**Title:** Effects of living and working in a hot environment on cognitive function in a quiet and temperature-controlled room: An oil and gas industry study

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**Abstract**

Weinvestigate the effects of seasonal heat stress on cognitive function in outdoor workers. Thirty-nine workers from an oil and gas industry in the Middle-East volunteered for cognitive testing before (5.30 to 7.00 am) and after (3.30 to 5.00 pm) their daily work-shift in hot (August – average daily temperature: ~41ºC) and temperate (January – average daily temperature: ~22ºC) seasons. While physical activity was reduced in hot compared to temperate season (average normalised acceleration: 96±33 *vs*. 112±31 × 10-3 g; -12.5±4.7%; P=0.010), the average core temperature during the work-shift was higher in the hot season (37.4±0.2 *vs*. 37.2±0.2ºC; P=0.002). Peak core temperature was 38.0±0.1ºC and 37.8±0.1ºC in hot and temperate seasons, respectively. Cognitive performance did not differ between seasons for tests of recognition memory (P=0.169), working memory (P=0.797) and executive function (P=0.145), independent of testing time. Whereas there was no significant main effect of testing time for tests of recognition memory (P=0.503) and working memory (P=0.849), the number of problems solved on the first choice for the executive function test was lower in the afternoon than the morning (-9.2±5.3%; P=0.039). There was no season × testing time interaction for any cognitive tests (P≥0.145). In the absence of hyperthermia, living and working in a hot environment does not alter cognitive function in oil and gas industry workers tested in a quiet and temperature-controlled room, with reduced clothing encumbrance (relative to work). Conclusions should not be extrapolated to more stressful situations (i.e., thermal stressor present, pronounced dehydration, noise).

**Key words:** Heat stress; Cognitive performance; Occupational setting; Body temperature.

**Introduction**

Numerous industries and occupational settings require individuals to perform physically demanding work, which increases metabolic heat production [1]. Also, many workers, such as those in the oil and gas industry, must wear personal protective equipment limiting heat dissipation capacity [2].These factors coupled with the climatic conditions in Middle-Eastern regions, with extreme heat during summer months (i.e., average air temperature/humidity during the day often exceeding 40ºC/50% rH), may cause substantial physiological strain in physically active individuals [3]. Under these conditions, a state of hyperthermia (core temperature >38.5ºC [4]) may develop, which can also impair aspects of cognitive function [6-7].

Numerous studies have indicated that acute exposure to environmental extremes (up to 50°C) may compromise cognitive functioning, in particular the number of correct detections in complex tasks [8,9,10]. Most studies are laboratory-based with participants wearing shorts and T-shirts during passive thermal stress [11], and there is limited research about the effects of heat exposure on cognitive function for active industry workers with protective equipment [1]. One such study examined changes in cognitive function during heat exposure (WBGT: 30.8–35.4°C) throughout the workday in foundry plant workers [12]. The authors reported slower reaction times and an increase in the number of errors during the Stroop colour word test. As task difficulty increases from simple reaction tasks to more complex psychomotor functions, the effects of heat stress on cognitive performance typically become more visible [5]. In the oil and gas industry context, it is therefore important that computerized batteries include a variety of tests that reflect aspects of cognitive function that may be affected during actual work-shifts.

Chronic heat exposure threatens numerous regulatory systems to maintain homeostasis, which may increase some of the challenges to physiological demands required of industry workers [1]. However, little has been done to assess the combined effects of living (i.e., for several weeks or months) and working (i.e., daily work-shifts of 8–10 h) in hot climates on cognitive function [13]. To date, the effects of chronic heat exposure on cognitive functioning have primarily been assessed from simulated environments (i.e., climatic chambers) typically with only a few hours of heat exposure [8,9], and very few studies enrolled industry workers as participants [14]. Oil and gas industry studies using ecological settings are required to prevent potential human errors resulting from heat-induced impairment in cognitive function, and eventually, improve productivity and safety in occupational environments [15].

This study investigated acute and chronic alterations in cognitive function in outdoor workers of an oil and gas industry during summer and winter seasons of a Middle-Eastern country (Qatar).

**Methods**

A group of 39 Asian (Nepali and Philippines) migrant male workers (age: 32±6 years old; height: 166±6 cm) from an oil and gas industry (labourers, n=11; scaffolders, n=10; mechanical helpers, n=8; carpenters, n=6; pipefitters, n=4) took part in this study after providing their written informed consent. The procedures were approved by the local ethics committee and were conducted according to international standards [16]. The project was approved by the ASPETAR Human Research Ethics Committee.

Testing was conducted on three separate occasions. The first session took place in April and consisted of eligibility determination and familiarization with cognitive testing. Afterwards, participants attended two main experimental sessions: one in hot (August in summer; average temperature during the day: ~41ºC [range: 29–47°C]) and one in temperate (January in winter; average temperature throughout the day: ~17°C [range: 10–26°C]) environments. During each experimental day, all participants had their cognitive function and vital signs assessed before (between 5.30 and 7.00 am) and after a regular work-shift (between 3.30 and 5.00 pm) performed in outdoor conditions (i.e., with solar radiation). Testing was conducted in a quiet and temperature-controlled room (22–24°C), with reduced clothing encumbrance (relative to work), in the absence of heat stressor. Core temperature was continuously monitored during the working days (one value every 60 s, accuracy 0.01°C) via an ingestible radio-telemetric thermistor (VitalSense® recording system, Mini Mitter, Respironics, Herrsching, Germany). Capsules were provided to the workers the day before with instructions to swallow it immediately upon waking. Temperature and relative humidity were continuously monitored during the working days (one value every 60 s, accuracy 0.01°C) by small one-channel dataloggers (iButtonTM, Maxim Integrated Products, Sunnyvale, CA, USA) located on the visor of the helmet. Physical activity was continuously recorded during the work-shift by a tri-axial accelerometer (Actical, Respironics Inc., Germany) located on the hip (right side). Participants wore durable coveralls of a dark colour. They performed a broad range of outdoor activities such as casual walking, driving vehicles, working with construction equipment, carrying light-to-heavy materials. Heat mitigation strategies in place included water stations and shaded areas. However, neither the nature of work tasks nor cooling strategies were specifically determined for each worker. This study is part of a larger project with the changes in immune function and voluntary force production capacity in the same individuals being documented elsewhere [17].

Participants performed three different cognitive tests from the CANTAB Eclipse battery (Cambridge Cognition, Cambridge, UK) assessing aspects of executive function, spatial planning, as well as working and visual recognition memory. Importantly, these tests have been used repeatedly in studies investigating cognitive changes in heat-stressed adults [5,7,8,18]. Tests were performed using a computer with a touchscreen monitor (One World Touch, Austin, TX) that was kept at a fixed distance of ~50 cm from each participant’s eyes for all test sessions. Being language-independent, culturally neutral and with no prior technical knowledge required, the CANTAB is suitable for use in diverse participant groups. The order of the cognitive tests was counterbalanced between participants to reduce any order effect but kept constant within participants. The test battery required ~20–25 min to complete and was administered by the same trained professional (NG) in accordance with the instruction manual.

Pattern recognition memory test is a measure of visual recognition memory that requires ~5 min to complete. Participants were presented with a series of 12 visual patterns one at a time every 3 s in the centre of the screen. These patterns were designed so that they could not easily be given verbal labels. Following the display of 12 patterns, participants were required to choose between a pattern they had already seen and a novel pattern; the patterns were presented in reverse order. The percentage of correct answers (accuracy) was recorded. To reduce any possible learning effect, different groups of patterns were randomly assigned such that participants never saw the same group twice throughout their testing sessions.

Spatial span test assesses visuospatial working memory capacity in ~5 min. Participants were presented with a screen with nine white squares. Some of these squares briefly changed colour in a variable sequence. They were instructed to touch the boxes that changed colour in the same order in which they were displayed. The number of boxes increased from two at the start of the test to nine at the end. The test was terminated after three failed attempts at a given level, and the maximum number of squares successfully recalled was recorded. The order and colour used was changed from sequence to sequence to minimise interference.

One touch stockings of Cambridge test, based upon the Tower of Hanoi test, requires executive function, spatial planning, and working memory. The test duration was 10–15 min. Participants were presented with two displays containing three coloured balls. The displays were presented such that they could be perceived as stacks of coloured balls held in stockings suspended from a beam. Along the bottom of the screen there was a row of numbered boxes. Participants were initially shown how to move the balls in the lower display to copy the pattern in the upper display. The experimenter completed one demonstration problem, where the solution required one move. Then each participant completed three further practice problems, one each of two, three, and four moves. For the test itself, participants were shown further problems and had to mentally calculate the minimum number of moves required to solve them, and then to touch the corresponding box at the bottom of the screen to indicate their response. The number of problems solved on the first choice (accuracy) was recorded. For this latter test, within a testing session, each measure was obtained by averaging the score obtained over four trials.

Body mass was recorded using electronic digital scales (TANITA HD-316, Tokyo, Japan) to the nearest 0.1 kg. Arterial oxygen saturation was measured via pulse oximetry (8000SL; Nonin Medical Inc, Plymouth, MN) on the right middle finger. Arterial blood pressure was recorded manually by the same investigator using a sphygmomanometer (Gamma G5, Heine Optotechnik, Herrsching, Germany) and mean arterial pressure was calculated as: diastolic blood pressure + 1/3 × (systolic blood pressure – diastolic blood pressure). Resting heart rate was monitored telemetrically with a Polar transmitter-receiver (T-31 Polar Electro, Lake Success, NY, USA). These vital signs were measured in a seated position after resting for 10 min.

Values are presented as mean±SD. Two-way repeated-measures analysis of variance (ANOVAs) [Season (hot *vs*. temperate) × Testing time (morning *vs*. afternoon)] were used to compare investigated variables. To assess assumptions of variance, Mauchly’s test of sphericity was performed using all ANOVA results. A Greenhouse–Geisser correction was performed to adjust the degree of freedom if an assumption was violated, while a Bonferroni post hoc multiple comparison was performed if a significant main effect was observed. Effect sizes were described in terms of partial eta-squared (ηp2, with ηp2≥0.06 representing a moderate effect and ηp2≥0.14 a large effect). Statistical testing was carried out in SPSS (v26, IBM Corp., Armonk, NY, USA). Data was considered significant if P≤0.05.

**Results**

The average core temperature during the work-shift was significantly higher during hot (37.4±0.2ºC [range: 37.0–37.8]) than temperate (37.2±0.2ºC [range: 36.9–37.6]) seasons (P=0.002) (Figure 1). Peak core temperature was higher in August than January (38.0±0.1 *vs*. 37.8±0.1ºC, respectively; P<0.001), also with all individual peak core temperatures < 38.3ºC. Average temperature / relative humidity on the visor of the helmet were 36.5±0.6ºC / 51.0±1.2% and 21.3±0.3ºC / 53.5±1.0% during work-shift in the hot and temperate season, respectively. The normalized physical activity (acceleration) was significantly lower during work shift in the hot (96±33 × 10-3 g [range: 35–151]) than the temperate (112±31 × 10-3 g [range: 49–200]) season (-12.5±4.7%; P=0.010).

Body weight, arterial oxygen saturation as well as systolic, diastolic and mean arterial blood pressures were lower in hot compared to temperate season (P≤0.032; ηp2≥0.11), independent of testing time (Table 1). Irrespective of the season, arterial oxygen saturation as well as systolic, diastolic and mean arterial blood pressures were lower, and heart rate higher, during the afternoon than morning sessions (P≤0.040; ηp2≥0.10).

There was no global effect of the season for Pattern Recognition Memory (77.5±18.2 *vs*. 77.6±16.6% correct; P=0.169, ηp2=0.05), Spatial Span (6.1±1.2 *vs*. 5.9±1.3 squares successfully recalled; P=0.797, ηp2=0.01) and Stocking Of Cambridge (8.3±1.4 *vs*. 8.8±1.5 problems solved on first choice; P=0.145, ηp2=0.07) (Figure 2). There was no significant main effect of testing time for Pattern Recognition Memory (P=0.503, ηp2=0.01) and Spatial Span (P=0.849, ηp2≥0.01), but the number of problems solved on the first choice for Stocking Of Cambridge was lower for morning than afternoon sessions (8.3±1.4 *vs*. 8.8±1.3; -9.2±5.3%; P=0.039, ηp2≥0.14). There was no season × testing time interaction for any cognitive tests (P≥0.145, ηp2≤0.07).

**Discussion**

We observed that chronic heat exposure had no meaningful impact on cognitive function despite the large differences in air temperature between hot (summer) and temperate (winter) environments. These observations differ from the study by Saini et al. [13] where scores on the postgraduate memory scale were worse when 107 male soldiers lived and were tested in desert conditions averaging 42°C compared with 27°C. Importantly, this apparent well-preserved cognitive function should not be ascribed to a lack of test sensitivity *per se*. Heat stress was previously found to affect the measured indices of cognitive function – One touch stockings of Cambridge [8,19], Pattern Recognition Memory [5,7] and Spatial Span [5,7,20] – used in the present study. These studies, however, used ‘extreme’ heat exposure (air temperature 44–50ºC in a climatic chamber), that elevated core temperature beyond 38.5ºC. Whereas core temperature values in the current study may appear relatively low (i.e., 37.4ºC) as compared to laboratory studies [5,7,8], these readings are in the range of those previously reported in other industry workers exposed to hot ambient conditions (e.g. 37.45ºC in aluminium workers) [21].

Some features of the experimental procedures and the tested population may also explain why cognitive function remained mostly unchanged between the summer and winter months. Firstly, the fact that cognitive tests were administered in a temperate environment (i.e., with participants allowed to remove their helmets and open their uniforms), likely generating a pleasant stimulus in the afternoon after working all day outdoors (i.e., also known as the principle of thermal alliesthesia) [22], and ~30 min post-work-shift may have partly allowed some adverse effects of heat stress to dissipate. Indeed, when quantifying the impact of heat stress on cognitive performance, the rate of change in body temperatures and the total thermal load should also be considered in addition to the absolute core temperature [8,9]. Regardless, under the present circumstances, there were probably sufficient attentional resources available to successfully complete the selected cognitive tasks after a day of work with or without heat exposure. Secondly, the *ad libitum* water consumption (i.e., even though hydration status was not assessed) probably allowed maintenance of body weight at pre-work-shift levels [23], which may have assisted in preventing impairments to cognitive performance generally observed with dehydration. In fact, dehydration at levels commonly observed across a range of occupational settings with environmental heat stress aggravates the impact of hyperthermia on performance in tasks relying on combinations of cognitive function and motor response accuracy [24]. However, during passive heat stress, Schlader et al. [18] demonstrated that mild dehydration has little impact on attention, memory, and executive function (i.e., measured with a similar standardized test battery). Thirdly, tested individuals were likely partially acclimated since they arrived in Qatar on average ~4 and ~8 months before familiarization (April) and hot (August) sessions, respectively, and therefore had lived and worked in warm conditions for at least 3–4 months when they were tested. Individual vulnerability to heat stress, as demonstrated by substantial inter-individual variability in response to the three cognitive tests *(Figure 2)*, may also relate to preferred working temperature across participants [25].

Cognitive tasks that place higher demands on brain processing usually show larger decrement during heat exposure than less demanding tasks [5,26]. In support, exertional heat stress when exercising at 5.5 km/h in 40°C compared to 20°C for a maximal duration of 90 min resulted in mild deficits in attention in unacclimated soldiers, while impairments were only apparent in complex but not simple cognitive tasks [27]. According to that rationale, our high-complexity tasks such as working memory (Spatial Span) and executive function (One touch stockings of Cambridge) would be the most vulnerable to heat exposure, whereas the recognition memory (Pattern Recognition Memory) less impacted. In our study, however, there was no negative effect of a working day with or without heat exposure on cognitive function, with even a significantly larger number of problems solved on first choice for Stocking Of Cambridge. This may be due to the modest elevations in core temperature in the two environmental conditions, presumably with a level of stress during the work-shift that was not severe enough to induce persistent changes when cognitive function was assessed at rest in a temperate room.

The reduction of physical activity during summer (i.e., reduced work:rest ratio), and by extension a lower rate of metabolic heat production (i.e., even though not quantified in our study), can partly explain the absence of alterations in cognitive functions despite slightly elevated core temperatures. This may have created a compensable heat stress environment. In addition, the highest individual core temperature observed during the work-shift was 38.3ºC (August). Despite high ambient and radiant temperatures in the mining, agricultural and construction sectors, in most cases core temperatures remained below 38.0ºC, whereby the risk of any heat-related illness or injury is low [1,21]. As suggested by Martin et al.[9], the fact that none of the workers reached 38.5ºC and became ‘hyperthermic’ in our study may explain the absence of acute effect (pre-*vs*. post- the working day) of a hot environment on cognitive functions.

Irrespectively of whether the participants worked in a temperate or hot environment, lower arterial oxygen saturation as well as systolic, diastolic, and mean arterial blood pressure values occurred after (afternoon) compared to before (morning) the work-shift. The effects of the work-shift on vital signs likely represent normal diurnal variations. Finally, the lower blood pressure values measured in hot compared to temperate conditions, independent of testing time, tend to suggest that chronic heat exposure may bring health benefits for outdoor workers [28]. Because vital signs were measured in a seated position after resting for 10 min, they are unlikely to reflect the cardiovascular effects of working in the respective environments.

One strength of this observational study was the use of real-world rather than simulated (laboratory) conditions and the recruitment of industry workers, unlike previous research investigating heat stress effects on cognitive function [8,9]. Additionally, our cognitive assessment relied on valid and reliable tests chosen to evaluate a variety of cognitive functions [29], while their reliability was not specifically assessed in our study. Implementing new testing procedures raises the possibility of improvement due to the occurrence of learning effects, while participants may also be stressed at the start of uncommon computerized testing [30]. Consequently, another important methodological aspect of our study was to implement a familiarization session to reduce bias that could potentially mask any cognitive impairment due to heat stress. Nonetheless, our understanding of the real impact of working in a hot climate on cognitive function remains incomplete, partially due to an inability to impose a constant level of physical activity across the two environmental conditions or to perform cognitive testing during the work-shift. An important consideration is that we assessed cognitive function in workers in response to a single day of work in the middle of the summer season. It is still not well understood how some of our observations may differ if obtained at different periods of the summer season (i.e., at the very beginning when participants are not yet acclimatized and heat stress may be viewed as a cognitive load or towards the end when more fatigue is presumably accumulated). Noteworthy is that eleven days of repeated passive exposure restored accuracy on a planning task to its baseline level (i.e., an improvement by ~25%), despite core temperature being elevated to 39°C [31].

In summary, oil and gas industry workers of a Middle-Eastern country (Qatar) have been assessed with a computer-based, cognitive test battery to determine the effects that thermal stress has on cognitive responses to a work-shift. These individuals suffered no detrimental effects of living and working in a hot environment on selected aspects of cognitive function (i.e., visual attention and working memory). Despite higher heat strain (i.e., slightly elevated core temperate and heart rate readings), the overall physiological stress remained relatively mild in the hot environment probably because workers following safety rules of the company reduced their physical activity during the work shift. Because participants were tested in a quiet and temperature-controlled room, with reduced clothing encumbrance (relative to work), conclusions should not be extrapolated to more stressful situations (i.e., thermal stressor present, pronounced dehydration, noise).

**Disclosure of Interest**

The authors have no conflicts of interest or financial ties to disclose and no current or past relationship with companies or manufacturers who could benefit from the results of the present study.

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**Figure legends**

**Figure 1 – Mean core temperature (A) and physical activity (B) across the work day during hot (August, black circles) and temperate (June, white squares) environments.**

*Data are expressed as mean±SD with n=37 and 29 participants for core temperature and physical activity, respectively.*

**Figure 2 – Cognitive function (A, Pattern Recognition Memory; B, Spatial Span; C, One Touch Stockings of Cambridge) corresponding to changes due to season (hot *vs*. temperate environments) and testing time (morning *vs*. afternoon sessions).**

*Data are expressed as mean±SD with n=39 participants for both Pattern of Recognition Memory and Spatial Span tests and n=29 for One touch Stockings of Cambridge performance.*

*Note that statistical analysis only considered data from hot and temperate environments (not the familiarization session).*