ORIGINAL ARTICLE

Effects of a general warm-up on anaerobic exercise performance in power and endurance athletes

Naoki Ushirooka . *Graduate School of Comprehensive Human Sciences. University of Tsukuba. Tsukuba, Japan.*
Kotaro Muratomi. *Graduate School of Comprehensive Human Sciences. University of Tsukuba. Tsukuba, Japan.*
Hirohiko Maemura. *Faculty of Health and Sports Science. University of Tsukuba. Tsukuba, Japan.*
Satoru Tanigawa. *Faculty of Health and Sports Science. University of Tsukuba. Tsukuba, Japan.*

ABSTRACT

Purpose: The purpose of this study was to compare the effects of a general warm-up (GWU) on anaerobic exercise performance between power and endurance athletes. Methods: Twenty male power athletes and twenty male endurance athletes participated in this study. The participants performed 20 minutes of cycling at 60% of their predicted maximum heart rate as a GWU. Their anaerobic exercise (countermovement jump [CMJ] and 6-second sprint cycling [SC]) performance was assessed before and after the GWU. Results: A significant interaction effect (group × time) was observed in CMJ height (p = .041). The endurance athletes showed a significant improvement in CMJ height after the GWU (p < .001), whereas the power athletes did not (p = .794). No significant interaction effects were observed in mean power (p = .957) and peak power (p = .197) during the SC. Conclusion: These results suggest that training history influences the effect of a GWU on anaerobic exercise performance, and endurance-trained individuals may benefit more from the GWU consisting of continuous cycling. Furthermore, these findings demonstrate that a one-size-fits-all warm-up cannot optimize an athlete's performance and emphasize the necessity of designing warm-up programs tailored to their training history.

Keywords: Performance analysis, Countermovement jump, Sprint cycling, Performance enhancement.

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Corresponding author. *Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8577, Japan.*
E-mail: cgtb0222@icloud.com
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INTRODUCTION

It is widely accepted that athletes need to warm up before competitive exercise to optimize their performance. A typical physiological effect of a warm-up is an increase in muscle temperature, which has been associated with increased muscle metabolism (Gray et al., 2011) and muscle fibre conduction velocity (Pearce et al., 2012). Enhanced performance after a warm-up is primarily attributed to physiological mechanisms resulting from this elevated muscle temperature. In anaerobic exercise such as vertical jump and sprint cycling, a 1°C increase in muscle temperature has been reported to enhance the performance by 2–5% (Racinais & Oksa, 2010).

However, it has been noted that there is substantial inter- and intra-individual variability in responses to warm-up (Afonso et al., 2024). Thus, for athletes and their coaches, understanding the individual characteristics that influence the effect of warm-up on exercise performance is crucial for designing individualized warm-up programs. Post-activation performance enhancement, observed shortly after brief, high-force contractions (Cuenca-Fernández et al., 2017), has been shown to be greater in individuals with more extensive training experience (≥ 2 years) (Xu et al., 2025). In contrast, there is limited information on the individual characteristics that influence the effect of a general warm-up (GWU). A GWU typically involves light-intensity aerobic exercise (e.g., cycling and jogging) and is intended to increase the temperature of the major muscle groups involved in the primary exercise (Bishop, 2003). Given that a GWU is one of the most widely performed routines for enhancing athletic performance, it is meaningful to investigate individual characteristics that influence its effect.

Skeletal muscle fibre composition may be an important individual characteristic that modulates the effect of a GWU on anaerobic exercise performance. In high cadence (160–180 rpm) cycling exercise, passively increasing muscle temperature enhances the utilization of creatine phosphate and adenosine triphosphate in type IIA fibres, leading to improved maximum power (Gray et al., 2008). In addition, the temperature coefficients of maximum and average power reportedly correlate with the percentage of type IIA fibres (Gray et al., 2006). This suggests that in exercises demanding fast muscle contractions, individuals with a greater percentage of type IIA muscle fibres may derive greater benefits from passive muscle warming. This is likely because type II fibres contribute more to power output than type I fibres during high-speed movements (Sargeant, 1994). Furthermore, continuous endurance training increases the percentage of type I fibres and decreases type IIA fibres (Bathgate et al., 2018). Conversely, sprint and resistance training have been shown to increase the percentage of type IIA fibres while decreasing or maintaining type I fibres (Andersen et al., 1994; Liu et al., 2003). Consequently, power athletes, who typically possess a high percentage of type IIA muscle fibres due to long-term sprint and resistance training, are more likely to benefit from a GWU that increases muscle temperature compared to endurance athletes.

However, to our knowledge, no studies have directly investigated the influence of training history on anaerobic exercise performance after a GWU. Previous research related to this issue has shown that, after performing 10 minutes of intermittent contractions at 50% of the maximum voluntary contraction (MVC) of the knee extensor muscles, power athletes exhibited a more significant decrease in knee extension force during the MVC than endurance athletes (Morana & Phane Perrey, 2009). These results likely occur because endurance athletes have a higher percentage of type I fibres, which are more resistant to fatigue (Tesch & Karlsson, 1985). On the other hand, minimizing fatigue is important for an effective warm-up, and a GWU of 10–20 minutes at an intensity less than 60% of maximum oxygen intake (VO_{2max}) has been proposed (Bishop, 2003). Thus, further research is needed to clarify the effect of a GWU with appropriate intensity on anaerobic exercise performance of individuals with different training histories.

Therefore, this study investigated the influence of training history on anaerobic exercise performance after a GWU at an appropriate intensity. We hypothesized that power athletes would show a greater improvement in anaerobic exercise performance than endurance athletes after the GWU.

MATERIAL AND METHODS

Participants

Twenty male power athletes (age: 19.5 years [19.0–20.0 years], height: 1.74 m [1.70–1.78 m], body mass: 68.5 kg [64.6–71.1 kg], body mass index: 22.6 [21.6–23.2]) and twenty male endurance athletes (age: 20.5 years [19.8–22.0 years], height: 1.71 m [1.67–1.72 m], body mass: 57.7 kg [55.9–60.0 kg], body mass index: 19.9 [19.2–20.6]) without musculoskeletal and cardiovascular injuries participated in the study. The power athletes were competitive sprinters in the 100 m, 200 m, or 110 m hurdles (sprint training experience: 7.0 years [5.8–8.0 years], average training frequency in the last 3 months: 5.0 times/week [5.0–5.0 times/week], average duration of single training session in the last 3 months: 180 min/session [150–180 min/session],World Athletics score (Spiriev & Spiriev, 2025): 922 points [888–984 points]), while the endurance athletes were competitive runners in the 5000 m and 10000 m (long-distance running training experience: 9.0 years [6.8–10.0 years], average training frequency in the last 3 months: 13.0 times/week [13.0–13.0 times/week], average duration of single training session in the last 3 months: 95 min/session [90–120 min/session], World Athletics score: 827 points [729–889 points]). All participants had experience with jumping and cycling exercises. Prior to the experiment, the participants were informed of the procedures, benefits, and potential risks of the study. They then signed an institutionally approved informed consent document to participate in the study. This study was approved by the Ethics Review Committee of the University of Tsukuba (No. 024-59, approval date: December 20, 2024).

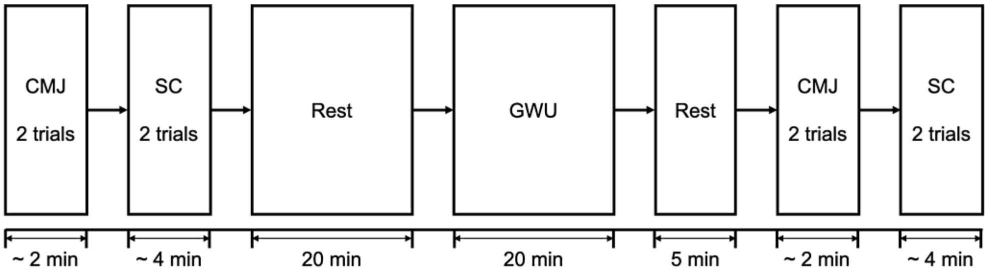
Measures

The participants performed the countermovement jump (CMJ) and the sprint cycling (SC) twice each before and after the GWU. The CMJ was performed on a force plate (Ex-Jumper, DKH Co., Tokyo, Japan), and ground reaction force data were sampled at 1000 Hz. Jump height was calculated from the ground reaction force data using an Excel analysis file created by Chavda et al. (Chavda et al., 2018). After completing the CMJ trials, the participants performed the SC on a cycle ergometer (Power Max VIII, KONAMI Co., Ltd., Tokyo, Japan). The average and peak power values shown on the ergometer display after the SC were recorded.

Heart rate data during the GWU was collected by attaching a heart rate monitor (Polar H10, Polar Electro Oy., Kempele, Finland) to the chest at a sampling frequency of 1 Hz. The average power during the GWU shown on the cycle ergometer (Wattbike Pro, Wattbike Ltd., Nottingham, United Kingdom) display was recorded. The participants rated their perceived exertion (RPE) for the lower limb muscles (RPE-LM) and respiratory system (RPE-RS) on a scale of 1 to 10 (Foster et al., 2001; Romaratezabala et al., 2018) after the GWU.

Procedures

All procedures were conducted in a temperature-controlled laboratory (room temperature 21.3 ± 0.75°C) between 8:00 AM and 7:00 PM. The participants were instructed to avoid strenuous physical activity, caffeine and alcohol for 24 hours prior to the test. After arriving at the laboratory and receiving a thorough explanation of the anaerobic exercise performance tests and the GWU, the participants put on athletic shoes and clothing. Their anaerobic exercise performance was then assessed before and after the standardized GWU.



Note. CMJ = countermovement jump; GWU = general warm-up; SC = sprint cycling.

Figure 1. Schematic representation of the study design and testing procedures.

The participants performed the CMJ and the SC twice each before and after the GWU. Each CMJ was performed with the participant's hands on their hips to eliminate the influence of arm swing. The depth of squatting during the CMJ was not restricted. Before the first CMJ trial, the participants were given a visual demonstration and instructed to jump as high as possible. To establish a baseline force for each CMJ trial, the participants were instructed to stand still on the force plate for two seconds after data collection began. The participants rested for one minute between the first and second CMJ trials. At each time point, the trial with the greater CMJ height was analysed. Three minutes after completing the two CMJ trials, the participants performed the SC on a cycle ergometer with the load set at 7.5% of body mass (Gray et al., 2006). The saddle was adjusted to an optimal position for each participant and maintained at this height for all subsequent trials. Both feet were secured to the foot pedals with belts. The participants were instructed to remain seated and pedal at maximum effort for six seconds. A three-minute rest period was provided between the first and second SC trials. At each time point, the trial with the higher average power was analysed.

After completing the anaerobic exercise performance tests, the participants rested in a seated position for 20 minutes. Following the rest period, the participants adjusted the saddle of the cycle ergometer (Wattbike Pro, Wattbike Ltd., Nottingham, United Kingdom) in preparation for the GWU. During the GWU, the participants cycled for 20 minutes at a pedalling cadence of 60–70 rpm, targeting an intensity of approximately 60% of their predicted maximum heart rate (HRmax = 208 - [0.7 × age]) (Tanaka et al., 2001). While maintaining this cadence, the pedal load was adjusted to achieve the target intensity of 60%HRmax. The duration and intensity of the GWU were selected based on previous studies showing that it caused minimal depletion of high-energy phosphates (Karlsson et al., 1970) and increased muscle temperature by 2–3°C (Cunha et al., 2010; Saltin et al., 1968). Five minutes after completing the GWU, the participants rated their RPE-LM and RPE-RS.

Analysis

G*Power software (version 3.1.9.6, University of Kiel, Kiel, Germany) was used to calculate the sample size needed for this mixed-design study (Faul et al., 2007). A minimum sample size of 17 per group was required to reach a statistical power level ($1 - \beta$) of 0.80 based on an α level of .05 and a predicted effect size of .25. The Shapiro-Wilk test was used to evaluate the distribution of all variables. As some variables were not normally distributed, a two-way (group × time) mixed-design nonparametric analysis of variance was used to examine changes in anaerobic exercise performance variables before and after the GWU between the power and endurance athletes (Wobbrock et al., 2011). When a significant interaction effect was found, the Wilcoxon signed-rank test was used to compare anaerobic exercise performance variables before and after the GWU within each group. The Mann-Whitney U test was used to examine the differences in average power during the GWU and RPE between the two groups. The intraclass correlation coefficient (ICC) was calculated to assess the reliability of the data obtained from the anaerobic exercise performance tests at each time point within each group. The statistical significance level was set at $p < .05$. All data are presented as medians (interquartile ranges). Effect size (r) was calculated to assess the magnitude of change within groups and differences between groups. The Hodges–Lehmann estimator was calculated to determine the median differences between the first and second attempts both before and after the GWU, along with their corresponding confidence intervals. In addition, the estimator was used to quantify the median difference between the before and after the GWU and its confidence interval. All statistical analyses were performed using statistical software (IBM SPSS Statistics ver. 28.0, IBM Corporation, Armonk, USA).

RESULTS

Table 1 shows the results of the within-group reliability tests for the anaerobic exercise performance variables at each time point. All performance variables showed high reliability (ICC = 0.879–0.965).

Table 1. Reliability of anaerobic exercise performance tests.

Test	Variables	Groups	Before		After	
			ICC (95%CI)	**Hodges–Lehmann estimator (95%CI)**	**ICC (95%CI)**	**Hodges–Lehmann estimator (95%CI)**
CMJ	Jump height (m)	Power athletes	0.917 (0.807–0.966)	0.011 (0.001–0.020)	0.879 (0.725–0.950)	0.008 (0.003–0.013)
		Endurance athletes	0.931 (0.836–0.972)	0.009 (0.002–0.014)	0.948 (0.876–0.979)	0.004 (-0.003–0.010)
SC	Average power (W)	Power athletes	0.858 (0.682–0.811)	32 (11–51)	0.893 (0.753–0.956)	18 (2–33)
		Endurance athletes	0.800 (0.568–0.915)	25 (8–43)	0.966 (0.917–0.986)	7 (-3–17)
	Peak power (W)	Power athletes	0.914 (0.799–0.965)	32 (24–40)	0.965 (0.914–0.986)	18 (12–23)
		Endurance athletes	0.949 (0.878–0.979)	22 (13–28)	0.957 (0.897–0.983)	7 (2–14)

Note. 95%CI = 95% confidence interval; CMJ = countermovement jump. ICC = intraclass correlation coefficient; SC = sprint cycling.

Table 2. Changes in anaerobic exercise performance variables after the GWU.

Test	Variables	Groups	Before	After	ES	Hodges–Lehmann estimator (95%CI)	*p*-value (η²)		
			Median (IQR)	**Median (IQR)**			**G**	**T**	**G x T**
CMJ	Jump height (m)	Power athletes	0.41 (0.39–0.45)	0.42 (0.40–0.44)	0.06	0.001 (-0.007–0.010)	< .001† (.754)	.003† (.207)	.041† (.106)
		Endurance athletes	0.25 (0.23–0.30)	0.27* (0.26–0.32)	0.72	0.013 (0.006–0.023)			
SC	Average power (W)	Power athletes	761 (681–791)	770 (695–813)	0.40	16 (-3–32)	<.001† (.680)	.041† (.105)	.957 (.000)
		Endurance athletes	501 (467–552)	506 (474–585)	0.50	12 (1–23)			
	Peak power (W)	Power athletes	889 (854–954)	912 (860–961)	0.37	10 (-3–26)	<.001† (.719)	<.001† (.336)	.197 (.043)
		Endurance athletes	601 (564–650)	629 (589–672)	0.88	22 (15–26)			

*Note. CI = confidence interval; CMJ = countermovement jump; ES = effect size; G = group. IQR = Interquartile range; SC = sprint cycling; T = time. * A significant difference before and after the general warm-up (p < .05). † A significant interaction effect, main effect of group, or main effect of time (p < .05).*

The average power during the GWU was significantly higher in endurance athletes (136 W [119–147 W]) than in power athletes (99 W [89–115 W]) (absolute average power: $p < .001$, $r = .67$; average power relative to body mass: $p < .001$, $r = .84$).

No significant differences between groups were observed in the average heart rate during the GWU (*p* = .134, *r* = .24, power athletes: 114.6 bpm [113.8–116.2 bpm], endurance athletes: 114.0 [112.5–115.0]). The results of the anaerobic exercise performance tests are shown in Table 2.

In CMJ height, a significant interaction effect (group × time) and main effects of group and time were observed. Post hoc tests revealed that the endurance athletes showed a significant increase in CMJ height after the GWU (*p* = .001, *r* = .72), whereas no significant change was observed for the power athletes (*p* = .794, *r* = .06).

Both average and peak power during the SC showed significant main effects of group and time, but no significant interaction effects.

No significant differences between groups were observed in RPE-LM (*p* = .819, *r* = .04) and RPE-RS (*p* = .932, *r* = .01).

DISCUSSION

The purpose of this study was to investigate the influence of training history on anaerobic exercise performance following cycling at an intensity appropriate for a GWU. The hypothesis that the power athletes would show greater improvement in anaerobic exercise performance than the endurance athletes following the GWU was not supported. Instead, the endurance athletes showed greater improvement in CMJ height. Furthermore, no significant differences between groups were observed in average and peak power during the SC. These results suggest that factors other than muscle fibre composition have a greater influence on the performance-enhancing effect of a GWU.

Many studies have demonstrated the positive effect of increasing muscle temperature on anaerobic exercise performance (Bergh & Ekblom, 1979; Sargeant, 1987; Tsurubami et al., 2020). Additionally, a study examining internal factors that modulate changes in exercise performance associated with increases in muscle temperature reported that individuals with a higher percentage of type IIA fibres showed greater improvements in anaerobic exercise performance with increases in muscle temperature (Gray et al., 2006). However, this finding was observed when muscle temperature was passively increased using hot water and electric blankets, and no studies have investigated whether similar results can be observed when muscle temperature is increased through active warm-up. To our knowledge, the present study is the first to address this issue.

A potential factor explaining the discrepancy between our results and the hypothesis may be the varying resistance to motor pattern interference caused by continuous exercise. Previous studies reported that preceding movement tasks have a negative impact on the performance of a subsequent task (Kay & Blazevich, 2009; Marquez et al., 2009). Specifically, there was no decrease in isometric ankle joint moment after MVC, but the peak concentric moment was significantly reduced (Kay & Blazevich, 2009). This reduction was accompanied by, and correlated with, significant reductions in peak triceps surae electromyographic amplitude. In addition, it has been reported that CMJ height decreased after 15 minutes of cycling at an intensity of approximately 140 bpm, which may be due to changes in the activation pattern of the lower limb muscles (Marquez et al., 2009). To our knowledge, there are no studies showing that endurance athletes are less affected by motor pattern interference than power athletes. However, a previous study on triathletes suggested that changes in respiratory and circulatory responses and running patterns after cycling vary depending on the competitive level of the participants (Millet et al., 2000). Furthermore, it has been reported that when marathon runners completed a 30 km trial and performed CMJ every 5 km, the CMJ height was highest at the 25 km point (Del Rosso et al., 2016). This suggests that well-trained endurance athletes may be resistant to motor pattern interference caused by continuous exercise, ensuring that the positive effect of the GWU on CMJ performance is not obscured. However, to our knowledge, there is no direct evidence that endurance training can suppress motor pattern interference after continuous exercise. Thus, further research is warranted to elucidate the effect of endurance training on changes in movements and muscle activation patterns during anaerobic exercise after continuous exercise.

Based on previous research found no difference in maximum heart rate between power athletes and endurance athletes (Whyte et al., 2008), this study applied the same estimation formula (Tanaka et al., 2001) to calculate maximum heart rate for all participants, setting the relative intensity of the GWU equally for both groups. In fact, there was no significant difference between the groups in RPE after the GWU. However, the average power during the GWU was higher in endurance athletes than in power athletes. This difference in power output could have led to different changes in muscle temperature between the two groups. In addition, a previous study (Racinais & Oksa, 2010) has demonstrated a strong association between muscle temperature and anaerobic exercise performance. Therefore, if the difference in average power during the GWU affects muscle temperature, this could adequately explain why the endurance athletes show greater improvements in anaerobic exercise performance than the power athletes. However, some studies have shown that muscle temperature increases depending on relative exercise intensity rather than absolute exercise intensity (Saltin et al., 1968; Saltin & Hermansex, 1966). Therefore, although we could not measure muscle temperature due to equipment limitations, it is unlikely that the difference in average power during the GWU caused a significant difference in muscle temperature changes between the groups.

This study has several limitations. First, the study was limited to verifying the effect of a cycling warm-up. Additional studies for other types of dynamic warm-ups would contribute to designing individualized warm-up programs. Furthermore, since the study was limited to male sprinters and long-distance runners, it is unclear whether the results can be applied to athletes in other sports or to female athletes. Conducting research on them could deepen our understanding of the influence of training history on warm-up effectiveness.

CONCLUSIONS

This study demonstrates that an individual's training history influences the effect of the GWU on anaerobic exercise performance, and individuals who regularly engage in endurance training may benefit more from the GWU. These findings suggest that the performance-enhancing effect of the GWU is not solely determined by muscle fibre composition but may also be associated with neuromuscular factors, such as resistance to motor pattern interference induced by continuous exercise. These findings indicate that a one-size-fits-all warm-up cannot optimize athletes' performance and emphasize the importance of individualized warm-up according to an athlete's training history. This research provides the fundamental knowledge necessary to shift from a uniform approach to designing individualized warm-up programs.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. N. Ushirooka, K. Muratomi, H. Maemura, S. Tanigawa contribute to the research concept and study design; N. Ushirooka, K. Muratomi, S. Tanigawa performed literature review and the experiment data collection; N. Ushirooka performed statistical analysis; N. Ushirooka, K. Muratomi, H. Maemura, S. Tanigawa contribute to data

interpretation; N. Ushirooka wrote the manuscript; K. Muratomi, H. Maemura, S. Tanigawa revised the manuscript. All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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