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Cover Page Footnote

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The Combination of Cooling Techniques in a Tropical Environment Improves Precision Performance in Young International Fencers

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Abstract

The performance of intense exercise in a tropical climate is associated with limited exercise capacity due to thermal strain. This limitation is exacerbated in sports requiring full protective equipment. Research evidence suggests disturbances in cognitive function due to thermal discomfort and/or protective equipment (e.g., helmets), and thus sports that require skills in decision-making, fast reaction times, precision, and/or inhibition can be greatly affected. The objective of this study was to investigate the effects of countermeasures on the psychological and physiological responses in young international fencers wearing full protective equipment during an ecological fencing task. Nine young international fencers performed an aiming task in tropical conditions (1) without cooling interventions and (2) with cumulative cooling interventions (i.e., pre+percooling and head+torso). Participants completed a battery of cognitive (i.e., simple and choice reaction times, Stroop test), affective (i.e., PANAS), and perception (i.e., thermal environment, Feeling Scale, rating of perceived exertion) tests in each session, and their heart rate, skin temperature, and fencing performances (i.e., execution time and total score) were checked at several time points. Although the results revealed no differences in the perception of the thermal environment or the cognitive and affective scores, the cooling interventions seemed to improve movement precision during the fencing task and limit the decrease in pleasurable feelings related to the physical task. This study suggests that attentional resources are more available with cumulative cooling interventions, which leads to better performance during an ecological fencing task in tropical conditions.

Keywords: aiming task, environmental constraints, cognitive performance, affective states, reaction time, thermal perception

Exercise in Tropical Environment: Constraints of Climate Conditions and Protective Equipment

Exercise in a tropical environment (i.e., hot and wet climate) increases the stress on the cardiovascular and thermoregulatory systems (Hue, 2011; Maughan, 2010; Maughan et al., 2012; Tucker et al., 2006; Voltaire et al., 2003; Watson et al., 2011) and disturbs both cognition (Coudevylle et al., 2018; Hocking et al., 2001; Johnson & Kobrick, 1998; Vasmatzidis et al., 2002) and affective states (Coudevylle et al., 2018; Lane et al., 2004; Maw et al., 1993). These disturbances may worsen in physically demanding professions that require protective equipment (e.g., permeable biological and chemical protective clothing, disruptive pattern combat uniforms, body armor, helmets, plastron, gloves, and goggles) or sports like cricket, motosports, equestrian sports, judo, taekwondo, and fencing (e.g., Carballo-Leyenda et al., 2018; Cheung et al., 2000; Neave et al., 2004; Taylor & Orlansky, 1993). Indeed, the authors of a cricket study pointed out that protective equipment might exacerbate the storage of body heat, especially since ventilation is not a specific requirement of protective helmets (Neave et al., 2004). Studies conducted in tropical environments have focused on the performances of specific populations using equipment, such as soldiers (e.g., Caldwell et al., 2011; Hocking et al., 2001) and athletes (e.g., Hue & Galy, 2012; Robin et al., 2019). For example, a study of swimmers showed that wearing a silicone swim cap in tropical conditions (water: $32.9 \pm 0.1^{\circ}$C, outdoors: shade, $29.2 \pm 0.2^{\circ}$C, $74 \pm 0.3\%$ relative humidity) increased the post-exercise delta core temperature (i.e., rectal temperature) and decreased 800-m crawl performance, whereas no difference was observed in the rating of perceived exertion (Hue & Galy, 2012). For certain sports that require special equipment for an athlete's safety (i.e., clothing, personal protective equipment like helmets or plastron), tropical conditions exacerbate the environmental strains (e.g., Caldwell et al., 2011) and might disrupt thermoregulation and individual performance (e.g., Hue & Galy, 2012). Moreover, studies of psychological parameters have also highlighted affective and cognitive impairments due to environmental thermal strains (Coudevylle et al., 2018; Hocking et al., 2001; Maw et al., 1993; Vasmatzidis et al., 2002), protective equipment (Taylor & Orlansky, 1993), and helmet use (Neave et al., 2004). Indeed, a study of the effects

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of helmet use by adolescent cricketers revealed impaired attention, vigilance, and reaction times following a 30-minute batting session when helmets were worn (Neave et al., 2004). These impairments could seriously affect performance in sports with high cognitive demands, such as taekwondo and fencing, which require focused attention, vigilance, and rapid and accurate decision-making not only for efficient performance, but also for personal protection and safety.

Cooling Strategies as Countermeasures to Cope with Tropical Constraints

For certain activities, a tropical climate can impose an additional load that endogenous thermoregulation alone is unable to compensate. In these cases, exogenous interventions (i.e., cooling interventions) can be effective countermeasures (Bongers et al., 2015, 2017; Carballeira et al., 2019; Coudevylle et al., 2019). Among them, external cooling before (i.e., precooling) and/or during (i.e., percooling) exercise mainly consists of restricting the increase in core temperature in order to limit the alteration in exercise performance (Bongers et al., 2015, 2017; Tyler et al., 2015; Wegmann et al., 2012). For example, wearing a cooling vest/garment before and/or during exercise can help limit the core temperature increase (e.g., Bongers et al., 2015, 2017), improve the rating of perceived exertion and thermal perception (e.g., Kenny et al., 2011; Luomala et al., 2012; Ruddock et al., 2017), and thus improve performance (Bongers et al., 2015, 2017; Luomala et al., 2012; Minniti et al., 2011; Tyler et al., 2015). Nevertheless, it is important to note that, despite its small proportion of the body surface, the head is an area of high sudomotor and thermal sensitivity (Cheung, 2007) that plays a major role in the perception of temperature sensation (Simmons et al., 2008). Thus, given the impact of head temperature on exercise capacity, mental performance, and perception of effort (Cheung, 2007), some studies have explored other cooling interventions focused on the face and head (e.g., Armada-da-Silva et al., 2004; Desruelle & Candas, 2000; Gordon et al., 1990). Overall, head cooling has been employed to alleviate heat stress in clinical settings (Hachimi-Idrissi & Huyghens, 2004; Holzer et al., 2005; Ku et al., 1996; Wang et al., 2004), on aircrew members (Nunneley & Maldonado, 1983), and during exercise (Armada-da-Silva et al., 2004; Desruelle & Candas, 2000; Gordon et al., 1990). It has been shown that head cooling improves physiological responses (e.g., Nunneley & Maldonado, 1983), thermal comfort (e.g., Nunneley et al., 1982), and cognitive responses in terms of reaction times, performance accuracy, and tasks of higher complexity (e.g., Lee et al., 2014; Nunneley et al., 1982), and it also reduces perceived exertion (e.g., Armada-da-Silva et al., 2004). Yet it should be noted that, among these studies involving exercise-induced hyperthermia, few have investigated the effect of cooling interventions in a population of international athletes wearing the required protective equipment and performing in an ecological situation: a tropical environment. The studies on cooling interventions have shown the improved efficacy of these countermeasures when they are combined in duration (i.e., percooling in combination with precooling; e.g., Bongers et al., 2015) and cooled area (i.e., head cooling in combination with torso cooling; e.g., Nunneley & Maldonado, 1983). Few studies, however, have investigated the effects of these cumulative cooling strategies (in duration and cooled area) on psychological and physiological parameters in international athletes practicing in a tropical environment. In the case of cognitively demanding sports, the effects of cumulative cooling strategies (i.e., pre+percooling and head+torso) on psychological responses might result in limited alteration in performances due to environmental thermal strains (e.g., tropical condition) and/or the protective equipment (e.g., protective clothing, mask, gloves).

Purpose of the Present Study

The literature reveals that exercise with (Caldwell et al., 2011; Hocking et al., 2001) and without (Hue, 2011; Maughan et al., 2012; Watson et al., 2011) protective equipment generates thermal strains in a tropical environment. It also reveals that psychological parameters (i.e., cognitive and affective responses) are important in cognitively demanding sports (Lorenzo et al., 2010; Marcora et al., 2009; Mellalieu & Hanton, 2008). The main objective of this study was therefore to investigate the effects of cumulative cooling strategies (i.e., pre+percooling and head+torso) on performance and psychological and physiological responses in young international fencers in full protective equipment during an ecological fencing task. In the present study, our hypothesis was that cumulative cooling strategies in tropical conditions would improve thermal comfort, affective state, cognitive and motor performances in a fencing aiming task compared to no cooling interventions.

Method

Participants

Nine voluntary young international fencers (four women, five men) from the Fencing “Pôle France Antilles-Guyane” were involved in this study (mean age: 15.44 $\pm$ 0.88 years), which was approved in advance by the Fencing Regional Center and the local institutional ethics committee. Participants were informed about the experimental procedure. They were also notified that they would remain anonymous and that their data were protected by the applicable legislation. Each participant was then asked to fill out an informed consent form in accordance with the Declaration of Helsinki, and all participants and their legal guardians provided this written consent before participating. All were acclimatized and had been living year-round in a tropical environment since infancy. They had to be healthy with no history of psychiatric, neurological, or vestibular disorders, and they had to comply with the medical requirements for Fencing "Pôle France". Caffeine, drugs, and alcohol were strictly prohibited 24 hours before the start of the experimental session.

Measures

Perception Assessment

Perception of the Thermal Environment. Participants were asked to rate their subjective thermal sensation, comfort, and acceptability on three continuous rating scales ranging, respectively, from −3 (*very cold*) to 3 (*very hot*), from −2 (*very uncomfortable*) to 2 (*very comfortable*), and from −1 (*clearly unacceptable*) to 1 (*clearly acceptable*) (see Xiong et al., 2015, for a similar procedure).

Feeling Scale. The valence (pleasure–displeasure, good–bad) component of affect was measured with the Feeling Scale (FS) (Hardy & Rejeski, 1989). Participants were invited to report how they felt at specific time points on a continuous rating scale ranging from −5 (*very bad*) to +5 (*very good*).

Rating of Perceived Exertion. The perception of exertion was evaluated by the 15-point Borg's Rating of Perceived Exertion (RPE) (Borg, 1998) that ranges from 6 (*no exertion*) to 20 (*maximal exertion*).

Affective Assessment

Affective states were assessed by the Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988). This short self-assessment questionnaire consists of 20 self-rated items on a 5-point scale ranging from 1 (*very slightly*) to 5 (*very much*) and grouped into two parts: 10 positive affect items (PA) (Cronbach's $\alpha = 0.88$) and 10 negative affect items (NA) (Cronbach's $\alpha = 0.69$).

Cognitive Assessment

Stroop Test. Participants were asked to perform the French adaptation of the Victoria Stroop test (Strauss et al., 2006). This test consists of three conditions of 24 stimuli each: colored dots for the dot condition, common words (i.e., when, but, thus, for) printed in colors for the word condition, and color names (i.e., red, blue, yellow, green) printed in colors not corresponding to the words themselves for the interference condition. In the dot condition, participants had to name the color of the dots as quickly as possible. In the word and interference conditions, they had to inhibit the written word in order to correctly name the color of the ink. For each condition, the participants performed a sample line to ensure that they understood the instructions. The completion time (seconds) and the number of errors (corrected, non-corrected, and total errors) were measured, and two interference scores were calculated: the "if" ratio (i.e., word/dot for time) and the "IF" ratio (i.e., interference/dot for time) (see Moroni & Bayard, 2009, for a similar procedure). In this study, only interference condition data were presented (i.e., completion time, number of total errors, and IF ratio).

Simple Reaction Time, Choice Reaction Time. Simple reaction time (SRT) and choice reaction time (CRT) were tested with two simple unimodal tasks. The participants were seated in front of a screen positioned at eye level, their dominant hand positioned on the home button. A black fixation cross followed by a black asterisk as the neutral visual stimulus was presented against a white background. They were instructed to focus on the fixation cross in the center of the screen and to press the response button as quickly as possible when the stimulus (i.e., black asterisk) appeared, without anticipating their responses. Latencies faster than 160 ms were considered as anticipation and removed from the statistical analyses (Delignieres et al., 1994). Participants were requested to use the same finger (i.e., index or middle finger) for all conditions and tasks. They attended a familiarization session one week before the first test session to ensure that they were fully familiarized with the task. Performances during the test sessions were assessed in milliseconds by calculating the median value for the trials. All tests were programmed with PsyScope (XB77) and performed on a Macintosh Apple computer with a 15-inch monitor.

Simple Reaction Time. In both conditions, stimuli appeared in the center of the screen and the participants had to press a designated response button on an AZERTY keyboard depending on the dominant hand (i.e., the "x" key for left-handers and the "period/semicolon" key for right-handers). In the SRT condition, each stimulus randomly appeared within an interval of 1400 ms to 2000 ms after positioning the hand on the home button, and participants performed 30 trials.

Choice Reaction Time. In the CRT condition, the stimuli randomly appeared on the side (left or right) of the screen and the participants had to press the corresponding response button on the AZERTY keyboard as quickly as possible (i.e., the "x" key, labeled with a sticker as "left," for the left side and the "period/semicolon" key, labeled with a sticker as "right," for the right side). Each stimulus randomly appeared within an interval of 1400 ms to 2000 ms after positioning the hand on the home button.

Participants performed 30 trials. For this condition, the number of errors was taken into account: that is, when the participants pressed the wrong button (score/30). However, since no errors were recorded, this variable was not statistically processed.

Physiological Measures

Heart rate and skin temperature were recorded pre-exercise and post-exercise. Heart rate (HR) was monitored continuously during the aiming task using a portable telemetry unit (Suunto Memory Belt, Suunto, Vantaa, Finland) with recording every 10 s and averages were then computed by block. Skin temperature was determined pre- and post-exercise using a skin thermistor (YSI 409, Yellow Springs Instruments, Yellow Springs, OH, USA) placed on the sternum (i.e., T_{stern} in °C) and secured with elastic tape. The cooling rate was calculated as the difference in T_{stern} from pre- to post-exercise (i.e., ΔT_{stern}).

Apparatus and Procedure

Environmental Conditions

The wet bulb globe temperature (WBGT) index was recorded during the experimental sessions with a QUESTemp°32 Portable Monitor (QUEST Technologies, Oconomowoc, WI, USA) that gave the indoor temperature (°C) and relative humidity (%).

Experimental Conditions

Participants performed two randomized experimental sessions separated by one week in a rectangular fencing gymnasium (9 m × 25 m) exposed to a tropical environment: the Tropical Condition (i.e., mean WBGT: 27.64 ± 0.27°C; mean relative humidity: 76.43 ± 2.19%) and the Cooling Condition (i.e., mean WBGT: 27.68 ± 0.11°C; mean relative humidity: 76.94 ± 2.95%). During each entire experimental session, they wore their personal protective equipment (i.e., jacket, plastron, breeches, stocking, shoes, mask, gloves, and sleeve) and used their own fencing weapon. During the Cooling Condition, they were asked to wear a cooling vest and light headwear regularly soaked (i.e., every 15 min) in ice water (4°C) under their protective equipment. To avoid dehydration due to the tropical environment, participants could drink *ad libitum* throughout the experimental sessions but were also invited beforehand to drink 6 ml of water per kilogram of body weight in the four hours before the start of the experimental sessions.

Aiming Task

The aiming task consisted of an ecological fencing task made up of three blocks of five trials with 10 s intervals between trials and 1 min intervals between sets of trials. Each trial took place at the beginning of a 14 m fencing strip and participants made round trips between marking cones to reach a standard round target located at the bottom of the fencing strip (i.e., 20 cm in diameter with ten 1 cm concentric circles) with their fencing sword (i.e., épée or foil) as accurately as possible (for a similar procedure, see Robin et al., 2019). The execution time in seconds and the total score were recorded for each block. The differences in amplitude (i.e., down and up) and direction (i.e., left and right) between the center of the target and the point of the fencing sword were measured for each trial to give the absolute and variable final position error for each trial (for a similar approach, see Przybyla et al., 2011). Then, the mean absolute error (AE) and variable error (VE) of each block were computed.

Procedure

Each experimental session comprised (1) a 30 min acclimation phase (e.g., seated without movement with protective equipment), (2) a test phase during which the subjects performed the cognitive tasks (i.e., Stroop test, SRT, and CRT) and answered the questionnaires (i.e., the PANAS, their perception of the thermal environment, and the FS), and (3) the ecological fencing performance task (i.e., the aiming task) preceded by a 30 min standardized warm-up. During and at the end of the aiming task, physiological measures (i.e., T_{stern}) were recorded and participants were asked to give their perceived rating of the task (i.e., RPE) and how they felt (i.e., FS) between each block. At the end of the three blocks, they were invited to answer other questions about their perception of the thermal environment.

Statistical Analyses

The Kolmogorov–Smirnov and the Levene tests were used to check the normality of distribution and the homogeneity of variance, respectively. As the assumptions of the normality of distribution and the homogeneity of variance were respected, parametric analyses were conducted to determine whether differences existed between experimental sessions (i.e., Tropical Condition versus Cooling Condition).

The block execution time, total score, AE, VE, RPE, HR averaged by block, and FS score were each analyzed with repeated measures ANOVAs with Condition (i.e., Tropical Condition, Cooling Condition) as the between-factor and Period (i.e., before the aiming task, block 1, block 2, block 3 for the FS; block 1, block 2, block 3 for the others) as the within-factor. When the application conditions were respected, *post hoc* analyses were conducted with Tukey's HSD test.

In addition to the cooling rate (i.e., ΔT_{stern}), the differential scores between the end of the aiming task and the beginning were computed for (1) the FS (i.e., ΔFS) and (2) the three measures of the perception of the thermal environment (i.e., ΔThermal, ΔComfort, and ΔAcceptability) in order to consider only the change in the measures. These differences were tested with a Student test to observe the impact of the condition in which the aiming task was performed on the cooling rate, change in pleasurable feelings, and perception of the thermal environment. A Student test was also applied to determine whether between-condition differences existed for the Stroop test data (i.e., completion time, total number of errors, interference scores), the simple and choice reaction times, and the PANAS scores (i.e., PA and NA). Technical problems mainly due to significant sweating and signal loss caused data from four subjects to be excluded from the HR analysis. For all statistical analyses, alpha was set at 0.05.

Results

Perception of the Thermal Environment

Differences between the Tropical Condition and the Cooling Condition for the differential scores of the perception of the thermal environment (i.e., ΔThermal, ΔComfort, and ΔAcceptability) are shown in Figure 1. No differences were found for ΔThermal ($t = -0.56$; $p > 0.05$), ΔComfort ($t = -0.41$; $p > 0.05$), or ΔAcceptability ($t = -0.92$; $p > 0.05$).

Feeling Scale

Repeated measures ANOVA revealed a significant main effect of Period [$F(3, 24) = 60.39$, $p < 0.001$, $\eta_p^2 = 0.88$], but no significant effect of either Condition [$F(1, 8) = 3.41$, $p > 0.05$, $\eta_p^2 = 0.30$] or the Condition × Period interaction [$F(3, 24) = 2.16$, $p > 0.05$, $\eta_p^2 = 0.021$]. Tukey's *post hoc* analysis indicated a decrease in the FS score during the aiming task in both conditions (see Figure 2A). Differential scores of the FS are illustrated in Figure 3. The results showed a significant difference: ΔFS was both negative and greater during the Tropical Condition compared with the Cooling Condition ($t = -9.43$; $p < 0.001$).

Rating of Perceived Exertion

For the perception of exertion, repeated measures ANOVA revealed a significant main effect of Period [$F(2, 16) = 31.86$, $p < 0.001$, $\eta_p^2 = 0.80$]. No significant effect was found for either Condition [$F(1, 8) = 0.76$, $p > 0.05$, $\eta_p^2 = 0.09$] or the Condition × Period interaction [$F(2, 16) = 1.16$, $p > 0.05$, $\eta_p^2 = 0.13$]. Tukey's *post hoc* analysis showed an increase in the RPE score during the aiming task, from block 1 to blocks 2 and/or 3, in both conditions (see Figure 2B).

Affective and Cognitive Assessment

The differences between the Tropical Condition and the Cooling Condition on the affective and cognitive measures are presented in Tables 1 and 2. Regarding affective states (Table 1), statistical analyses showed no inter-condition differences for either positive ($t = 0.69$; $p > 0.05$) or negative ($t = -1.11$; $p > 0.05$) affect. For the Stroop test (Table 1), no inter-condition differences were found for the completion time ($t = 0.20$; $p > 0.05$), the total number of errors ($t = 0.67$; $p > 0.05$), or the IF ratio ($t = 1.33$; $p > 0.05$). The statistical analyses for the reaction times (Table 2) showed no significant differences for the SRT ($t = 0.51$; $p > 0.05$) or CRT ($t = 0.32$; $p > 0.05$).

Physiological Measures

The cooling rate with ΔT_{stern} is presented in Figure 4. The statistical analyses showed no inter-condition differences ($t = -1.29$; $p > 0.05$).

For HR (see Figure 5; $n = 5$), repeated measures ANOVA revealed a significant main effect of Period [$F(2, 8) = 31.33$, $p < 0.001$, $\eta_p^2 = 0.89$], but no significant effect of either Condition [$F(1, 4) = 0.16$, $p > 0.05$, $\eta_p^2 = 0.04$] or the Condition × Period interaction [$F(2, 8) = 1.40$, $p > 0.05$, $\eta_p^2 = 0.26$]. Tukey's *post hoc* analysis indicated a continuous increase in mean HR during the aiming task in both conditions (see Figure 5).

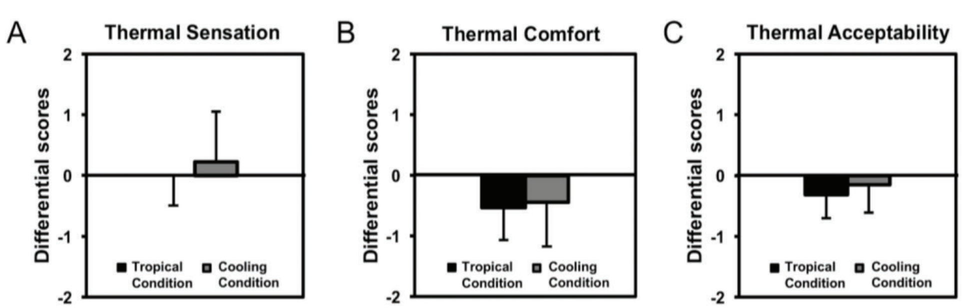

Figure 1. Differences between the Tropical Condition and the Cooling Condition of the differential scores of the perception of the thermal environment. This figure illustrates the comparison of the differential scores of thermal sensation (A), thermal comfort (B), and thermal acceptability (C) between the Tropical Condition and the Cooling condition. The error bars represent standard deviation from the mean.

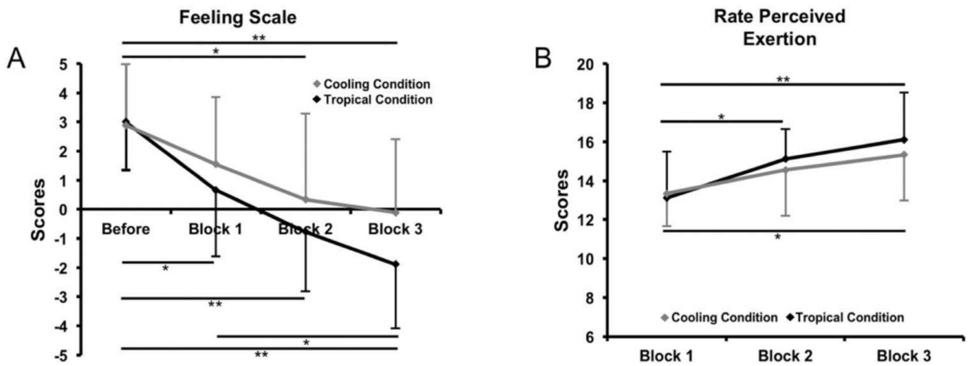

Figure 2. Differences between the different moment of the aiming task of the FS and the RPE scores. This figure illustrates the comparison of mean scores of FS (A) and RPE (B) during the different moment of the aiming task in Tropical Condition and Cooling Condition. The error bars represent standard deviation from the mean. Significant differences between scores on the different moment of the aiming task have been marked: *$p < 0.01$ and **$p < 0.001$.

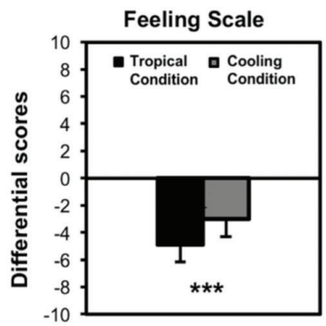

Figure 3 Differences between the Tropical Condition and the Cooling of the differential scores of the FS. This figure illustrates the comparison of differential scores of FS between the Tropical Condition and the Cooling Condition.

Table 1
Comparison of Stroop test and PANAS between Tropical Condition and Cooling Condition.

	Tropical Condition	Cooling Condition	
	Mean ± SD	**Mean ± SD**	***p* value**
Stroop test			
Completion time (s)	19.49 ± 3.85	19.00 ± 8.47	*ns*
Total number of errors	1.11 ± 1.05	0.78 ± 0.97	*ns*
IF ratio	1.71 ± 0.37	1.56 ± 0.36	*ns*
PANAS			
Positive affect	23.00 ± 7.55	21.22 ± 8.44	*ns*
Negative affect	11.78 ± 3.56	13.00 ± 3.00	*ns*

Note. Means and standard deviations for the Stroop test and PANAS scores by Tropical Condition and Cooling Condition.

Aiming Task

Results of the execution time and total score are presented in Figure 6. Repeated measures ANOVA on execution time (Figure 6A) revealed the significant main effect of Period [$F(2, 16) = 9.78$, $p < 0.01$, $\eta_p^2 = 0.55$], but no significant effect of either Condition [$F(1, 8) = 1.71$, $p > 0.05$, $\eta_p^2 = 0.18$] or the Condition × Period interaction [$F(2, 16) = 0.09$, $p > 0.05$, $\eta_p^2 = 0.01$]. Tukey's *post hoc* analysis indicated a shorter execution time in block 3 compared to block 1 in both conditions (see Figure 6A).

For the total score (Figure 6B), repeated measures ANOVA showed a significant main effect of Condition [$F(1, 8) = 40.81$, $p < 0.001$, $\eta_p^2 = 0.84$], but no significant effect of either Period [$F(2, 16) = 3.30$, $p > 0.05$, $\eta_p^2 = 0.29$] or the Condition × Period interaction [$F(2, 16) = 0.53$, $p > 0.05$, $\eta_p^2 = 0.06$]. Tukey's *post hoc* analysis revealed a better total score in Cooling Condition for each block compared with the Tropical Condition (see Figure 6B).

The results for the mean absolute and variable final position errors are presented in Figures 6C and 6D, respectively. Repeated measures ANOVAs revealed a significant main effect of Condition for AE [$F(1, 8) = 33.19$, $p < 0.001$, $\eta_p^2 = 0.81$] and VE [$F(1, 8) = 19.25$, $p < 0.01$, $\eta_p^2 = 0.71$], but no significant effect of Period for AE [$F(2, 16) = 2.11$, $p > 0.05$, $\eta_p^2 = 0.21$] or VE [$F(2, 16) = 0.30$, $p > 0.05$, $\eta_p^2 = 0.04$]. No Condition × Period interaction effect was found for AE [$F(2, 16) = 0.36$, $p > 0.05$, $\eta_p^2 = 0.04$] or VE [$F(2, 16) = 0.29$, $p > 0.05$, $\eta_p^2 = 0.04$]. Compared to the Tropical Condition, Tukey's *post hoc* analysis indicated a lower AE for the three blocks and a lower VE for block 2 in the Cooling Condition (see Figures 6C and 6D).

Discussion

The objective of this study was to investigate the impact of cumulative cooling strategies (i.e., pre+percooling and head+torso) on performance and psychological and physiological responses in young international fencers wearing their full protective equipment during an ecological fencing task.

Aiming Task

Performance analyses revealed a main effect of Period for the execution time but no effect of Condition. On the

Table 2
Comparison of reaction time tests between Tropical Condition and Cooling Condition.

	Tropical Condition	Cooling Condition	
	Median ± SD	Median ± SD	*p* value
Simple reaction time (ms)	429.22 ± 51.38	424.89 ± 47.55	*ns*
Choice reaction time (ms)	514.39 ± 62.88	508.61 ± 58.08	*ns*

Note. Medians and standard deviations for the reaction time tests by Tropical Condition and Cooling Condition.

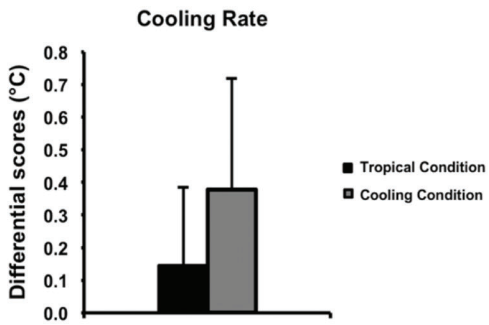

Figure 4. Differences between the Tropical Condition and the Cooling Condition of the cooling rate. This figure illustrates the comparison of differential scores of the skin temperature between the Tropical Condition and the Cooling Condition. The error bars represent standard deviation from the mean.

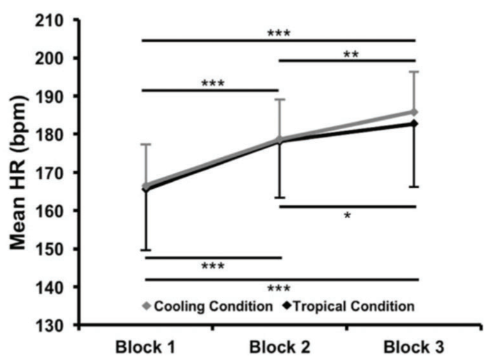

Figure 5. Differences between the different moment of the aiming task of the mean HR. This figure illustrates the comparison of mean HR during the different moment of the aiming task in Tropical Condition and Cooling Condition. The error bars represent standard deviation from the mean. Significant differences between scores on the different moment of the aiming task have been marked: *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

other hand, the main effects of Condition (without an effect of Period) were observed for the total score, AE, and VE. Results for execution time showed an improvement in the aiming task independently of the condition variable. These results suggest that the participants took the task seriously and tried to improve their performances in terms of speed as the blocks progressed, in both the Tropical and Cooling Conditions. Although the cumulative cooling interventions did not seem to influence the execution times, results for the total score, AE, and VE showed a notable positive effect of these interventions in the Cooling Condition. Indeed, whereas no between-condition differences were found for the execution time and the reaction time tasks, the beneficial effects of the cumulative cooling interventions were focused on movement accuracy. The results of AE and VE suggest fewer errors in the Cooling Condition than in the Tropical Condition but also less variability in these errors. Thus, the athletes appeared to be more accurate in the Cooling Condition, which would have led to an increase in their total scores when they wore the cumulative cooling countermeasures. As claimed by several authors regarding the global workspace theory (Baars, 1997), alleviating thermal stress should increase attentional resource availability (e.g., Lee et al., 2014; Schmit et al., 2017). In our study, the greater availability of attentional resources with the cumulative cooling interventions enabled the participants to better focus on a requested task and thus, by improving accuracy, perform better as reflected by higher scores.

Perception of the Thermal Environment

No between-condition difference was found for the perception of the thermal environment (i.e., ΔThermal, ΔComfort, and ΔAcceptability). Interestingly, a study on running performance in the heat using neck interventions investigated the efficacy of a cold collar compared with an uncooled collar and no collar (Minniti et al., 2011). Although performance was improved in the cold collar condition compared with the two others, the authors observed that the thermal sensation was highest (i.e., hottest) in the uncooled collar condition, suggesting discomfort when the collar was worn uncooled to the point of increasing thermal perception. In our study, the cumulative cooling interventions were not sufficient to improve the perception of thermal comfort. As Neave et al. (2004) pointed out about ventilation, which is not a specific requirement for protective helmets, the interventions in our study may have had poor technical characteristics. Indeed, wearing a cooling vest under the equipment did not seem sufficient to improve thermal perception. The constraint of an additional non-breathable thickness may have nullified or greatly reduced the efficiency of cooling. Nevertheless, it is interesting to note that although the cooling intervention did not improve the perception of thermal comfort, it did not seem to degrade it either.

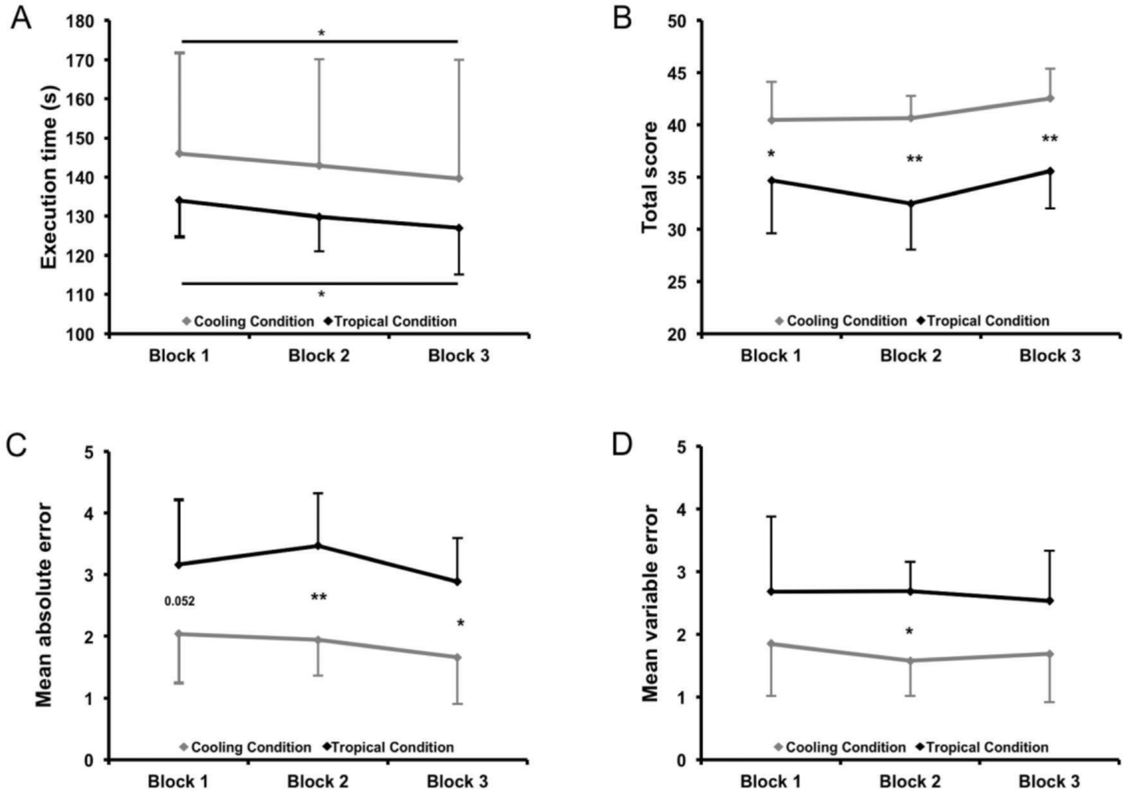

Figure 6. Differences between the Tropical Condition and the Cooling Condition of the fencing performance during the aiming task. This figure illustrates the comparison of execution time (A), total score (B), mean absolute error (C), and mean variable error (D) between the Tropical Condition and the Cooling Condition during the aiming task. The error bars represent standard deviation from the mean. Significant differences between scores on the different moment of the aiming task (A) and between conditions (B–D) have been marked: $*p < 0.05$, $**p < 0.01$, and $***p < 0.001$.

Cognitive and Affective Assessment

The comparison of results obtained for the Stroop test (i.e., completion time, total number of errors, and IF ratio) and the reaction time tasks (i.e., simple and choice) showed no difference between conditions. Whereas studies have highlighted that wearing protective equipment like helmets can cause cognitive impairment in attention, vigilance, and reaction times (e.g., Neave et al., 2004), our results suggest that the cooling interventions we tested were not sufficient to limit the supposed helmet-induced impairment and/or improve cognitive performance in the Cooling Condition. Although some authors have found that cooling the neck and head has no effect on cognitive performance during passive heating (e.g., Simmons et al., 2008), others have suggested a greater influence of neck cooling on more complex cognitive tasks during exercise-induced hyperthermia (e.g., Lee et al., 2014). Indeed, Lee et al. (2014) showed a positive effect of neck cooling only in cognitive tasks of higher complexity. In our study, although the head/neck cooling was provided by headwear mainly covering the athletes' heads, no positive or negative effect was observed for the cognitive tests. It should nevertheless be noted that the participants performed their aiming task more accurately, as reflected by the increases in their total scores in the Cooling Condition. Such enhanced performance during an ecological and demanding task required high levels of concentration and attention, in addition to high physical skills, and this was made possible by the partial restoration of cognitive resources with the cumulative cooling interventions (Lee et al., 2014; Schmit et al., 2017). Thus, the cognitive tasks in our study may not have been sensitive or complex enough to detect a beneficial effect of the cumulative cooling interventions. Furthermore, the lack of significant difference in our cognitive tasks may also be partly explained by the population. Indeed, studies of elite fencers have shown superior reaction times and total response times compared with novice fencers (Williams & Walmsley, 2000a, 2000b). Future studies should therefore consider this specific population in order to adapt the cognitive assessment.

Regarding the affective states, no between-condition differences were found for either positive or negative affect. A previous study on halftime cooling (i.e., cooling during a recovery between two efforts) observed pre-exercise differences with a higher score for positive affect in a cooling condition compared with control condition (Hornery et al., 2005). The authors, who also observed an improved performance in the cooling condition, concluded to a placebo effect caused by the heightened pre-exercise psychological state. In our study, as no differences in affective states were found before the exercise (i.e., the aiming task), the cooling condition did not seem to have favored a change in psychological state in terms of affect. This implies that the improved performance, as reflected by a better total score and lower AE and VE, cannot be due to a placebo effect. This in turn suggests the efficacy of cumulative cooling interventions on aiming task performance.

Rating of Perceived Exertion and Feeling Scale Score

Statistical analyses of the RPE and FS scores during the aiming task showed a main effect of Period, with an increase in the RPE score and a decrease in the FS score in the Tropical and Cooling Conditions. Correlations (data not shown) highlighted a relationship between these modifications, with a significant negative correlation between RPE and FS for both blocks and conditions, except for block 1 in the Tropical Condition. These obvious results agree with the literature and suggest that the participants correctly performed the aiming task, finding it increasingly more difficult (e.g., Hardy & Rejeski, 1989). However, although the statistical analyses showed no main effect of Condition for the FS, comparison of ΔFS revealed a significant difference with greater amplitude during the Tropical Condition compared with the Cooling Condition: the pleasurable FS score decreased less in Cooling Condition than in Tropical Condition. As no difference was found between conditions before the aiming task, the smaller decrease in pleasurable feelings (i.e., FS score) in the Cooling Condition suggests the better stability of the athletes' feelings during the task and a greater sense of well-being when they were clothed in the cooling interventions. Interestingly, as the RPE was not different between conditions, the difficulty perceived by the fencers was steady in both conditions. Thus, these results suggested that the cumulative cooling interventions in our study improved or limited the decrease in well-being (i.e., pleasurable feelings) induced by the demanding task. The combined techniques may have contributed to a "psychological benefit" compared to the Tropical Condition, favoring a better focus on the aiming task and leading to improved task accuracy.

Physiological Measures

The statistical analyses of the physiological measures showed an effect of Period but no effect of Condition on HR ($n = 5$). HR increased in the Tropical and Cooling Conditions during the aiming task, suggesting its demanding nature. This was corroborated by the increase in the perception of exertion (i.e., RPE) in both conditions, highlighting the intensity of the task (Borg, 1985) and the fencers' hard-working involvement in it, whatever the condition.

Regarding the cooling rate, no difference between conditions was found for ΔT_{stern}. The lack of difference between conditions for ΔT_{stern} suggests the inefficiency of our cooling intervention for this parameter. A study on the thermoregulatory influence of a cooling vest concluded that this intervention did not rapidly reduce elevated body temperature and did not improve the cooling rate (Lopez et al., 2008). In our study, although our cooling interventions were combined (i.e., pre+percooling and head+torso) to maximize their effects, our results failed to show the effectiveness of this combination on the change in T_{stern}. This could also be explained by the protective equipment the participants were wearing: full fencing protective clothing and mask. Indeed, as noted by Neave et al. (2004) regarding cricket helmets, ventilation is not the main requirement of protective equipment and no ventilation might exacerbate the storage of body heat. In our study, the fencers' protective equipment (i.e., clothes, plastron, gloves, and mask) constituted a thermal strain in addition to the high relative humidity in both conditions. As evaporation is hindered in a hot and wet environment (Armstrong, 2000), the addition of a humid layer, even if cooled (i.e., the regularly refreshed cooling vest and headwear in the Cooling Condition) may have impacted the evaporation process, limiting the dissipation of the heat load and leading to no improvement in the cooling rate.

Limitations and Perspectives

Although no impairment was found, it is regrettable that no improvement was observed for most of the parameters. In addition to the small sample size, the quality of the cooling interventions (i.e., cooling vest and light headwear) and the very specific population were the main limitations of the study. First, this type of cooling technique, consisting of wearing a vest soaked in ice water, might not be appropriate under another piece of equipment whose technical properties of breathability are limited. However, the effects of this additional constraint might have been somewhat offset by the cooling characteristics of the technique. Second, the young acclimatized high-level population of athletes, who are used to performing with personal protective equipment, might have developed strategies over years of practice to counterbalance the supposed equipment-induced impairment, thus not allowing the cooling interventions in this study to bring them the expected benefits on cognitive and affective variables. Compared to lower-level athletes, this high-level population may be more able to accept constraints like thermal strain and therefore may be less sensitive to an improvement in thermal stress. Moreover, studies are needed for more in-depth exploration of cognitive functions in a larger sample, given the small size of this highly specific population of international fencers. Caution is also needed regarding the physiological measures, given the small sample size for the analyses of HR. Last, as this study investigated the cooling rate only through skin temperature, future studies should examine the core temperature to investigate more precisely the effect of cooling interventions during an ecological exercise in a tropical condition.

Conclusion

Globally, this study revealed a positive effect of cumulative cooling interventions on the performance of an aiming task during an ecological fencing exercise. As only performance and the FS were improved with these cooling interventions, the limitation or stabilization of unpleasurable feelings in the Cooling Condition may have allowed the athletes to allocate more resources in a constraining and demanding environment to better focus, be more accurate, and thus improve their aiming performance. In addition, by including an ecological task, this study on international young fencers offers the advantage of a focus on the efficiency of cooling techniques during an intermittent exercise, thus enriching the limited database on high-level athletes.

From an applied perspective, although combined techniques have not shown physiological improvements to date, they might be used during competition to psychologically limit the negative impact of the Tropical Condition on pleasurable feelings and improve aiming performances. In accordance with the rules of the sport, these techniques could be paired with other strategies during breaks (e.g., cold drink ingestion, fans, spray bottles) and completed with non-conventional strategies as proposed by Coudevylle et al. (2019). In their mini review, the authors advised coaches and athletes to consider inter-individual differences in the acceptability and effectiveness of the same technique across athletes and emphasized the need to include the selected techniques (conventional and non-conventional) in the performance routine to obtain and maintain a flow state for longer times during competition. Last, the results of this study (1) open up interesting perspectives on cooling strategies for disciplines loading mainly anaerobic metabolism and/or requiring protective equipment and (2) reinforce the critical importance of improving the technical characteristics of protective sports equipment, especially for comfort, breathability, and durability.

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