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Cover Page Footnote

We would like to thank the “maître d’armes” Patrice Carriere and the athletes of the pole France Antilles-Guyane.

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The Influence of Tropical Climate on Cognitive Task Performance and Aiming Accuracy in Young International Fencers

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Abstract

This study examined how a tropical climate (TC) influences the cognitive and aiming task performances of young international fencers. The participants performed the tasks in TC and an air-conditioned room. In each session, they completed questionnaires evaluating affective states, fatigue, and comfort and thermal sensations. They also carried out cognitive tasks (simple and choice reaction time, attention, and vigilance tasks) and a motor task testing aiming accuracy with a sword while wearing protective clothing and a mask. TC, which was observed to decrease thermal discomfort, was revealed to decrease aiming accuracy and positive affective states. There was no deleterious effect on cognitive task performance, nor on negative affective states, or fatigue and increased thermal discomfort. These results showed that TC can negatively influence motor performance.

Keywords: fencing, cognitive task, aiming accuracy, tropical environment, affective states

Introduction

The Olympic sport of fencing is practiced all over the world. Competitions are sometimes held in tropical climates (TCs) or gymnasiums without air-conditioning (AC). This study evaluated the impact of a TC (i.e., hot and wet) on the cognitive performance, affects, and accuracy of an ecological aiming task in young international fencers. The athletes wore their personal protective equipment, including the mask, and used their own sword (i.e., épée or foil).

According to Kosonen and Tan (2004), the thermal environment (including heat and hygrometry) is one of the most important indoor environmental factors that affect human mental and physical performances. Many authors have observed that heat stress is associated with decreased performances for multiple cognitive tasks (Berg et al., 2015; Gaoua, 2010; Qian et al., 2015; Robin, Coudevylle, Hue, & Sinnapah, 2017) and physical activities (Gonzalez-Alonso, Crandall, & Johnson, 2008; Hue & Galy, 2012; Maughan, 2010; Périard et al., 2014). The physiological responses of the human body to heat have been well documented (Hancock & Vasmatzidis, 2003), but the effects of heat stress on human cognitive abilities are less well understood, with the research findings being inconsistent (Gaoua, 2010; Robin et al., 2017). For example, Ramsey and Kwon (1992) reported that simple mental tasks show little, if any, decrement in the heat. However, they also observed that more complex tasks (e.g., perceptual motor or vigilance tasks) showed the onset of decrements between 30℃ and 33℃, regardless of the duration of exposure. Gaoua, Racinais, Grantham, and El Massioui (2011) found that working memory was impaired in the heat and suggested that heat exposure might compete with cognitive processes. Hancock and Vastmatzidis (2003) pointed out that attentional resources are progressively drained as the level of environmental stress increases (e.g., in TC), and Robin et al. (2017) suggested that TC imposes a supplementary constraint on cognitive resources. Indeed, the maximal adaptability model (Hancock & Warm, 1989) assumes that heat exerts its detrimental effects on performance by competing for and eventually draining attentional resources. In a notable example, Chase, Karwowski, Benedict, Quesada, and Irwin-Chase (2003) used a visual dual task on computer and observed a performance decrement

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at 35℃ compared with 20℃ due to the participants' inability to successfully allocate attention to the tasks. Hocking, Silberstein, Lau, Stough, and Roberts (2001) suggested that cognitive task performance deteriorates when the total resources are insufficient for both the task and the thermal stress. Last, Qian et al. (2015) suggested that thermal stress induces central fatigue, which decreases motivation particularly when individuals are performing an attention task with high cognitive demand, such as fencing.

According to Azémar (1999), fencing requires a combination of physical attributes like speed, agility, accuracy, and power, as well as the mental capacity to anticipate, react, and make split-second decisions. It thus calls on cognitive processes such as attention, vigilance, reaction time, visual perception, and decision-making (Hijazi, 2013). Cognitive tasks like simple and choice reaction time tasks, Stroop tests, and vigilance tasks should therefore be helpful in evaluating the influence of TC on fencers' cognitive performances. However, it is also important to carry out an ecological motor task in conditions close to those of the real situation (i.e., fencing strip, protective clothing, mask, and sword) to better understand how TC affects motor performance. An aiming accuracy task with an épée or foil seems to be a good compromise and corresponds to a specific fencing exercise used by "maîtres d'armes" (i.e., fencing coaches).

According to Kobrick and Johnson (1991), motor and cognitive performances are dependent on psychological factors and affective states. These latter can be assessed by questionnaires like the PANAS (Positive and Negative Affect Schedule; Watson, Clark, & Tellegen, 1988) and are generally categorized as positive and negative. An individual with positive affect (PA) feels enthusiastic, active, and alert, and PA is conceptualized along a continuum ranging from an optimal state of energy, concentration, and pleasure in commitment to a state of sadness and lethargy (Villodas, Villodas, & Roesh, 2011). Negative affect (NA) is the experience of unpleasant emotions, including feelings of anger, disgust, guilt, fear, and nervousness. Gaoua, Grantham, Racinais, and El Massioui (2012) showed an increase in NA in very hot environments (50℃) and suggested that the subjective state of the individual might be the main factor affecting cognitive performance in hot environments. Physical activity under thermal stress is also associated with NA (Kobrick & Johnson, 1991; Lane, Terry, Stevens, Barney, & Dinsdale, 2004; Wallace et al., 2017). According to Beedie, Terry, and Lane (2000), it is advisable to evaluate affect during stressful exercise because it can predict performance and reflect the individual's ability to cope with an opponent (Acevedo & Ekkekakis, 2001). To our knowledge, few studies have focused on the affective state during effort in TC and none has done so in fencing. Hue (2011) studied cyclic sports and reported that TC, which increased thermal discomfort (i.e., the condition of mind that expresses dissatisfaction with the environment), was particularly disabling for motor performance.

The aim of this study was to evaluate the influence of TC on cognitive task performance, affective states, and motor performance. In line with Ramsey and Kwon (1992), we hypothesized that TC would have a more deleterious effect on complex tasks (e.g., Stroop interference, vigilance) than on simple tasks (e.g., simple reaction time, Stroop color and word). Moreover, as suggested by Johnson and Kobrick (1998), vigilance was expected to be affected by TC. Qian et al. (2015) proposed that heat stress has a potential fatigue-enhancing effect, and we also hypothesized that TC (compared with AC) would decrease PA and increase NA and the feeling of fatigue. A further hypothesis was that participants would express higher thermal discomfort in TC than in AC and, last, given that precision in fencing requires mental processes (e.g., attention, vigilance, and concentration) that can be negatively influenced by TC, we predicted that the fencers' aiming accuracy would be lower in TC than in AC.

Method

Participants

Eleven young international fencers gave their informed consent to participate in the study (3 women, 7 men; mean age = 16.1 years, *SD* = 1.66; age range 14–19 years). All were living in a tropical environment throughout the year and were part of the Fencing Pole France Antilles-Guyane in Pointe-à-Pitre. One participant was excluded due to a between-sessions injury. This study adhered to the Helsinki Declaration II and was approved by the local ethics committee of the University of Antilles.

Measures, Material, and Tasks

Temperature

TC is characterized by consistently high monthly temperatures, often exceeding 18℃ throughout the year, and rainfall that exceeds evapotranspiration for at least 270 days per year (Salati, Lovejoy, & Vose, 1983). The present experiment was conducted in a rectangular fencing gymnasium (9 m × 25 m). Sessions were conducted in AC conditions (mean temperature = 21.4℃, *SD* = 0.4; hygrometry = 43.5% rH, *SD* = 2.9) or TC conditions (mean temperature = 27.6℃, *SD* = 0.2; hygrometry = 67.8% rH, *SD* = 2.6). Temperature and hygrometry were recorded during the sessions with a WGBT QUESTemp◦ 32 Portable Monitor (QUEST Technologies, Oconomowoc, WI, USA).

Perception of the environment and feeling of fatigue

Thermal sensation, comfort, and acceptability were recorded on three 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 (for a similar procedure, see Xiong, Lian, Zhou, You, & Lin, 2015). The feeling of fatigue was recorded on a 7-point scale ranging from 1: not at all tired to 7: totally tired.

Affective states

The participants completed the French version of the PANAS (Lapierre, Gaudreau, & Blondin, 1999), which consists of ten PA states (i.e., active, alert, attentive, determined, enthusiastic, excited, inspired, interested, proud, and strong) and ten NA states (i.e., guilty afraid, ashamed, distressed, guilty, hostile, irritated, jittery, nervous, scared, and upset). Intensity was rated on a 5-point scale (from 1: very slightly to 5: very much). For each participant, the mean NA and PA dimensions of the PANAS were measured.

Stroop test

Participants were asked to perform the French adaptation of the Victoria Stroop test (Strauss, Sherman, & Spreen, 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, subjects must name the color of the dots as quickly as possible. In the Word and Interference conditions, subjects must 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 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).

Simple reaction time, choice reaction time and vigilance task

Simple reaction time (SRT), choice reaction time (CRT), and vigilance were tested with three 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. Participants 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. 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 and vigilance task

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 occurred within an interval of 1400 to 2000 ms after positioning the hand on the home button, and participants performed 30 trials. In the vigilance condition, the stimulus randomly occurred within an interval of 5000 to 15 000 ms after positioning the hand on the home button. The latter task required more vigilance than the SRT condition and the trials were therefore reduced to 15.

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 for the left side and the "period/semicolon" key for the right side). Each stimulus randomly occurred within an interval of 1400 to 2000 ms after positioning the hand on the home button. Participants performed 30 trials. For this condition, a number of errors was considered, when the participants pressed the wrong button (score/30).

Aiming task

Participants had to perform three blocks of five trials that consisted of aiming their sword (épée or foil) at a standard round target (20 cm in diameter) composed of ten 1 cm concentric circles. The athletes wore their personal protective equipment and mask. As illustrated in Figure 1, in each trial, they had to start at the beginning of a fencing strip (which measures 14 m) and make round trips between studs before reaching the target at the opposite end of the fencing track as

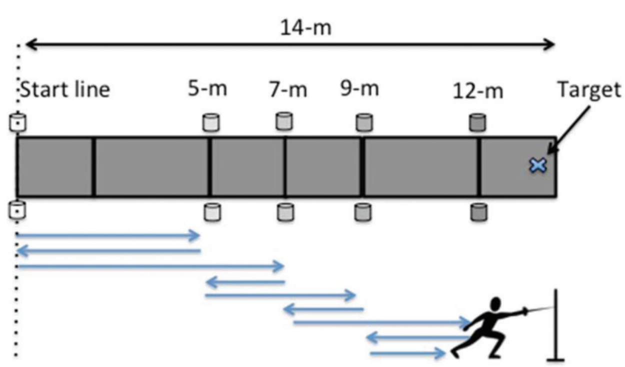

Figure 1. Illustration of the movement of athletes during each aiming trial realized on the fencing track.

precisely as possible. After each trial, they had 10 seconds to go back to the starting lane and begin the next trial of the block. For each trial, the amplitude and direction errors were measured. Moreover, each block execution time was recorded with an electronic stopwatch (Geonaute ONstart 100, temporal resolution of 1 ms). The participants had a 1-minute pause between blocks.

Procedure

The participants completed the two sessions, TC and AC, in randomized order, with a 1-week interval. Before each session, they completed a control self-report questionnaire evaluating their consumption of medicine, drugs, and alcoholic drinks in the previous 24 hours. Moreover, it should be noted that the participants had to drink 6 ml of water per kilogram of body weight in the 4 hours before the start of the experiment and could drink ad libitum throughout the experiment. For each session, they had a 30-minute acclimation phase (e.g., seated without movement) wearing protective clothing, and at the end of this phase they completed the scales assessing their environmental perceptions and feelings of fatigue, and the PANAS.

They then performed the cognitive tasks. Next, they warmed up for 30 minutes before performing the aiming task.

Data Analysis

The dependent variables (except for the aiming task) were compared using the Student *t* test in function of the climate condition (TC vs. AC).

For each trial performed within the blocks of the aiming task, we measured the differences in amplitude (up and down) and direction (right and left) between the center of the target and the point of the sword. The mean absolute error (AE) and the variable error (VE) for both the amplitude and direction components were computed and retained as dependent variables. Each block execution time, in seconds, was also computed. The block execution times and AE and VE for the amplitude and direction were submitted to ANOVAs (with repeated measures) using the temperature condition (TC vs. AC) and the block (block 1 vs. block 2 vs. block 3) as within-participant factors. All significant main effects and interactions were broken down via the Newman–Keuls test. All variables were normally distributed and tested with the Kolmogorov–Smirnoff test, except for the left–right response errors in the CRT task, for which the Wilcoxon (non-parametric) test was used. Alpha was set at 0.05 for all analyses, and effect sizes (η^2) are indicated.

Results

Affective States

The Student *t* test revealed lower PA scores in TC than AC [$t(9) = 2.62$, $p = 0.027$, $\eta^2 = 0.23$]. The analysis did not reveal any significant difference in NA between climate conditions [$t(9) = 1.23$, $p = 0.25$, $\eta^2 = 0.12$]; see Table 1.

Table 1
PA and NA summary scores.

Affect	AC		TC	
	M	SD	M	SD
PA scores	25.77	6.83	21.05	7.97
NA scores	11.84	2.54	12.46	2.69

Note. PA = positive affects; NA = negative affects; AC = air conditioning; TC = tropical climate.

Environmental Perception and Fatigue

TC was perceived as warmer [$t(9) = 3.79$, $p = 0.004$, $\eta^2 = 0.30$], less comfortable [$t(9) = 3.31$, $p = 0.009$, $\eta^2 = 0.27$], and less acceptable [$t(9) = -6.86$, $p = 0.000$, $\eta^2 = 0.43$] than AC. The latter results are illustrated in Figure 2.

The Student *t* test did not reveal any significant difference between climate conditions concerning fatigue [$t(9) = 0.00$, $p = 1.00$, $\eta^2 = 0.00$].

Cognitive Tasks

The Student *t* test did not reveal any significant difference between climate conditions concerning SRT [$t(9) = 0.17$, $p = 0.86$, $\eta^2 = 0.01$], CRT [$t(9) = 1.12$, $p = 0.29$, $\eta^2 = 0.11$], Stroop color [$t(9) = 0.47$, $p = 0.64$, $\eta^2 = 0.06$], Stroop word [$t(9) = 1.85$, $p = 0.10$, $\eta^2 = 0.17$], Stroop interference [$t(9) = 1.78$, $p = 0.11$, $\eta^2 = 0.16$], or vigilance [$t(9) = 0.98$, $p = 0.35$, $\eta^2 = 0.09$]. There was no difference in the left–right response errors in the CRT task [$Z = 0.53$, $p = 0.59$]. Last, there was no difference in the completion time for the “if” ratio and the “IF” ratio and in the number of corrected, non-corrected, and total errors (all $p > 0.05$) in the Stroop interference.

Aiming Task

Amplitude

The ANOVAs computed on AE and VE for amplitude revealed a significant main effect of the climate condition [$F(1, 18) = 8.63$, $p = 0.009$, $\eta^2 = 0.35$ and $F(1, 18) = 4.79$, $p = 0.046$, $\eta^2 = 0.22$, respectively]. The post-hoc Newman–Keuls tests revealed that the athletes showed higher AE and VE in TC condition than in AC condition ($p < 0.05$). The analyses on AE and VE did not reveal any significant main effect of block [$F(2, 36) = 0.13$, $p = 0.88$, $\eta^2 = 0.00$ and $F(2, 36) = 0.52$, $p = 0.60$, $\eta^2 = 0.00$, respectively] or any interaction between block and climate condition [$F(2, 36) = 1.34$, $p = 0.27$, $\eta^2 = 0.03$ and $F(2, 36) = 1.28$, $p = 0.29$, $\eta^2 = 0.03$, respectively] (Figure 3).

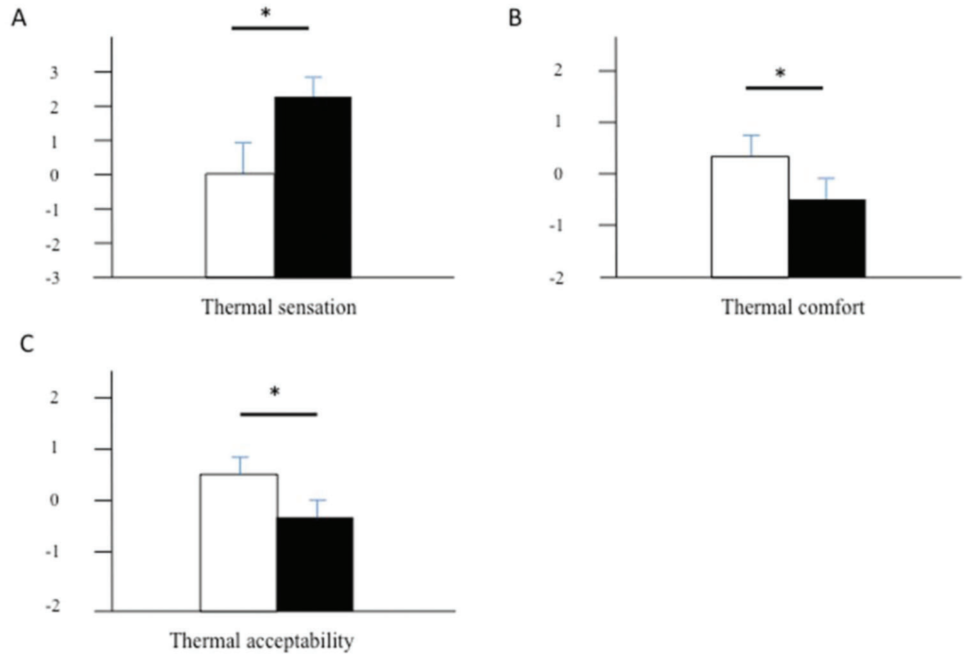

Figure 2. Thermal sensation (A), thermal comfort (B), and thermal acceptability (C) scores in tropical climate (TC, black bars) and air-conditioning (AC, white bars) conditions. I-beams indicate the 95% confidence intervals for the mean values. Significant difference, $p < 0.05$.

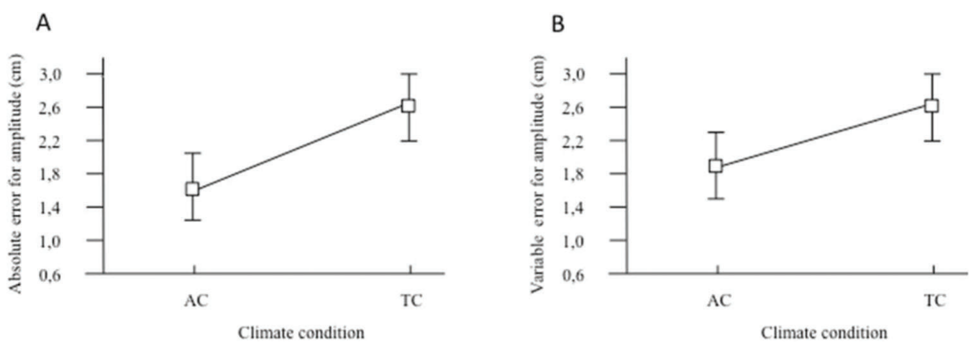

Figure 3. Main effects of the absolute errors (A) and the variable errors (B) for the amplitude of the aiming performance as a function of the climate condition. AC, air conditioning; TC, tropical climate. $p < 0.05$. I-beams indicate the 95% confidence intervals for the mean values.

Direction

The ANOVAs computed on AE and VE for direction did not reveal any significant main effect of the climate condition [$F(1, 18) = 2.29$, $p = 0.11$, $\eta^2 = 0.11$ and $F(1, 18) = 2.48$, $p = 0.13$, $\eta^2 = 0.11$, respectively] but revealed a significant main effect of the block for VE only [$F(2, 36) = 3.28$, $p = 0.49$, $\eta^2 = 0.15$]. The post-hoc Newman–Keuls test revealed more errors in block 1 than in block 2 ($p = 0.04$) (Figure 4). The analyses on AE and VE did not reveal any significant interactions between the block and climate conditions [$F(2, 36) = 0.35$, $p = 0.70$, $\eta^2 = 0.00$ and $F(2, 36) = 1.41$, $p = 0.26$, $\eta^2 = 0.03$, respectively].

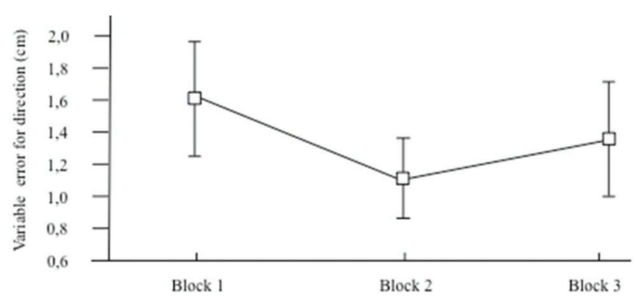

Figure 4. Main effect of the variable error for the direction of the aiming task performance as a function of the blocks. $p < 0.05$. I-beams indicate the 95% confidence intervals for the mean values.

Movement time execution

The ANOVA did not reveal a significant main effect of climate condition [$F(1, 18) = 1.87$, $p = 0.19$, $\eta^2 = 0.09$] but showed a significant main effect of block [$F(2, 36) = 10.92$, $p = 0.000$, $\eta^2 = 0.23$] and an interaction between the block and climate conditions [$F(2, 36) = 5.96$, $p = 0.006$, $\eta^2 = 0.15$]. The post-hoc Newman–Keuls test revealed that in TC the participants were slower in block 1 than in blocks 2 and 3 and slower in block 2 than in block 3 ($p = 0.01$) (Figure 5).

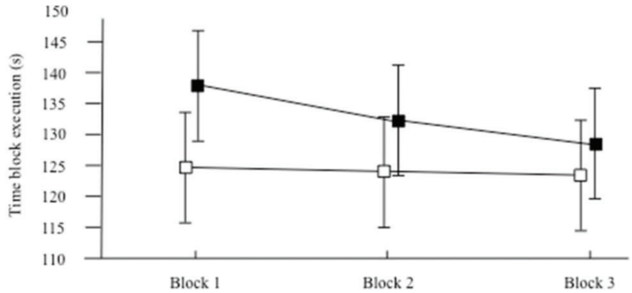

Figure 5. Significant interaction between the climate condition, TC (black squares) vs. AC (white squares), and the blocks for the movement time execution. $p < 0.05$. I-beams indicate the 95% confidence intervals for the mean values.

Discussion

The aim of this study was to evaluate the influence of a TC on cognitive tasks, affective states, and aiming task performance in young international fencers.

Cognitive Tasks

Contrary to the hypotheses, the results of the current study revealed no deleterious effect of TC on the performance of the SRT and CRT, Stroop interference, and vigilance tasks. This is contrary to the results of Ramsey and Kwon (1992) but confirms those recently reported by Robin et al. (2017). Those authors observed no significant main effect of climate condition (AC vs. TC) in a mental rotation task performed by acclimatized and good imagers. Moreover, in the current study, the results of the SRT and CRT tasks are consistent with those of Gaoua et al. (2012), who showed that simple task (i.e., SRT and CRT) performances were not affected by heat stress. However, using a more complex cognitive task (i.e., planning task), those authors observed that performances were significantly reduced due to the "hot" environment. As noted by Gaoua (2010), it is difficult to conclude whether heat exposure has (Cian et al., 2000; Ernwein & Keller, 1998; Hancock, 1982; Hocking et al., 2001) or does not have (Amos, Hansen, Lau, & Michalski, 2000; Nunneley, Dowd, Myhre, Stribley, & McNee, 1979) an adverse effect on cognitive function.

According to Johnson and Kobrick (1998), the most vulnerable cognitive function in hot and humid conditions (i.e., TC) is probably the maintenance of alertness. Vigilance tasks, which are particularly important in the field of sports activities, require participants to remain attentive to a device and to respond to the appearance of random and uncommon signals (Delignières, 1994). Most studies based on this type of task have revealed a significant deterioration in vigilance when the temperature is between 30℃ and 35℃ (Hancock, 1982; Mortagy, 1971). However, the results of the current study did not reveal a main effect of the climate condition on the vigilance task. The absence of a significant effect of TC on cognitive task performance raises the issue of task difficulty: it may be that our CRT, Stroop interference, and vigilance tasks were not sufficiently complex, particularly for international fencers. Further research is needed using tasks that involve more complex processes in order to determine whether TC has deleterious influences on cognitive processes and whether psychological factors (e.g., motivation, self-handicapping strategies) would explain the motor performance decrease in TC that we will now discuss.

Aiming Task

The main result of this study is that TC negatively influenced motor task accuracy. The decrease in aiming task performance in TC compared with AC may have been due to the supplementary constraint that TC imposes on cognitive resources. As recently suggested by Robin et al. (2017), this can be explained by the maximal adaptability model (Hancock & Warm, 1989), which assumes that heat exerts its detrimental effects on performance by competing for and eventually draining attentional resources. Indeed, Hancock and Vastmatzidis (2003) noted that attentional resources are progressively drained by rising environmental stress. Moreover, Hocking et al. (2001) argued that task performance deteriorates when the total resources are insufficient for both the task and the thermal stress. Gaoua (2010) suggested that humans have a limited cognitive capacity because of the many external stimuli constantly competing for conscious access to the vast global workspace (Baars, 1997) that ensures successful outcomes. It can be assumed that the resources needed for aiming accuracy, added to the resources assigned for thermal stress, which can be considered as a cognitive load, exceeded the total resources of the global workspace.

It is important to note that direction accuracy was less but not significantly affected by TC in comparison with AC, whereas the amplitude error in TC significantly increased. This might be explained by the fencers' need to pay more attention to direction in ecological situations, as direction is a smaller touch constraint than amplitude. In the aiming task used in the current study, the target was composed of concentric circles with amplitude and direction equally represented (in terms of touch possibility surface). Therefore, we assume that aiming accuracy for amplitude exerted more attentional demand in the experimental task than it would have in dual exercise. The supplementary resource needed for aiming amplitude accuracy would have no influence on task performance in AC but would overtake the total resources of the global workspace when added to the resources assigned for thermal stress in TC, thereby decreasing motor precision. We might also assume that the control of direction needs fewer attentional resources than the control of movement amplitude, as proposed by Robin et al. (2007) in a tennis accuracy task. In addition, according to the participants' coach, the control of distance in ecological situations seems to require considerable attentional resources compared with the control of direction and amplitude, for which there was no uncertainty in the aiming task. The fact that TC negatively influenced aiming task accuracy seems to be an important element to take into account when helping fencers train. Further research is needed to evaluate the influence of TC in more ecological conditions where the distance to the target can be varied.

Last, the results concerning movement time execution revealed that in TC, the participants were faster in block 2 than in block 1 and faster in block 2 than in block 3. As proposed by Lan, Wargocki, Wyon, and Lian (2011), the thermal discomfort caused by hot temperature and high hygrometry probably prompted the participants to accelerate their movements in order to finish the task more quickly. This point will be discussed in the following section.

Environmental Perception

Hue (2011) showed that TC is particularly disabling to motor performance and increases thermal discomfort. The participants in our study expressed more thermal discomfort and felt warmer in TC, making this climate less acceptable than the neutral environment represented by AC. In line with Lan et al. (2011), we can therefore assume that TC negatively influences aiming accuracy in fencing. Indeed, many authors have suggested that the feeling of thermal discomfort may be responsible for impaired task performance (Gaoua et al., 2012; Kosonen & Tan, 2004; Robin, Coudevylle, & Anciaux, in press; Wijayanto, Toramoto, Maeda, Sonomi, & Tochihara, 2017). Moreover, it is important to note that other studies have shown that TC, which adds a high level of hygrometry to thermal stress, also affects thermal comfort (Lan, Lian, Liu, & Liu, 2008; Robin et al., in press). An increase in humidity reduces the loss of human heat by evaporation, which can then increase the feeling of discomfort. For example, Kosonen and Tan (2004) showed that even at 27℃, a change in relative humidity (rH) from 35% to 75% significantly increased the discomfort of the participants. However, the adaptive model of thermal comfort predicts that people become adapted to the environment (e.g., hygrometry, heat) to which they are most exposed (de Dear & Brager, 1998). Hwang and Chen (2007) showed that residents of Taiwan, which is characterized by a hot and humid climate, appear to be more tolerant of their environment than people living in temperate zones because they are acclimatized to the TC. These results were recently confirmed by Wijayanto et al. (2017), who observed that people who were non-acclimatized to TC found the environmental conditions warmer and less comfortable than those who were acclimatized, and they also reported having more negative feelings. Therefore, it is likely that the cognitive and motor performances of those who live year round in TC are less negatively affected by this deleterious climate than those living in neutral climate. Further research is needed to compare acclimatized with non-acclimatized athletes and to evaluate more precisely the influence of high hygrometry in aiming task performance. However, as recently evoked by Coudevylle, Sinnapah, Robin, Collado, and Hue (2019), we could suggest to consider acclimatizing athletes by conducting training sessions in a tropical environment before the start of competitions.

Affective States

Gaoua et al. (2012) proposed that the subjective state of individuals is the main factor affecting task performance under conditions of heat stress. Our study showed that the athletes had significantly lower PA in TC than in AC and confirmed the results recently obtained by Coudevylle, Poparoch, Sinnapah, Hue, and Robin (2018) with students in tropical and neutral conditions. As PA is related to social activity, satisfaction, and the frequency of pleasant events (Watson et al., 1988), it may have been more pleasant for the athletes to be in AC than in TC, as confirmed by the results for thermal comfort. However, there was no significant difference in NA between AC and TC, which contrasted with the finding of Gaoua et al. (2012), who observed that participants expressed more NA after a brief exposure to a very hot environment (50℃) than in neutral conditions (24℃). This discrepancy could be explained by the difference in the definition of "hot" in these two experiments. Moreover, a low NA score denotes calmness and serenity, which might apply to international athletes who live all year round in TC (Villodas et al., 2011). Indeed, as already noted, de Dear and Brager (1998) argued that humans become adapted to the thermal environments to which they are most exposed. Hwang and Cheng (2007) observed that the Taiwanese (living in a hot and humid climate) have a high tolerance of humidity because they are acclimatized to it. It can be assumed that the participants of the current study were more tolerant of TC and experienced less NA probably due to acclimatization (Coudevylle et al., 2019).

Fatigue can also influence task performance (Lan et al., 2011). However, the feeling of fatigue did not differ between the AC and TC conditions. This result contrasted with the finding of Qian et al. (2015), who proposed that heat stress has a potential fatigue-enhancing effect. This discrepancy has two possible explanations: the participants were acclimatized to TC, which may have limited the deleterious effects of heat stress, and they were also internationally ranked athletes whose good physical condition may have delayed the onset of fatigue. In addition, although Hue (2011) suggested that environmental conditions, including hygrometry and ambient temperature, have a strong influence on fatigue and the performance of cyclic exercise, the motor task of our study, although intense, was probably not long enough (9 minutes including 2 minutes of rest) to induce early fatigue onset.

Hygrometry has attracted little attention in the heat stress literature but seems to be an important factor (Pepler, 1958). Vasmatzidis, Schlegel, and Hancock (2002) showed that high rH (70%) at 34℃ was more detrimental to task performance (i.e., time-sharing) than a lower level (30%). The rH in AC in our study was 43.5%, in great part due to the AC system, whereas in TC it was 67.8.2%, and this factor may have influenced the participants' affect and/or aiming task accuracy. Further research is needed to investigate the hygrometry effects on PA, NA, and motor performance.

Limitations

The small number of participants is a limitation of this study, but one that is difficult to overcome when the sample is international athletes. Our sample was similar to those in many studies of young or elite athletes (Neave et al., 2004; Périard et al., 2014), particularly in fencing (Devienne, Ripoll, Audiffren, & Stein, 2000; Williams & Walmsley, 2000). Moreover, every year, only 15 young fencers competing at the national or international level are accepted into the French Caribbean Fencing Pole. One of them started the experiment and participated in the first session but was unable to participate in the second session because of an injury.

The use of only one scale for fatigue estimation (Samn & Pirelli, 1982) is another limitation. As in Robin et al. (in press), fatigue was used as a control variable and future research using more a complex subjective estimation of fatigue is needed. Moreover, studies with more dependent variables, such as cognitive tasks performed during the physical effort phase, are needed to better understand the influence of TC. Additional researches using more complex tasks performed in TC and qualitative measures are needed for a better understanding.

Conclusion

This study showed that TC can negatively influence aiming task accuracy in young international fencers without affecting performance in cognitive tasks. This decrease in motor performance can be explained by the thermal discomfort due to TC and the loss in positive affect that can lower the motivation to exert effort. We therefore recommend "maîtres d'armes" (i.e., fencing coaches) to favor training in AC in order to preserve positive affective states and aiming accuracy, except when competitions in TC are upcoming. Indeed, in a mini-review recently published, Coudevylle et al. (2019) evoked strategies to cope with the TC of Tokyo Olympic/Paralympic Games 2020. The researchers suggested the use of subjective strategy as cold suggestion and the use of objective intervention as cooling vest, provided that it does not disturb the athletes, during timeouts in duel sports in tropical environments. The authors also encouraged the realization, a few weeks before competitions in TC, of acclimation training in order to become psychologically and physiologically accustomed to the negative consequences of this detrimental environment. Finally, it is recommended to athletes to arrive on site early enough to have the time to test individual strategies and find the most effective one in terms of cognitive abilities (e.g., reaction time, attention), perceptions (e.g., affects or thermal comfort), and feelings and emotions (e.g., motivation, self-confidence, or flow states). Further research should evaluate whether motivation or self-handicapping strategies explain the negative influence of TC and whether the use of cooling techniques (e.g., ice cooling jacket or head cooling, cold water ingestion) would limit the deleterious effects of this climate on fencers' motor performance.

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