Influence of warm-up duration and recovery interval prior to exercise on anaerobic performance

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ABSTRACT: The purpose of the study was to determine the impact of different active warm-up (AWU) durations and the rest interval separating it from exercise on anaerobic performance. Eleven male physical education students (22.6 ± 2.52 years; 179.2 ± 4.3 cm; 82.5 ± 9.7 kg; mean ± SD) participated in a cross-over randomized study, and they all underwent the Wingate test after three AWU durations: 5 min (AWU5), 15 min (AWU15) and 20 min (AWU20), with recovery (WREC) or without a recovery interval (NREC) separating the AWU and anaerobic exercise performance. All the AWUs consisted of pedalling at a constant pace of 60 rpm at 50% of the maximal aerobic power. The rest interval between the end of warm-up and the beginning of exercise was set at 5 min. During the Wingate test, peak power (PP), mean power (MP) and the fatigue index (FI) were recorded and analysed. Oral temperature was recorded at rest and at the end of the warm-up. Likewise, rest, post-warm-up and post-Wingate heart rate (HR) and rating of perceived exertion (RPE) were recorded during each session. The ANOVA showed a significant effect of recovery interval, warm-up duration and measurement point on RPE scores (P<0.001). Although the effect of AWU duration on MP and PP was significant (P<0.05), the effect of the recovery interval on both parameters was not significant (P>0.05). Moreover, the analyses showed a significant interaction between recovery interval and AWU duration (P<0.001 and P<0.05 for MP and PP respectively). The AWU15 duration improves the MP and PP when associated with a recovery interval prior to exercise of 5 min. However, the AWU5 duration allows better improvement of power output when the exercise is applied immediately after the warm-up. Consequently, physically active males, as well as educators and researchers interested in anaerobic exercise, must take into account the duration of warm-up and the following recovery interval when practising or assessing activities requiring powerful lower limb muscle contractions.

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INTRODUCTION

Although the warm-up is a fundamental part of the process of training, considered as a prerequisite for the achievement of good athletic performance [1, 2, 3], it is still usually based on trial and error on the part of the athlete or the coach, rather than on scientific studies [4]. In a school context, the content of warm-up procedures in physical education is still under discussion [5], despite its importance in athletic performance and motor learning [6]. Its effect on the performance is determined by the intensity, duration and the recovery interval between warm-up and exercise [4, 7] and is related essentially to the rise of core temperature. An increase in muscle temperature can affect performance as a result of a decrease in the viscous resistance of muscles and joints [8, 7, 9], which can be responsible for a 4% improvement of leg muscle power for each 1°C elevated [10]. Although numerous studies have focused on the duration, the mode of exercise and the intensity of warm-up [11, 2, 12, 13], relatively few studies have been interested in the recovery interval separating the warm-up from exercise performance [14, 7, 3]. Moreover, studies investigating the effect of warm-up procedures on anaerobic performance have used various protocols including different intervals of passive recovery between the warm-up and the subsequent task. Those intervals vary from 5 min in the studies of Chaâri et al. [2], Atan [15] and Abdelmalek et al. [16]; 3 min in the studies of Chbourou et al. [17] and Hamouda et al. [18]; 2 min in the studies of Gharbi et al. [19], Yaicharoen et al. [20] and Bishop and Maxwell [21]; and no recovery interval in the studies of Chbourou et al. [22] and Bishop et al. [23]. In competition, this interval can vary, in terms of sports rules, from a few minutes in athletics, up to 45 min in swimming. The
scientific literature indicates that the post warm-up recovery interval should not exceed 10 min according to Zochowski et al. (7), 20 min according to West et al. (3) and 5-15 min according to Poprzęcki et al. (14). According to Bishop (8), the post warm-up recovery period should be more than 5 min but less than 15-20 min.

Thus the aim of this study was to examine the effect of different active warm-up (AWU) durations and the recovery interval prior to exercise on anaerobic performance.

MATERIALS AND METHODS

Participants. Eleven male physical education students (age, 22.6 ± 2.52 years; height, 179.2 ± 4.3 cm; body mass, 82.5 ± 9.7 kg and BMI, 25.7 ± 2.8; mean ± SD), all volunteers, signed a formal consent to take part in this study after receiving a thorough explanation of the protocol. All the participants were not specially trained for either endurance or effort involved in sprint and performed ~15 h/wk of various physical activities as part of their university course. The study protocol complied with the Helsinki declaration on human experimentation and was approved by the Clinical Research Ethics Committee of the National Centre of Medicine and Science of Sports of Tunis (CNMSS).

Experimental procedures

Participants were familiarized with the cycle-ergometer and high-velocity cycling and test rules to minimize the learning effect during the course of the study. Then they performed an incremental test on an electromagnetic cycle ergometer, Monark 894E (Stockholm, Sweden). The six test sessions were held in a random order. Three sessions were conducted without a recovery period (NREC) and three others with a 5 min passive recovery period, between the end of the warm-up and the beginning of the Wingate test. The AWU protocols consisted in pedalling 5, 15, and 20 min at 50% of the maximal aerobic power at a constant pace of 60 rpm. Each test session began with a 30 min rest in a seated position. Oral temperature (Toral), heart rate (HR) and blood pressure were then measured respectively with a digital thermometer (Omron, Paris, France; accuracy 0.05°C), a heart rate monitor (POLAR S410) and a tensiometer (Omron, 705 CP, Japan). Likewise, the rest, post-warm-up and post-Wingate heart rate (HR) and Toral were recorded during each session.

The laboratory temperatures were recorded with an electronic thermometer (Exacto, Strasbourg, France, precision 0.1°C), controlled by an electric heater, and were kept stable (17.7 ± 1°C). The subjects were instructed to avoid any kind of strenuous activity for 24 hours before each test, to sleep normally, and to wear the same sportswear and shoes for every session.

Rating of perceived exertion (RPE)

The rating of perceived exertion (RPE), defined by feelings of stress, strain, discomfort, and fatigue which an individual feels during exercise, was determined using the Borg scale [24]. RPE scores were recorded at the end of the warm-up (post-WU), before (pre-Win) and at the end of the Wingate test (post-Win). The RPE scale allows participants to give a subjective exertion rating for the physical task. The scale presents a 15-point scale ranging from 6 (very very light) to 20 (very very hard). The higher the RPE score, the higher is the rating of perceived exertion. The RPE scale is a commonly used assessment to prescribe exercise intensity. It is a reliable indicator of physical discomfort, has sound psychometric properties and is strongly correlated with several other physiological measures of exertion [25, 26].

Anaerobic capacity test

The Wingate test was conducted on a friction-loaded cycle ergometer (Monark 894E, Stockholm, Sweden) interfaced with a microcomputer. The seat height and handlebars were appropriately adjusted for each subject. The Wingate test consisted of a 30-second maximal sprint against a constant body mass-related resistance (0.087 kg · kg−1 body mass) as proposed by Bar-Or [27]. Subjects were verbally encouraged throughout the test to avoid pacing and to sustain a maximal effort throughout the test. The highest power output over 1 sec (PP) and the mean power (MP), corresponding to the ratio between total work done and time allocated to do it, were recorded at the end of the test. The fatigue index (FI), i.e., the percentage decrease in power output, was equal to the difference between the highest (PP) and the lowest power (PL) divided by the highest power [2, 28, 11]: Fatigue index = [(PP - PL)/PP] × 100

Statistical analyses

All statistical tests were processed using STATISTICA software (StatSoft, France). Data were reported as mean ± SD. Data normality was assessed through the Shapiro-Wilk W-test, and all variables showed normal distribution. Once the assumption of normality was confirmed, parametric tests were performed. HR, T and RPE data were analysed using a three-factor ANOVA (2 [recovery conditions] × 3 [warm-up durations] × 4 [measurement points]) with repeated measures. A two-way ANOVA (2 [recovery conditions] × 3 [warm-up durations]) with repeated measures was used to analyse the Wingate test performance data. When ANOVA revealed a significant difference, post-hoc multiple comparison using Fisher’s LSD test was conducted. A probability level of 0.05 was selected as the criterion for statistical significance. Furthermore, the effect size *partial *η2* was calculated. The thresholds for small, moderate, and large effects were defined as 0.20, 0.50 and 0.80, respectively.

RESULTS

Rating of perceived exertion, heart rate and temperature. Concerning the RPE, the three-way ANOVA indicated that the main effect of recovery interval was significant (F(1,10)=36.42; P<0.001; η2 = 0.789), with post hoc tests showing that the RPE scores recorded in NREC conditions were significantly higher than the WREC one (P<0.001). In addition, the effect of AWU duration was significant
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(F_{(2, 20)} = 32.73; p<0.001; \eta^2 = 0.765), with post hoc tests showing that the RPE scores recorded after AWU_{15} were significantly higher than after AWU_{5} (P<0.001) and lower than those recorded after AWU_{20} (P<0.01). The effect of measurement point was also significant (F_{(4,40)} = 156.43; P<0.001; \eta^2 = 0.939), with the post hoc test showing that the RPE scores recorded after the warm-up were significantly higher than those recorded before the Wingate test (P<0.01) and lower than those recorded after the Wingate test (P<0.001). The interaction effects of recovery interval \times AWU duration; recovery interval \times measurement point; and AWU duration \times measurement point were significant: (F_{(1,10)} = 157.71; P<0.001; \eta^2 = 0.940; F_{(2, 20)} = 4.04; P < 0.05; \eta^2 = 0.287 and F_{(3,30)} = 620.54; P<0.001; \eta^2 = 0.984 respectively). The post hoc analyses showed:

(i) HR recorded without a recovery interval was significantly higher than that recorded with 5 min interval of passive recovery (P<0.001);
(ii) AWU_{15} and AWU_{20} induce an elevation of HR higher than AWU_{5} (P<0.001); (iii) HR recorded at the end of AWU procedures was significantly higher than HR before the Wingate test (P<0.001). The interactions recovery interval \times measurement point and AWU duration \times measurement point were significant (F_{(3,30)} = 156.93; P<0.001; \eta^2 = 0.940 and F_{(6,60)} = 3.95; P< 0.01; \eta^2 = 0.283 respectively), with post hoc analyses showing that:

(i) pre-Wingate HR recorded in WREC conditions was lower than that recorded in NREC (P<0.001); and (ii) post- Warm-up HR recorded after AWU_{15} and AWU_{20} and AWU_{5} was higher than after AWU_{5} (P<0.001). Likewise, the pre-Wingate HR recorded after the AWU was lower than that recorded after AWU_{15} and AWU_{20} (P<0.01 and P<0.05 respectively).

However, the interaction recovery interval \times AWU duration \times measurement point was not significant (F_{(6,60)} = 1.08; P>0.05).

Concerning T_{oral}, the three-way ANOVA indicated that the main effects of recovery interval and AWU duration were not significant (F_{(1,10)} = 4.75; P>0.05 and F_{(2,20)} = 1.83; P>0.05 respectively). The effect of the measurement point was significant (F_{(3,30)} = 25.67; P<0.001; \eta^2 = 0.719). The post hoc analyses showed that (i) T_{oral} recorded after AWU was significantly higher than T_{oral} in all the AWU durations (P<0.001). (ii) Pre-Wingate T_{oral} was significantly higher in WREC than in NREC conditions (P<0.05).

Mean power

Mean values for PP (n = 11) after the different warm-up durations (AWU5, AWU15 and AWU20) are shown in Figure 1.

The two-way ANOVA (2 (recovery interval) \times 3 (warm-up durations)) indicated that the main effect of the recovery interval was not significant (F_{(2,20)} = 1.32; P>0.05). However, the effect of AWU duration was significant (F_{(2,20)} = 3.95; P< 0.05; \eta^2 = 0.284). The post hoc analysis showed that MP recorded after AWU_{5} and AWU_{15} was significantly higher than after AWU_{20} (P<0.05 for both durations). In addition, there were no significant differences between MP values recorded after AWU_{5} and AWU_{15} (P>0.05). Likewise, the interaction effect of warm-up duration \times measurement point was significant: (F_{(2,20)} = 10.95; P<0.001; \eta^2 = 0.523), showing that: (i) In the WREC conditions, the MP values recorded after AWU_{15} were significantly higher than those recorded after AWU_{5} (P<0.01) and AWU_{20} (P<0.01). However in the NREC conditions, the highest values of MP were recorded after AWU_{5} in comparison with AWU_{15} (P<0.01) and AWU_{20} (P<0.01). (ii) If MP values recorded in the NREC conditions.
two recovery conditions were higher after AWU$_{15}$ $(P<0.001)$ and AWU$_{5}$ $(P<0.05)$, in respectively WREC and NREC, those values still show no changes after the AWU$_{20}$ $(P>0.05)$.

**Peak power**

Peak power (PP) values registered in the different experimental conditions (WREC and NREC) and after the different AWU durations, i.e., AWU$_{5}$, AWU$_{15}$ and AWU$_{20}$, are shown in Figure 2. The two-way ANOVA $(2 \text{ (recovery interval)} \times 3 \text{ (warm-up durations)})$ showed no significant effect of recovery interval on PP values $(F_{(1,10)} = 0.02; P>0.05)$. However, the effect of warm-up duration was significant $(F_{(2,20)} = 6; P<0.01; \eta^2 = 0.375)$. The post hoc analysis showed: (i) no significant difference between PP values recorded after AWU$_{5}$ and AWU$_{15}$ $(P>0.05)$; (ii) a significant difference in PP values between AWU$_{5}$ and AWU$_{20}$ $(P<0.05)$ and between AWU$_{15}$ and AWU$_{20}$ $(P<0.01)$.

In addition, the interaction recovery interval $\times$ warm-up duration was significant $(F_{(2,20)} = 5.4; P<0.05; \eta^2 = 0.350)$, showing that: (i) if in the WREC condition PP values recorded after AWU$_{15}$ were higher than those recorded after AWU$_{5}$ and AWU$_{20}$ $(P<0.05$ and $P<0.01$ respectively), in the NREC condition there were no significant differences between PP values recorded after the three AWU durations. (ii) The PP value recorded after AWU$_{5}$ was statistically lower in WREC than in NREC conditions $(P<0.05)$. This value was higher after AWU$_{15}$ in WREC than in NREC conditions $(P<0.05)$. However, it still showed no changes after AWU$_{20}$ $(P>0.05)$.

**Fatigue index**

The two-way ANOVA $(2 \text{ (recovery interval)} \times 3 \text{ (warm-up durations)})$ showed no significant effect of recovery interval on the FI $(F_{(1,10)} = 2.75; P>0.05)$, no significant effect of the warm-up durations $(F_{(2,20)} = 0.89; P>0.05)$ and no interaction between them $(F_{(2,20)} = 0.09; P>0.05)$.

**DISCUSSION**

The major finding of our study was that the 5 min recovery interval does not affect either MP or PP values. An AWU$_{5}$ leads to a better performance when practised directly without a recovery interval separating it from the all-out 30 s exercise test. AWU$_{15}$ allows better improvement of anaerobic performance, when associated with a 5 min recovery interval prior to exercise. The AWU intensity was set at 50% of maximal aerobic power because many studies have shown that warm-up intensity higher than 60% of VO$_{2\text{max}}$ could alter performance during a subsequent cycling sprint [29, 9, 28]. The recovery interval was set at 5 min because it was found that a recovery interval of more than 5 min, but less than 15-20 min, provides the greatest ergogenic effect on short-term performance [8].

**Rating of perceived exertion and heart rate**

The results of the present study show that the RPE scores recorded in NREC conditions were significantly higher than in the WREC one $(P<0.001)$; the RPE scores recorded after AWU$_{15}$ were significantly higher than after the AWU$_{5}$ $(P<0.001)$ and lower than those recorded after AWU$_{20}$ $(P<0.01)$. The RPE scores recorded after the warm-up were significantly higher than those recorded before the Wingate test $(P<0.01)$ and lower than those recorded after the Wingate test $(P<0.001)$. The current data are in agreement with previous findings, in which higher RPE scores were observed after the Wingate test than after different warm-up procedures, e.g. music WU [30, 22], and durations [2]. However, others observed no variations in RPE scores between music and no music warm-up [31]. The 5 min recovery after all AWU durations causes a significant decrease in RPE estimations at the pre-Wingate measurement point $(P<0.001)$, indicating a decrease in the discomfort sensation of our participants. Similar results were obtained by Yaicharoen et al. [20], where active warm-up procedures were followed by a passive 2-min rest period. After this period (pre-bout), RPE scores were significantly lower than in post-AWU in all WREC and NREC conditions. Furthermore, West et al. [3] found that an interval of post-AWU rest allows a diminution of RPE scores and HR of swimmers from $-11$ to $-9$ and 123 to 98 beats·min$^{-1}$, respectively, which is in accordance with the findings of Ozyener et al. [32] showing that after a moderate warm-up oxygen uptake (VO$_{2}$) can return close to the resting value within approximately 5 minutes.

Concerning the HR, our results show an increase of this parameter after all AWU durations. However, the increase of HR was higher after AWU$_{15}$ and AWU$_{20}$ than after AWU$_{5}$. The durations AWU$_{15}$ and AWU$_{20}$ cause higher HR changes, representing approximately a value of $\sim 70\%$ of HR$_{\text{max}}$, and an RPE estimation of $\sim 11-12$. The present findings support those of previous studies [33, 22, 28, 20].

**Anaerobic performance**

Concerning the MP and the PP, our results show no effect of the recovery of these parameters: the rest interval of 5 min between the cessation of warm-up and the onset of high intensity exercise did not affect either the MP or the PP, when compared to the no recovery condition. Similar results were obtained by Poprzęcki et al. [14], showing that an interval of rest (5 or 15 min) separating the warm-up from the onset of exercise did not affect either anaerobic power or acid base variables. However, Alikhajeh et al. [34] found that 5 min passive rest following a 10 min dynamic warm-up was better than a period of 15 min for the improvement of sprint performance in young soccer players. In addition, several studies have demonstrated the effect of the post-warm-up rest interval preceding a swimming performance: West et al. [3] and Zochowski et al. [7] demonstrated that both the rest intervals of 20 min and 10 min, respectively, were better than 45 min. A 20 or 10 min post-warm-up recovery period helped to maintain an elevated core temperature and also made it possible to perform 200 m freestyle swimming better as opposed to 45 min recovery [3, 7].

Warm-up procedures enhance performance by increasing muscle temperature. A rise in muscle temperature results in multiple physi-
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The authors declared no conflict of interests.

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CONCLUSIONS

Our results demonstrated that warm-up enhances anaerobic performance through increasing muscle temperature and concomitantly enhancing muscular power. A 5-min aerobic warm-up is a sufficient duration for the improvement of muscular power, essentially when the anaerobic exercise performance is applied immediately after the warm-up. However, the 15-min warm-up duration is better when followed by a 5 min rest interval. This recovery interval did not cause a drop in core temperature and then in anaerobic performance.

Consequently, physically active males, as well as coaches, teachers and researchers, interested in anaerobic exercise, must take into account the duration of warm-up and the following recovery interval when practising or assessing activities requiring powerful lower limb muscle contractions.

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