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Research article

The effect of a silicone swim cap on swimming performance in tropical conditions in pre-adolescents

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Abstract

We tested whether the silicone swim caps (SC) worn by young swimmers in a tropical climate negatively influence aerobic performance. Nine trained pre-adolescents [11.8 (\pm 0.8) years] swam randomized 800-m trials (water: 32.9°C, outdoors: shade, 29.2 \pm 0.2 °C, 74 \pm 0.3 % rh) with a SC or a nude head (NH). Performance times and heart rate (HR) were monitored continuously. Rectal temperature (T_{rec}) was measured before and after trials. The rating of perceived exertion (RPE) was assessed. Stroke frequency (SF), stroke length (SL) and stroke index (SI) were measured every 50-m. The SC trial was significantly longer than NH (799 \pm 16 and 781 \pm 16 seconds, respectively). Mean delta T_{rec} was significantly greater in SC (0.2 \pm 0.1°C vs. -0.1 \pm 0.1°C in SC vs. NH), mean SI was significantly different in SC versus NH (1.83 \pm 0.07 vs 1.73 \pm 0.06); but RPE and mean HR, SF and SL showed no change. We conclude that a silicone swim cap worn in tropical environment significantly decreased 800-m crawl performance without affecting HR or RPE. Silicone swim caps worn by young swimmers in a tropical environment may also have negative effects on training capacity.

Key words: Swimming, hot/wet environment, pre-adolescents, aerobic exercise, performance

Introduction

Performance, fatigue and exhaustion during exercise in the heat, especially during exercise performed in field conditions, have recently been presented as a hot topic (Schlader et al., 2011).

When confronted by heat stress, one of the guidelines is to limit, stop or cancel all athletic activities at a wet bulb globe temperature (WBGT) of 26-29°C (American Academy of Pediatrics, 2000). This is fairly simple to do in regions that have the four-season pattern of temperature change with only occasional temperature spikes, but it is much more problematic in tropical climates, where temperatures often exceed 25°C and humidity exceeds evapotranspiration for at least 270 days per year (Salati et al., 1983). For people living in these climates, one of the most important guidelines for sports activities is to limit the amount of clothing worn in order to enhance thermoregulatory processes. Guadeloupe, with a mean temperature of 25-26°C and a mean relative humidity of 80-82%, has a tropical climate that has been demonstrated to act as a passive warm-up all day and night long (Racinais et al., 2004).

It has long been acknowledged that children and adolescents do not adapt as effectively as adults do to

temperature extremes, such as high climatic heat stress (Bar-Or, 1998). Several recent reviews and articles reassessed children's thermoregulation during exercise in the heat (Falk and Dotan, 2008; Inbar et al., 2004; Rowland, 2008) and reported discrepant findings. Some found no maturational differences in thermal balance or endurance performance during exercise in the heat (Rowland, 2008), whereas others noted that children are more likely to be susceptible to heat-related injury in extreme environments (Falk and Dotan, 2008). Still others observed that prepubertal boys are better thermoregulators than both young adults and the elderly (Inbar et al., 2004). There is consensus today on three points: characterizing children's physiological responses and performance outcomes during exercise in the heat is far from complete (Rowland et al., 2008), children and adults employ different thermoregulatory strategies (Falk and Dotan, 2008), and children and young adults exposed to hot climates need to follow proper guidelines to prevent heat injury or performance decrement (American Academy of Pediatric, 2000).

Swimming in Guadeloupe can be a distinct challenge, as the annual mean ocean temperature is 26°C and, for almost 6 months of the year, the water in Olympic swimming pools is over 30°C, whereas the recommended pool temperature for competitive swimming is 27-28°C (Aquatic Exercise Association, 2008). Nevertheless, athletes who swim competitively train every day. A particularly interesting question thus concerns the extent to which swimming is affected by a tropical climate. The thermal balance of swimmers is well known to be regularly challenged because of the high heat transfer coefficient of water (Wade and Veghte, 1977). Most studies have reported the effect of cold water on thermoregulation (Costill et al., 1967; Sloan and Keatinge, 1973), but one study found that swimming in high water temperature increased heart rate in relation to hyperthermia and increased skin circulation and esophageal temperature to the same extent as running in a hot environment (Holmér and Bergh, 1974). These authors noted an increase of 8 beats·min⁻¹ in heart rate during a 20-min submaximal swimming exercise (approximately 50% of VO_{2max}) in 34°C water as opposed to 26°C water. Swimming is thus a sport that induces high thermoregulatory stress in a tropical climate, as recently confirmed (Hue et al., 2007).

One easy way to enhance thermoregulation in competitive swimmers in Guadeloupe is to remove the silicone swim cap that is usually used for gliding as well as hygienic reasons. Targeted active cooling of the head during exercise has been recognized as efficacious in

improving subjective tolerance and/or the physiological response to heat stress (Nunneley et al., 1971). Comprising only 8-10% of the body surface area (Brown and Williams, 1982), it can account for the dissipation of 30% of the resting heat load and almost 20% during moderate-intensity exercise (Nunneley et al., 1971). Similarly, the dorsal head (*i.e.*, the part of the head covered by the swimming cap) is only a very small part of the body surface but its immersion in cold water (*i.e.*, 12°C) has been demonstrated to substantially increase core cooling (Giesbrecht et al., 2005) because of the great amount of blood flow in the scalp and the lack of vasoconstriction in scalp blood vessels in response to cold water as opposed to the surface vessels in other body areas (Froese and Burton, 1957). Very recently, Simmons et al. (2008) demonstrated the major subjective importance of the head in the perception of temperature sensation.

The aim of this study was thus to test aerobic swimming performance during an 800-m event in pre-adolescents with and without a silicone swim cap. We hypothesized that removing the cap in a hot/wet environment would permit better thermoregulation, which in turn would increase performance.

Methods

Subjects

Seven male [11.7 (\pm 0.9) years] and two female [11.9 (\pm 0.2) years] competitive swimmers participated in this study. All were regionally and inter-regionally ranked swimmers, native to Guadeloupe, and currently living and training there [training in swimming for 3.6 (\pm 0.3) years]. The group belonged to the same club affiliated with the Guadeloupe Swimming League and regularly trained five times a week for a total of 7 hours of swimming, or 13 to 15 km per week. The training camp was based at an outdoor 25-m swimming pool. The swimmers were in the competitive season at the time of the study. Pubertal stage [1.3 (\pm 0.1) of the Tanner classification as assessed by a physician] was determined according to pubic hair and gonadal development (Tanner and Whitehouse, 1976). Anthropometric and physiological measurements were made one week before testing and are presented in Table 1. Informed written consent was given by all pre-adolescents and their parents. The protocol was approved by the ethics committee of Guadeloupe University.

Anthropometry

Body mass loss (kg) was measured on a scale by changes in nude body mass (\pm 0.1 kg) (Planax Automatic, Terailon, Chatoux, France). The subjects were weighed in the same conditions before and after exercise. Body fat content was estimated from the skinfold thickness, expressed in millimeters, representing the sum of four different skin areas (biceps, triceps, subscapula, and supra-iliac) measured on the right side of the body with the Harpenden skinfold caliper following the method described by Durnin and Rahaman (1967). The equation of Durnin and Rahaman (1967) was used to determine the percentage of fat body mass (FBM). Lean body mass (LBM) was determined from body mass and FBM. Buoyancy was evaluated by the measurement of hydrostatic lift (HL) as described by Chatard et al. (1990).

Experimental protocol

Swimmers came to the pool one week before the two 800-m events to perform two 15-m sprints, without diving, to measure their maximal swim speed. The best performance in the 400-m event (MAS₄₀₀) of the current competitive season was recorded for each swimmer and taken as the maximal aerobic test (Chatard et al., 1995; Chollet et al., 2000). The event was held in a 27°C swimming pool in conditions detailed elsewhere (Hue et al., 2007; Rodriguez, 2000).

The 800-m event

Each subject performed two trials at approximately the same time of day to minimize the influence of circadian variation on internal body temperature (Wenger et al., 1976). For the duration of the study, the subjects were asked to maintain similar daily activity and adequate dietary and fluid intake. The trials began at 5 PM to minimize the effects of the sun and to take into account the daily training rhythms of the swimmers. All subjects performed two randomized 800-m crawl trials in the tropical environment (water: 32.9 \pm 0.1 °C, outdoors: shade, 29.2 \pm 0.2 °C, 74 \pm 0.3 % rh) on two separate days. In one trial they wore a silicone swim cap (SC) for the 800-m event and in the other they swam with nude heads (NH). The warm-up distances and intensities were standardized; in both conditions (SC and NH), the warm-ups were performed wearing a swimming cap, as required in Guadeloupean swimming pools for hygienic reasons.

Table 1. General characteristics and swim profiles of the 9 trained swimmers.

Subject #	Gender	Age (yr)	Height (m)	Weight (kg)	Tanner Stage (a.v.)	FBM (%)	LBM (kg)	HL (kg)	15m Sprint (s)	Time of the MAS ₄₀₀ test (s)
1	♀	11	1.57	41.2	2.0	24.0	31.9	.9	11.60	410
2	♀	12	1.56	44.1	2.0	23.9	34.2	1.5	11.10	396
3	♂	12	1.53	30.9	1.6	11.0	28.9	.4	10.23	360
4	♂	11	1.63	42.7	1.4	12.1	37.2	.5	10.80	364
5	♂	13	1.58	36.8	1.0	12.5	32.4	.7	10.40	375
6	♂	12	1.55	49.2	1.8	19.0	40.0	1.8	10.40	339
7	♂	10	1.48	33.9	1.0	14.0	29.6	.5	10.30	342
8	♂	11	1.43	34.8	1.0	18.4	26.8	.9	10.20	385
9	♂	11	1.49	33.4	1.0	13.5	29.8	1.5	10.60	366
Mean		11.4	1.53	38.6	1.4	16.5	32.3	1.0	10.80	371
SEM		.3	.02	2.0	.1	1.7	1.4	.2	.20	8

Tanner stage: pubertal stage; a.v.: Arbitrary value; FBM: fat body mass; LBM: lean body mass; HL: hydrostatic lift; 15-m sprint: maximal swim speed; MAS₄₀₀: maximal aerobic speed at the end of a 400-m test.

Heart rate (HR) was monitored continuously using a portable telemetry unit (Polar Sport-tester PE 4000, Polar OY, Kempele, Finland) with recording every 5 seconds. The data were analyzed with Polar software (Polar Electro OY, Professorintie 5, Kempele, Finland). Rectal temperature (T_{rec}) was measured by the medical doctor before and immediately after the trials with a rectal thermometer (Microlife Corporation, Taipei, Japan). After each trial, the subjects were asked to rate their perceived exertion (RPE) using the Borg scale (Borg, 1973).

Stroke frequency, stroke length and stroke index

The stroke frequency (SF), expressed as the number of complete arm cycles min^{-1} , was measured for each 12.5-m with a frequency meter (Stopwatch Stroke base 3 time, Seiko, Japan) over three complete stroke cycles. The stroke length (SL) was calculated by dividing the speed, expressed as the distance per second, by the stroke frequency in a 12.5-m segment. The stroke index (SI) was calculated by multiplying the velocity by the stroke length (Costill et al., 1985). This index has been demonstrated to be reliable for assessing swimming skill (Costill et al., 1985).

Statistical analysis

After a normal distribution was verified using the Shapiro-Wilk test, the effects of wearing a swim cap on performance (time, speed and $\%MAS_{400}$), heart rate, and SF, SL and SI were analyzed using a two-way ANOVA for repeated measures (condition \times distance). When differences were observed, Scheffé's post-hoc test was used with the contrast method. Temperature and body mass were analyzed using a two-way ANOVA for repeated measures (condition \times time). The rate of perceived exertion was analyzed using a Student's *t* test for paired comparisons. Significance was defined as $p < 0.05$. Data are presented separately as mean \pm SEM.

Results

Performance was influenced by the swim cap condition, with a significant gain of 18.6 ± 5.0 seconds in NH compared with SC ($p < 0.01$). The 800-m kinetics showed a significantly longer time and lower speed for the SC condition compared with the NH condition at 550-m, 650-m, 700-m and 800-m (time \times conditions $p < 0.04$, Figure 1).

The intensity of the NH condition, expressed in $\%MAS_{400m}$, was significantly higher when compared with that of the SC condition (95.2 ± 2.0 vs 92.8 ± 1.8 $\%MAS_{400m}$; $p < 0.05$); however, HR was similar between tests (189 ± 2 vs 186 ± 3 bpm, in NH vs SC, respectively). SI was significantly different in SC versus NH (1.83 ± 0.07 vs 1.73 ± 0.06 ; $p < 0.05$). In contrast, mean SF and SL showed no significant differences. Within the trials, significantly higher values of SF and SI were noted at 550-m and 800-m for the SC condition compared with the NH condition, whereas SL showed significantly lower values ($p < 0.05$, Figure 1). Although rectal temperature did not differ after the warm-up (i.e., 37.6 ± 0.1 vs 37.7 ± 0.3 in NH and SC, respectively), the post-exercise delta T_{rec} was significantly higher ($p < 0.05$) in the SC condi-

tion (0.2 ± 0.1 °C vs -0.1 ± 0.1 °C in SC vs NH). Body mass was not significantly decreased (0.1 ± 0.1 and 0.2 ± 0.1 kg in NH and SC, respectively) after each trial compared with before the trial. There was no difference in RPE (13.6 ± 0.9 vs 13.0 ± 0.6 , in NH and SC, respectively).

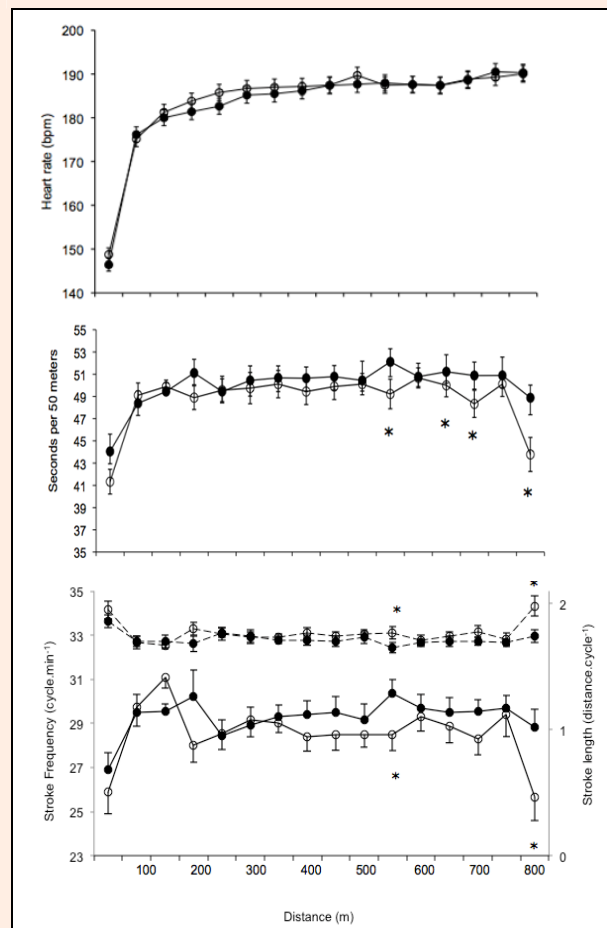


Figure 1. Heart rate, HR; time kinetics: seconds; stroke frequency (down) and stroke length (up) during SC and NH 800-m events. * SC Significantly different ($p < 0.05$) from NH.

Discussion

The most important finding of this study was that removing the silicone cap usually used by competitive swimmers increased the pre-adolescents' swimming performance in warm water.

To the best of our knowledge, this study is the first to investigate the response of acclimatized pre-adolescents to a tropical environment and clothing constraints. Most studies of children's or pre-adolescents' responses to heat exposure have investigated briefly exposed non-acclimatized children/pre-adolescents or those acclimated for only a short time to a hot climate (Rowland, 2008). The subjects of the present study were young competitive swimmers, native to and living and training in Guadeloupe, which has a tropical climate that has been demonstrated to be deleterious to endurance performance. This has been demonstrated in athletes even when they

are natives of and living in the hot and wet climate (Voltaire et al., 2003). We can therefore assume that the results of the present study would have been even more pronounced in non-acclimatized pre-adolescents.

Because we did not measure skin temperature or core temperature during the exercise, we have no data on the kinetics of total body temperature changes. However, the warm-ups were performed in the exact same conditions for the two randomized tests and the rectal temperatures were not different after the warm-ups. We can therefore assume that the changes in rectal temperature were due to the 800-m exercise bouts and not to the warm-ups. Although we did not use a specific test to measure thermal sensation or thermal comfort, the RPE scale has been demonstrated to be valid for measuring the conscious perception of effort in hot conditions (Crewe et al., 2008; Tucker et al., 2004).

One might assume that the mean difference of 18.6 sec in the performance times of these swimmers reflected diminished motivation and/or an inability to maintain the same exercise intensity between the 800-m events. Yet a drop in intensity for the second trial (SC or NH) can be easily rejected, whether objectively or subjectively evaluated, since the trials were randomized and HR, which is frequently used as a reliable indicator of objective exercise intensity (Hue et al., 2006; Léger and Thivière, 1988), did not differ between tests. Moreover, the high values of HR and the %MAS_{400m} suggested that the pre-adolescents did their best in both trials and were able to maintain the high intensity currently reported in the literature for highly-trained young athletes (Billat, 2001) and swimmers (Bentley et al. 2005). The subjective assessment of intensity could have influenced performance, particularly since the 800-m event is the longest trial of the Federation International de Natation Amateur program for young swimmers. However, this subjective intensity, evaluated by the Borg scale at the end of each trial, did not show significant differences within or between the SC and NH trials. The plausible explanation for the difference in performance times is that the swimmers were unable to maintain the same speed during the SC trial for objective or subjective reasons. As recently demonstrated for the use of oral adjuvant during exercise in the heat (Mündel and Jones, 2010), swimming without a silicone cap may be a more pleasant and rewarding/motivating experience within the brain, therefore extending the exercise performance. Another explanation could be that NH produces bradycardia relative to SC. As far as we know, this phenomenon, which is well known during cold water face immersion at rest (Finley et al., 1979) or after exercise (Al Haddad et al., 2010), has never been noted during warm water immersion. Moreover, no study to our knowledge has been conducted showing that bradycardia is greater during head immersion than during face immersion.

It might be surprising that the silicone swim cap could cause heat stress sufficient to decrease thermal comfort and thus performance, because the difference in rectal temperature (both between trials but also after versus before exercise) was very slight. However, a water temperature of 33°C was shown to be a potential thermal stress inducing a significantly higher T_{rec} than a tempera-

ture of 28°C during a long but slow swimming test (Fujishima et al., 2001). Moreover, although the dorsal head (*i.e.*, the part of the head covered by the swimming cap) represents only a very small part of the body surface, it is hypothesized that it permits substantial heat loss because of the great amount of surface blood flow in the scalp and the lack of vasoconstriction in scalp blood vessels, as opposed to surface vessels in other body areas (Froese and Burton, 1957). Furthermore, cooling the head and face during exercise has been demonstrated to reverse the hyperthermia-induced increase in RPE during both passive heating (Armada-da-Silva et al., 2004) and exercise (Mündel et al., 2007) and the thermal strain and discomfort during passive heating without affecting the core temperature (Mündel et al., 2006; Nunneley and Maldonado, 1983). Very recently head cooling has been demonstrated to attenuate the increase in core temperature during passive heating (Simmons et al., 2008). As stated by Cheung (2007), “the efficacy of either face fanning or head cooling to influence either brain temperature or physiological responses and performance is not universally evident in the literature and the possible mechanisms selectively used during this phenomenon are unclear but results issued from head cooling or head fanning would tend to support the idea that afferent feedback from cooling the head, irrespective of actual brain temperature, may play an important role in regulating exercise intensity and pacing by promoting an improved subjective perception of heat stress.”

Such a phenomenon (*i.e.*, a decrease in performance or power output without marked hyperthermia or increase in T_{rec}) has been demonstrated in cycling by Tattersson et al. (2000), Hue et al. (2010) and very recently Schlader et al. (2011), who reported lower work output during thermal warming versus thermal and non-thermal cooling despite similar HR, mean skin and rectal temperature. Schlader et al. (2011) noted that changes in temperature are not a requirement for the initiation of thermoregulatory behaviour in humans and that thermal sensation and thermal discomfort are capable behavioral controllers. It is possible that despite the very low change in core temperature, the greater sensitivity to heat changes and the heightened subjective sensitivity to increases in core temperature in children (Anderson and Mekjavic, 1996) could have prevented them from performing as well with the swim cap as without it.

It was interesting to note that the time losses in the SC 800-m (a mean of 18.6 sec) began at about 550-m and continued up to 800-m. The biomechanical parameters indicated that SI was significantly greater in NH condition, whatever the swim speed. The significantly higher values of SF and SI and lower SL between 550-m and 800-m in the SC 800-m confirmed this observation. This demonstrates that the swim cap globally altered swim performance. The SI is based on the assumption that, at a given speed, the swimmer with the greatest stroke length has the most effective swimming technique and skill (Costill et al., 1985). In the present study, the increase in SI without a swim cap thus indicated greater swimming skill in NH condition. This greater efficiency was most likely related to the lower thermal stress in NH, which made it easier to recruit more motor units for each arm

stroke cycle, thereby resulting in the higher efficiency.

Our data indicate two important points about swimming performance in tropical conditions: 1) wearing a silicone swim cap affects performance during a single continuous exercise in young swimmers, and 2) wearing a silicone swim cap during long-distance training sessions accentuates thermal stress and may thus lead to reduced training intensity, which in turn could affect competitive performance. We suggest the need for innovation in the textiles used for caps and for studies to develop technical means to optimize performance in hot/wet conditions.

Conclusion

In conclusion, this study showed that removing a silicone swim cap in tropical conditions increased the 800-m performance in young swimmers, probably in relation with thermoregulation processes and/or subjective perception. Competitive swimmers spend considerable time in the water. In order to prevent illness, preserve wellness, and make swimming training in a tropical climate safer and more enjoyable, we recommend that young competitive swimmers and their coaches envisage removing the silicone swim cap during training sessions and competitions of 800-m or more in tropical environmental conditions. However, further research is needed in the area of thermoregulation in relation with swimming performance.

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Key points

- Swimming in tropical climate represents a physiological stress
- Swimming with swim cap in warm water could induce thermal stress
- Thermoregulation processes have to be used in order to make training in tropical climate safer