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Effect of stride frequency on thermoregulatory responses during endurance running in distance runners

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ABSTRACT

Changing stride frequency may influence oxygen uptake and heart rate during running as a function of running economy and central command. This study investigated the influence of stride frequency manipulation on thermoregulatory responses during endurance running. Seven healthy endurance runners ran on a treadmill at a velocity of 15 km/h for 60 min in a controlled environmental chamber (ambient temperature 27 °C and relative humidity 50%), and stride frequency was manipulated. Stride frequency was intermittently manipulated by increasing and decreasing frequency by 10% from the pre-determined preferred frequency. These periods of increase or decrease were separated by free frequency running in the order of free stride frequency, stride frequency manipulation (increase or decrease), free stride frequency, and stride frequency manipulation (increase or decrease) for 15 min each. The increased and decreased stride frequencies were 110% and 91% of the free running frequency, respectively (196 ± 6, 162 ± 5, and 178 ± 5 steps/min, respectively, $P < 0.01$). Compared to the control, stride frequency manipulation did not affect rectal temperature, heart rate, or the rate of perceived exhaustion during running. Whole-body sweat loss increased significantly when stride frequency was manipulated (1.48 ± 0.11 and 1.57 ± 0.11 kg for control and manipulated stride frequencies, respectively, $P < 0.05$), but stride frequency had a small effect on sweat loss overall (Cohen's d=0.31). A higher mean skin temperature was also observed under mixed frequency conditions compared to that in the control ($P < 0.05$). While the precise mechanisms underlying these changes remain unknown (e.g. running economy or central command), our results suggest that manipulation of stride frequency does not have a large effect on sweat loss or other physiological variables, but does increase mean skin temperature during endurance running.

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1. Introduction

The ability of humans to run long distances in hot temperatures may have been an evolutionary advantage (Bramble and Lieberman, 2004; Carrier, 1984; Lieberman, 2015). One of the crucial factors for running long distances in hot conditions is heat dissipation by sweating to maintain body temperature. While many studies have investigated the factors that affect cardiovascular and metabolic response during running (Carter et al., 2002; Crews, 1992; de Ruiter et al., 2014; Fletcher et al., 2009; Helgerud et al., 1990; Tseh et al., 2008), thermoregulation during running is not well understood.

Many factors affect physiological responses during running, including running experience, running form, stride frequency, sex, exercise intensity, and psychological state (Carter et al., 2002; Crews, 1992; de Ruiter et al., 2014; Fletcher et al., 2009; Helgerud et al., 1990; Tseh et al., 2008). Stride frequency is not a common factor in all runners since there are a number of combinations of stride length and frequency that runners adopt (Cavanagh and Williams, 1982). Stride frequency has been reported to decrease with fatigue (Candau et al., 1998; Dutto and Smith, 2002) while others reported an increased frequency (Kyröläinen et al., 2000;

Abbreviations: ANOVA, analysis of variance; HR, heart rate; RPE, rate of perceived exertion; T_{re}, rectal temperature; T_{sk}, local skin temperature; �$_{sk}$, mean skin temperature; $\dot{V}O_{2max}$, maximum oxygen consumption

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Place et al., 2004). Results from previous studies suggest that oxygen uptake increases (economy of running decreases) with stride frequencies that are 20% above or below the freely chosen running frequency (Cavanagh and Williams, 1982; de Ruiter et al., 2014; Hunter and Smith, 2007; Morgan et al., 1994). Running economy has been shown to affect human thermoregulation during running, and lower elevations in both esophageal and rectal temperatures (T_{re}) and reduced sweat loss were seen at high levels of running economy compared to those at low levels (Gant et al., 2004; Smoljanic et al., 2014). Therefore, both increasing and decreasing stride frequency may influence running economy and thermoregulatory response during running. In addition, alterations in stride frequency elevate heart rate (HR) during running (de Ruiter et al., 2014; Knuttgen, 1961). Increasing cycling cadence also elevates HR (Gotshall et al., 1996). This may be partly associated with increasing central command (a signal arising from the motor cortex) and muscle mechanoreflex activation (afferent signals from working muscles that respond to muscle mechanical stimuli), which increase HR (Gladwell and Coote, 2002; Williamson et al., 1995) and sweating (Amano et al., 2014; Kondo et al., 1997; Shibasaki et al., 2004). These studies also suggest that running frequency may influence thermoregulatory responses. However, regardless of the underlying mechanism (e.g. running economy and/or central command), whether manipulation of stride frequency affects thermoregulation during running remains unknown.

To identify the factors affecting human thermoregulation during running, we investigated the influence of stride frequency manipulation on thermoregulatory responses during endurance running. Since both increasing and decreasing stride frequency can potentially affect thermoregulatory responses, we investigated the influence of stride frequency manipulation on thermoregulation by increasing and decreasing stride frequency. Although previous studies investigated the influence of stride frequency on metabolic and heart rate responses during short periods of running (2–6 min) (Cavanagh and Williams, 1982; de Ruiter et al., 2014; Hunter and Smith, 2007; Morgan et al., 1994), the running periods were too short to evaluate thermoregulatory responses. In contrast, stride frequency manipulation cannot occur for long durations (e.g. one hour). Therefore, we intermittently manipulated stride frequency by mixing both increases (+) and decreases (−) with free frequency running in the order of free stride frequency, stride frequency manipulation (+ or −), free stride frequency, and stride frequency manipulation (+ or −) for 15 min each. We hypothesized that running with an altered stride frequency (increasing or decreasing) would increase the elevation of T_{re}, HR, rate of perceived exertion (RPE), and sweat loss during endurance running on a treadmill.

2. Materials and methods

2.1. Ethical approval

Prior to the study, each subject was informed of the purpose and procedures involved in the study. All subjects provided written informed consent. This study was approved by the Human Subjects Committee of the Graduate School of Human Development and Environment, Kobe University (Kobe, Japan), and conformed to the standards set forth in the latest revision of the Declaration of Helsinki.

2.2. Participants

Seven male distance runners participated in this study [age, 21.4 ± 0.9 years; height, 172.0 ± 2.9 cm; weight, 58.4 ± 1.5 kg; maximum oxygen consumption ($\dot{V}O_{2max}$), 72.0 ± 1.9 ml/kg/min]. All runners belonged to the Kobe University track club, and their best record in the 5000-m event was 16.3 ± 0.2 min. At the time, no subject was receiving medication, and all were non-smokers.

2.3. Experimental protocol

All experiments were conducted in an environmental chamber (SR-3000; Nagano Science, Osaka, Japan) maintained at an ambient temperature of 27 °C and relative humidity of 50% with minimal air movement. Subjects reported to the laboratory on four different days, as follows: 1) to assess $\dot{V}O_{2max}$, 2) to perform a 30-min running test, 3) to perform a 60-min running test with a freely selected stride frequency, and 4) to perform the 60-min running test with intermittent manipulation of stride frequency. On the first visit to the laboratory, $\dot{V}O_{2max}$ was determined by an incremental running test. After a warm-up running period on a motorized treadmill (AR200; Minato Medical Science, Osaka, Japan) at a velocity of 10.0 km/h for 3 min, the initial belt speed was set to 15.6 km/h and increased 1.2 km/h every 2 min. After reaching 19.2 km/h, the speed was increased 0.6 km/h every 2 min, and the incline was increased 2% each minute, with no alterations to the speed after reaching 20.4 km/h, until voluntary exhaustion. Respired gases obtained from samples drawn continuously from a gas mask were analyzed using a gas analyzer (AE300S; Minato Medical Science, Osaka, Japan), and breath-by-breath gas-exchange variables were calculated. The $\dot{V}O_{2max}$ was calculated from the average oxygen consumption over the last 30 s of the test.

On the second visit, a 30-min running test was conducted to determine freely chosen stride frequency and customize changes in stride frequency to ± 10% from the free stride frequency. This stride frequency was selected, since it was possible to increase the cost of running based on a previous report (Hunter and Smith, 2007). Subjects ran on the treadmill at 15 km/h for 30 min. Free stride frequency was determined from 5 to 10 min of the running period before manipulating the stride frequency ± 10% from the free stride frequency every 10 min. A metronome was used to adjust step frequencies.

On the third and fourth visits, a 60-min running test was conducted with or without stride frequency manipulation in a random order. Upon arrival at the laboratory, nude body weight was measured and subjects were prepared for running. Running tests were conducted on a treadmill with a 0% slope, and participants wore running shorts with their own running shoes used during their daily exercise. During the stride frequency manipulation trial, stride frequency was changed every 15 min, and increases or decreases in frequency were separated by 15 min of free frequency running. The order for changing stride frequency was 1: free stride frequency, 2: stride frequency manipulation (10% increase or decrease), 3: free stride frequency, and 4: stride frequency manipulation (10% increase or decrease). The order for increasing or decreasing stride frequency was randomized between subjects. We used this intermittent mixed stride frequency model since stride frequency manipulation would be difficult to continue for 60 min, as shown in our pilot studies (data not shown). Therefore, we employed the intermittent running protocol described above in this study.

2.4. Measurements

During the 60-min running experiment, the T_{re}, local skin temperature (T_{sk}) at four sites (chest, upper arm, thigh, and calf), HR, whole-body weight reduction, RPE, and stride frequency were determined.

T_{re} and T_{sk} were measured using a copper-constantan thermocouple. To measure T_{re}, the tip of the thermocouple was

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