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ARTICLE

Attentional processes and performance in hot humid or dry environments: review, applied recommendation and new research directions

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Abstract – Many important sporting events are organized in hot ambient conditions. In addition, given the global warming around the world, and because heat also concerns millions of people living in hot-dry and/or hot-humid environments, individuals often perform cognitive and/or cognitivo-motor tasks under heat stress conditions. Hot environment can negatively affect aerobic and high intensity performances and can also negatively influence mental performances and cognitive function as executive functions and attention. This review was realized in order to provide a better understanding of the influence of the heat on cognition as attentional processes. In addition, applied recommendations and strategies (*e.g.*, acclimation, cooling, mental technics), that individuals can use during learning, training or competitions performed in hot environments, are discussed. Finally, new directions in research are proposed.

Key words: attention, performance, heat, exercise, strategy

Résumé – Processus attentionnel et performances en climat chaud et/ou tropical : revue, recommandations appliquées et perspectives de recherche. De nombreux événements sportifs importants sont organisés dans des conditions ambiantes chaudes. De plus, du fait du réchauffement climatique terrestre et parce que la chaleur concerne également des millions de personnes vivant dans des environnements chauds et secs et/ou chauds et humides, les personnes réalisent souvent des tâches cognitives ou cognitivo-motrices en condition de stress thermique. Un environnement chaud peut affecter négativement les performances aérobies et de haute intensitées, mais peut également influencer négativement les performances mentales et le fonctionnement cognitif comme les fonctions exécutives et l'attention. Cette revue a été réalisée afin de permettre une meilleure compréhension de l'influence de la chaleur sur l'exercice et la cognition comme les processus attentionnels. De plus, des recommandations et des stratégies appliquées (*e.g.*, acclimatation, refroidissement, techniques mentales) qui peuvent être utilisées pendant les apprentissages, le travail, les entranements ou les compétitions effectuées dans des environnements chauds, sont discutées. Enfin, de nouvelles directions de recherche sont proposées.

Mots clés : attention, performance, chaleur, exercice, stratégie

Attentional processes are very important components of successful performance in cognitive and/or cognitivo-motor tasks (Moran, 2009). Attention is considered as a multi-dimensional construct (Posner & Rothbart, 2007) that can be divided into three different neural processing networks: The alerting, the orienting and the executive attention networks (Wallace, 2015). The alerting network is preparing for a stimulus by establishing and maintaining a state of alertness and activates the thalamus, the parietal and the frontal cortices (Coull, 2004; Liu *et al.*, 2013). The orienting network selectively directs attention to cued areas of space and focus on relevant elements. It activates the basal ganglia, the parietal and the prefrontal lobes (Posner, 2012). Finally, the executive attention network is involved in planning, decision-making, coordination of concurrent actions, action inhibition, conflict resolution, and/or action. This network activates anterior cingulate, frontal and prefrontal cortices (Posner & Petersen, 1990).

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School, work and sport competitions are full of various distractions that can disrupt individuals' attentional processes (Moran, 1996). Among these distractions, heat stress is frequently viewed as a factor that can negatively influence performance capability and cognitive functions as attentional processes and executive function (Douzi, Dupuy, Theurot, Smolander, & Dugué, 2020; Hancock & Warm, 1989) and can induce an early onset on mental fatigue, which can be defined as the inability to maintain optimal cognitive performance (Qian *et al.*, 2015). Many cognitive tasks and/or sport activities need high cognitive functioning (Schmit, Hausswirth, Le Meur, & Duffield, 2017). The purpose of this review is twofold. Firstly, it aims to take stock of work on the influence of heat stress on the performance in tasks that involve cognitive processes such as attention. Secondly, this review proposes the use of different applied strategies as acclimation, cooling and/or mental technics during learning, training and sport competition involving attentional resources. After developing the impacts of the heat on cognitive and/or psychomotor performances, we will evoke the main models mentioned in the literature.

1 Theoretical point concerning attentional processes, climates and performances heat and cognitive performances

As previously evoked, attention can be divided into three distinct neural processing networks: Alerting, orienting and the executive attention networks (Wallace, 2015). These networks were separately tested by Liu *et al.* (2013), who used the Attention Network Test, under heat stress condition. The authors revealed no performance changes in alerting and orienting networks, but declines in executive attention network in a hot environment compared to a neutral condition. Indeed, the orienting and alerting networks used resources from other brain areas including the executive attention network in order to allow maintenance of performance in simple tasks. However, the executive attention network that needs more neuronal resources, in order to perform complex cognitive tasks, are greater impaired than the alerting and orienting networks (Hocking, Silberstein, Lau, Stough, & Roberts, 2001). For example, in a visual dual computer task, fewer performances were observed in the heat compared to thermal neutral condition due to the participants' inability to successfully allocate attention to the tasks (Chase, Karwowski, Benedict, Quesada, & Irwin-Chase, 2003). It is therefore important to note that the influence of heat stress on performance depends on the complexity of task. For examples, simple cognitive tasks (*e.g.*, working memory, reaction times, simple attention tasks) are less vulnerable and can improve in hot environments (Gaoua, Racinais, Grantham, & El Massioui, 2011; Hocking *et al.*, 2001; Simmons, Saxby, McGlone, & Jones, 2008) but if the thermal stress does not disturb the homeostasis (Hancock, 1986) and if body temperatures are lower than hyperthermia (*i.e.*, core temperature > 38.5 °C, Schmit *et al.*, 2017). In addition, when the core temperatures increase, the performance in simple tasks like reaction time is maintained (Gaoua *et al.*, 2011). These improvements may results from an improvement of the nerve conduction velocity (De Jesus, Hausmanowa-Petrusewicz, & Barchi, 1973), a decrease in the latency of transmission of the motor action potential (Racinais *et al.*, 2008) and an increase in cerebral blood flow (Grego *et al.*, 2004). Before cognitive performance impairment, there seems to a be a "plateau" of performance linked to an activity of compensation of brain areas additional to those generally involved in the task (Liu *et al.*, 2013). On the contrary, more complex tasks that imply higher order cognitive functions (*e.g.*, visual memory, executive function and planning) appear to be decreased in hot condition, particularly when the core or skin temperatures rise (Gaoua *et al.*, 2011; Gaoua, Grantham, Racinais, & El Massioui, 2012). Liu *et al.* (2013) declared "*tasks demanding lower attention are less vulnerable to the effect of hyperthermia than those requiring more attention*" (p. 223). As the complexity of task increases, the lower amount of heat stress is needed to perturb cognitive function (Hancock & Vasmatzidis, 2003). Finally, above 40 °C of core temperature, a global and non-specific slowing effect of hyperthermia, on psycho-motor response speed, appeared regardless of task complexity (Bandelow *et al.*, 2010) probably due to individual's maximal capacity to tolerate an overall cognitive strain beyond which the level of task performance could not be maintained (Schmit *et al.*, 2017). It is also important to note that complex cognitive task performance can be altered, in hot environments, independly of variation in core temperature (Gaoua *et al.*, 2012). Indeed, the latter authors showed that the elevation of skin temperature was responsible for impaired complex cognitive task performance and proposed that a rapid increase in skin temperature competes with cognitive resources needed to complete the task.

2 Explanatory models of the effects of heat on cognitive performances

Many researchers agree that there are limited neural "resources" or "capacity" for cognitive processing such as attention (Baddeley, 1986; Hocking *et al.*, 2001; Kahneman, 1973). For example, divided attentional performance is regulated by a limited central capacity system that's why the fact that two or more tasks can be realized simultaneously depends on their combined demands on the attentional resources available (Moran, 2009). Baars (1993, 1997) developed the Global Workspace Theory that suggests that consciousness enables multiple neuronal networks to cooperate and compete in solving problems, and he suggested that individuals have a limited cognitive capacity due to different external stimuli constantly competing for the limited conscious access to the vast global workspace in order to obtain a successful outcome. For example, working memory was impaired by hot environments (Gaoua, Racinais, Grantham, & El Massioui, 2011), which seems to indicate that heat stress might compete with cognitive processes. In addition, attentional resources are progressively drained as the level of environmental stress increases (Hancock & Vasmatzidis, 2003) and it was proposed that the heat would impose a supplementary constraint on cognitive resources (Robin, Coudevylle, Hue, & Sinnapah, 2017). The brain uses more neural resources in order to maintain the same performance in simple tasks performed in hot conditions until the resources are overloaded, leading to a decrease in performance in higher order cognitive skills (Hocking *et al.*, 2001; Wallace, 2015). The electroencephalographic (EEG) technic can be considered as an objective measure of the cognitive load, especially when a task is performed under hot environmental conditions (Shibasaki, Namba, Oshiro, Crandall, & Nakata, 2016; Zhu, Liu, & Wargocki, 2020). Indeed, by measuring EEG activity, it was recently shown that theta power was higher in the heat, which represents an additional cognitive load that can impair performance by inducing a saturation of the resources available to perform complex cognitive tasks (Gaoua, Herrera, Périard, El Massioui, & Racinais, 2018). Hancock & Warm (1989) also developed another theory: The Maximal Adaptability Model that attributes performance decrement, in hot environments, to attentional resource depletion. According to this model, stressors range from "hypostress" to "hyperstress", while at the middle of this continuum there is a "normative zone". In the latter and also considered as comfort zone, cognitive adjustments to task demands are easily obtained and the performances are optimal (Hancock & Vasmatzidis, 2003). However, as the level of stress due to ambient temperature, body temperatures (*i.e.*, central or skin) or task complexity increase, attentional resources are progressively drained. Initially, arousal levels increase (Liu *et al.*, 2013) and the people concerned benefits the remaining resources efficiently so that there is no performance decrement or, sometimes, performance enhancement (Hancock & Vasmatzidis, 2003; Hocking *et al.*, 2001). Nevertheless, if the level of stress increases, the continuous drain of attentional resources can progressively decrease task performance (Hancock & Vercruyssen, 1988), and further increase can move the body outside the physiological zone of maximal adaptability (*i.e.*, homeostasis) that can be potentially dangerous or even fatal. Moreover, Gaoua *et al.* (2012) evoked that cognitive functioning is also sensitive to changes in skin temperature. This sensitivity could be explained by the alliesthesial effect (Cabanac, 1971) according to which thermal stimuli can lead to feelings of displeasure or pleasure depending on individual body's existing thermal state. Pleasant thermal stimuli bring the body back to, while unpleasant stimuli take it away from homeostasis (Cabanac, 1987). It is therefore possible that a sudden change in environmental conditions, such as moving from an air-conditioned environment to a warm environment, could be seen as a cognitive load which places additional attention demands on a limited global workspace (Baars, 1993), leaving fewer resources available for concurrent tasks. Finally, the increase in negative affects (Gaoua *et al.*, 2012), or the decrease in positive affects (Robin *et al.*, 2019) can also negatively influence the performance of cognitive or cognitivo-motor tasks when they are performed in the heat or hot and humid ambient conditions such as tropical climate, which will be discussed.

3 The specificity of tropical climate

A tropical climate is hot and humid environment that is characterised by a high level of hygrometry (*i.e.*, $>70\%$ relative humidity) and hot temperatures that can be considered as environmental stressors (Robin, Coudevylle, Hue, & Toussaint, 2018). Tropical environments lead to increase the exercise-induced stress on the thermoregulatory and cardiovascular systems (Hue, 2011; Maughan, 2010) and can also negatively influence cognitive performances such as selective attention (Coudevylle, Poparoch, Sinnapah, Hue, & Robin, 2018), vigilance (Hocking *et al.*, 2001), short-term memory (Johnson & Kobrick, 1998), mental rotation (Robin *et al.*, 2017), affective states (Coudevylle *et al.*, 2018), thermal comfort (Robin, Coudevylle, Hue, & Toussaint, 2018) and feeling of fatigue (Robin, Coudevylle, & Anciaux, 2020). The negative effects of tropical climate have been demonstrated for motor performances in cyclic (Gonzalez-Alonso, Crandall, & Johnson, 2008; Kenefick, Cheuvront, & Sawka, 2007; Voltaire, Berthouze-Aranda, & Hue, 2003), team (Mohr, Nybo, Grantham, & Racinais, 2012), or accuracy sports as fencing (Robin *et al.*, 2019). It is important to note that these negative effects may worsen in sports that necessitate protective equipments (*e.g.*, helmets, plastron, gloves) such as cricket, taekwondo, fencing, American football or equestrian. For example, Robin *et al.* (2019) showed that a tropical climate decrease fencer's aiming task (*i.e.*, a task requiring attentional processes as concentration) accuracy, performed with a sword, while wearing protective clothing and a mask.

4 Heat stress and early onset of fatigue

A warm environment amplifies the perceived effort (Périard, Cramer, Chapman, Caillaud, & Thompson, 2011), decreases thermal comfort (Willmott *et al.*, 2017), promotes the onset of early mental fatigue (Schmit *et al.*, 2015), lengthens the duration of a race and increases the number of drops-outs in long-duration events (Chabert, Hermand, & Hue, 2019). Heat stress induces failures in the transmission of neural drive at cortical, spinal and neuromuscular function (Racinais, Gaoua, & Grantham, 2008). The latters can cause functional decline of central nervous system that lead to mental fatigue (Nybo, 2008), and decline in peripheral nervous system that lead to peripheral fatigue (Crewe, Tucker, & Noakes, 2008). For example, Qian *et al.* (2015) investigated the influence of a hot environment on mental fatigue during sustained attention task in a scanner (*i.e.*, psychomotor vigilance test). The authors showed that heat stress causes higher subjective fatigue ratings and worse reaction time performance. They suggested that heat stress caused by a hot environment has a potential effect of mental fatigue enhancement when performing highly cognition-demanding attention task. In addition, it is possible that mental fatigue could limit physical performance through higher perception of fatigue (Marcora, Staiano, & Manning, 2009). Studies using self-paced or fixed intensity exercise revealed that premature mental fatigue occurs in hot environment compared to neutral environments (Schlader, Simmons, Stannard, & Mundel, 2011; Tatterson, Hahn, Martin, & Febbraio, 2000). According to authors, different factors can promote early onset of mental fatigue under thermal stress condition as an anticipatory or unconscious regulation of power output (Hartley, Flouris, Plyley, & Cheung, 2012), a reduction of arousal or motivation (Bridge, Weller, Rayson, & Jones, 2003) and alterations in the electrical activity in the brain's frontal area. It would therefore seem relevant to use strategies (*e.g.*, acclimation, which will be discussed below), to combat premature fatigue and the decline in motor, psychomotor and cognitive performances under heat stress (Racinais, Sawka, Daanen, & Périard, 2019).

5 Strategies to counteract the effects of heat stress

It is important to determine strategies that allow better regulation (*e.g.*, cooling intervention, hydration) and better adaptation to this hyperthermia (*e.g.*, acclimatization, mental preparation) without risk to health (Coudevylle, Sinnapah, Robin, Collado, & Hue, 2019). Cooling strategies (Bongers, Hopman, & Eijsvogels, 2017) and fluid ingestion to limit dehydration (Tatterson *et al.*, 2000) may be effective interventions. However, Racinais *et al.* (2015) evoked that a recent consensus statement suggested that heat acclimation is the "most important intervention one can adopt to reduce physiological strain and optimize performance (during training and competition in the heat)'' (p. 1164), that is why this strategy will be first developed.

5.1 Acclimation

Repeated exposures to heat allow for a physiological conditioning known as acclimation when exposed to hot rooms, saunas, baths or hot natural environments (Armstrong & Maresh, 1991). Acclimation induces numerous integrated physiological adaptations that improve performance in the heat and reduce the risk of serious heat illness (Casa, 2018). Indeed, heat acclimation confers biological adaptations that reduce physiological strain (*e.g.*, body temperature and heart rate) and thermal discomfort, and improve exercise capacity as endurance (Racinais *et al.*, 2015; Sawka, Périard, & Racinais, 2015). It is important to note that acclimation can also limit the negative effects of hyperthermia on cognitive task such as planning accuracy and working memory (Racinais *et al.*, 2017), psychomotor task (Walker, Dawson, & Ackland, 2001) or attention (Radakovic *et al.*, 2007), which should promote the performance in exercise involving these processes. Acclimation had beneficial effect on the central nervous system, but not on the peripheral nervous system (Racinais *et al.*, 2017), and seems to prevent decrements (Curley & Hawkins, 1983) or protect (Radakovic *et al.*, 2007) cognitive performances such as sustained attention. Tyler, Reeve, Hodges, & Cheung (2016) found that the most common duration in research concerning acclimation was 7 to 14 days, with greater adaptations for regimens lasting 14 days in order to maximise improvement. Acclimation does not seem to affect thermal comfort at rest but it can improve the ratings of the latter during training and competition in hot environments for both endurance and team-sports athletes (Kelly, Gastin, Dwyer, Sostaric, & Snow, 2016; Sunderland, Morris, & Nevill, 2008) that could permit to release attentional resources generally induced by thermal discomfort due to heat stress (Robin *et al.*, 2017, 2019). It was recently suggested that athletes accustomed to enduring high intensity and duration exercises in hot environments would perceived the exercise difficulty as less, compared with less accustomed athletes to such conditions which would, in particular, reduce dropouts in long-term sporting events (*e.g.*, marathon, walking or triathlon) (Coudevylle *et al.*, 2019). This is the reason why acclimation in a tropical climate, which combined heat and high level of relative humidity, would allow to benefit from physiological and psychological adaptation to this "extreme'' climate (Racinais *et al.*, 2015; Voltaire *et al.*, 2002). Indeed, it has been shown that acclimation in hot and humid condition (*i.e.*, tropical climate) improved exercise in hot and dry environment (Fox, Goldsmith, Hampton, & Hunt, 1967; Hue, Antoine-Jonville, & Sara, 2007) and provide a better resistance to cognitive task (*e.g.*, short-term memory and mental arithmetic test) performance during heat exposure (Wijayanto, Toramoto, Maeda, Sonomi, & Tochihara, 2017). However, the fact that Piil, Mikkelsen, Junge, Morris, & Nybo (2019) found that acclimation cannot protect individuals from being negatively impacted by hyperthermia when performing complex tasks relying on a combination of cognitive performance and motor function lead us to suggest that acclimation could de complemented by other strategies such as cooling or hydration to counteract the effect of heat.

5.2 Hydration

Water deficit and consumption are know to play important roles in mental and possibly in physical performances (Cian, Barraud, Malin, & Raphel, 2001; Gmez-Pinilla, 2008; Sawka & Noakes, 2007) and are major confounding variable when studying cognitive processes in thermal stress condition (Gaoua, 2010). Dehydration caused by body water loss is exacerbated in the heat (Sawka & Pandolf, 1990) when compared to neutral conditions. Indeed, hot environments lead to increased sweating caused by physiological thermoregulatory processes (Schlader *et al.*, 2011) that induce dehydration that is accentuated during exercise (Ando *et al.*, 2015). Several studies showed that dehydration inferior to 2% body weight has little influence on simple task performance (Brisswalter, Collardeau, & Arcellin, 2002; Epstein, Keren, Moisseiev, Gasko, & Yachin, 1980; Gopinathan, Pichan, & Sharma, 1988). When no cognitive impairment is reported during dehydration, this could be linked to higher levels of temporal and frontal brain activities used to compensate for the stress linked to the water deficit (Kempton *et al.*, 2011), and allow the maintenance of performance level despite the disturbances of the central nervous system functioning (Maughan, Shirreffs, & Watson, 2007). Contrariwise, passive or active dehydration of about 2.8% of body weight impaired short-term memory and reaction time performances (Cian *et al.*, 2000), speed and accuracy of complex tasks such as visual motor tracking, and attentional processes as vigilance (Baker, Conroy, & Kenney, 2007; Epstein *et al.*, 1980; Gopinathan *et al.*, 1988; Tomporowski, Beasman, Ganio, & Cureton, 2007) and increase fatigue and reduce the desire to exert effort (Armstrong & McDermott, 2012; Gorby, Brownawell, & Falk, 2010). In addition, dehydration of 3–5% of body weight impaired sustained attention, resource management and tracking performance as well as the performance of more simple tasks such as choice reaction time and monitoring (Bradley & Higenbottam, 2003). In line with the Global Workspace theory (Baars, 1993), we may envisage that dehydration, considered as a stressor, could compete for executive attention and compromise cognitive function (Cohen, 1980) up to a point (3–5%) where performance on simple tasks that require less attention than complex tasks should also be impaired (Gaoua, 2010). That is why, Lieberman *et al.* (2005) recommends anticipating water loss and suggests starting fluid intake before reaching 1 or 2% body weight loss, and before heat stress and/or exercise induced dehydration does not start to negatively influence cognitive processes. Since it is necessary to maintain the ability to realize complex cognitive computations (Schmit *et al.*, 2017), during exercise performed in the heat, Edmonds, Crombie, & Garner (2013) have suggested ingesting cold drinks (*i.e.*, about 4 °C) or ice slushies prior to the event for preventing dehydration potentially promoting cognitive performance in the heat. It seems therefore that cold drink ingestion, in addition to limiting dehydration, could be utilized as a cooling strategy.

5.3 Cooling

To deal with the deleterious effects of heat stress, cooling can be efficient strategies (Bongers *et al.*, 2017). These strategies aim to slow endogenous body heat accumulation, which can potentially preserve cognitive task performance (Schmit *et al.*, 2017). Decreasing skin temperature and maintaining a modest increase in core temperature can improve sport performance in thermal stress conditions (for a review see, Douzi *et al.*, 2020). Cooling strategies are generally classified as internal (*e.g.*, ice slushy, slurry, cold water ingestion, and drinks with or without menthol) or external strategies (*e.g.*, cold water immersion, cooling vest, ice towels, cool showers, menthol application, or combined methods) that have been shown to reduce core temperature (Bongers, Thijssen, Veltmeijer, Hopman, & Eijsvogels, 2015; Ross, Abbiss, Laursen, Martin, & Burke, 2013) and to serve to alleviate the alterations such as thermoregulatory responses induced by hyperthermia (Douzi *et al.*, 2020). For example, it has been shown that individuals can improve their motor performance between 6 and 21% by using: cold water immersion (Castle *et al.*, 2006; Rinaldi, Trong, Riera, Appel, & Hue, 2018), neck cooling collar (Cuttell, Kiri, & Tyler, 2016), menthol mouth rinse (Mndel & Jones, 2010), menthol applied to the torso or to the face (Hermand, Collado, & Hue, 2020; Schlader *et al.*, 2011), cold drinks ingestion (Mndel, King, Collacott, & Jones, 2006), ice slurry ingestion (Stevens, Dascombe, Boyko, Sculley, & Callister, 2013; Riera, Trong, Sinnapah, & Hue, 2014), the application of cooling garments (Abdallah, Krug, & Jensen, 2015) cold packs (Racinais *et al.*, 2008) or water spray (Stevens *et al.*, 2016). In addition, cooling strategies could protect cognitive processes against hyperthermia when performing complex tasks that necessitate mental computation such as updating memory or planning (Schmit *et al.*, 2017). The latters also proposed that these strategies could reduce the difficulties the central nervous system faces in coping with the accumulation of the stressors (*e.g.*, heat stress and cognitive demand), allowing thus an increase in attentional resources in order to improve cognitive functioning and performance (Chase *et al.*, 2003; Robin *et al.*, 2019). Indeed, a study showed that participants who used precooling cold immersion strategy, one our before exercise, had higher visual discrimination task performance, under hyperthermia, compared to control (Clarke, Duncan, Smith, & Hankey, 2017). Similarly, while hot environments generally induce an increase in skin temperature which can cause discomfort (Robin *et al.*, 2019), unpleasantness (Coudevylle *et al.*, 2019) and deteriorate cortical activity (Gaoua *et al.*, 2012), limiting this temperature increase by using cold vest, ice packs or cold towels could help to cool the skin and thus promote the performance of athletes in cognitively demanding tasks such as fencing (Collado *et al.*, under review). Finally, it seems that the combinations of external (*e.g.*, cold vest, ice pack, cold towel) and internal cooling techniques (*e.g.*, cold drinks ingestion, ice slurry) used in pre- and per- cooling, or the use of mental strategy (Coudevylle *et al.*, 2019) could temporarily protect athletes performance from the effects of heat stress when performing prolonged psychomotor tasks (Gibson *et al.*, 2019; Schmit *et al.*, 2017).

5.4 Mental technics training

As with physical exercise, it seems that specific cognitive training can be beneficial to athletes (Romeas, Guldner, & Faubert, 2016) especially to optimize sport performance in hot environment. Many long-term exercises require the maintenance of optimal cognitive functioning such as decision-making, sustained attention, and/or concentration both for achieving performance (Schmit *et al.*, 2015), and for limiting the risks of injuries (Armstrong, 2007). For example, the individual psychomotor performance improved, from pre- to post-tests, in rally drivers who had trained for four days with race simulators in thermal stress condition (Walker *et al.*, 2001). Mental or psychological skills training could improve cognitive performance in hot environment due to arousal regulation (Wallace, 2015). The author suggested that the use of top-down regulation of mental skills could limit cognitive performance decrease by staying, for longer, in the normative zone (Hancock & Vasmatzidis, 2003). For example, Barwood, Thelwell, & Tipton (2008) tested whether training a set of four psychological skills (*i.e.*, goal setting, positive self-talk, mental imagery, and arousal regulation) could increase the distance covered during three 90-minute "time trials'' performed in the heat. The author showed that the participants ran significantly faster (*i.e.*, 8%) and suggested that this combination of mental skills suppressed the temptation to reduce exercise intensity in hot environment. Since it was not possible to distinguish the effect of each of the mental skills, Wallace *et al.* (2017) hypothesized that motivational self-talk could be beneficial for exercise and cognitive performance in the heat. Indeed, this psychological skill had already shown to have positive effect, in neutral thermal condition, on cognitive processes such as mood, attention and concentration (Hatzigeorgiadis, Zourbanos, Galanis, & Theodorakis, 2011) and endurance exercise (Barwood, Corbett, Wagstaff, Mc Veigh, & Thelwell, 2015) performances. Motivational self-talk is a top-down regulation strategy that requires individual to continuously re-appraise negative self-talk with self-contextualized motivational (Hardy, 2006) and instructional statements that include cue aiming and focusing or directing attention such as "Focus on the trajectory'', strategy, technique, and kinesthetic attributes of a skill (Hatzigeorgiadis *et al.*, 2011). Motivational self-talk makes it possible to actively reformulate negative statements (*e.g.*, "I'm in pain'', "I'm going to stop'') to positive and motivational statements (*e.g.*, "I can do it'', "I will finish''). These statements influence participant's attention and appraisal process, which allows behavioural performance (Meichenbaum, 1977). Indeed, Wallace *et al.* (2017) investigated the effectiveness of two weeks of motivational self-talk intervention on exercise and cognitive performances in the heat. The authors showed that this mental skill increased time to exhaustion (*i.e.*, endurance capacity) as well as executive function (*i.e.*, working memory, attention, speed processing or detection-performances) without adding significant cognitive load or deplete attentional resources.

6 New directions in research

Listening to music, during physical exercise, is a common practice for legions of athletes (Terry & Karageorghis, 2011). Music presents a stimulus that allows to divert attention to external stimuli (*e.g.*, Karageorghis & Terry, 1997) and to focus less on kinesthetic and internal sensations (*e.g.*, pain, thermal sensation and thermal discomfort). Music has positive effects on perceived exertion reduction (Ruscello, D'Ottavio, Padua, Tonnelli, & Pantanella, 2014), emotional response (Hutchinson *et al.*, 2018), physiological efficiency (Bacon, Myers, & Karageorghis, 2012) and motor performance (Terry Karageorghis, Saha, & D'Auria, 2012). More interestingly, a study showed that listening to music was beneficial to running performance and perceived exertion in hot environments (Nikol, Kuan, Ong, Chang, & Terry, 2018). The authors evoked that the benefit may arise from attentional processes, where listening to music would mask the signals of fatigue caused by limited processing capacity, resulting in a reduction in perceived effort and encouraging individuals to work harder and/or for longer (Hardy & Rejeski, 1989). The listening to music seems to be an interesting strategy that can be used during learning and or training sessions, in the heat. However, the use of music can be prohibited in sport competitions due the rules, or certain athletes may prefer the use of personal internal mental strategies such as mindfulness to promote their concentration.

Mindfulness corresponds to a state of awareness and attention to the present moment (Bishop *et al.*, 2004), which includes attention to environmental, mental, and physical stimuli without making evaluations (Kabat-Zinn *et al.*, 1992). Mindfulness has three components: "Awareness'' of current bodily sensations, emotions and thoughts, non-judgmental "acceptance'', and "commitment'' to goal-relevant attention focus and behaviour (Cox, Roberts, Cates, & McMahon, 2018; Thienot *et al.*, 2014). Dispositional mindfulness (*i.e.*, the tendency to be mindful in everyday life) seems to promote sport performance (Birrer, Röthlin, & Morgan, 2012). For example, Haase *et al.* (2015) found that mindfulness intervention changed the way athletes in cycling process interoceptive afferent informations and improved their ability to regulate anxiety related to unpleasant feelings, though and sensation. Carraça, Serpa, Palmi, & Rosado (2018) proposed that the relation between performance and mindfulness could refer to sense of control over oneself and the environment (Aherne, Moran, & Lonsdale, 2011), and to the altering perceptions of barriers or distractions (Kee & Wang, 2008), which would potentially concerned heat stress and its consequences such as fatigue or thermal discomfort (Coudevylle *et al.*, 2019). In addition, athletes who benefited from the mindfulness techniques also used positive motivational self-talk, which leads us to suggest the use of combinations of individualized strategies in order to compensate for or limit the negative effects of heat stress (Kee & Wang, 2008).

Finally, Coudevylle *et al.* (2019) recently mentioned the potentially beneficial effect of using menthol ingestion techniques to create a cooling sensation and modify thermal perception. Indeed, without lowering body temperature (Barwood *et al.*, 2015), menthol can induce a cool feeling (Mndel & Jones, 2010) by stimulating the cold receptors (Cheung, 2010), which can benefit performance in hot environments (Riera *et al.*, 2014; Stevens *et al.*, 2016). Few studies, deals with the use of menthol to increase attentional performance and obtained inconsistent results. For examples, Ilmberger *et al.* (2001), tested the influence of menthol, in the form of essential oil administered by inhalation, on attentional function but did not obtained significant reaction time differences between the experimental and the control groups. On the contrary, a dose of essential oil improved performance on a cognitively demanding rapid visual information processing task and attenuated participant's mental fatigue (Kennedy *et al.*, 2018). While encouraging, the latter result need to be confirmed and should be investigated for potential use in an exercise context in a hot environment.

7 Conclusion

Hot environments can improve both cognitive processes (*e.g.*, reaction time) and anaerobic motor performance (*e.g.*, single sprint performance) when core temperature is inferior to hyperthermia (*i.e.*, core temperature $> 38.5\,°C$). Beyond this threshold, performances plateau before declining when body temperature and task complexity increase (Schmit *et al.*, 2017). Indeed, hyperthermia and heat stress induce additional demand on the limited cognitive workspace that can degrade motor, psychomotor and cognitive performances and leading to potential risks for athletes performing in hot environments. The use of strategies to counteract the effects of heat stress on performance should be considered and tested individually. Acute hydration, cooling interventions or positive motivational self-talk seem to increase performance in cognitive tasks, sport and can lower the perceived load of high temperature. In addition, recent researches suggest the use of combined cooling methods and strategies to improve cognitive functioning as attentional process and sport performances in the heat. Finally, the use of music, mindfulness or even menthol, which can benefit attentional processes, seem to be potentially useful during learning, training and competition performed in the heat.

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