport National Swim Centre (Figure 2). The time between the completion of warm-up and the beginning of competition was either 10 minutes or 45 minutes, and each subject performed after both warm-up protocols. Half the subjects performed the 10-minute protocol on day 1 and the 45-minute protocol on day 2, and the other half performed the trials in the opposite order. Blood lactate and heart rate were measured immediately after warm-up and 3 minutes before, immediately after, and 3 minutes after the time trial. Rating of perceived exertion was measured immediately after warm-up and immediately after the time trial.

**Measurements**

**Heart Rate.** Participants' heart rates were measured during the testing protocol using a Polar Vantage heart-rate monitor (Polar Electro, Finland). Measurements were taken at poolside immediately after the warm-up and time trial, while the participants were resting pre-time trial, and 3 minutes after the time trial. Post-warm-up and post-time-trial heart rates were measured while participants were standing on an underwater platform (identical to standard training conditions), and pre-time-trial resting heart rates were measured while participants were standing on the pool deck. Participants were in an upright position, experiencing lower-body positive hydrostatic pressure. This might have caused a slight increase in heart rate.
when compared with a supine position. The upright position was standardized across all subjects and treatments, and differences from measurement in a supine position are not directly relevant.

**Blood Lactate.** Blood samples were obtained via finger prick and analyzed using an automated lactate analyzer (Lactate Pro, Kyoto, Japan) for blood lactate concentrations.

**Rating of Perceived Exertion.** Subjects were asked to rate their perceived exertion using the Borg 20-point scale after both the warm-up and the 200-m time trial.

**Statistical Analysis**

A 2-way repeated-measures analysis of variance (warm-up condition × time) was used to compare differences between the 10- and 45-minute rest conditions at different time points during the protocol and to determine whether varying the time between warm-up and time trial influenced performance in a 200-m time trial. In addition, a 2-way repeated-measures analysis of variance (warm-up condition × time) was used to establish significant changes in heart rate and blood lactate at 4 different time points in both the 10-minute and 45-minute protocols. Bonferroni post hoc comparisons were used to determine where specific differences occurred when a significant main or interaction effect was present. All statistics were protected from type I error at the \( P < .05 \) level of significance. Statistical analysis was performed using the statistical software package SPSS, version 11.5, for Windows (SPSS Inc, Chicago, Ill, USA). Data are presented as mean ± SD unless otherwise indicated.

**Results**

There were no significant effects of gender or stroke style (breaststroke or freestyle), so the data were collapsed into 1 group. All the results are reported on the full group's data.

**Time-Trial Performance**

The mean time for the 200-m time-trial performance was 136.80 ± 20.38 seconds and 138.69 ± 20.32 seconds for the 10- and 45-minute rest conditions, respectively. The participants were 1.89 seconds faster \((P < .001, \text{Figure 3})\) after 10 minutes versus 45 minutes recovery. The differences in performance were evident during the final 100 m of the time trial, as reflected in the 50-m split times (Figure 4). The first 50 m were significantly faster in both conditions \((P < .001)\) and then slowed for the final 150 m. The swimmers were able to maintain their pace, however, until the end of the time trial in the 10-minute rest condition, whereas they continued to get slower in the 45-minute rest condition.

**Heart Rate**

Heart rate decreased from the end of the warm-up to the pre-time-trial measurement in both conditions \((P < .001)\). Heart rate remained significantly higher, however, after
Figure 3 — Mean (SD) 200-m time-trial freestyle and breaststroke performance time after a standardized warm-up protocol and either 10 minutes or 45 minutes recovery in trained national-level swimmers (N = 10). *P < .05.

Figure 4 — Mean (SD) split times during the 200-m swimming time trial after a standardized warm-up and either 10 minutes (diamonds) or 45 minutes (squares) recovery in trained national-level swimmers (N = 10). *Significant differences between conditions, P < .001. **Significant differences between conditions, P < .05.

10 minutes rest (109 ± 14 beats/min) as opposed to 45 minutes (94 ± 21 beats/min; P < .05). Heart rate was significantly different between conditions immediately after the time trial (P < .001). Heart rate for the 10-minute-rest group was significantly elevated (179 ± 8 beats/min) when compared with the 45-minute-rest group (175 ± 8 beats/min; Figure 5).
Figure 5 — Mean (SD) heart rate (top) and blood lactate (bottom) for the 10-minute (diamonds) and 45-minute (squares) recovery conditions after a standardized warm-up (post-warm-up), just before beginning a 200-m short-course time trial (prerace), immediately after (postrace 1) the time trial, and 3 minutes postrace (postrace 3) in trained national-level male and female swimmers (N = 10). Matching letters indicate significant differences between time points, P < .05. *Significant differences between conditions, P < .05.

**Blood Lactate**

Lactate concentrations were not significantly different from the end of the warm-up to the pre-time-trial values for either condition. Blood lactate increased significantly (P < .001) from 2.3 ± 0.6 mmol/L and 2.3 ± 0.8 mmol/L pre-time trial to 11.6 ± 1.4 mmol/L and 12.1 ± 1.3 mmol/L post-time trial for the 10- and 45-minute rest conditions, respectively. Blood lactate remained elevated 3 minutes post-time trial but was not significantly different from the concentration immediately after the time trial. There were no differences in blood lactate at any time point between conditions (Figure 5).

**Rating of Perceived Exertion**

Participants’ rating of perceived exertion was not significantly different between conditions. It did, however, increase significantly from 12.1 ± 1 and 11.8 ± 0.6 for the 10- and 45-minute rest conditions during the warm-up to 17 ± 1 and 16.7 ± 0.9, respectively, after the time trial (P < .001).

**Discussion**

The results of the current study support the original hypothesis that shortening the length of time between the warm-up and race from 45 minutes to 10 minutes benefits 200-m time-trial performance and, presumably, competitive performance.
Cardiovascular Effects

Heart rate decreased significantly from the end of the warm-up to pre-time-trial values in both conditions, indicating that the participants did have time to recover from the activity. Although \( \text{VO}_2 \) was not measured, it was found that the participants had significantly higher heart rates before the 200-m time trial in the 10-minute rest conditions than with the longer recovery period (Figure 5). Previous studies have reported similar results and have attributed the performance improvements to an elevated baseline \( \text{VO}_2 \) at the commencement of exercise after the warm-up.17 Consequently, we speculate that less initial work was completed anaerobically, leaving greater anaerobic energy stores for the end of the time trial. This benefit might have elicited the faster split times (lower fatigue) in the final 100 m of the time trial in the 10-minute rest condition (Figure 4).

Metabolic Effects

It has been suggested that performance changes after an active warm-up might be caused by residual metabolic acidemia.18 This response was not evident in the results of the current study—there were no significant differences in blood lactate concentrations between conditions at any time point (Figure 5). Lactate concentrations did not change significantly from the end of warm-up to pre-time-trial values, suggesting that the warm-up protocol used was not intense enough to increase blood lactate. Indeed, residual \( \text{VO}_2 \) values of approximately 80% during exercise are needed to increase muscle perfusion and speed \( \text{VO}_2 \) kinetics.18 The warm-up intensity used in the current study was subjectively estimated using the Borg scale.16 Exercise during the warm-up was perceived as “somewhat hard,” or approximately 12 on the RPE scale. This level approximates 70% to 75% of the maximal heart rate.19

Thermoregulatory Effects

The onset of sweating during maximal exercise occurs soon after an active warm-up, whereas increases in skin and core temperature are attenuated in comparison with identical exercise without warm-up. The conversion of chemical energy into mechanical work is relatively inefficient, and, as a result, exercising muscles produce a considerable amount of heat. Muscle temperature increases rapidly from resting (~36°C) within 3 to 5 minutes of the initiation of moderate-intensity exercise.20 Performance increases associated with elevated muscle temperature are attributed to a decrease in viscous resistance of muscle, increased speed of rate-limiting reactions, increased oxygen delivery to muscle, and increased nerve-conduction velocity. Heat dissipation varies between individuals depending on their sweat rate, body composition, and size. Muscle temperature in trained athletes with an efficient thermoregulatory system typically returns to near baseline values within 30 minutes of the cessation of exercise. Thus, the 45-minute rest condition might have been too late to benefit the changes in core and muscle temperature associated with the warm-up. This can only be speculated, however, because core and muscle temperature were not measured in this study.

Warm-up structure depends on the type of activity to be undertaken, the environmental conditions, constraints unique to the event, and the athlete's fitness level.
Physically trained individuals experience considerably improved efficiency of the thermoregulatory system during exercise, mainly as a result of enhanced heat loss via increased skin blood flow and sweat rate. Similarly, body core temperature rises more slowly in the aquatic environment than in air because swimming-pool water temperature is typically below skin temperature, thereby acting as a heat sink. Consequently, athletes might require a longer, more intense warm-up to sufficiently increase core and muscle temperature to the level associated with performance improvements.

A warm-up intensity of 40% to 60% VO\textsubscript{2}max is necessary to elicit the required increases in muscle temperature. Higher work intensities have been associated with the depletion of high-energy phosphates, accumulation of H\textsuperscript{+}, and impaired performance. Lower intensities are insufficient to induce any ergogenic effects. It has been suggested that a warm-up intensity of 70% VO\textsubscript{2}max is optimal for moderately trained athletes competing in intermediate performance. The optimal duration of the warm-up depends on its intensity. In general the warm-up must be long enough to elevate baseline levels of VO\textsubscript{2} while causing minimal fatigue, typically between 10 and 25 minutes.

**Practical Applications**

The recovery-period duration after the warm-up has an effect on performance. It must be long enough to allow for replenishment of phosphocreatine stores. Nearly complete resynthesis typically occurs within 5 minutes of the cessation of exercise. It is important, however, that the recovery period not be so long that muscle temperature and VO\textsubscript{2} return to baseline, thereby negating the ergogenic effects of the warm-up. It has been suggested that VO\textsubscript{2} can return to close to baseline within 5 minutes of exercise, thereby presenting conflicting indications for recovery time. The main finding in this study was that performance was enhanced after 10 minutes of recovery post-warm-up as compared with the 45-minute recovery condition. The improvements in performance were evident in the split times, which were faster during the final 100 m of the time trial after the 10-minute recovery condition. This might be attributable to an increased heart rate at the initiation of the time trial as an indication that the participants had less time to rest and presumably began the trial with an elevated baseline VO\textsubscript{2}. Heart rate remained significantly higher post–time trial after the 10-minute than after the 45-minute recovery condition. Test–retest performance in elite swimmers has been found to be highly correlated, supporting the assumption that variations observed in the present study might be a result of the intervention.

**Conclusions**

Two-hundred-meter swimming time-trial performance was enhanced after a standardized warm-up and 10 minutes as compared with 45 minutes of recovery. The mechanisms eliciting the better performance after a 10-minute recovery are unclear but might include elevated heart rate (and possibly oxygen uptake) at the initiation of the subsequent 200-m time-trial performance. It appears that the warm-up is most effective when it is intense enough to activate physiological and metabolic
processes and is coupled with a short recovery time before the subsequent race to maintain these benefits.

Coaches can use this information while preparing their athletes for competition. They should be aware of the timing of a swimmer’s event in the competition schedule and plan the timing of the warm-up accordingly. Event organizers can help by ensuring that there is an alternative pool available for warm-up while the competition is proceeding to allow athletes who are not competing until the end of the program a chance to warm up optimally.

Acknowledgments

The authors express their gratitude to Victoria Amateur Swim Club and head coach Randy Bennet for their participation in this study. Canadian Sport Centre Pacific provided invaluable technical assistance.

References


