ARTICLE IN PRESS

Autonomic Neuroscience: Basic and Clinical xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Autonomic Neuroscience: Basic and Clinical

journal homepage: www.elsevier.com/locate/autneu

Cold acclimation and cognitive performance: A review

Douglas M. Jones[a,b,*], Stephen P. Bailey[c], Bart Roelands[a], Michael J. Buono[b], Romain Meeusen[a]

[a] Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel, Belgium
[b] San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, United States
[c] Elon University, 100 Campus Drive, Elon, NC 27244, United States

ABSTRACT

Athletes, occupational workers, and military personnel experience cold temperatures through cold air exposure or cold water immersion, both of which impair cognitive performance. Prior work has shown that neurophysiological pathways may be sensitive to the effects of temperature acclimation and, therefore, cold acclimation may be a potential strategy to attenuate cold-induced cognitive impairments for populations that are frequently exposed to cold environments. This review provides an overview of studies that examine repeated cold stress, cold acclimation, and measurements of cognitive performance to determine whether or not cold acclimation provides beneficial protection against cold-induced cognitive performance decrements. Studies included in this review assessed cognitive measures of reaction time, attention, logical reasoning, information processing, and memory. Repeated cold stress, with or without evidence of cold acclimation, appears to offer no added benefit of improving cognitive performance. However, research in this area is greatly lacking and, therefore, it is difficult to draw any definitive conclusions regarding the use of cold acclimation to improve cognitive performance during subsequent cold exposures. Given the current state of minimal knowledge on this topic, athletes, occupational workers, and military commands looking to specifically enhance cognitive performance in cold environments would likely not be advised to spend the time and effort required to become acclimated to cold. However, as more knowledge becomes available in this area, recommendations may change.

1. Introduction

Athletes, occupational workers, and military personnel are often required to compete, work, or perform military duties, respectively, in cold environments. An abundance of evidence suggests that exposure to cold temperatures, such as exposure to cold air or immersion in cold water, impairs cognitive performance (Lockhart et al., 2005; Makinen et al., 2006). For example, athletes such as open water swimmers often compete in varying water temperatures, with some water temperatures reported as low as 10 °C (Tipton and Bradford, 2014). Temperatures of this degree have been shown to impair memory, reaction time (simple and choice), attention, and decision making (Stang and Wiener, 1970; Davis et al., 1975; Spitznagel et al., 2009; Muller et al., 2012). Cognitive impairment is also possible in several occupational groups that work in cold environments. Data presented by Lincoln and Conway (1999) suggest that cold air exposure and cold water immersion are continuous problems among Alaskan fishermen, resulting in numerous occupational injuries and fatalities every year. Perhaps some of harshest cold environments are experienced by military personnel, in which exposure is heavily dictated by constantly changing weather, enemy positions, and battlefield information. During the winter months of 1950 on the Korean Peninsula, Chinese forces attacked United States troops near Chosin Reservoir as temperatures dropped to − 37 °C, causing thousands of cold casualties and demonstrating the severe impact that cold can have on military operations. (Orr and Fainer, 1951; Paton, 2001).

The extent to which cognitive impairments occur as a result of cold exposure is heavily dependent upon the temperature, duration, air or water flow rate, and other situational variables surrounding the cold exposure, such as degree of thermal protection, fatigue, and variations in individual responses to cold. An inability to remain cognitively competent can lead to poor athletic performance and higher numbers of injuries and casualties in workers and military personnel (Wallace and Vodanovich, 2003). Several strategies have been adopted by these communities to mitigate the debilitating effects of cold, yet most rely solely on clothing or equipment for protection from the cold (Rintamaki, 2000; Anttonen et al., 2009). There is little evidence available in the literature for other interventions that target prevention of cold-induced cognitive impairments. One potential strategy that is currently being explored is the use of tyrosine supplementation.

* Corresponding author at: Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel, Belgium
E-mail address: douglas.jones@vub.ac.be (D.M. Jones).

https://doi.org/10.1016/j.autneu.2017.11.004
Received 15 July 2017; Received in revised form 18 October 2017; Accepted 14 November 2017

Please cite this article as: Jones, D.M., Autonomic Neuroscience: Basic and Clinical (2017), https://doi.org/10.1016/j.autneu.2017.11.004

Tyrosine supplementation has shown promising results in combating cold-induced cognitive impairments, but is most effective when administered two hours prior to cold exposure, which may not offer adequate cognitive protection during accidental cold exposure situations (Mahoney et al., 2007). Research has been advanced in other environmental extremes to examine novel ways to attenuate cognitive performance decrements, such as acclimating soldiers to hot environments to protect them from heat-induced cognitive decrements during subsequent heat exposures (Radakovic et al., 2007). Findings presented by Radakovic et al. (2007) suggest that neurophysiological pathways are sensitive to the effects of temperature acclimation and, therefore, one potential strategy for attenuating cold-induced cognitive impairments may be the use of cold acclimation. Cold exposure that is repeated over several days, weeks, or months can improve perceptions of cold stress, in that subjects report less intense cold sensations and improved thermal comfort (Makinen et al., 2006) and, if cold exposures are significant, the process of cold acclimation occurs, which can improve heat retention, heat generation, and energy conservation (Launay and Savourey, 2009). These perceptual and physiological changes may provide an optimal response to improve cognitive performance during subsequent cold exposures. Cold acclimation, if shown to provide cognitive protection from cold-induced impairments, may be superior to other strategies with regards to unplanned cold exposures in that, after successful cold acclimation, no special clothing, equipment or supplementations is necessary for protection from cold. Physiological effects of cold acclimation have been shown to last for several months and can be maintained through intermittent cold exposures (Tipton et al., 2000).

The purpose of this review is to provide an overview of literature that has examined the influence of repeated cold stress, and specifically cold acclimation, on measurements of cognitive performance in an effort to determine whether or not repeated cold stress (with or without evidence of cold acclimation) provides beneficial protection against cold-induced cognitive impairments. Additionally, a brief overview of acute cold exposure and its impact on cognitive performance, as well as a short review of cold acclimation, will be presented. Lastly, recommendations for future research will be discussed. Athletes, occupational workers, and military personnel, as well as other individuals or groups that frequent cold environments, may find this information useful. Enhanced performance and less risk for cognitive errors may be possible if it is shown that cognitive performance can be improved following repeated cold stress or cold acclimation.

2. Acute cold stress and cognitive performance

Acute cold exposure is experienced by exposure to either cold air or immersion in cold water and, depending on the severity of each, may result in different physiological outcomes. A meta-analysis by Pilcher et al. (2002) concluded that, after reviewing 22 environmental exposure studies, exposure to cold air or cold water less than 10 °C resulted in cognitive impairment. Exposure to cold air can lower skin temperature and initiate mild shivering without impacting core temperature, which has been shown to worsen tracking and reaction time, and cause greater cognitive distraction (Russell, 1957; Kissen et al., 1964; Enander, 1987). Further evidence for reductions in cognitive performance resulting from exposure to cold air are presented by Thomas et al. (1989), who exposed subjects to 5 °C air for 60 min, which resulted in a drop in skin temperature, but not core temperature. However, they still observed an impairment in complex cognitive function. They report that this impairment was not a result of whole body cooling, but rather cognitive distraction caused by reduced skin temperature and a change in thermal sensation. Shurtleff et al. (1994) observed a decrease in performance on a matching-to-sample memory task when subjects were exposed to 4 °C air for 60 min and also noted a drop in skin temperature and were confident that whole body cooling did not occur in their experiment, which also suggests that cognitive impairment was caused by changes in peripheral temperature. Although an abundance of evidence suggests that cognitive distraction causes a decrease in performance upon exposure to cold temperatures, there is also evidence suggesting that exposure to cold can improve cognitive performance, although this appears to be restricted primarily to measures of alertness (Patil et al., 1995; Marrao et al., 2005). The cause for this improvement is thought to be related to the arousal theory (activation of the sympathetic nervous system) and is supported by observations of increased norepinephrine upon exposure to cold (Enander, 1987; Shurtleff et al., 1994; Leppaluoto et al., 2001). However, more research is needed to determine the actual cause of why some individuals exhibit alertness impairments related to distraction and others show improvements in alertness related to arousal. Perhaps variation in norepinephrine sensitivity is a mediator to these conflicting cognitive responses.

Immersion in cold water causes a drop in skin temperature with a significant shivering response that may not be adequate to defend a fall in core temperature (Tipton and Bradford, 2014). Exposures of this type, depending on the duration, can result in whole body/brain cooling and are associated with a myriad of cognitive impairments that range from worsened memory to, in severe hypothermia, unresponsiveness (Egstrom et al., 1972; Hoffman, 2001). Immersion in cold water that is significant enough to reduce core temperature, and thus brain temperature, is thought to impair cognitive performance by slowing neuronal conduction and reducing effectiveness of synaptic transmission (Hoffman, 2001). Taylor et al. (2016) also suggest that alterations in catecholamines caused by cold exposure can negatively impact cognitive performance due to the fact that several catecholamines are required for normal cognitive function. When core temperatures drop below 35.0 °C, Coleshaw et al. (1983) suggest that 70% of information is unable to be retained. At core temperatures between 34.0 and 35.0 °C, concentration is significantly impaired and complex tasks are 175% slower compared with performance on tasks that are performed at non-hypothermic body temperatures (Hoffman, 2001). Research suggests that, when thermal protection is used and whole body cooling is prevented, cognitive impairments may be limited to those previously described by the distraction theory (Bowen, 1968). Diminished attention (Spitznagel et al., 2009; Solianik et al., 2014; Solianik et al., 2015), reduced accuracy (Shurtleff et al., 1994), worsened short-term memory (Baddeley et al., 1975; Davis et al., 1975; Patil et al., 1995; Muller et al., 2012; Solianik et al., 2014; Solianik et al., 2015), longer reaction times (Stang and Wiener, 1970; Makinen et al., 2006; Muller et al., 2012; Solianik et al., 2014; Solianik et al., 2015), and decreased efficiency of cognitive tasks (Lockhart et al., 2005; Makinen et al., 2006) are all likely to occur if cold exposure is severe enough to cause distraction from the task or result in whole body cooling that could slow neuronal and synaptic activity. These impairments can greatly impact the ability of athletes, occupational workers, and warfighters to remain alert, respond quickly, and remember crucial information.

3. Cold acclimation

Physiological and perceptual adjustments resulting from repeated cold stress can occur naturally (acclimatization), such as when athletes repeatedly train outdoors and workers perform their daily tasks in cold environments, or in laboratory settings (acclimation) where cold water immersion baths or cold air chambers are used. Cold acclimation is a unique strategy to attenuate responses to cold in that there are no clothing, equipment, or supplementations required for protection during subsequent cold exposures. As long as cold acclimation is successful and maintained, cold acclimation can lessen the physiological and perceptual stress experienced during cold exposure, which may be ideal when the exposure is unplanned (i.e. accidental cold water immersion). Cold acclimation can last for several months (Tipton et al., 2000), but is eventually lost if regular cold exposure is not maintained