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

AUTHORS: Frikha M[1,4], Chaâri N[1], Mezghanni N[2], Souissi N[1,3]

[1] Research Laboratory "Sports Performance Optimization" National Center of Medicine and Science in Sports (CNMSS), Tunis, Tunisia
[2] High Institute of Sport and Physical Education, Sfax University, Sfax Tunisia
[3] National Observatory of Sport, Tunis, Tunisia
[4] College of Education, King Faisal University, Al Ahsa, KSA

Corresponding author:
Frikha Mohamed
College of Education, King Faisal University, Al Ahsa, KSA
Phone :+ 966 54 266 4804, GMT+3.
+216 22310026 GMT+1.
E-mail: mfrikha@kfu.edu.sa; hfrikha@hotmail.fr

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.

CITATION: Frikha M, Chaâri N, Mezghanni N, Souissi N. Influence of warm-up duration and recovery interval prior to exercise on anaerobic performance. Biol Sport. 2016;33(4):361–366.

Received: 2014-10-22; Reviewed: 2014-08-24; Re-submitted: 2016-08-24; Accepted: 2016-08-25; Published: 2016-10-11.

Key words:
active warm-up
recovery
anaerobic performance

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 Chtourou 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 Chtourou 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 894^E (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 (T_{oral}), 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 T_{oral} 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 894^E, 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] for HR and T; 2 [recovery conditions] × 3 [warm-up durations] × 3 [measurement points] for RPE) 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 η^2"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; $P<0.001$; η^2 = 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

($F_{(2; 20)}$ =32.73; p<0.001; η^2 = 0.765), with post hoc tests showing that the RPE scores recorded afterAWU_{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 ($F_{(2; 20)}$ =156.43; P<0.001; η^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 × AWU duration; recovery interval ×measurement point; and AWU duration×measurement point were significant: ($F_{(2;20)}$ =3.92; P<0.05; η^2 = 0.281); ($F_{(2;20)}$ =31.76; P<0.001; η^2 = 0.760) and ($F_{(4;40)}$=17.35; P<0.001; η^2 = 0.634) respectively. However, the interaction recovery interval × AWU duration× measurement point effect was not significant ($F_{(4; 40)}$ =2.55; P>0.05).

Concerning heart rate (HR), the three-way ANOVA indicated that the main effects of recovery interval, AWU duration and measurement point were significant ($F_{(1; 10)}$ = 157.71; P<0.001; η^2 = 0.940; $F_{(2; 20)}$ = 4.04; P < 0.05; η^2 = 0.287 and $F_{(3;30)}$ = 620.54; P<0.001; η^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 × measurement point and AWU duration×measurement point were significant ($F_{(3;30)}$ = 156.93; P<0.001; η^2 = 0.940 and $F_{(6;60)}$ = 3.95; P< 0.01; η^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 $AWU_{20}$was higher than after AWU_5 (P<0.001). Likewise, the pre-Wingate HR recorded after the AWU_5 was lower than that recorded after AWU_{15} and AWU_{20} (P<0.01 and P<0.05 respectively).

However, the interaction recovery interval × AWU duration× 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; η^2 = 0.719). The post hoc analyses showed that (i) T_{oral} recorded after AWU was significantly higher than T_{rest} 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 power (MP) 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 Figure1.

The two-way ANOVA [2 (recovery interval) × 3 (warm-up durations)] indicated that the main effect of the recovery interval was not significant ($F_{(1 ; 10)}$ = 1.32; P>0.05). However, the effect of AWU duration was significant ($F_{(2;20)}$ = 3.95; P< 0.05; η^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 recovery interval warm-up duration effect was significant ($F_{(2;20)}$ = 10.95; P<0.001; η^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

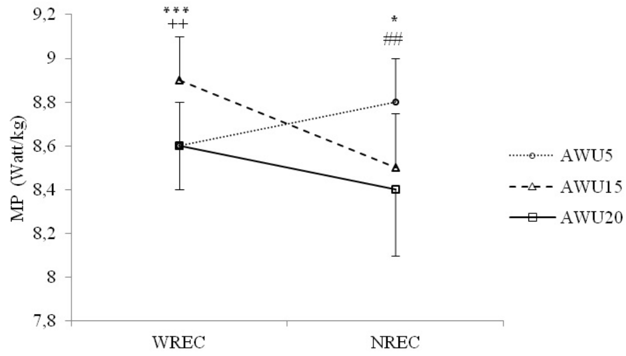

FIG. 1. Mean values of MP (n = 11) after the different warm-up durations (AWU5, AWU15 and AWU20) and the recovery interval (WREC and NREC).

Note: + Significant difference with AWU5 and AWU20 in WREC at the level of: ++p<0.01; # Significant difference with AWU15 and AWU20 in NREC at the level of: ##p<0.01; *Significant difference between WREC and NREC in AWU5 and AWU15 at respectively: *p<0.05; ***p<0.001; MP: mean power; AWU5: 5 minutes of pedalling at 50% of the maximal aerobic power; AWU15: 15 minutes of pedalling at 50% of the maximal aerobic power; AWU20: 20 minutes of pedalling at 50% of the maximal aerobic power; WREC: 5 min recovery interval separating the AWU and the Wingate test; NREC: no recovery interval separating the AWU and the Wingate test.

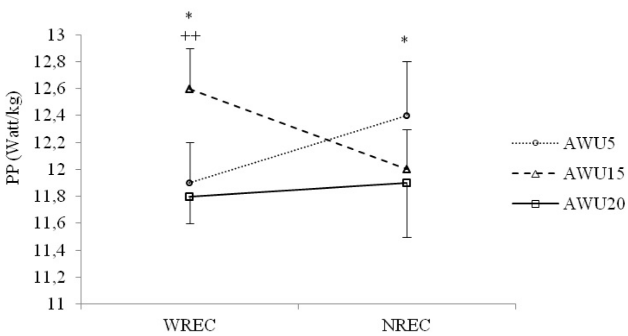

FIG. 2. Mean values for PP (n = 11) after the different warm-up durations (AWU5, AWU15 and AWU20) and the recovery interval (WREC and NREC).

Note: +Significantly different with AWU5 and AWU20 in WREC at respectively: ++p<0.01; *Significant difference between WREC and NREC in AWU5 and AWU15 at the level of: *p<0.05; MP: mean power; AWU5: 5 minutes of pedalling at 50% of the maximal aerobic power; AWU15: 15 minutes of pedalling at 50% of the maximal aerobic power; AWU20: 20 minutes of pedalling at 50% of the maximal aerobic power. WREC: 5 min recovery interval separating the AWU and the Wingate test; NREC: no recovery interval separating the AWU and the Wingate test 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 Figure2.The two-way ANOVA [2 (recovery interval) × 3 (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 × 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 (recovery interval) × 3 (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_{2max} 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 afterAWU_{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 ~ 70% of HR_{max} and an RPE estimation of ~ 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 10min 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 physiological and metabolic changes, such as increases in oxygen delivery to muscles, decreases in the viscous resistance of muscle and joints, and increases of nerve conduction rate [7, 35, 36]. It has been suggested that the rise in muscle temperature is the major contributing factor [8]. Our results demonstrate that temperature rises significantly after all warm-up durations ($P<0.001$), independently of the duration. Similar results were found by Racinais et al. [9], Souissi et al. [11], Chaâri et al. [28] and Frikha et al. [37]. As indicated in the literature, temperature rises rapidly within the first 3-5 min of exercise and reaches a plateau after 10-20 min. [8, 3]. Likewise the rest interval of 5 min did not cause decreases in temperature, which is in accordance with data indicating that a recovery period of between 5 and 15–20 min helps to prevent a drop in muscle temperature, and thus maintains the ergogenic effect of the warm-up [38, 39, 7].

The greater improvements of MP and PP after AWU_{15} and AWU_5 durations in respectively WREC and NREC conditions are related not only to the rise of core temperature [28, 8], but also to the resynthesis of phosphocreatine (PCr) stores. Although this parameter was not measured in our study, several studies have shown that the resynthesis of PCr stores, responsible for the improvement of short-term performance, is largely complete within ~5 min of exercise [8, 32]. We can speculate that the improvement of muscular power (i.e. MP and PP) after AWU_{15} duration in WREC conditions is related to the complete resynthesis of PCr stores [32] and to an elevated baselineVO_2 at the commencement of exercise after the AWU_{15} compared to the AWU_5 duration [40].

The effect of the rest interval was different with the three warm-up durations: if MP and PP were different between the WREC and NREC conditions with AWU_5 and AWU_{15} ($P<0.05$), they still show no changes with AWU_{20}. This allows us to deduce that an active warm-up of 5 min is better to improve anaerobic performance than 15 min or 20 min when it is applied directly without a rest interval. However, 15 min duration is better for this performance when a rest interval of 5 min is introduced. Our results show, as found by Chaâri et al. [2], that increasing the duration of AWU beyond 15 min does not contribute to the improvement of anaerobic performance even when associated with an interval of recovery prior to exercise. It seems that the 20 min duration of warm-up causes some fatigue and discomfort to our subjects, as indicated by higher scores in RPE estimations.

Concerning the FI, our study shows that this parameter was not affected by either the recovery conditions or the AWU durations. In fact, the physiological basis of this index, as mentioned by Lericollais et al. [41] and Souissi et al. [11], is questionable. It is likely that the effect of warm-up duration on the FI would have been masked by its intrinsic (corresponding to the percentage decrease between PP and the minimal power recorded during the test) variability [11, 22].

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.

Acknowledgments

The authors wish to express their sincere gratitude to all the participants for their maximal effort and cooperation. This study was financially supported by the Ministry of Higher Education, Scientific Research and Information and Communication Technologies.

Conflict of interests: the authors declared no conflict of interests regarding the publication of this manuscript.

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