The Effects of Indoor Temperature and CO_2 levels as an Indicator for Ventilation Rates on Cognitive Performance of Adult Female Students in Saudi Arabia

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Student Declaration

I, Riham Ahmed, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Educational buildings are complex spaces to design, as they need to perform well in all aspects of environmental conditions. Research has clearly established that problems with indoor environmental quality in classrooms, including, but not limited to, thermal and air quality, can directly influence students' outcomes and learning. There is a growing body of evidence that improved environmental conditions in classrooms increases productivity and improves the performance of mental tasks, such as improved concentration and recall. It is of particular importance to investigate the effects in educational buildings relying on mechanical for ventilation and cooling in the hot desert climates like Saudi Arabia where great reliance on air conditioners occurs, especially after energy has become cheap and affordable.

An experimental approach was adopted in this study via an intervention study in a selected female university building to investigate the effects of classrooms' temperature and CO_2 levels on a set of vigilance and memory tasks exemplifying the basic yet most critically important functions involved in the process of learning. The experiments were performed using a blind cross-over design with repeated-measures. Data analysis was performed using a multi-variable multilevel statistical analysis approach. The study is based on two classrooms' physical environmental measurements data collected from 499 adult female participants. After considering the possible confounders of the study, the main findings highlight the potential benefits of effectively managing indoor temperature and CO_2 levels in the air-conditioned university/college buildings in Saudi Arabia for improved educational environments in which students are expected to learn and produce. The research concludes that temperature affects the accuracy of tasks differently according to the type of task while performance in all tasks improved significantly when CO_2 levels decreased from 1800 ppm to 600 ppm and also from the currently recommended levels by ASHRAE of 1000 ppm to 600 ppm.

Nomenclature

AC	Air conditioners
AMV	Actual mean vote
ASHRAE	American Society of Refrigerating and Air-Conditioning Engineers
°C	Degree Celsius
CO_2	Carbon dioxide
IAQ	Indoor air quality
IEQ	Indoor environmental quality
ppm	Parts per million
RH	Relative humidity
PMV	Predicted mean vote
s	Seconds
SBS	Sick building syndrome
SD	Standard deviation
GPA	Grade Point Average

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List of Publications Coming out of This Research

Journals:

- Jaber Ahmed R.; Mumovic D.; Ucci M. (2018). The Combined Effects of Temperature and Ventilation Rates on Cognitive Performance for tasks conducive to learning. Journal paper*.

- Jaber Ahmed R.; Mumovic D.; Ucci M. (2018). Whether Classrooms' Temperature or CO_2 Levels has Greatest Influence on Adult students' Cognitive Performance. Journal paper *.

- Jaber Ahmed R.; Mumovic D.; Ucci M. (2018). A Multi-level Modelling Statistical Analysis Approach for the Effects of Thermal Comfort and Acclimatisation on Cognitive Performance in Educational Buildings Located in the Hot Climates Relying on Air-Conditioners for Cooling and Ventilation. Journal paper *.

**(Owing to the nature of this research work, which determined finalising the results and drawing the conclusions after the analysis and interpretation of a huge set of data, these publications were delayed till the end of study and now ready for submission).*

Book Chapters:

Mumovic D.; Jaber Ahmed R.; Chatzidiakou L. (2018). Designing for Health and Comfort and Cognitive Performance in Schools: What Do We Know?
In: Daniels H. ed. *Handbook of Educational Buildings' Design.* Oxford University. Routledge.

Conferences:

Jaber Ahmed R.; Mumovic D.; Ucci M. (2018). Implications to Buildings' Besign and HVAC Operation in the Hot Arid Countries Relying on HVAC System for Cooling and Ventilation. International Building Physics Conference (IBPC2018). (*submitted abstract and paper is in progress*).

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Ahmed R.M. (2014). Field study on the economic impact of the working environments in non-temperate climates. WIT Transactions on Ecology and The Environment, 18, p.161-173.

Ahmed R.M. (2014). The Role of Temperature and Ventilation Rates in Hot Dry Climates. ASHRAE First International Conference in Doha, Qatar (2014). Conference presentation. URL: file:///C:/Users/ucft588/Downloads/TechProgram_HotClimates_0204%20(2).pdf

Ahmed R.M. (2014). The Inter-Related Relationship between Thermal Comfort, Indoor Air Quality and Students' Cognitive Performance. Conference presentation at the Academy of Neuroscience for Architecture (ANFA). URL: https://www.brikbase.org/sites/default/files/ANFA2014_ExtendedAbstracts_01_1.pdf

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Chapter 1: Introduction

1.1 Rationale for the Study: Research Background

Poor conditions leading to substandard indoor air quality (IAQ) in classrooms have been frequently cited in the literature over the past two decades. The education system in Saudi Arabia has been transformed immensely in the past few decades, and especially for women, since in Saudi Arabia women were not allowed to be educated until recently (Baki, 2004). Accordingly, a huge gap between males and females has arisen in all aspects of life. The Saudi Arabian higher education system is quite young; about 65% of the government universities were established in the last 15 years (Alrashidi and Phan, 2015). However, at the university level, the field of education for women is still limited, and the specialisations that they are allowed are very limited relative to the fields of education that men are allowed. Hence, currently the Saudi government is investing heavily in womens' buildings' sector, particularly for higher education, to empower gender equality and allow competition in the labour market.

This evolution of educational buildings infrastructure determines the designing and building of healthy educational buildings conducive to learning. There is considerable research worldwide on the importance of good quality ventilation and the impact of poor IAQ in educational buildings. ASHRAE standards for ventilation and IAQ are the most commonly used, and they are the ones followed in Saudi Arabia. Thus, ventilation rates in educational buildings were expected to comply with the ASHRAE standards. However, very limited data is available to date in this context of study. A study by Al-Subaie (2014) provided evidence based on data collected from 36 primary schools, indicating that classroom ventilation rates in educational buildings in Saudi Arabia do not meet the ASHRAE building standards. Therefore, only one study is not sufficient for drawing robust conclusions, which was even conducted in primary schools and not university buildings.

In addition, it is particularly important to conduct more studies in this climatic context since the occupants in Saudi Arabia rely heavily on air conditioners (ACs) for cooling and ventilation. According to survey results based on data gathered from commercial and residential sectors in Saudi Arabia, ACs operate from January to December, with many households keeping ACs running 24 hours. It was indicated that ACs' temperature setting often lies, on average, between 19 and 20°C, which was regarded by the Ministry of Water and Electricity-Kingdom of Saudi Arabia (2009) as 'excessively lower than comfortable sensible temperature'. However, it was found according to thermal comfort intervention studies that the temperature indoors should follow the change in outdoor temperature, rather than being kept constant for the entire year (e.g. Frontczak, 2011).

In the hot desert climate of Saudi Arabia, people living year-round in air-conditioned spaces are quite likely to develop high expectations for homogeneity and cool temperatures and may become more sensitive if thermal conditions deviate from the centre of the comfort zone they have come to expect (de Dear and Brager, 2002). The results from the ASHRAE RP-884 (1995) suggested that occupants of air-conditioned buildings become more finely adapted to the narrow constant conditions typically provided by mechanical conditioning. Accordingly, one can imply that occupants are expected to be more sensitive to temperature variations in Saudi Arabia, and their physiological adaptation (i.e., acclimatisation) to changes in the narrow temperature, which often lies, on average, between 19 and 20°C, as mentioned earlier, is most likely to affect their thermal comfort preference and sensations. Therefore, the effect of 'air-conditioner acclimatisation' cannot be neglected in this context. Nevertheless, this issue of air-conditioner acclimatisation has not been investigated in the relevant studies to date within the scope of either thermal comfort or productivity/cognitive performance (e.g. Lan and Lian, 2009; Lan et al., 2010; Maula et al., 2016) and thus is less understood. More research is therefore needed in this regard.

In addition, among the problems associated with the total reliance on ACs for cooling and ventilation is that most ACs re-circulate a significant portion of the indoor air to maintain comfort and reduce energy costs associated with heating or cooling outside air. Owing to the high occupancy densities in classrooms of educational buildings, the internal heat gains increase, leading to high carbon dioxide (CO_2) levels, increased emissions of body odours and increases in various indoor pollutants (physical, chemical and microbial) (Chatzidiakou et al., 2014). Therefore, the circulated air is most likely unable to dilute the elevated CO_2 levels in the air and the oxygen levels decrease accordingly, especially because ACs do not alter the amount of oxygen in a room. Evidence was provided that moderate deficiency in the amount of oxygen reaching the tissues has been shown to have a direct impact on cognitive performance by causing changes in visual, motor, somatosensory, and mental function. Performance in intelligence tests, reaction time, speech comprehension, hand steadiness, and visual contrast discrimination are some of the mental functions that have been shown to be negatively affected (Hornbein, 2001).

Furthermore, visual function changes with oxygen deficiency include narrowing of the visual field and vision blurring (Klemp et al., 2007). Therefore, IAQ and its implications associated with health and performance in the air-conditioned buildings is one of the most incisive aspects of environmental quality in educational buildings' design. Not only this, several researchers have associated classrooms' ventilation rates with cognitive function outcomes, such as decision making, attention, concentration, and memory (e.g. Coley et al., 2007; Satish et al., 2011; Bakó-Biró et al., 2012). Moreover, very few studies have considered the nested confounding variables (the key factors that might affect the cognitive functions, such as the amount of sleep, stress, etc.), hence statistically significant results were not achieved in most of the studies (e.g. Haverinen-Shaughnessy and Shaughnessy, 2015).

Furthermore, providing sufficient classroom ventilation rates alone is not sufficient to provide a good learning environment. Increased evidence shows that indoor temperature and occupants' thermal comfort can substantially influence health and productivity, and the relationship between work performance and temperatures was quantified by a number of researchers. For instance, Sepannen et al. (2003, and 2006) have suggested a relationship between work performance and temperature; however, it was revealed that the relationships found have a high level of uncertainty. Moreover, the results obtained were not consistent. According to the relationship developed by Sepannen et al. (2003), no effect on performance was found in the temperature range of 21–25°C. However, according to Sepannen et al. (2006), they meta-analysed 24 relevant studies and suggested that performance of tasks such as text processing, simple calculations (e.g. addition, multiplication) increases with temperatures up to 21–22°C, and that performance decreases with temperatures above 23–24°C. Therefore, the results obtained were inconsistent, and thus further investigation is still needed into this particular range of temperatures.

Furthermore, the results obtained from thermal comfort and IAQ studies are mostly linked to office-work performance while scarce data is obtained from real classroom environments. Even the research of the two main robust studies available (Wargocki and Wyon, 2013; Bako-Biro et al., 2012) was conducted on children. On-going research is focusing on children's performances, as they are more vulnerable to toxic effects from environmental hazards. The science of developmental neuropsychology recognised that more complex thinking executive functions (such as perception of time, abstract understanding of language and selective attention) occur approximately from the age of 9 to 23 years (Gogtay et al. 2004; Anderson, 2002), which suggests that investigating the effects on performance of adult students is of equal importance. Furthermore, a comparative mental rotation task study on the variations in brain activity between children and college students revealed that a change that affects both brain activation and performance on mental rotation tasks occurs sometime between childhood and adulthood (Roberts and Bell, 2000), which emphasises the importance of conducting studies on adult students.

1.2 Research Aims

The main aim of this research is to investigate the effects of classrooms' temperatures and CO_2 levels which are most likely to have an effect on the cognitive performance in the tasks conducive to learning based on published research to date, versus the effects of prevalent classrooms' temperatures and CO_2 levels (as an indicator for indoor ventilation rates) in the mechanically educational buildings relying solely on air conditioners (ACs) for cooling, and also for ventilation in Jeddah, Saudi Arabia, where the case study building is selected.

The research hypotheses is that the current prevalent classrooms' temperatures and CO_2 levels (as an indicator for indoor ventilation rates) in the educational buildings of adult of adult female students in Jeddah, Saudi Arabia relying solely on air-conditioners for both cooling and ventilation, can contribute to optimum cognitive performance in the tasks conducive to learning.

Also, an outcome of the study is to identify whether CO_2 levels or temperature has the greater impact on the cognitive performance tasks considered in this study.

1.3 Research Questions

Accordingly, the main research questions are formulated as follows:

1. What would be the effect on the cognitive performance tasks conducive to learning of adult female students in the educational buildings in Jeddah-Saudi Arabia when:
   - Maintaining the baseline temperature currently set in the educational buildings' classrooms, while decreasing CO_2 levels from the 1000 ppm currently recommended by ASHRAE standards to 600 ppm, and also from the current mean baseline CO_2 levels in educational buildings to 600 ppm.
   - Conversely, maintaining CO_2 levels at 600 ppm while increasing the temperature from the baseline temperature currently set in the educational buildings' classrooms to 25°C (the upper limit of temperature after which performance is expected to deteriorate on the basis of findings of relevant studies to date).
2. Accordingly, what could be the recommended settings for indoor temperatures and CO_2 levels in educational buildings for adult female students with reference to the ASHRAE standards which is followed in Saudi Arabia?
3. What would be the implications of the findings arising from the questions above for the design of educational buildings located in hot climates and relying on ACs for cooling and ventilation?

1.4 Specific Objectives

1. First, to gather information about the baseline temperature and mean CO_2 levels in the educational buildings in Saudi Arabia for adult female students, particularly in Jeddah, where this study is conducted.
2. Accordingly, decide on the exposure conditions (combining temperatures and CO_2 levels) and hence conduct an intervention study.
3. To perform a pilot study prior to the intervention to support the study and test the tools and methods proposed (a detailed description of the study is provided in the methodology chapter).
4. On the basis of the information gathered, to carry out a full intervention study in the selected case study building.

1.5 Novelty of Research

The novelty of this study lies in that:

- The study was conducted in Saudi Arabia from which scarce data is available up to date with specific regard to IAQ and thermal comfort fields of study in educational buildings and the effects of indoor temperature and ventilation rates on cognitive performance. The study also considers the effect of acclimatisation to ACs, arising from cheap and affordable energy in this affluent society – an aspect which has not been explored yet. Moreover, the study focused on adult female students. This provides a novel contribution to the knowledge as the current information on the effects of room temperatures and IAQ are mostly based on schoolwork by children.

- The study adopts a multivariable multilevel statistical analysis approach, which took into account the nested structure of the data while adjusting for the possible confounding variables. This approach has not been adopted in the most relevant studies, except for one study (Haverinen-Shaughnessy and Shaughnessy, 2015); however, non-significant results were obtained owing to the limited sample size.

- The study is well-controlled (i.e., maintains strict control of all variables, and the assessment and exposure protocols adopted minimise bias), which enables a valid comparison between the outcomes using a multivariable multilevel statistical analysis approach that accounted for the possible confounders of the study to distinguish the effects of temperatures and CO_2 levels investigated from other influences.

- A well-trusted neurobehavioral battery was used which integrates validated tests. The nine-button ('9Buttons') keyboard was used instead of the typical computer keyboard, which has the advantage of having only nine buttons for the purpose of the given tasks and thus helped to minimise distraction when selecting the buttons as quickly as possible and thus the chances of obtaining biased results.

1.6 Thesis Outline

Chapter 1: Introduction

This introductory chapter sets the research in context by giving background information to identify the rationale for the study.

Chapter 2: Literature Review

The objective of this literature review is to identify the current state of knowledge with regard to the associations of indoor temperatures and ventilation rates and/or CO_2 levels and human cognitive performance. The chapter also gives an overview of the current standards and buildings' regulations, and the standards applied in Saudi Arabia. Human performance aspects will be highlighted with specific regard to learning in particular. Following this, the confounders that act as the physical influencing factors on human performance will be reviewed. These pieces of information together weave the insight into the main concepts forming the basis of this study for deriving the methodology and protocol of study.

Chapter 3: Research Context

This chapter provides an overview of the context of the study in terms of an identification of the educational infrastructure in Saudi Arabia, the climate, the socio-economic status and the cultural influence.

Chapter 4: Methodology

This chapter describes the methods proposed for the study. First, the protocol of the study will be discussed with a clear identification of the selected exposure conditions. Following this, the case study building will be described. Afterwards, human participation, sample size and the protocol for recruitment will be discussed. The physical monitoring protocol and the equipment used, as well as the collection of subjective responses from the participants, will be discussed afterwards. This is followed by the cognitive performance assessment protocol and assessment tool used. Following this, the data analysis procedures will be discussed, and finally the chapter concludes with the ethical approval which was obtained prior to the study.

Chapter 5: Pilot Study

This chapter describes a pilot study, which was conducted prior to the intervention study in the same case study building. The main purpose of the pilot study was to verify the methods proposed and help to identify the reference conditions prevalent in the context of the study before commencing the intervention study and thus being able to apply modifications when needed. The chapter begins with a description of the protocol of the study, including physical monitoring protocol, the subjective measurements collection and the assessment tool for cognitive performance, and an identification of the tasks considered for this study. This will be followed by a presentation of the results obtained. A discussion will be provided afterwards, followed by the conclusions and the lessons learnt for application on the bigger scale intervention.

Chapter 6: Results of the Intervention Study

The chapter begins by presenting the sociodemographic characteristics of the studied population. Afterwards, the average values of the physical environmental parameters are presented, followed by the subjective measurements of questionnaire responses, and then a preliminary descriptive analysis will be provided. Afterwards, the estimated effects obtained from the univariable multilevel analysis are presented, followed by the effects obtained from the multivariable multilevel analysis.

Chapter 7: Discussion

This chapter discusses the findings of the study. First, the associations of the exposure conditions and the accuracy and speed of performance are discussed, followed by the associations of the investigated temperatures and CO_2 levels and the accuracy and speed of performance independently. Implications for educational buildings' design in the context of the hot climates relying on ACs for ventilation and cooling are discussed afterwards. The chapter concludes with the limitations of the study.

Chapter 8: Conclusions and Future Work

This is the final chapter, which outlines the principal findings of the study and provides suggestions for future work.

Chapter 2: Literature Review

The previous chapter sets the research in context by giving background information to identify the rationale for the study with regard to the effects of indoor temperature and CO_2 levels on cognitive performance and the knowledge gap in this premise before identifying the research aims and objectives. This chapter reviews the current state of knowledge with regard to the reported effects of indoor temperatures and ventilation (CO_2 levels) on human cognitive performance from relevant studies up to date. Human performance will be highlighted with specific regard to learning in particular. Following, the confounders that act as the physical influencing factors on human performance will be reviewed. This information together weaves the insight into the main concepts forming the basis of this study for deriving the methodology and protocol of study. Accordingly, the methodology proposed for the study will be discussed in the following chapter.

2.1 Human Performance and Productivity

Human performance is a behavior, a process, a procedure, a way of working or functioning, or an accomplishment (Human Performance and Productivity Resources, 2017). Productivity is the measure of the efficiency of production whereas performance deals with the way in which someone functions to accomplish something successfully (Nicholls T., 2011). Task performance is usually used to reflect productivity and the speed at which the tasks are performed is one of the common measures of performance. For many types of task, there exists a speed–accuracy trade-off (Wickelgren, 1977), meaning that, within the capacity of a person, that person can either perform the task very fast with a large number of errors or very slow with very few errors (the effects on performance measures occur in two opposite directions). Sometimes only one of these two performance indicators is affected by the environmental conditions.

In human performance studies, the response time and other time-related measures have been used to attain information on the speed of work. The importance of speed and accuracy may differ according to the type of task. In addition, subjects in experiments concerning measurements of work performance may have the capability to compromise accuracy for speed. It is consequently quite difficult to compare the task speed obtained under two different conditions and conclude that the condition with the lower speed is worse for performance unless we know that the error level under this condition was greater than or at least identical to that under another condition. It was therefore concluded that the performance is reduced in a condition in which speed is lower and there are more errors made (Wickelgren, 1977). In studies in which either accuracy or speed was not affected, either speed or accuracy was separately used as a measure of performance (e.g. Hancock and Vasmatzidis, 1998; Pilcher et al., 2002; Wargocki et al., 2004; Wargocki and Wyon, 2007a, b; Lan and Lian, 2009; Lan et al., 2009).

This study focuses on human performance in terms of cognitive performance and learning in particular as follows:

2.1.1 Cognitive Performance

Cognition is the process by which individuals make meaning of the environment; it reflects one’s thoughts, beliefs and modes of thinking and problem solving (Wilt et al., 2011). The term "cognition" could be defined as the processes adopted by organisms to organise information, including acquiring information (perception), selecting information (attention), representing information (understanding) and retaining information (memory) in addition to using the retained information to guide behaviour, which is reasoning and coordination of motor outputs (Bostrom and Sandberg, 2009). Intellectual disability affects functioning in three domains: conceptual (e.g. memory, language, reading, writing, maths, knowledge acquisition), social (e.g. empathy, social judgement, interpersonal skills, friendship abilities), and practical (e.g. self-management in areas such as personal care, job responsibilities, money management, recreation, organising school and work tasks) (American Psychiatric Association, 2013). General cognitive/intellectual ability could be divided into language and communication, learning and memory, attention and vigilance, processing speed, and executive functioning.

Learning and memory refers to abilities to register and store new information (e.g. words, instructions, procedures) and retrieve information as needed (OIDAP, 2009; WHO, 2001). Impaired memory functioning can arise from a variety of internal or external factors, including depression and stress, which may affect an individual's ability to sustain work, and/or a lessened ability to learn and remember instructions or work-relevant material. Attention and vigilance refer to the ability to sustain the focus of attention in an environment with ordinary distractions (OIDAP, 2009). Normal functioning in this domain includes the ability to sustain, shift, divide, and share attention (WHO, 2001). People with impairments in this domain may have difficulty attending to complex input, holding new information in mind, and performing mental calculations. They may also exhibit increased difficulty attending in the presence of multiple stimuli, can be easily distracted by external stimuli, need more time than expected to complete normal tasks, and tend to be more error prone (American Psychiatric Association, 2013).

Processing speed refers to the amount of time it takes to respond to questions and process information and has been found to account for variability in how well people perform many everyday activities, including untimed tasks (OIDAP, 2009). This domain reflects mental efficiency and is central to many cognitive functions (National Institutes of Health).

With regard to executive functioning, it is generally used as an overarching term encompassing many complex cognitive processes such as planning, prioritising, organising, decision making, task switching, responding to feedback and error correction, overriding habits and inhibition, and mental flexibility (American Psychiatric Association, 2013; Elliott, 2003; OIDAP, 2009). It has been described as a product of the coordinated operation of various processes to accomplish a particular goal in a flexible manner (Funahashi, 2001). Impairments in executive functioning can lead to disjointed and disinhibited behaviour reflected in the form of impaired judgement, organisation, planning, and decision making, and difficulty focusing on more than one task at a time (Elliott, 2003).

Nevertheless, it is important to mention that among the most striking characteristics of human cognition is its variability. This variability is present both between people (inter-individual variability) and within a given person (intra-individual variability). According to an online report release by the Committee on Psychological Testing, Institute of Medicine in Washington (Psychological Testing in the Service of Disability Determination, 2015), the most basic level of interpretation is simply to compare an individual's testing results with the normative data collected in the development of the measures administered. This level of interpretation allows the examiner to determine how typical or atypical an individual's performance is in comparison to same-aged individuals within the general population. Normative data may or may not be further specialised on the basis of ethnicity, gender, and educational status.

There is some degree of variability in how an individual's score may be interpreted on the basis of its deviation from the normative mean due to various schools of thought. One example of an interpretative approach would be that a performance within one standard deviation of the mean would be considered broadly average. Performances one to two standard deviations below the mean are considered mildly impaired, and those two or more standard deviations below the mean typically are interpreted as being at least moderately impaired. In addition to comparing an individual's performances to that of the normative group, it also is important to compare an individual's pattern of performances across measures. This type of comparison allows for identification of a pattern of strengths and weaknesses. For example, an individual's level of intellectual functioning can be considered a benchmark to which functioning within some other domains can be compared. If all performances fall within the mildly to moderately impaired range, an interpretation of some degree of intellectual disability may be appropriate, depending on an individual's level of adaptive functioning.

It is important to note that any interpretation of an individual's performance on a battery of tests must take into account that variability in performance across tasks is a normal occurrence (Binder et al., 2009), especially as the number of tests administered increases (Schretlen et al., 2008). However, if there is significant variability in performances across domains, then a specific pattern of impairment may be indicated.

2.1.2 Learning

Learning is a main concept in educational psychology. It has been widely documented that individual differences in academic performance can be predicted by mechanisms that influence the rate and depth of learning across many domains. These mechanisms include working memory and speed of information processing (e.g. Ackerman, 1988; Lubinski, 2005). The first step in the cognitive learning process is attention. In order to begin learning, a student must be paying attention to what they are experiencing. Next, the information has to be put into memory in a process called storage. There are three levels of memory through which information must travel to be truly learnt. First, the information is stored in the sensory register. However, it stays only for 20 seconds or up to a minute. Then, the information moves from the sensory register into short-term memory. After rehearsing the information, by repeating it or taking notes or studying it, it moves to the long-term memory. The long-term memory holds information indefinitely and has an unlimited capacity (Diamond, 2016).

Tasks conducive to learning like numerical problem-solving tasks require the coordinated interaction of multiple brain regions (Rosenberg-Lee et al., 2011; Varma and Schwartz, 2008). Moreover, working memory is predominantly engaged during a wide range of numerical problem-solving tasks. Also, numerical problem-solving tasks rely on cognitive control given that efficient cognitive control requires the concerted coordination between multiple brain regions (Menon, 2016). For learning languages, signalling between neurons between the left and right hemispheres is crucial, as well as the connectivity between the brain and speech motor processor (Snell and Richard, 2003). Also, working memory plays a significant role, as well as sustained attention (Porter et al., 2011). For studying grammar and comprehension for example, short-term memory is most demanded (Cooke et al., 2002). For learning creativity-demanding subjects, it was revealed that creative insight depends in part on combinations of existing ideas, concepts, and perceptions that have been stored in the brain over time; i.e.: memory is highly engaged (Runco and Torrance, 2015).

Hence, it can be noted that memory, sustained attention, and coordination between left and right hemispheres play significant roles in performing cognitive tasks conducive to learning. Therefore, the cognitive performance assessment tasks considered for this study were selected so that they focus on these functions particularly. The cognitive performance assessment tasks considered for this study will be discussed in detail in the methodology chapter.

2.2 The Effects of Key Confounders on Human Performance

2.2.1 Indoor Lighting

Light was known to have the ability to synchronize human's endogenous circadian pacemaker with the environment and has been previously described as an agent in improving cognitive performance. For instance, in a study by Van Dijk et al. (2001), light was associated with the circadian rhythm and the quality of sleep and thus cognitive performance as a consequence. A stable alignment of the circadian sleep–wake rhythm and sufficient sleep are essential for proper cognitive functioning. If sleep and wakefulness occur out of phase with the internal biological time, several cognitive functions such as learning are impaired (Wright et al., 2002).

Moreover, the intensity of artificial lighting has been shown to have a range of effects on occupants' mood and their ability to concentrate. Dynamical lighting systems with variations in illumination and colour temperature are proposed to benefit productivity and health (van Bommel, 2006; Hoffmann et al., 2008). For instance, Suk and Choi (2016) examined the effect of different artificial lighting's colour on cognitive performance. The intensities of LED lights of 3500 K (yellow colour), 5000 K (natural colour), and 6500 K (crisper white/blue colour) were investigated and standard fluorescent lights was used as a control. It was found that the 6500 K condition (crisper white/blue colour) led to stimulation of higher alertness states and the greatest enhancement of academic performance, following the predictions of the so-called 'Yerkes-Dodson Law', which postulates that there is a curvilinear relationship between mental arousal and performance. It was concluded that, people tend to perform best at certain intermediate levels of mental arousal (in this case, under the 6500 K lighting condition) and worse when these levels are either too low or too high.

2.4.2 Day Time (Morning/Afternoon Effects)

It was believed that cognitive performance and alertness are two determinants for work efficiency, varying throughout the day and depending on bright light, which varies from morning time to afternoon for instance (Leichtfried et al., 2015). It was suggested that brief exposure to bright light in the morning hours can improve subjective measures of mood and alertness. According to Lockley et al. (2006), the extent of the physiological changes depends on whether the light exposure occurs before or after the midday hours. However, in a study by Smolders and Kortab (2017) which investigated the effect of correlated colour temperature (CCT) on alertness and vitality in the morning vs. afternoon, it was revealed neither clear beneficial effects of exposure to white light with a higher colour temperature on mental wellbeing and performance, nor activating effects on physiological arousal during regular daytime hours.

The main difference between performance during daytime and afternoon could be explained by the effect of different wavelengths of light during daytime relative to afternoon. It was proven that daytime absence of short wavelength light to phase delay sleep onset (Figueiro and Rea, 2010). However, light of long wavelength was found to have stronger effects on brain activity associated with alertness as compared to short wavelength in the afternoon hours (Sahin and Figueiro, 2013).

2.4.3 Physical Activity

Multiple cross-sectional studies have demonstrated that physical activity is associated with improved cognitive function (Smith et al., 2013). It was suggested by a number of studies that the beneficial effects of physical activity on academic performance are due to improved cognitive functions, such as attention, concentration and working memory (e.g. Trudeau and Shephard, 2008; Tomporowski et al., 2008; Bailey et al., 2009). Results from some studies suggested that aerobic exercise may improve complex processing abilities but may have little impact on simple reaction time measures (Kramer et al., 1999). Higher levels of self-reported physical activity have also been associated with quicker reaction time among community-dwelling volunteers (Hillman et al., 2006). Moreover, scientific evidence based on neuroimaging approaches over the last decade has demonstrated that the efficacy of physical activity improves cognitive health across the human lifespan.

A growing body of evidence supports the influence of exercise on vitality and function of the central nervous system and promoting resistance against neurological disorders. According to these studies, exercise has the extraordinary capacity to enhance mental health. It was discussed that aerobic fitness enhances functional aspects of higher order regions involved in the control of cognition. More active or fitter individuals are capable of allocating greater attentional resources to the environment and are able to process information more quickly. These data were suggestive of the fact that aerobic fitness enhances cognitive strategies enabling subjects to respond effectively to an imposed challenge with a better yield on task performance (Gomez-Pinilla and Hillman, 2013). Therefore, participants' general aerobic exercise trend and fitness level will be considered when analysing the data to minimise the effects of the confounding factors.

2.4.3 Sleeping Hours

Sleep is important for human physical, intellectual and emotional health (Neinstein et al. 2008). According to Curcio et al. (2006), sleep is an active, repetitive and reversible behaviour serving several different functions, such as repair and growth, learning or memory consolidation, and restorative processes. Therefore, it was concluded that sleep deprivation would result in impairment of psychological and neurocognitive functions (Curcio et al., 2006). It was suggested that sleep deprivation especially impairs cognitive performances that depend on the prefrontal cortex. This includes higher functions, such as language, executive functions, divergent thinking, and creativity (Horne, 1993). Numerous studies have shown that short sleep, long sleep and sleep problems are associated with poorer cognitive function (e.g. Kronholm et al., 2009; Nebes et al., 2009; Xu L et al., 2011).

The need for sleep varies considerably between individuals (Shneerson, 2000). The average sleep length is between 7 and 9 hours per day (Kripke et al., 2002; Carskadon and Dement, 2005; Kronholm et al., 2006). A study by Trockel et al. (2000) to evaluate health-related variables on academic performance found that sleep had the largest effect on semester GPA compared to the other health-related variables such as exercise, nutrition intake, mental health, stress and time management. There was a significant relationship between sleep habits and higher GPA ($p<0.001$). Long sleepers (sleep 7 hours or more hours) were found to achieve higher GPAs than short sleepers (sleep 6 or fewer hours) (Kelly et al., 2001). It was indicated that the lower GPAs of the short sleepers may have been the result of a decreased ability to focus on education-related activities. Therefore, the research methodology adopted for this study was informed of the fact that sleeping for 7 hours or more on the night before participation would be mandatory and that participants with general sleeping deprivations would not be eligible for participation.

2.4.4 Caffeine

Human cognitive performance is widely perceived to be enhanced by caffeine at usual dietary doses. According to Nehlig (2010), caffeine was found to facilitate learning in tasks in which information is presented passively but has no effect on tasks in which material is learnt intentionally. Caffeine also facilitates performance in tasks involving working memory to a limited extent, but hinders performance in tasks that heavily depend on working memory, and caffeine appears to improve memory performance under suboptimal alertness conditions. Moreover, depending on the dosage, baseline arousal level can determine the improvement or impairment of psychomotor performance (Robeline and Rogers, 1998). It was indicated that the half-life of caffeine (time taken for the body to eliminate one-half of the caffeine) in healthy adults is approximately five hours (Pfeifer and Notari, 1988), and that the typical overnight abstinence of 10–14 hours results in substantial elimination of systemic caffeine by early morning (Lelo et al., 1986).

Accordingly, this has informed the research design for achieving a methodological convenience out of naturally occurring overnight abstinence by simply asking the participants to forgo their usual morning caffeine beverage prior to testing. It was indicated that extending the abstinence period substantially beyond the traditional period of overnight or 24 hours removes the confounding effect on results as a result of withdrawal effects prior to administration of caffeine. Studies that have employed designs incorporating long-term withdrawal have yielded consistent evidence of caffeine having little or no net benefit for cognitive performance for adults (James, 1998; James et al., 2005; Judelson et al., 2005; Rogers et al., 2013) and children (Heatherley et al., 2006).

2.4.5 Anxiety

Anxiety has been defined as a ‘tense, unsettling anticipation of a threatening but vague event, a feeling of uneasy suspense (Rachman, 2004). It is noteworthy to mention that anxiety is a reaction to stress (Goette et al., 2015). This negative feeling involves the interaction between vigilance, attention, perception, reasoning, and memory, which are central in cognitive processing (Rachman, 2004). It was suggested that stress in humans seems to have different effects on the various stages of memory (the memory process: encoding, consolidation, and retrieval) and can be enhanced by emotional arousal. According to Derakshan and Eysenck (2009 a, b), anxiety impairs the efficiency of attentional control but it has less of an effect on performance effectiveness.

Results of studies on the effects of anxiety and cognitive performance in general reveal that high-anxious individuals’ performances decrease as the task complexity increases (e.g. Darke, 1988; Richards et al., 2000; Ashcraft and Kirk, 2001; Derakshan et al., 2009 a, b). This was explained by the suggestion that difficult tasks put higher demands on the central executive, and, to overcome the negative effects of anxiety on performance, the high-anxious individuals need to use extra processing resources of the central executive in order to achieve a satisfactory performance (Eysenck, et al., 2007). Also, there have been a great number of studies that have found that the high-anxious individuals are more prone to distraction or more affected by task-irrelevant stimuli than the low-anxious (e.g. Bar-Haim et al, 2007; Cisler and Koster, 2010). Moreover, there is a great number of studies that found that anxiety also increased distractibility in tasks that did not involve task switching (e.g. Friedman and Miyake, 2004). Furthermore, Miguel (2010) found that anxiety impairs dual-task coordination. Accordingly, it could be concluded that it is well-documented that anxiety impairs cognitive performance from different aspects and thus to achieve a methodological convenience while also avoiding the occurrence of confounding effects on the results, it was decided that the participants experiencing anxiety or being stressed for personal reasons would not be eligible for participation.

2.4.6 Noise

A number of studies have already documented the adverse effects of noise, using 'real-life' noise stimuli (e.g. multiple conversations, traffic noise) on certain cognitive functions, namely: attention, working memory and episodic recall in healthy adults (e.g. Wright et al., 2014). Furthermore, it was found that in healthy adults environmental noise adversely affects many cognitive domains. Noise is considered as a pervasive and influential source of stress. Although noise has diffuse effects, which are shared with many other chronic forms of stress, it also exerts its own specific influences on various forms of cognitive and motor response. Noise may affect performance by impairing information processing or, alternatively, by inducing shifts in strategic response. There is evidence of both forms of stress effect. Specifically, noise increases levels of general alertness/activation and attentional selectivity. It does not influence performance speed, but it reduces performance accuracy and short-term/working memory performance (Szalma and Hancock, 2011).

Another mechanism that possibly underpins noise effects on performance is the degradation of working memory (Hockey, 1986). An alternative explanation underlying noise effects is based on the fact that noise was found to increase the mental workload imposed by a given task environment, thereby reducing the cognitive resources available for allocation to task performance (Becker et al., 1995). Conversations are most often thought of as being the most annoying noise source indoors, and phone ringtones can also be a significant annoyance (Sundstrom et al., 1994). According to the Building Bulletin 93 in the United Kingdom for the regulation of noise levels in classrooms, the upper limit for the indoor ambient noise level for lecture rooms, classrooms, general teaching areas, seminar rooms, tutorial rooms, and language laboratories shall not exceed 35 $L_{Aeq,30mins}$ dB in the newly built educational buildings and 40 $L_{Aeq,30mins}$ dB in the refurbished ones. For study rooms (individual study, withdrawal, remedial work, teacher preparation) and libraries, the upper limit for the indoor ambient noise level was set to be 40 $L_{Aeq,30mins}$ dB in the newly built buildings and 45 $L_{Aeq,30mins}$ dB in the refurbished ones (Acoustic design of schools: performance standards Building Bulletin 93, 2015).

2.3 The Effects of Indoor CO_2 Levels (as an Indicator for Ventilation), Indoor Temperatures, and Thermal Comfort Sensations on Human Performance

People spend about 80–90% of their time indoors. Therefore, there is a continuous and dynamic interaction between people and their surroundings that produces physiological and psychological strain on them, which consequently leads to changes in health, well-being and performance (Parsons, 2000; Clements-Croome, 2006; Lan et al., 2010; Lieble et al., 2012). With specific regard to educational buildings, among the main responsibilities of any educational institution is its responsibility to foster cognitive development. Hence, one of the main concerns of education is how to make learning more effective than it really is.

Low ventilation rates were found to be responsible for the increased exposure to indoor air pollutants (primarily CO_2 concentration levels), which is assumed to be the primary reason for adverse effects on occupant health and performance. CO_2 concentration is mostly used to indicate indoor air pollution when considering IAQ since it is the main respiratory waste product from humans. CO_2 is seen as a harmless gas; however, it can contribute directly to increased tiredness and a loss of concentration (Kajtar et al., 2012). It was suggested that exposures to pure CO_2 even at levels typically occurring indoors can potentially have negative effects on some health symptoms and on some types of cognitive performance.

There is little data obtained from university buildings to date; however, studies of IAQ in schools have repeatedly found that CO_2 levels are in excess of the ASHRAE threshold of 1000 ppm (e.g.: Dorizas et al., 2015a; Haverinen-Shaughnessy et al., 2011; Muscatiello et al., 2015; Shendell et al., 2004; Toftum et al., 2015). Moreover, a number of studies on indoor environments in school buildings provided evidence that there is a correlation between students' health and work performance with the CO_2 concentrations in the classrooms (e.g. Daisey et al., 2003; Lee and Chang, 1999; Lugg and Batty, 1999; Myhrvold and Olsen, 1997). It was also indicated that CO_2 levels, which exceed the recommended level of 1000 ppm, can cause a reduction in the students' performance assessed by short-term computer-based tests, whereas good air quality in classrooms can enhance students' concentration and also teachers' productivity (Myhrvold et al., 1996; Wargocki et al., 2005).

Further, low ventilation rates in classrooms have also been associated with lowered attention and ability to concentrate (Bako-Baro et al., 2012), and increased absenteeism from class (Shendell et al., 2004). Myhrvold and Olesen (1997) conducted a field study in 35 Norwegian classrooms to determine the students' concentration by measuring their reaction times with different ventilation rates. They found that by increasing the ventilation rate from 4 l/s per person to 12 l/s per person, the students' reaction times were 5.4% less (i.e. faster). In three learning performance studies conducted by Ito et al. (2006) and Murakami et al. (2006) in Japanese classrooms using three subject groups (Theoretical, Memorization I and Memorization II), the researchers found that by increasing the ventilation rate from 0.6 to 5 l/s per person, the learning performance was improved by 6.6%. Wargocki and Wyon (2006; 2007a, b) investigated the impact of an increasing ventilation rate on the performance of 10-year-old school children using parallel performance on tasks representing eight different types of schoolwork, from reading to mathematics. The authors found that by increasing the ventilation rate from 5 l/s per person to 10 l/s per person, the schoolwork performance improved by 15%.

In two UK classrooms, it was found that the pupils' work rate increased by 7% in the mathematical tests of addition and subtraction as a result of increasing the supplied fresh air from 0.3–5 l/s per person to 13–16 l/s per person (Wargocki and Wyon, 2007 a, b). Mendell and Heath (2005) concluded that there is suggestive evidence for an association between ventilation rates and the two prerequisites of an efficient learning process, namely attention and performance. Haverinen-Shaughnessy et al. (2011) also showed a significant positive association between ventilation rates in classrooms and academic performance of students. Wargocki and Wyon (2013 a, b) performed three experiments in which they adjusted the existing outdoor air supply of the mechanical ventilation of schools by altering the fan capacity. They aimed at increasing ventilation rates from ~3 l/s per person to 10 l/s per person. They found a significant improvement in the numerical tasks when increasing the ventilation rates and suggested that doubling the outdoor air supply rate from ~3 l/s per person to 10 l/s per person would improve the performance of schoolwork in terms of speed by about 14%.

With regard to the studies which investigated the direct effects of CO_2, Satish et al. (2012) conducted a laboratory experiment on the effects of CO_2 levels at normally occurring indoor concentrations on human decision making. Their study suggested that at 1000 ppm and 2500 ppm, a significant reduction in decision-making performance occurred compared to CO_2 concentrations of 600 ppm, which pointed to the importance of considering CO_2 itself as an air pollutant. Allen et al. (2015) obtained similar results pertaining to performance in a decision-making test, as in the study by Satish et al. (2012). A study by Kajtar and Herczeg (2012) showed that performance in proofreading was negatively affected when ten subjects were exposed for 2–3 hours to elevated levels of CO_2 at 3000 ppm. Coley et al. (2007) found that increased levels of CO_2 from a mean of 690 ppm to a mean of 2909 ppm led to a significant reduction in attention by about 5%. It could be noted that very limited studies have investigated the effect of CO_2 as a pollutant, even though no significant results were obtained, mostly because of the small sample size. Hence, these could be considered as studies giving mainly indications rather than drawing conclusions; therefore, more investigation is needed.

Moreover, recent experiments showed that inadequate ventilation rates in classrooms can result in a high prevalence of acute health symptoms, better known as building-related symptoms or Sick Building Syndrome (SBS) symptoms (e.g.: Daisey et al., 2003; Norbäck and Nordström, 2008; Salleh et al., 2011). Some of the SBS symptoms, particularly headache and dizziness, have been reported to cause a 6.5% decrease in the amount of text typed in the simulated office work, a 2.5% and 3.8% decrease in performance in additional tests, a 3.4% decrease in performance in logical reasoning, a 3.1% decrease in performance in a reaction time test, and a 2% decrease in performance in a code substitution test (Wargocki, 1998). In an experimental study by Menzies et al. (1997), the workers who were provided with individually-controlled ventilation systems reported fewer SBS symptoms and also reported that IAQ at their workstation improved productivity by 11%, compared to a 4% decrease in productivity for the control population of workers. Workers who reported SBS symptoms took longer time to respond in a computerised neurobehavioral test, where the error rates in this test decreased, but non-significantly. In a second computerised neurobehavioral test, workers with symptoms had a 30% higher error rate but response times were unchanged. Average changes from the four performance outcomes yielded a 14%

decrement in performance among those with SBS symptoms (Nunes et al., 1993). The symptoms commonly associated with SBS also characterise the diagnostic criteria for generalised anxiety disorder and panic disorder. Outbreaks of SBS have been known to occur particularly in buildings served by mechanical heating, ventilation, and air-conditioning (HVAC) systems (Redlich et al., 1997), given that inhalation is the main route of exposure to the majority of allergens in indoor air.

In addition, it was revealed that the increases in indoor CO_2 levels are associated with and an increase in absenteeism by 10–20% (Shendell et al., 2004). Sundell et al. (2011) concluded that low ventilation rates are associated with increased absenteeism and more respiratory symptoms in school children, on the basis of their review of five school studies. Simons et al. (2010) and Mendell et al. (2013) agreed that lower ventilation rates are associated with higher absenteeism among children at school. Increased absenteeism is likely to have negative consequences for learning (Shendell et al., 2004; Mendell et al., 2013). Hence, it was noted that scarce data is obtained from studies on adult students. It is of primary importance to investigate the effects on adult students since it was indicated that learning experience is driven by the learners when they are adult students; however, learning experience for children is driven by the teacher.

It could be implied accordingly that adult learning is more related to knowledge acquisition and the desire to learn, rather than being a radical thought for its time. Hence, the students needed to be self-motivated and encouraged to stay for a significant amount of their time in the classrooms, in which they needed not to feel stressed because of the physical environment or obligated to stay at. This is particularly important especially since it was proven that the science of developmental neuropsychology recognised that more complex thinking executive functions (such as perception of time, abstract understanding of language and selective attention) occur approximately from the age of 9 to 23 years (Gogtay et al. 2004). Therefore, there is an insistent call for investigating the effects on adult students.

In addition to the effects of inadequate ventilation, according to a number of studies, indoor temperatures have been associated with performance. Air temperature is the commonly used indicator of thermal environment in indoor environmental quality (IEQ) and productivity research. It is generally agreed that there should be an optimum temperature or, more precisely, a temperature range for optimum performance. Furthermore, most of the effects documented in productivity studies have demonstrated that the percentage of error increases when temperature increases, with specific regard to the performance in vigilance, reasoning and memory tasks (e.g.: Ma¨kinen et al., 2006; van Orden et al., 1990; Thomas et al., 1989; Shurtleff et al., 1994). In addition, Wargocki and Wyon (2007) suggested that avoiding elevated temperatures in classrooms can improve the performance in schoolwork, referring to the decrease in temperature from 25°C to 20°C which contributed to a statistically significant increase in the speed of the performance of computational tests and two language tests. Later, Wargocki and Wyon (2013) revealed that the percentage of error was significantly reduced in numerical task when temperature was reduced from 25°C to 20°C and concluded that the recommended range of temperature in classrooms is 20 to 22°C and that reducing classroom air temperature by 1°C would improve performance in terms of speed by about 4%.

Moreover, Niemalä et al. (2002) reported a decrement in productivity of call centre workers when the temperature was above 25°C and concluded that higher temperatures in an office environment decrease performance. This is supported by another temperature intervention study, which was carried out in an office building by Toftum et al. (2005). A significant negative effect was observed when room temperature was raised from 20–22°C to 24–26°C on the performance of only the cognitive tasks involved in performing mental arithmetic, not the trivial task of entering the numbers on the keyboard. Furthermore, Seppänen et al. (2003) proposed a relationship, claiming a decrease in performance by 2% per 1°C increase of the temperature in the range between 25 and 32°C, while no effect on performance was observed in the temperature range between 21 and 25°C. A meta-analysis was developed later by Seppänen and Fisk (2006), in which they reanalysed old and new studies (total of 150 assessments of performance from 26 studies), indicating that performance increases with temperatures up to 20–23°C, performance decreases with temperatures above 23–24°C and performance peaked at 21.6°C.

In contrast, Witterseh (2004) investigated the effect of temperature on simulated office work (including multiplication, typing and addition tests), and found that there was no significant effect of temperature on performance from 22°C (at which participants felt thermally neutral) to 25°C (at which participant felt slightly warm discomfort). An earlier study by Lan et al. (2009) investigated the effect of room temperature on performance of neurobehavioral tests in the laboratory. Four temperatures were investigated, namely 19°C, 24°C, 27°C, and 32°C. It was concluded that room temperature affected the performance of neurobehavioral tests differentially, depending on the type of task. The accuracy of most tests peaked at 24°C or at 27°C relative to 19°C and 32°C. Nevertheless, it was indicated that low temperatures are related to decreased performance in manual tasks through the effect on dexterity of hands because of stiffening joints and slow muscular reaction, numbness, and a loss in strength (e.g.: Lan et al., 2009; Seppänen et al., 2003; Parsons, 2000). Hence, it could be implied that the results obtained are confounding and therefore further investigation is needed in the range between 20°C and 25°C.

By focusing on educational studies, it was suggested that moderate changes in class room temperature, even within the comfort zone, can affect student's abilities to perform mental tasks requiring concentration such as addition, multiplication and sentence comprehension, as supported by Zeiler and Boxem (2009). Nevertheless, while the effects of temperature on performance are broadly recognised, it could be noted that the effects on adult students' performance have received much less attention, and the results obtained from studies on school/university work are limited to date.

Moreover, room temperature does not only influence productivity directly, but can also affect performance indirectly through its impact on prevalence of SBS symptoms or satisfaction with air quality (Seppänen et al., 2006). The increased temperatures can also negatively affect the efficiency and effectiveness of thinking psychologically, as well as physiologically (Clements-Croome, 2008). According to Lan et al. (2011a), increased temperatures can result in negative physiological responses such as eye problems for instance and changes in respiratory patterns and oxygen exchange, which may consequently affect health and performance naturally.

In addition, thermal comfort has a great influence on the productivity and satisfaction of indoor building occupants. The interaction between people and the thermal environment is complex and has been the subject of a number of studies. Numerous studies have tried to establish a quantitative relationship between thermal comfort and productivity. For instance, Kosonen and Tan (2004) illustrated how the productivity loss can be minimised through improved thermal comfort design criteria using a predicted mean votes (PMV) index; however, only the effects of feeling too warm on productivity were reported and no relationship between PMV and productivity was created. Lan et al. (2011) suggested that the optimal range of thermal comfort sensation should be from slightly cool (PMV=–0.5) to neutral (PMV=0). With regard to the actual thermal sensation votes (TSVs), not the predicted ones, Jensen et al. (2009) found that the optimum performance occurred when TSV was -1 (cool).

Roelofsen (2001) proposed an optimum range for performance between TSV=–0.5 to TSV=0.1, i.e. from a slightly cool sensation to almost neutral. Most results support that optimum performance is obtained within the comfort zone of TSV between –0.5 and 0.5, i.e. between slightly cool and slightly warm sensations. Tham and Willem (2010) found that higher mental arousal occurred when lower TSVs were obtained. The overall relationships obtained from different studies indicated that a hot environment may lead to a significant deterioration in motivation, while optimum performance can be achieved slightly below neutral. Thermal discomfort (feeling too warm or too cold) was reported to most likely lead to reduced performance. However, the effect of neutral sensation on performance was not fully understood. Some researchers indicated that the most comfortable temperature yielded optimal work performance, while other researchers provided evidence that better performance occurred outside the comfort zone owing to the arousal effect of the environment. For instance, Federspiel et al. (2004) measured the productivity of call centre workers in the United States. They found no significant effect of temperature on productivity in the comfort zone. Overall, it can be noted that scare data is available on the associations between occupants' thermal comfort and performance from the hot climate countries relying on ACs for cooling and ventilation.

In this premise on thermal comfort, human physiological responses to the surrounding thermal environment are a critical point that is worth pointing out. According to Brager and de Dear (1998), human adaptation to the thermal environment, physiological expectation as well as one’s past thermal exposure experience plays a crucial role in man's thermal comfort sensation. With response to a particular environmental factor, such as ambient temperature, the term acclimation may be more appropriate (Bligh and Johnson, 1973). In the context of thermal comfort, human adaptation and/or acclimatisation/acclimation may involve all the processes which people go through to improve the fit between the environment and their requirements (Brager and de Dear, 1998). The adaptive opportunity can be separated into three different categories: physical, physiological and psychological (Nikolopoulou et al., 1999). Hence, optimum indoor temperature is mainly driven by adaptation, which subsumes all physiological mechanisms of acclimatisation. Interestingly enough, in a study by Yamtraipat et al. (2005), it was indicated that acclimatisation to using home ACs can affect thermal comfort sensation considerably. They found that the neutral temperature reported by the group who use ACs at home was lower compared to the group who were not using ACs at home. Therefore, this air-conditioner acclimatisation effect shall not be neglected in this study. To date, this area has not been investigated in relevant research.

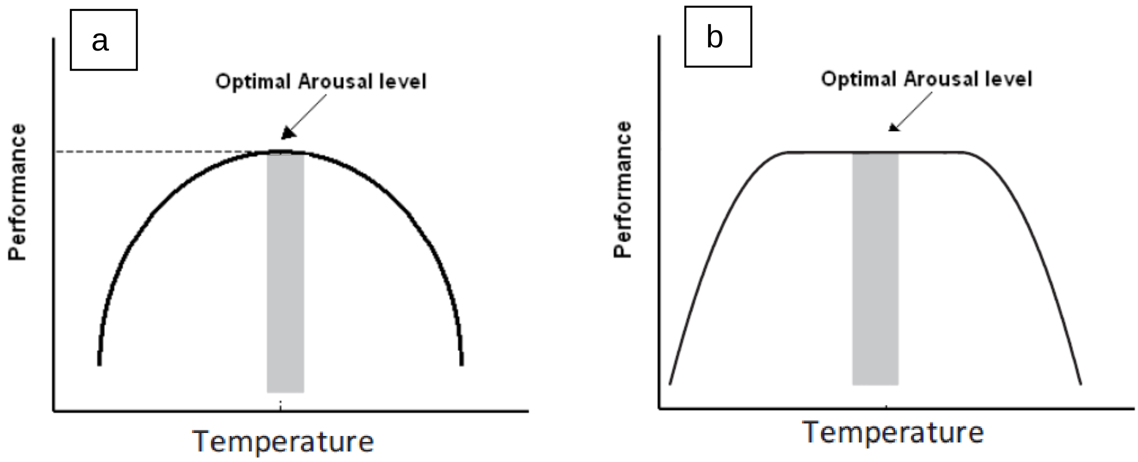
Moreover, adverse effects on productivity were found associated with sick building syndromes (SBS) according to a number of studies (e.g. Raw et al., 1990), where research indicates that SBS symptoms are 30–200 percent more frequent in mechanically ventilated buildings (USEPA, 2007). For instance, SBS leads to an increase in self-reported illness absences and reduced productivity in offices (Wargocki et al., 2000, Brightman, 2005; Singh, 1996). Uncomfortable temperature and humidity, chemical and biological pollution, physical condition, and psychosocial status are some of the factors identified as root causes of SBS (e.g.: Simonson et al., 2002, Wang et al., 2007; WHO, 1983). Symptoms experienced by people with SBS include irritation of the eyes, nose, and throat, headache, cough, wheezing, cognitive disturbances, depression, light sensitivity, gastrointestinal distress and other flu like symptoms (Burge et al., 1987; Mendell and Smith, 1990; Hudnell et al., 1992).

2.4 The Effect of Indoor Temperature on Arousal

Among the cognitive functions that have been thoroughly discussed in the most relevant human performance research in the scope of indoor environmental exposures are the attention/arousal functions. Attention functions differ from the other cognitive functions in that they underlie the activity of the cognitive functions. The efficiency in being able to inhibit distracting stimuli during task performance is heavily dependent on the availability of working memory capacity. Attention helps loading working memory capacity determined by forbidding giving participants a secondary task, and thus improves the ability to ignore distracters and focus on task-relevant targets (de Fockert et al., 2001).

According to Costa et al. (2012), attention functions serve somewhat as command operations for one or more cognitive functions. There are two alternative hypothetical models for the relation between temperature and arousal (presented in Figure 2.1). Figure 2.1(a) describes the arousal model of human performance with an inverted U-shaped curve (Yerkes and Dodson, 1908). The model indicates that optimal task performance occurs at optimal arousal levels at an optimal temperature, and performance is relatively poorer at lower and higher temperatures. An alternative to this model is the maximal adaptability model (presented in Figure 2.1(b)) (Hancock and Vasmatzidis,1998). This model suggests an extended U-shaped curve, showing that mental resources are used to compensate for the stress effects of temperature outside the range of optimal temperature, which allow optimal performance to be maintained in a wider range of temperatures to some point depending on the capability of adaption or actually the tolerance and will collapse beyond this point.

Figure 2.1: (a) Yerkes–Dodson law applied to temperature and performance (Yerkes and Dodson, 1908). (b) The maximal adaptability model (Hancock and Vasmatzidis, 1998). The grey area indicates optimal temperature.



Relevant studies typically evaluated cognitive performance by speed (response time) and/or accuracy (percent errors), e.g. characters typed per unit time, number of completed addition/multiplication units per unit time etc. (e.g. Wargocki et al., 1999, 2000; Bakó-Biró et al., 2004; Witterseh et al., 2004; Lan and Lian, 2009; Lan et al., 2009, 2010). Accuracy and speed are the two distinct aspects of cognitive performance. Accuracy is a measure of the quality of a behaviour. It is another aspect of performance and has been defined as freedom from error in discrete tasks (Drury, 1999). Measures of accuracy may include the number of correct attempts, correct percentages, and/or probability of correct detections (Gawron, 2000).

2.5 The Adaptive Thermal Comfort (ATC) Model and Performance

The Adaptive Thermal Comfort (ATC) theory assumes that thermal comfort can be obtained at higher temperatures by two mechanisms (de Dear and Brager, 2001):

1- By adaptive behaviors such as adjusting clothing, opening windows, or reducing activity level;
2- By becoming habituated to higher temperatures, so that the physiological responses that take place become acceptable. It is assumed that if higher temperature are found acceptable, they will have no negative effects on performance (de Dear et al., 2013; Lyten and Kurves, 2013).

In the context of thermal comfort, human adaptation may involve all the processes which people go through to improve the fit between the environment and their requirements. The adaptive opportunity can be separated into three different categories: physical, physiological and psychological (Nikolopoulou et al., 1999). Human physiological responses to the surrounding thermal environment is regulated by the nervous system automatically which mediates a loop to regulate the physiological thermoregulation, in which an unconscious feedback (acclimatization) occurs in order to directly affect humans' physiological thermoregulation set points (de Dear et al., 1997).

Hancock and Vasmatzidis (1998) suggested that a zone of psychological and physiological adaptability exists, in which people can tolerate thermal stress and within which there will be no effect on cognitive performance. In the study by Lan et al. (2011a) on the effects of thermal discomfort on physiological responses, it was indicated that the physiological responses that occurs when increasing temperatures which may cause thermal discomfort can result in symptoms such as headaches, difficulty in concentrating, and thinking clearly. As a result, these symptoms are expected to have negative direct negative effects on cognitive performance. However, it was suggested that the cognitive performance deficit can be compensated by exerting more efforts. Tanabe et al. (2007) showed that this is only possible for a limited time.

In this regards, brain-imaging studies have provided some reliable evidence with regard to the effect of the thermal environment as a stimulus of the brain in conditions where the thermal environment can cause thermal stress. For instance, Hocking et al. (2001) has showed that exposure to thermal stress conditions cause changes in electrical activity in the brain during cognitive performance in a neural activity, which was believed to cause behavioural arousal by a number of researchers (e.g.: Hull et al., 1965). Therefore, the findings by Pepler and Warner (1968) were not surprising when they showed that thermal conditions providing optimum comfort may not give rise to maximum efficiency. A better explanation was provided by Ramsey and Kwon (1992) who have explained that the type of task as well as the duration of exposure represent a major variable that influences performance, where they have provided an evidence that perceptual motor task decrement under thermal stress is significant compared to simple task performance under the same condition. According to Toftum et al. (2004), if the thermal environment causes sweating or shivering, mental concentration and productivity may decrease. In a discussion by Tham (2004), it was indicated that physiological effects can outweigh the effects of thermal discomfort, and thus it was implied that the underlying mechanisms need to be examined more closely.

It is worth noting that in the adaptive theory, the prime contextual variable is the climate. Climate is an overarching influence on the culture and thermal attitudes of any group of people and on the design of the buildings they inhabit. In relation to the outdoor climate, Humphreys (1978) plotted the indoor comfort temperature against the outdoor monthly mean temperature from a number of surveys conducted world-wide. It was found that the relationship for the free-running buildings was closely linear, however; for heated and cooled buildings the relationship is more complex. de Dear and Brager (1998) later made a division between buildings which are centrally air conditioned and those which are naturally ventilated. They argued that occupants of building which are air-conditioned have different expectations than the occupants of naturally ventilated buildings (de Dear and Brager 1999). The data by de Dear and Brager (1998) and Humphreys (1978) were then re-analysed by Humphreys and Nicol (2000), where comfort temperatures as a function of outdoor temperature for both; free-running buildings, and for buildings with heating and cooling were plotted. Nicol et al. (1999) has highlighted accordingly that although only the outdoor temperature was used to calculate comfort temperatures in the plotted diagrams of this analysis, the comfort temperature is clearly a function of more than that, adding that the clothing insulation also depends on outdoor temperature.

With specific regard to Saudi Arabia, it is still unclearly understood whether this adaptive comfort model applies or not, especially that the variation of insulation values of customs is very limited.

2.6 Building Standards

ASHRAE Standard 62 and its subsequent incarnations as Standard 62.1 (commercial, institutional and high-rise residential) and Standard 62.2 (low-rise residential) have served as the most prominent ventilation standards since the first was published in 1973. The standard recommended ventilation rates of 7.5 l/s to 9 l/s per person to achieve a roughly 80% level of odour acceptability, as judged by individuals entering the room from relatively clean air. The standard recommends a guideline level of maximum 1000 ppm CO_2 for indoor spaces, given that this value of 1000 is a guideline value only and not considered a regulated standard (ASHRAE Standard 62.1-2013). IAQ guidelines from Europe like BMLFUW (2006), UK Department of Education (2006), NO-Folkehelseinstituttet (1996), the German Working Group on Indoor Guidelines of the Federal Environment Agency, and the States Health Authorities agreed that CO_2 can be regarded as harmless if the CO_2 levels are below 1000 ppm. CO_2 can be regarded elevated if between 1000 and 2000 ppm, and hygienically unacceptable if above 2000 ppm (Lahrz et al., 2008). Also the present guidelines for good indoor air quality in classrooms in Europe, EN13779 (2004) and EN15251 (2007), classify IAQ into high, medium, moderate, and low quality that correspond to values of CO_2 concentration levels of 250 ppm, 500 ppm, 800 ppm, and 1200 ppm respectively.

In the UK, CO_2 concentration levels have been chosen as the key performance indicator for the assessment of IAQ and ventilation in schools. Building Bulletin 101: Ventilation for School Buildings (2014) (the UK Regulatory Framework for Schools) refers to proposed performance-based standards limiting the level of CO_2 concentration to 1500 ppm over a full school day from 9:00 AM to 3:30 PM and specifies a minimum ventilation rate of 3 l/s per person in all teaching and learning spaces when they are occupied. Furthermore, the regulations recommend that a ventilation rate of 8 l/s per person should be achievable under the control of occupants, although it may not be required at all times if the occupancy density decreases. From these standards, ASHRAE standards are the most commonly used and they are the ones followed in Saudi Arabia.

With regard to thermal comfort and the ranges of indoor environmental conditions that are acceptable to achieve thermal comfort for occupants, the ASHRAE Standard 55- Thermal Environmental Conditions for Human Occupancy, provides the minimum requirements for acceptable thermal indoor environments as: recommended temperatures of 20.5–25.5°C in classrooms during winter and 24.5–28°C during summer. However, these recommendations are based on the rational and adaptive thermal comfort models, and based on data gathered from the UK, Europe, Africa, Australia, Asia and America (Zomorodian et al., 2016), but not from the Arab Peninsula region and with no specification to the air-conditioned educational buildings that solely rely on air-conditioners for cooling and ventilation.

2.7 Summary

First, the effects of indoor temperatures and ventilation rates on human performance were discussed. On the basis of the studies reviewed, it was found that the results of the studies differ in terms of the magnitude of the effects. Nonetheless, it was generally agreed that low ventilation rates in classrooms have also been associated with lowered attention and ability to concentrate. Moreover, it was revealed that the increase of indoor CO_2 levels in classrooms are associated with deteriorated students' performance. With regard to the effect of temperature on performance, most of the effects documented in productivity studies have demonstrated that the percentage of error increases when temperature increases, with specific regard to the performance in vigilance, reasoning and memory tasks. Nevertheless, it was noted that the studies conducted on adult students are limited compared to the studies conducted on children. Most importantly, the true implication for productivity and performance in air-conditioned buildings located in the hot arid climates remains unknown to date. Also, the majority of the results were linked to office-work performance while scarce data was obtained from real classroom environments.

Moreover, the chapter discussed the effects of thermal comfort on performance, since it is evident that thermal comfort sensations have a great influence on the productivity and satisfaction of indoor building occupants. It was generally concluded that thermal discomfort distracts attention and generates complaints, while warmth lowers arousal, exacerbates SBS symptoms, and has a negative effect on mental work, while optimum performance can be achieved slightly below neutral thermal sensation.

Further, human performance, learning and cognitive performance were discussed in relation to the scope of the study. The influence on human's cognitive performance by age, amount of sleeping hours, diet or coffee, and other parameters were highlighted. The effects of these parameters (confounders) have not been considered in relevant research to date. The following chapter will provide an overview of the research context in order to weave the information together for deriving the methodology and protocol of study.

Chapter 3: Research Context

The previous chapter reviewed the current state of knowledge with regard to the associations of indoor temperatures, ventilation rates, CO_2 levels, and thermal comfort and human cognitive performance. In addition, a clear identification of human performance and learning, as well as the effects of other physical parameters on human performance was provided. This chapter focuses on the contextual factors in Saudi Arabia, which adds to the synthesis of the research. Both IAQ and temperature are of a great concern to the occupants in Saudi Arabia because most people spend almost all of their time indoors to escape from the harsh climatic conditions outdoors. Therefore, Saudi Arabia was chosen for an intervention in this study owing to its hot arid climatic conditions and the total reliance on ACs for ventilation and cooling (and achieving thermal comfort) as a consequence. Also, Saudi Arabia was chosen after attention was paid recently by the government to females' education and thus to educational buildings, consequently no studies have been conducted to date on this premise. The chapter overviews the development of females' education which has occurred recently in Saudi Arabia, as well as the cultural and socio-economic contexts in the country and the climatic context in Jeddah where the intervention was conducted.

3.1 Social and Cultural Context

The Kingdom of Saudi Arabia (KSA), commonly known as Saudi Arabia, was founded in 1932 by King Abdula-Aziz Bin Saud. It is located in southwestern Asia and occupies a huge percentage of the Arabian Peninsula (Ministry of Culture and Information, 2013). The current population of Saudi Arabia is 32,488,183 as of January 25, 2017, according to the latest United Nations estimates, of which 45% are females (World meters, 2017). According to the Central Department of Statistics and Information (2017), over 30% of the population are foreigners. This was due to the shortage in citizen manpower, which has led the government and employers to hire foreign expatriates from various countries. Since the 1970s, a large inflow of foreign workers has entered the country. Therefore, the citizens are ethnically diverse; the majority (90%) is Arab, while the rest (10%) are of Asian and African origins (Alhawsawi, 2013). The population growth rate is 3.5%, and it is among the countries with the fastest growth rates in the world (Onsman, 2010).

At the core of the issue of women's education is the underlying concept of gender segregation (Hamdan, 2005). The segregation of the students (single-sex schooling) is associated with cultural, social and traditional values (Wiseman, 2010).

Dressing options for women are often dictated by societal acceptance (Indraganti, 2010), rather than thermal comfort. In Saudi Arabia, the typical women's clothing attire in the typical hot desert climate generally consists of a light dress or blouse with a skirt or light trousers, women's briefs, ankle-length socks and ladies' shoes and a silk dress on top which is known as *Abaya*. It is worth noting that clothing and cultural habits of clothing are among the influential factors on the preferable indoor temperature for thermal comfort (Nicol,1993).

3.2 Climate and Use of Air Conditioners

The climatic context plays the primary role in choosing Saudi Arabia for this study. This research was conducted in Jeddah, the second largest population in Saudi Arabia after the capital Riyadh. Jeddah is unlike other Saudi Arabian cities, since it retains its warm temperature even in winter. The average temperature is ~37°C throughout the year, while being ~2°C higher during July and August (Climate Data for Saudi Arabia). This has consequently led to the total reliance of occupants on ACs not only for cooling and achieving thermal comfort, but also for ventilation. Furthermore, the climate is expected to become even harsher by the middle of this century for the whole region, relative to the 1990s. An increase in temperature by ~2.5°C is estimated according to regional climate model projections of the average temperature changes (°C) across the Gulf region (Alpert et al., 2008).

The total reliance on ACs for cooling and achieving thermal comfort is believed to have significant effects on occupants' perceptions of the temperature of comfort. Owing to Brager and de Dear (1998), human adaptation to the thermal environment is affected by the physiological expectation as well as one's past thermal exposure experience. Most importantly, the perception of optimum indoor temperature is mainly driven by adaptation, which subsumes all physiological mechanisms of acclimatisation. This is in addition to all behavioural and psychological processes, which building occupants undergo in order to improve the "fit" of the indoor climate to their personal or collective requirements (Brager and de Dear, 1998).

In addition, Yamtraipat et al. (2005) indicated that acclimatisation to using home ACs could affect thermal comfort sensation considerably. According to survey results of a study which gathered data from commercial and residential sectors in five main cities in Saudi Arabia, ACs operate from January to December, where many houses keep ACs running 24 hours. It was indicated accordingly that setting ACs' temperature is often kept excessively lower than the 'comfortable sensible' temperature (Ministry of Water and Electricity (MOWE) Kingdom of Saudi Arabia, 2009). Bligh and Johnson (1973) suggested that repeated exposure to low ambient temperature can result in the diminishing of humans' physiological responses, defined as "habituation to the cold". Therefore, habituation, acclimation and/or adaptation to the ACs' temperature at home plays a significant role in this study, owing to the possible effects that are expected to be reflected on participants' thermal sensations and thus on their cognitive performance.

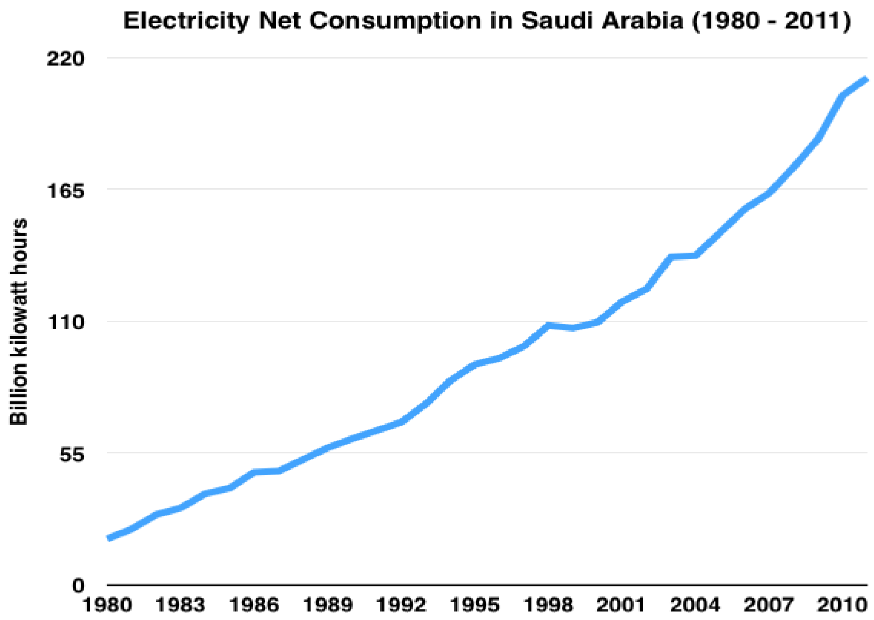
Furthermore, in a sense, acclimation to the ambient thermal environment is extended to the demand of energy required to run the buildings in order to achieve the desired thermal satisfaction. According to a number of studies, only 1°C rise in set air-conditioner temperature could significantly reduce energy consumption by ~6% (e.g. Tham,1993; Yang and Su, 1997; Yamtraipat et al., 2004). With particular regard to the harsh climatic conditions in the Arabian Peninsula, a study which was conducted in Kuwait by Al-Ajmi et al. (2009) concluded that increasing the thermostat temperature by 1°C could save about 10% of space cooling energy, as supported by Sekhar et al. (2002) and Cena and de Dear (2001).

Moreover, the total reliance on ACs for ventilation and cooling can have significant health implications. It was proved that disease transmission in air-conditioned buildings that occurs via inhalation of airborne infectious aerosols (small particles produced by coughing and sneezing that contain viruses) is easier, relative to naturally ventilated buildings (Aliabadi, 2011). In a study by Al-Mijalli (2016) in conducted in Riyadh, Saudi Arabia, in which 252 samples of indoor air and air conditioners of 25 schools were collected. It was found that the highest level of bacterial contamination was detected in schools' classrooms, and particularly during lessons (due to overcrowding). According to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 2000), the health effects caused by microorganisms that are in indoor environments with air conditioning systems can be infective or immunological. Diriba et al. (2014) revealed that lack of cleaning and checking out of the heating, ventilation and air conditioning systems (HVAC) may allow microbial growth, which causes rhinitis, bronchitis, pharyngitis, pneumonia, conjunctivitis and keratitis in the users.

3.3 Socio-economic Context

Saudi Arabia is an oil dependent country, as it owns important oil and gas resources. Over the recent decades, Saudi Arabia has enjoyed a rapid economic growth, which has led to a high per capita income. It has become the economically richest country in the Middle East (Ministry of Finance, 2014). Currently, Saudi Arabia has the largest proven petroleum reserves in the world (about 25% of the world reserves). Because of the massive revenue coming from oil, the country has developed rapidly and has become one of the leading economic and political powers in the region (Ministry of Finance, 2014). Nevertheless, an increased domestic oil consumption has occurred owing to this economic growth (Figure 3.1). Because of the strong economic, and industrial growth, which is paralleled by high population growth, electricity consumption has increased significantly since 1970 (Alkhathlan and Javid, 2013).

Figure 3.1: The trend of electricity consumption in Saudi Arabia (1980–2010) (Duffy, 2014).



Oil prices are extremely low in Saudi Arabia (Alkhathlan and Javid, 2013), which can explain why Saudi Arabia's energy consumption is much higher than in the advanced industrialised countries, where fifty-one percent of energy is used for air-conditioning operation (Saudi Arabia energy efficiency report).

3.4 Overview of the Education System in Saudi Arabia

The education system in Saudi Arabia has transformed immensely since its inception in 1925. Before that date, education was most commonly utilised in mosques in which students were taught to write and read Arabic to recite the holy Qur'an (Al-Liheibi, 2008; Alsharif, 2011). However, the education system as it stands today can be attributed to the Directorate of Education, which established a formal system in 1925 (Alsharif, 2011).

The number of students increased significantly from 536,000 in 1970 to 5,274,205 in 2013 (Ministry of Education, 2014; Oyaid, 2009). Currently, there are 25 governmental and eight private universities in Saudi Arabia (Ministry of Higher Education, 2014). The Saudi Arabian higher education system is quite young; about 65% of the government universities were established in the last 15 years (Alrashidi and Phan, 2015). Therefore, it can be noted that the government invests heavily in education, which reflects the government's awareness of the importance of education to sustain the country's development. According to Bashehab and Buddhapriya (2013), education is the cornerstone of building a knowledge-based economy, which will support sustainable development and economic growth.

However, at the university level, the field of education for women is still limited, as the specialisations do not correspond to the needs of the labour market. For instance, the enrolment of women in the fields of science and technology is low, and the fields of engineering and agriculture remain predominantly male territory. To date, female students are not admitted to the college of engineering, and limited seats are available to them at the college of medicine and college of science for instance (Ministry of Higher Education, Statistical

Book, 2006-2007). Therefore, after the recent call for gender equality, more fields of specialisation at universities are expected to admit females during the coming years, which will lead to the increase in female enrolments at the university level and thus an expansion in universities' and/or colleges' building stock is expected to occur over the coming few years.

The school week in Saudi Arabia is five days long, from Sunday to Thursday, with Friday and Saturday as the weekend. The academic year is the same across the country for primary, intermediate and secondary schools, and also for the university level. The year is divided into two terms, each of which lasts 18 weeks. The average duration of classes is 45 minutes (Alrashidi and Phan, 2015).

3.5 Summary

In this chapter, the research context was described in terms of the climatic context, educational infrastructure, socio-economic and cultural aspects. Saudi Arabia is home to some of the highest summer temperatures ever recorded on earth, besides experiencing extremely arid climates. It is also the largest oil reservoir on earth. As a result of the wealth in the country, ACs have become cheap and affordable and thus became the main mode for ventilation and cooling to achieve thermal comfort. Most importantly, the severity of the harsh climatic conditions outdoors in Saudi Arabia and the complete reliance on air conditioners indoors has created the so-called 'AC acclimatisation effect'. The possible implications for the induced AC acclimation effect will be considered in the methodology proposed and data analysis protocol, wherein lies the novelty of this research since the acclimatisation effect in this scope of study has not been investigated in relevant studies, and the effect it may have on productivity remains unclear to date.

Moreover, the socio-economic factors have influenced occupants' behaviours of using ACs; as energy has become cheap and affordable, the Saudis have been using ACs heavily, and set the temperatures at lower temperatures than are 'comfortable sensible temperatures' (Ministry of Water and Electricity

(MOWE) Kingdom of Saudi Arabia, 2009). This is in addition to the limitation of ACs' temperature management awareness, along with the absence of cost-benefit calculations pertaining to building design and operation in the country. Furthermore, the clothing layers worn by women in Saudi Arabia and the black-coloured traditional dress known as 'Abaya' influenced by cultural issues is another important aspect which is considered in the study, together with the AC acclimation effect, in terms of the possible effects on thermal comfort and its association with cognitive performance.

In addition, the government recently started to invest heavily in education, which reflects the government's awareness of the importance of education to sustain the country's development, as the future of the country cannot solely depend on oil resources. This has led to a significant increase in school and university enrolment, especially for women. The country is now seeking to promote gender equality and to empower women's education and eliminate gender disparity at all levels of education. Therefore, a huge development in women's universities and/or colleges is expected to happen during the coming years not only because of the insistent need to promote gender equality in education in Saudi Arabia, but also because of the need to admit female students to study the scientific fields that are currently admitted only to men. Accordingly, a female university has been selected as a case study for the intervention.

With these factors in mind, the next chapter will discuss the methodological approach proposed for the study.

Chapter 4: Methodology

After reviewing the key concepts forming this research in the previous chapters, this chapter describes the methods proposed for the study. First, the protocol of the study will be discussed with a clear identification of the selected exposure conditions. Following that, the case study building will be described. Afterwards, human participation, sample size and the protocol of recruitment will be discussed. The physical monitoring protocol and the equipment used, as well as the collection of subjective responses from the participants, will be discussed afterwards. This will be followed by the cognitive performance assessment protocol, and assessment tool used. Following this, the data analysis procedures will be discussed and, finally, the ethical approval which was obtained prior to the study will be provided. The proposed methodology will be applied first in a pilot study prior to the intervention to verify the methods proposed and thus apply modifications when needed accordingly for the bigger scale intervention study. The pilot study will be discussed in the following chapter with a presentation of the results obtained and lessons learnt for application to the intervention.

4.1 Experimental Design

An experimental approach was adopted in this study via an intervention study in a selected female university building. The experiments were performed using a blind cross-over design with repeated-measures, i.e. the comparisons between conditions were always within-subject comparisons, to eliminate any bias due to individual differences in the ability to perform schoolwork. The intervention study started in September 2012 and lasted for almost 12 months, exclusive of semester breaks and examination periods. An overview of the case study building and selection criteria are described in details in section 4.2.

4.1.1 Gathering Information about the Mean Set Classroom Temperature in Adult Female University Buildings and CO_2 levels

It is worth mentioning that, prior to the intervention, and also prior to the pilot study, a brief questionnaire was disseminated on the educational buildings in Jeddah for adult females, seeking information about the mean classroom temperature, and thus the baseline temperature of exposure during the intervention was defined. The survey was disseminated to secondary schools, in addition to universities, since only seven universities exist in Jeddah. Only one question was asked about the set AC temperature in classrooms. Also, a clarification was made, either the reported temperature is set constantly throughout the academic year or varies with the seasons (sample is provided in Appendix A).

With regard to the baseline CO_2 levels in classrooms in the educational buildings in Jeddah for adult females, due to practicality reasons and time and money constraints, it was not possible to gather this information from the educational buildings in Jeddah. Nevertheless, 25 classrooms in the case study building were monitored prior to the intervention and prior to the pilot study. Based on the information gathered, the baseline CO_2 levels were decided.

After data were collected from the questionnaires, which lasted for three weeks, a pilot study was conducted to examine the feasibility of adopting the proposed methodological approach and to test the tools of assessment. In addition, the pilot study was conducted to find the baseline CO_2 levels that could be set during the intervention. Moreover, on the basis of real experimentation during the pilot study as well as the observations and feedback from the participants, modifications to the proposed methodology were applied. Next chapter will discuss the pilot study in details.

4.1.2 Objective Measurements

Objective measurements of the physical environment were collected from the selected classrooms in which the intervention took place; namely, air temperature, air velocity, relative humidity, mean radiant temperature, CO_2 concentration levels, noise levels and lighting intensity. In parallel, subjective measurements were collected from the participants by distributing questionnaire forms primarily seeking information about their thermal perception during the exposure conditions. This was in addition to collecting sociodemographic data about the participants, and also gathering information related to the confounding variables which were found to be most likely associated with either cognitive performance or thermal comfort perceptions including age, ethnic background, clothing layers worn, etc. A sample of the questionnaire used in the intervention study, as well as the pilot study, is provided in Appendix B.

With regard to the exposure conditions, only temperature and CO_2 concentration levels were the independent variables which were manipulated, while the other environmental physical parameters were kept within constant ranges during the exposure conditions (namely, sound levels, lighting intensity, and relative humidity).

The CO_2 levels that were aimed at were 600 ppm, 1000 ppm, and 2000 ppm, preliminary at the pilot study. Accordingly, if these values were achieved successfully, they would be intended for the intervention study. CO_2 levels of 1000 ppm represented the reference according to the existing guidelines for acceptable IAQ, defined by the ASHRAE in schools which recommend a minimum classroom ventilation rate of 5 l/sec per person to keep indoor CO_2 concentrations at or below 1000 ppm (ASHRAE, 2016). CO_2 levels of 600 ppm were selected as the baseline condition since a number of studies have referred to the significant impairment of decision-making skills and cognitive performance at elevated CO_2 concentrations compared to 600 ppm (e.g. Satish et al., 2012). Experimentation was needed to find out the maximum levels of CO_2 that could be achieved after modulating the dampers using the building management system (BMS). This was to be discovered during the pilot study before the intervention.

For achieving the CO_2 levels within the intended ranges of 600 ppm and 1000 ppm at the times of experimental exposures, the BMS was used by modulating the fresh air dampers, exhaust dampers, and return dampers together to reach the desired CO_2 set points required. Nonetheless, for achieving CO_2 levels within ranges of 2000 ppm, the damper of the fresh air was shut by the BMS, thus putting the command of the dampers in manual mode, which caused the dampers to no longer be controlled by the BMS. However, after experimentation during the pilot study, the maximum CO_2 levels reached were 1800 ppm.

With regard to the indoor temperatures selected for the study, temperatures of 20°C, 23°C and 25°C were aimed at. The temperature of 20°C was selected, since it was found to be the most common temperature set in more than 75% of the educational buildings surveyed prior to the intervention study (based on information gathered from 338 secondary schools out of the total number of ~450 schools approached, and all the university buildings surveyed). A temperature of 25°C was selected, since, according to the evidence cited in the literature, the majority of studies have agreed that performance decrement is most likely to occur at temperatures below 20°C and above 25°C. Higher temperatures than 25°C could have been selected for investigated as well; however, from a practical point of view, a maximum of three conditions was manageable in terms of the fieldwork time schedule and also for minimising the carryover effect, which is the main disadvantage of within-subjects comparisons. The temperature of 23°C was selected since it lies in between. These temperatures were set and controlled in the selected classrooms at the times of experimental exposures via the BMS, since there were no thermostat controls in the classrooms in the case study building.

4.1.3 Exposure Conditions

Table 4.1.3: A 3 × 3 factorial design was proposed for the exposure conditions, with independent variables temperature and CO_2 levels as follows:

	CO_2: 600 ppm	**CO_2: 1000 ppm**	**CO_2: 1800 ppm**
T1: 20°C	Condition 1: T= 20°C*CO_2 = 600 ppm	Condition 2: T= 20°C*CO_2 = 1000 ppm	Condition 3: T= 20°C*CO_2 = 1800 ppm
T2: 23°C	Condition 4: T= 23°C*CO_2 = 600 ppm	Condition 5: T= 23°C*CO_2 = 1000 ppm	Condition 6: T= 23°C*CO_2 = 1800 ppm
T3: 25°C	Condition 7: T= 25°C*CO_2 = 600 ppm	Condition 8: T= 25°C*CO_2 = 1000 ppm	Condition 9: T= 25°C*CO_2 = 1800 ppm

The participants were exposed to the different exposure conditions on the same weekday to avoid any influence of weekday on the within-subject difference between conditions. Also, the participants were exposed to the different exposure conditions on the same day time to avoid any influence of day time on the cognitive performance as discussed in the literature chapter.

Nevertheless, exposures took place away from intervals directly before lunchtime to avoid the likeliness of hunger, which was found to lower the blood flow rate (Klabunde, 2007) and thus contributing to the sensation of being cold (e.g. Shaw, 2016) regardless of the ambient temperature. The exposure conditions were introduced to the participants using a blind intervention approach. Each exposure condition lasted for ~5 weeks, which covered exposure of all participants.

On a day prior to the first exposure, the participants attended a practice session. Participants were instructed to forgo their morning coffee on the days of the experimental exposures, and not to drink sodas, energy drinks, and avoid eating chocolate. In addition, it was suggested that minimising caffeinated beverages is favoured for the 5 to 7 days prior to participation. According to James and Rogers (2005), it was indicated that a period of several days to one week is sufficient to remove caffeine withdrawal effects. Moreover, weight loss pills were instructed not to be consumed by the participants prior to participation for 5 to 7 days, since they are among the medications which contain caffeine. Participants were also instructed to avoid intense physical activity for at least 12 hours prior to participation and to have adequate amounts of sleep during the nights before participation of not less than 7 hours. No restrictions were made on clothing; participants were allowed to wear their typical clothes during the experimental exposures.

4.2 The Case Study Building

The building was selected because it represents the typical college buildings' architectural style and also has the BMS used since the early 90s for HVAC systems, which is the central CAV ventilation system (supplying constant air volume). This ventilation system was required for the purpose of the study to manipulate temperature and CO_2 levels as required. The two classrooms were almost identical in shape and size. It has also been locally recognised in the stock of higher educational buildings in the kingdom. Educational buildings in Jeddah are generally built with concrete and brick walls with no or poor insulation. The selection criterion of the case study building was also set according to the willingness of the organisation to collaborate.

The building has a "T" shape, with the T leg facing south, functioning as an auditorium. The head of the T is divided into two wings, which are composed mostly of classrooms and faculty offices. The central part contains the main entrance and a double-height circular shaped atrium, which is covered by a geodesic dome. The mechanical rooms are located on the ground floor. Driveways and the parking area are located at the north end of the building (Figure 4.1). The building is a reinforced concrete structure comprising 53 classrooms and has around 2,000 students enrolled aged 15–23. The building is a typical example of a modern architectural style in Saudi Arabia (Figure 4.2). It was constructed in 1999. All classrooms are ceramic floored and have windows which do not open. Also, the windows are reflective and recessed for solar shading, with single glazing, and are always covered with internal blinds during daytime. The external walls have no thermal insulation. The opening sizes are minimised to ~35% of the facade surface area. The outdoor areas have hard surfacing with some vegetation on the eastern facade.

The university comprises three departmental schools, namely the School of Business, School of Law and School of Arts and Humanities. Each of these schools occupies the surface area of an entire ground floor forming a three-story building. As mentioned above, the mechanical ventilation system in the building is a CAV system, in which the supply airflow rate is constant but the supply air temperature is varied. The commissioning of Air Handling Units (AHU) in the building was set at 25% supply of outdoor fresh air of the design value. It is worth noting that, it was not possible to set the supply of outdoor fresh air at 100%, since 25% supply of outdoor fresh air is the maximum that can be set on the building management system used in this building. Nevertheless, it is known that this arrangement most likely provided a minimum flow much higher than required because of the non-linear relationship between flow and damper stroke, especially if the dampers are oversized (Functional Testing Guide). Therefore, it was assured that this was sufficient to provide the minimum requirement of outdoor air supply that complies with ASHRAE Standard 62-2014.

With regard to the Building Management System used in the building (BMS), Honeywell Building Management System is the one used, which provides single-point monitoring and control of the building's HVAC, lighting and energy management. Temperature and CO_2 have separate controllers independent of each other. AHU are conveyed to each classroom through galvanised steel pipes hidden under the false ceiling-suspended tiles, and spread to the rooms via ceiling air diffusers of size 60 x 60cm. Air is returned to the AHUs via ceiling return air diffusers.

Figure 4.1: Site location of the building. Source: [Online] Dar Alhekma University, Jeddah, Saudi Arabia. Available at: https://maps.google.co.com [Accessed on 13th Sept. 2012].

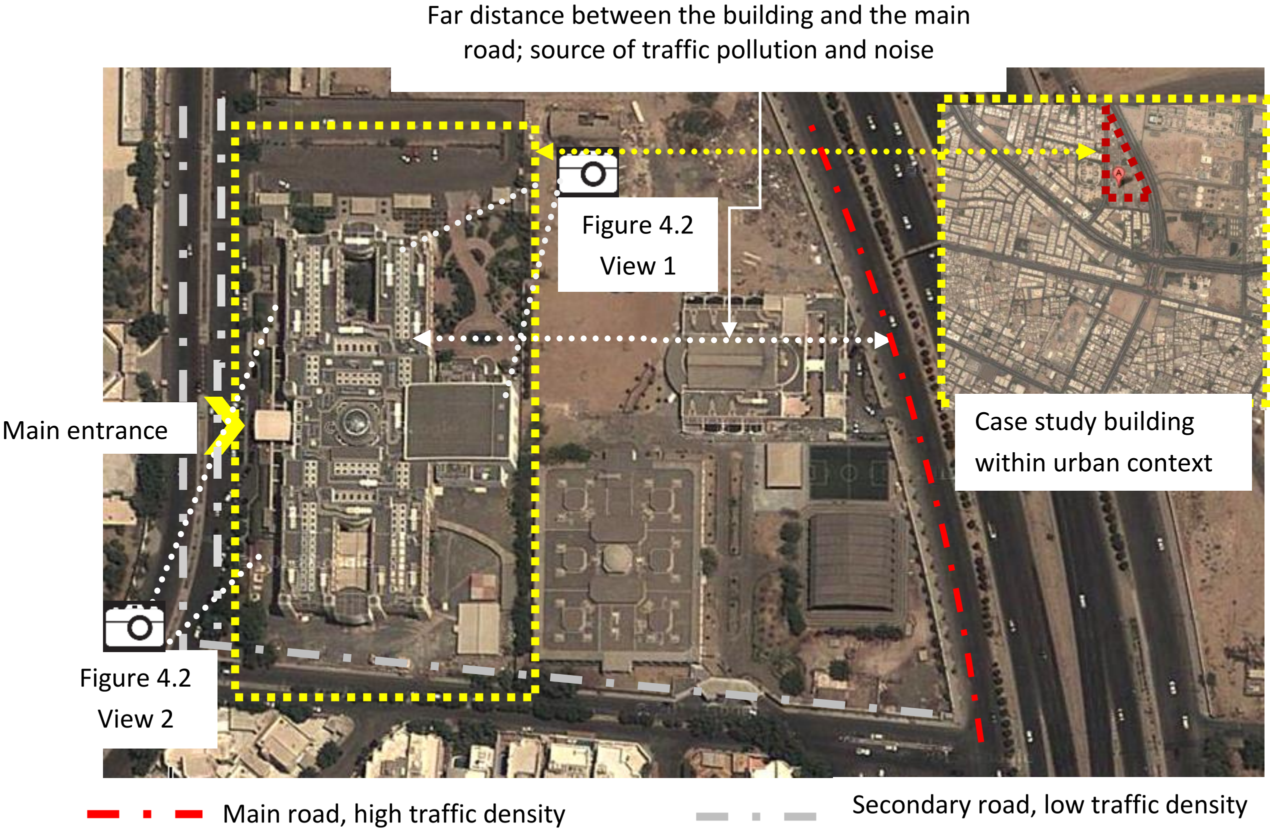
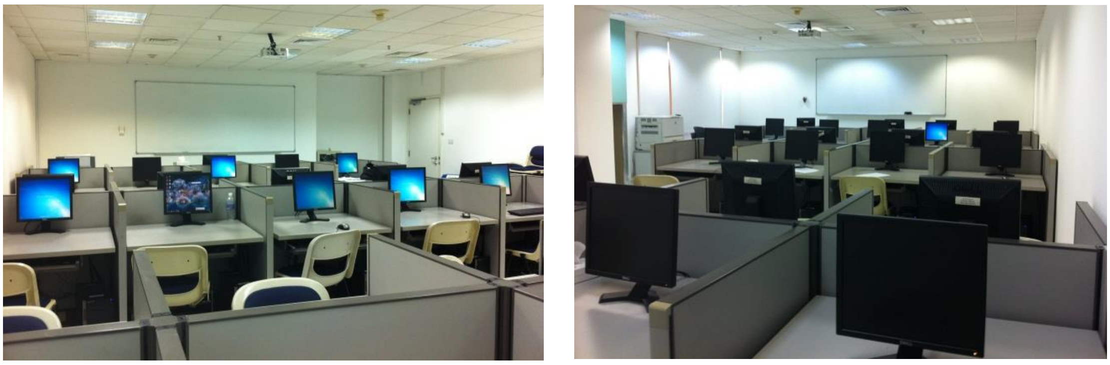


Figure 4.2: External views of the building. **View 1:** left, the eastern façade showing the outdoor recreational area. **View 2:** right, the western façade showing the main entrance of the building (photo courtesy of the researcher, rights reserved for Dar Alhekma University).

Since the cognitive performance battery adopted is computer-based, the computer labs were selected for monitoring. And, since the purpose of the study was to investigate the effects in real classroom environments, permission to conduct the study in more than one classroom was asked of the building management. The permission was given for two classrooms. The classrooms were selected so that they both were almost of an equal size (~50m^2), and were both located inside the building on the inner alleys with no walls exposed to direct sunlight. This avoided the effect of radiant temperature on the ambient air temperature.

Moreover, since the selected classrooms were located on the inside corridors away from window's direct sun exposure, the participants' thermal comfort sensation was thus ensured from not being influenced by the warm-windows effect. Both selected classrooms were designed to accommodate 30 computers for 30 students plus one computer for the instructor (Figure 4.3). The call for participation was open daily during the weekdays in both classrooms on the basis of whichever one was available. However, a balance of experiments was almost achieved between the two classrooms (an equal number of observations obtained from both classrooms). This was achieved by having a sequence of alternated exposures between the classrooms. In order to minimise the effect of distraction attributed to the ambient noises from the passing students in the corridors, the selected classrooms were located at the end of the corridors where less movement was more likely happening, given that the different courses were taught in different classrooms and the students had to move from one class to another accordingly.

Figure 4.3: The selected classrooms (photo courtesy of the researcher, rights reserved for Dar Alhekma University).



4.3 Human Participation

4.3.1 Sampling Size

The study was designed to have 90–95% power at 95 percent level of significance. Using this information the sample size was calculated using the following formula, Danial sample size formula:

$$\text{Sample size : } n = \frac{Z^2 P (1- P)}{d^2}$$

Where; n = sample size

Z = statistic for a level of confidence (95% level of confidence used, therefore Z value is 1.96)

P = expected prevalence or proportion, and

d = precision (In a standard situation, d is considered 0.05 to produce good precision and smaller error of estimate).

$$n = \frac{1.962(0.5)(1-0.5)}{(0.05)\ 2} = 385$$

P can be estimated from previous studies; nevertheless, most of the results obtained from relevant studies were non-significant owing to the sample size. In addition, scarce data about the effects of classrooms' temperature and CO_2 on cognitive performance is obtained from Saudi Arabia, where no relevant studies have been conducted. It was suggested that if it is impossible to come up with a good estimate for P, one may set P equal to 0.5 to yield the maximum sample size (Daniel, 1999; Lwanga and Lemeshow, 1991).

Calculation was done using P=0.5 and d=0.05, as P could not be estimated in this study. The sample size was 385. However, the size was over-estimated since the duration of the experiment was long (over one year) and many withdrawals were expected, and particularly in this context of study where research consciousness is absent. Therefore, the students were invited in large numbers since the intervention was intended to be conducted over a long duration of time and it was therefore expected that not all the students would be able to participate the nine times required. At the beginning of the intervention, 640 participants contributed, from which 627 came back for participation in the following condition. In the following condition, 618 participants contributed. Afterwards, 606 participants contributed, followed by 596 participants, followed by 581, followed by 564, and then 551 participants afterwards. Finally 499 participants contributed to all of the conditions of exposure, which was still larger than the required sample size.

Table 4.3.1: Summary of the schedule of exposure conditions at the intervention study, and the number of participants who participated in each of the exposure conditions.

Sequence of exposures	Con. 1	Con. 5	Con. 3	Con. 2	Con. 9	Con. 6	Con. 7	Con. 8	Con. 4
Number of weeks	5	5	5	5	5	5	5	5	5
Number of participants	640	627	618	606	596	581	564	551	499
Number of exposures	640	627*2 = 1254	618*3 = 1854	606*4 = 2424	596*5 = 2980	581*6 = 3486	564*7 = 3948	551*8 = 4408	499*9 = 4491

499 participants were exposed to all of the experiment exposure conditions, where each of them performed the cognitive performance test nine times.

4.3.2 Recruiting the Participants and the Selection Criteria of Participation

All classrooms in the case study building were visited prior to the experiment to announce the experiment and introduce the experiment protocol, the cognitive performance tests, and the questions involved in the questionnaire surveys. All students from the different departments were invited in order to widen the scope of students' contribution to the experiment with different intellectual backgrounds and thus to minimise cognitive performance test bias. It was made clear that participation was to be based on the participants' free will. Written consents forms were disseminated to the participants after their acceptance to participate, so that they could sign it and be registered for participation. It was also announced that ethical approval was obtained for conducting this experiment in accordance with the regulations of the University College London (UCL), and that no harm would come to the participants (consent form and information sheet are provided in Appendix F).

From the volunteers who wanted to participate, the selection process was based on their overall health status, as volunteers with chronic illnesses and/or allergies were not invited. Also all participants invited were non-smokers and were expected to be available throughout the whole intervention duration. The participants were all female students, aged 15–23 years. Participants were also asked to have adequate amounts of sleep and a good rest on the nights before participation, since sleep has been proven to influence humans' cognitive performances (Sandberg and Bostrom, 2008).

To increase participants' motivation to perform the tests seriously, community service hours (which is a requirement by the university for graduation as a way of teaching young people that they should understand that they have obligations as citizens or residents of an area to help benefit their community) were offered to the participants every time they contributed depending on their performance. In addition, to encourage them to come back for the remaining conditions of exposures, 50 more community service hours were offered every time they participated, providing them with 450 points after participating nine times. Fifty more points were provided at the end, and thus they obtained the 500 points required by the university before graduation.

At first, the participants were invited to contribute in the first exposure condition (defined in section 4.1.3). After ~5 weeks' time the participation for the first conditions was closed and the participants were invited to contribute in the following condition of exposure, where all participants were exposed to the same conditions, in the same order of exposure shown in Table 4.3.1 (i.e. condition 1, condition 5, condition 3, condition 2, condition 9, condition 6, condition 7, condition 8, and condition 4). This sequence was chosen based on observations from the pilot study. During the pilot study (in which the order of exposure condition was set as:, condition 1, condition 2, condition 3, condition 4, condition 5, condition 6, condition 7, condition 8, and condition 9), it was reported by the majority of participants (over 80%) that the last four exposure exposures were the least favoured. Also it was noted that the withdrawals of participants from the experiment occurred starting the last three weeks. A feedback was received from the participants who withdrawn indicating that the main reason for their withdrawal was that they have noticed that the exposure conditions were changing from unfavoured conditions to become worse, which discouraged them from coming back. Therefore, it was decided to change the order of exposure in the intervention in a way that would be uneasy for the participants to predict the forthcoming ones, and also in a way that doesn't make the unpleasant, or less favoured conditions subsequently to minimize/ limit the discourage of the participants as much as possible.

During the intervention, it was clearly announced to the participants that the order of exposure conditions has changed from that of the pilot study, and the conditions themselves has slightly changes as well. This was to alter any perception taken by the participants who contributed in the pilot study based on their past experiences, and stop passing it to the participants who are participating for the first time in the intervention. Therefore, achieving a blind exposure to the participants.

This trend continued until quite a large number of participants (the same participants) reached the ninth condition (499 participants, which exceeded the number estimated by the sample size calculations). To ensure that the learning effect was removed, a wash-out period was kept between the conditions (rest time interval between conditions). This was easily achieved by not conducting the study during examination periods, semester breaks, which were evenly distributed throughout the academic year, and, of course, the intervention stopped during the summer vacation.

4.4 Indoor Environment Quality Monitoring Protocol

Eight participants contributed at the same time after an arrangement was based on their free time, and an average of four experiments were conducted per day. The participants arrived to the intervention classrooms 30 minutes before performing the cognitive test to allow time to adapt to the classroom adjusted conditions of exposure. It was not affordable, according to the available research budget, to equip all computers with the 9Button keyboards and cognitive performance software; therefore, only eight participants contributed at a time. The location of these computers was selected so that they were away from the direct airflow from the ACs outlet diffusers placed at the ceiling. Although a study by Tomasi et al. (2013) showed that no relevant effect on thermal comfort was caused by the exhausted air position; however, it was observed during the pilot study that the participants who were sitting directly under the outlet diffusers reported heaviness on their head and headache and were unable to complete the cognitive test.

The lighting units were distributed equally on the ceilings. Hence the selection of the computers' location, which were selected to be equipped with cognitive performance software, was primarily in accordance with the location of the diffuser inlets and outlets. Afterwards, the participants were asked to begin the cognitive performance tests. Each cognitive performance test lasted for around 30 minutes. Another five minutes afterwards were provided for the participants to fill the questionnaire surveys. During the exposures, participants' behaviours were observed and recorded by the researcher with the aim to use them when needed for any justification of the performances in the cognitive tasks and/or the questionnaire responses.

4.4.1 Classroom Environment's Physical Measurements

Monitoring indoor temperature, relative humidity, CO_2 concentration levels, air speed, and sound levels took place every day simultaneously at the time of exposure. Measurements made every second were averaged over two-minute intervals. The equipment was located in a central location in the classrooms, since the outlets and inlets of the ACs were distributed equally in the ceiling, at a height of 1.1 m from the ground level in accordance with the prescriptions of the ASHRAE Standard 55 and ISO 7730 Standard (2010). The measurements were initiated at 8:00 AM and data were collected continuously from 8:00 AM until 3:00 PM, after which the activities in the buildings cease and the students start to leave the building, and hence no experimental exposure was conducted. Classrooms were monitored under closed conditions, i.e. keeping doors and windows and windows' curtains closed as best possible during the exposure durations. Simultaneously, the mean of daily outdoor temperature and relative humidity was monitored during the intervention study. Light intensity was calculated by multiplying the number of lighting units by the illuminance intensity of the units, given that no dimming was possible.

4.4.2 The Equipment Used

The equipment used is listed in Table 4.4.2. The airflow rate coming out of the diffusers was measured during the exposures using the Testo Large Vane Anemometer. The vane anemometer was used to measure both the airflow rate from the supply and from the return air diffusers. Afterwards, the measurement of the return airflow rate was deducted from the supply airflow rate to estimate the net airflow rate in the classrooms. Since the air velocity coming from the diffusers was too low, EE576 compact air velocity transmitter probe (accuracy: ± 0.05m/s), a strip along the probe's tube was mounted manually, and the sensor was oriented inside the Large Vane Anemometer to provide optimal precision and maximum sensitivity.

Indoor ambient noise levels were measured using a data-logging sound-level meter. All equipment was calibrated before exposing the participants to the experimental conditions every time, to ensure reliability and accuracy in the readings taken during the intervention study. The main advantages of the equipment used lie in their portable sizes, very low noise properties, simplicity of operation, robustness and power supply independency.

Table 4.4.2: Summary of the equipment used.

Parameter	Equipment	Sampling Intervals	Range and Accuracy
Ambient Temperature	HOBO U12 Temp/RH/Light/Ext	2 min.	range: -20°C to 50°C (-4°F to 122°F) accuracy: ±0.2°C from 0°C to 50°C
Relative humidity	HOBO U12 Temp/RH/Light/Ext	2 min.	range: 0 to 100% RH accuracy: ±2.5% from 10 to 90% RH, resolution: 0.05% RH
Air flow rate	Testo Large Vane Anemometer Kit EE576 compact air velocity transmitter probe	5 min.	range: 50 to 4000 fpm accuracy: (±1.5% of reading) (accuracy: ± 0.05m/s)
Indoor CO_2 levels	Telaire 7001 infra-red gas monitor	5 min.	accuracy: 50 ppm or 5% of the reading
Ambient sound levels	Data-Logging Sound-Level Meter	5 min.	range: 30-130 dB(A) accuracy: (± 1.4 dB(A))

4.5 Subjective Measurements: Questionnaires

PMV was not calculated in this study. According to Bako-Baro et al. (2012), the calculated PMV index was always underestimating subjective ratings, which could have been due to uncertainties in the value of the parameters used in the PMV calculations such as changes in activity and clothing ensembles. Thus, the actual mean votes (AMV) were collected. The rating scale used for TSV is based on the ASHRAE/ISO seven-point thermal sensation scale, defined as: hot (3), warm (2), slightly warm (1), neutral (0), slightly cool (–1), cool (–2) and cold (–3).

The questionnaire also included a question about participants' clothing level at the time of participation (choices were provided). Clothing levels were then estimated based on the tables provided in the ASHRAE Standard 55 listing the garments insulation values which were added up to estimate the values of clothing ensembles (Table 4.5). The questionnaire included a list of the most likely combinations that could be worn by the participants in their context, so the participants were asked to choose from the list provided. There was no restriction on adjusting the clothing attires when necessary for achieving and maintaining thermal neutrality.

Table 4.5: 'Clo' values estimated on the basis of ASHRAE Standard 55.

Clothing type	Clo.
Shirts	
Sleeveless/scoop-neck blouse	0.12
Short-sleeve knit sport shirt	0.17
Short-sleeve dress shirt	0.19
Long-sleeve dress shirt	0.25
Long-sleeve flannel shirt	0.34
Trousers	
Short shorts	0.06
Walking shorts	0.08
Straight trousers (thin)	0.15
Straight trousers (thick)	0.24
Dress and skirts	
Skirt (thin)	0.14
Skirt (thick)	0.23
Short-sleeve shirtdress (thin)	0.29
Long-sleeve shirtdress (thin)	0.33
Head Scarf (close to the light shirt/short)	0.06

The questionnaires were disseminated to the participants directly after they finished their cognitive performance assessment. The questionnaire included a question about participants’ age, their ethnic background, how many years they have spent in Saudi Arabia if not Saudi and their level of physical activity in general. Also, it asked whether the participants performed any kind of physical activity within two hours prior to participation, and/or if they had a caffeinated beverage within two hours of participation, and/or if they had breakfast on the same day of participation, and how many sleeping hours they had during the night before participation. The questionnaire also included a question about the trend of using ACs in general at home for drawing an idea of the participants' physiological habituation to the cold (Always: 24 hours; often: 18–23 hours; or sometimes: less than 18 hours per day). A question about the difficulty level of the cognitive tests was included as well. Moreover, a question was included on whether the participants were feeling stressed for any personal reasons. A question regarding detecting intolerable thermal discomfort that may lead to focus impairment during the exposures was included, and also a question on detecting numbness in fingers during the exposures. In addition, a blank space for writing comments was also provided at the end.

In numerous field studies, measured CO_2 has been associated with subjectively assessed acute health symptoms (e.g. Apte et al., 2000; Erdmann et al., 2002; Seppanen et al., 1999). Significant associations were observed with headache, fatigue, eye, nose, and respiratory tract symptoms, even in buildings where CO_2 levels were below 5000 ppm; the prevalence of symptoms continued to decrease with the CO_2 level even below 800 ppm (e.g. Myhrvold et al., 1996; Norback et al., 2013; Seppanen et al., 1999; Tsai et al., 2012). An association was found between elevated temperatures and sensory irritation of the eyes and upper airways at room temperatures above 22°C (Mizoue et al., 2004). Several of the studies also indicate that a temperature increase increases the prevalence of eye irritation symptoms (Mendell et al., 2002; Jaakkola et al. 1989). Furthermore, high temperature may lead to desiccation of the eyes. Accordingly, a question about detection of symptoms like headache, fatigue, irritation of the eyes and/or nose was included.

Owing to cultural issues, it was not possible to ask about the menstrual cycle since it is suggested that menstrual cycle could have an effect on females' behaviours/moods. With regard to the metabolic rate, the tables in ISO 8996 (2004) ergonomics for determining metabolic heat production/metabolic rate was used. For seated occupants, it is usually estimated as 1.2 met.

In higher education, most Saudi universities use English as the language of instruction in some scientific courses, such as medicine and engineering (as English is essential and the language of these domains), while Arabic is used in non-scientific courses (e.g., courses of humanities). However, other courses like history, in which English is not the language of instruction, students are still required to complete English language coursework as an additional compulsory unit (Alafaleq and Fan, 2014).

4.6 Cognitive Performance Assessment Protocol

4.6.1 The Neurobehavioral Battery Used

The BARS was chosen for this study. BARS was developed for a broad range of working populations with varied education levels and cultural backgrounds (Anger et al., 1996 and Rohlman et al., 2003). Copyright of the BARS testing system software is held by Oregon Health Sciences University (OHSU). The software was rented from OHSU for two years to cover the duration of the pilot study and the intervention. Each BARS test was programmed in Allegiant SuperCard software, version 2.0; external input routines programmed in Symantec C++ (v.7.0) handled the response input timing for all tests.

Eight computerised neurobehavioral tasks were used to evaluate participants' performance, namely Symbol Digit (SDT), Simple Reaction Time (SRT), Continuous Performance Test (CPT), Digit Span (DST), Match-to-Sample (MTS), Reversal Learning (RL), Serial Digit Learning (SDL), and Alternative Finger Tapping (ALT TAP). Each test in BARS allows the investigator to set test parameters such as instruction language, test duration, and stimulus set (Anger et al., 1994).

Features of BARS that enable this broad application include simple language instructions broken down into basic concepts (step-by-step training with competency testing at each instruction step). The purpose of instructions is to train the subjects to perform the tasks. It was ensured that all subjects understood the instructions correctly. In BARS, three main principles were employed to train the subjects to perform the tasks effectively: (a) precise language, (b) attention focusing, and (c) interactive instruction or feedback (a drawing of a smiling face, chosen as the most universal symbol of approval) appears when the subjects made the correct response (Ekman and Friesen, 1975).

When the correct response was not produced within a given time frame, a text prompt was used for focusing (e.g. the text prompt "Press three to continue" was used to direct the subject's attention from reading the instructions to performing the correct response). When the correct response was not forthcoming within a set time, the outlined key and the text prompt began to "flash" (appear and disappear) intermittently. Feedback was provided after each task, and the tasks were designed in a way that subjects could not proceed until they had corrected their mistakes. Lan et al. (2014) argued that this approach is more appropriate because it would feature much better the realism of working environment where people normally adjust the pace of work based on the error rate.

According to Lan et al. (2009), continuous effort during prolonged exposures cause fatigue and less motivation, and that people could maintain high performance under adverse (hot or cold) environmental conditions only for a short time. Accordingly, cognitive tasks' assessment duration was set to 30 minutes as a maximum. Nine-button keyboards or 9Button drivers (Figure 4.5) were used instead of the typical computer keyboards. These 9Button drivers have the advantage of having only nine buttons for the purpose of the given tasks; where these buttons are larger compared to the numbers of the typical keyboards and thus distraction was minimised when selecting the buttons as quickly as possible.

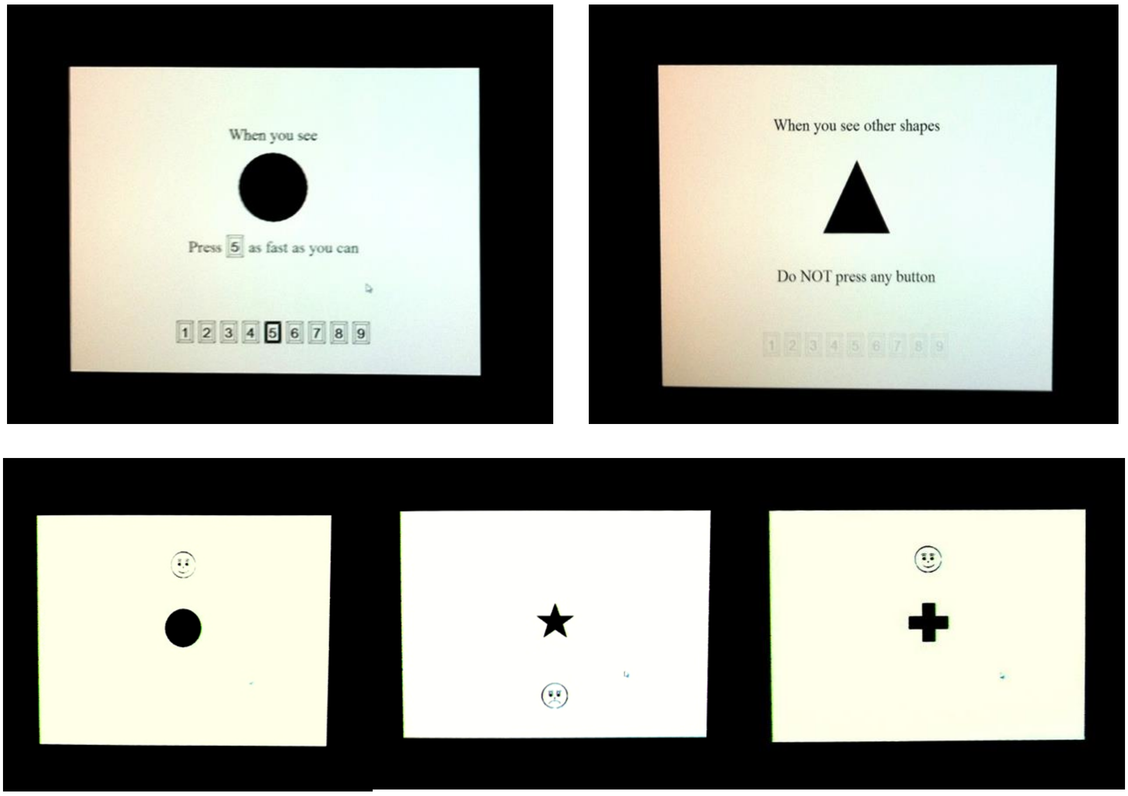
Figure 4.5: The Nine-button keyboards ‘9Button’, developed by BARS manufacturers (photo courtesy of the researcher).

4.6.2 Description of the Neurobehavioral Tests Considered in the Study

Continuous Performance:

The CPT measures sustained attention. Symbols are presented in an unpredictable order. The participant has to press a button quickly at the appearance of a pre-selected symbol or when two symbols appear consecutively. Figure 4.6 shows an example where the participant is asked to press 5 when the circle appears and not to press any button when the triangle appears. Nonetheless, other symbols like plus and star shapes might also appear, thus the participant is not expected to press any button similar to the triangle with the sharp edges. This task helps in evaluating a person's sustained and selective attention, impulsivity, general alertness and motor speed. The outcome measures for this task cover percentages of correct selections and reaction time per seconds.

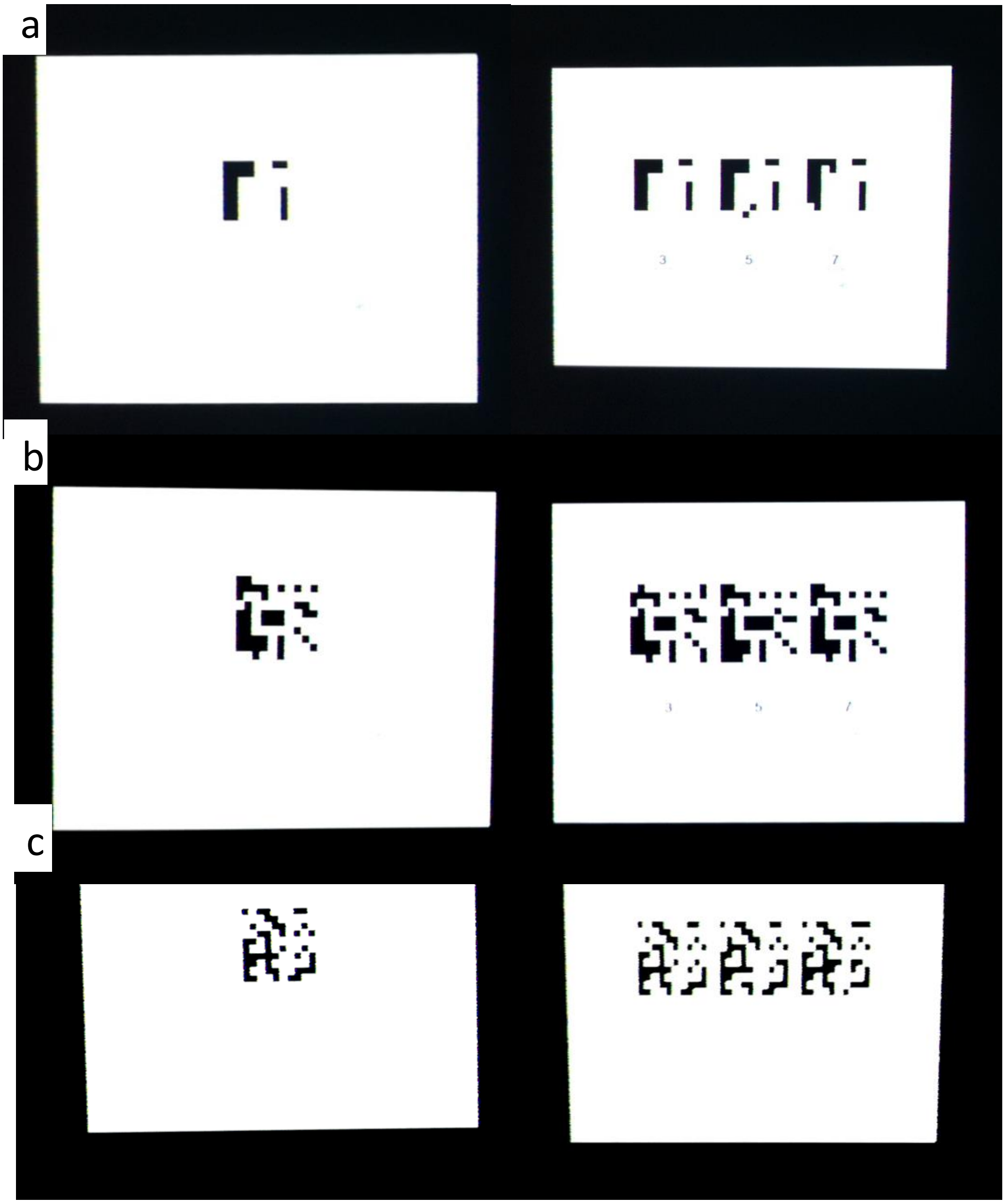
Figure 4.6: Examples of the continuous performance symbols appearing in the continuous performance test (CPT).



Match-to-Sample:

Match-to-Sample visual search (MTS) is a visual search matching task, with a speed/accuracy trade-off. It can help in evaluating picture recognition as an indicator for the visual-memory capacity. Efficient performance on this task requires the ability to search among the targets and ignore the distractor patterns, which have elements in common with the target. This task has formed the basis for human-centred cognitive test batteries since the 1980s (Englund et al., 1987). The participant is shown a complex set of visual patterns in the middle of the screen, and then, after a brief delay, a varying number of similar patterns are shown for the participant to choose from. The participant is asked to press on the number of the correct pattern. Reaction time is measured by the press on the 9Buttons driver. The outcome measures for this task cover percentages correct and reaction time per seconds.

Figure 4.7: A variety of visual patterns, starting with very easy patterns at the beginning of the test (a), then followed by more tricky patterns (b) and then relatively more complicated ones (c).



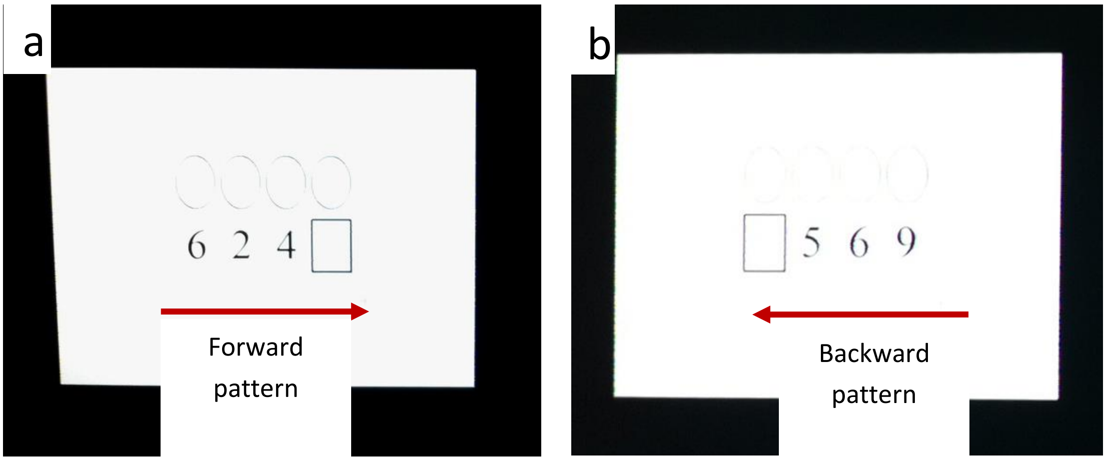
Simple Reaction Time:

SRT is a task which measures simple reaction time through delivery of a known stimulus to a known location to elicit a known response. Like CPT, it is useful for testing general alertness and motor speed. This task helps in evaluating response speed and accuracy to visual signals. The outcome measures for this task cover percentages correct and reaction time per seconds.

Reversal Learning:

The Reversal Learning test (RLT) is a simple task of attention in which a series of numbers between one and nine are read or shown to the participants who must, after the series is completed, repeat the series in order orally or by typing the numbers. The test is then repeated with new numbers, but participants are asked to repeat them backwards (that is, reverse of the order in which they were read). This task helps in evaluating digital memory capacity, speed and accuracy of coordination between right and left hemispheres of the brain and is also useful for testing general alertness and motor speed. Also, the task requires the function of ventral and medial-prefrontal cortex areas of the brain, therefore, it is used in evaluating decision making (Cambridge cognition). The outcome measures for this task cover percentages correct and reaction time per seconds.

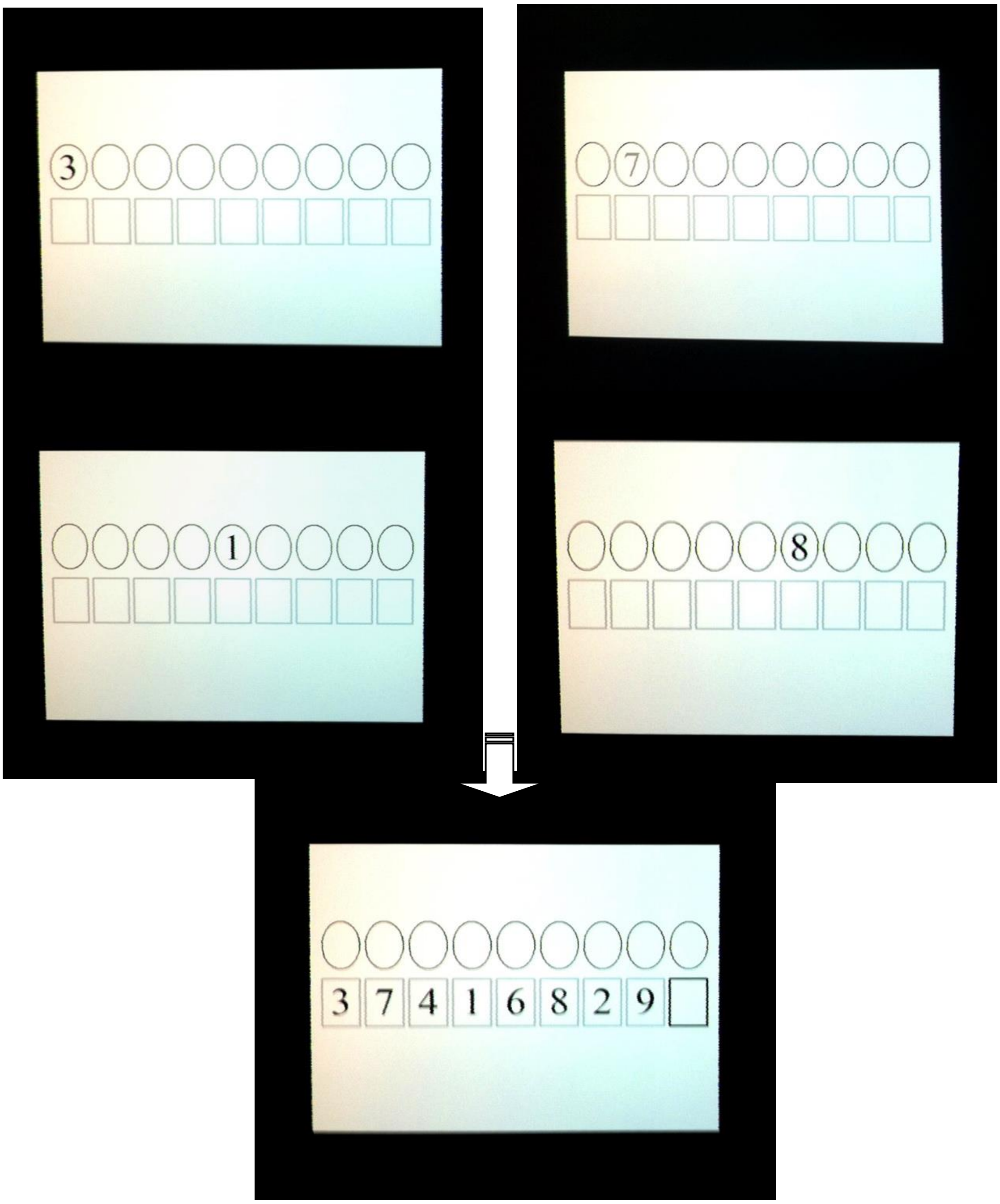
Figure 4.8: Example of four digits, which have disappeared and the participant is required to retrieve the digits back in a forward (a) and in a backward pattern (b).



Serial Digit:

The Serial Digit test (SDL) is comprised of a series of digits disappearing one by one and the participants are asked to retrieve the digits back all together. This task requires a number of processes that are closely related to the frontal lobes. The repetition of digits in their correct order is a process of serial position processing. This processing is related to the ability to sequence and temporally order events (Karkas and Karkas, 2006). This task also helps in evaluating the capacity of memory. The outcome measures for this task cover percentages correct and reaction time per seconds.

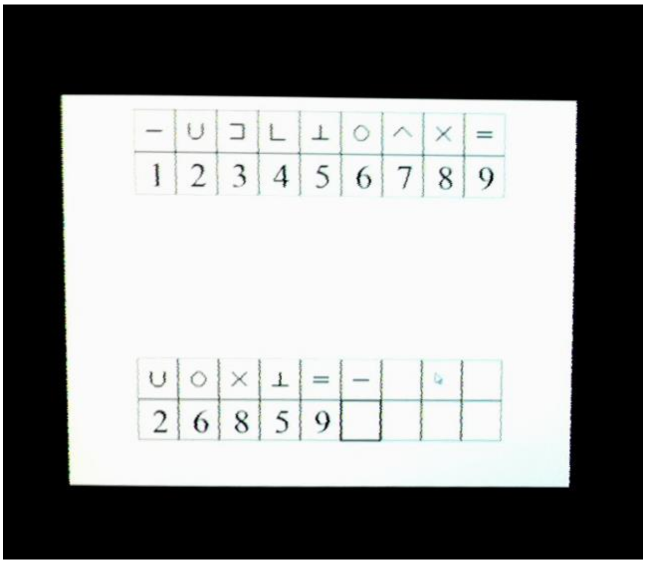
Figure 4.9: The nine digits disappearing one by one and the participant is required to retrieve back the nine digits all together.



Symbol Digit:

The digit symbol task (DST) of psychomotor performance and its computer-based alternative (the symbol digit test of complex scanning and visual tracking) constitute the most widely used and sensitive tests in human behavioural neurotoxicology research, and are used as indicators for learning disorders (Anger, 2003). This task presents nine symbols, each paired with a number between one and nine in a matrix as shown in Figure 4.10 below the matrix, a similar matrix is displayed but with only the number (digit symbol) or symbol (symbol digit), and the participants must add the missing number of each pair, as quickly as possible. In the digit symbol exercise, motor performance is more challenging in that people have more practice writing numbers than symbols. While the motor component of the digit symbol would appear to make this a very different task than when the person writes numbers or types them, so both symbol digit and typing tests correlate well. The outcome measures for this task cover percentages correct and reaction time per seconds.

Figure 4.10: Example of one of the digit symbol matrices used.



Alternative Tapping:

This is a task of motor speed and coordination. The participants are instructed to press a button as many times as possible in a fixed time period, such as 30 seconds. This may occur with the dominant and subsequently the non-dominant hand, and alternating between two buttons with one or both hands. As shown on Figure 4.11, the participants are asked to press on one for filling a rectangle for measuring motor speed and accuracy of typing using preferred right or left hands. After then the participants are asked to press 1 then 9 using alternative hands for measuring the coordination between right and left hemispheres of the brain. The outcome measures for this task cover percentages correct and reaction time per seconds.

Figure 4.11: Typing task measuring motor speed and accuracy of typing using right and left hands.

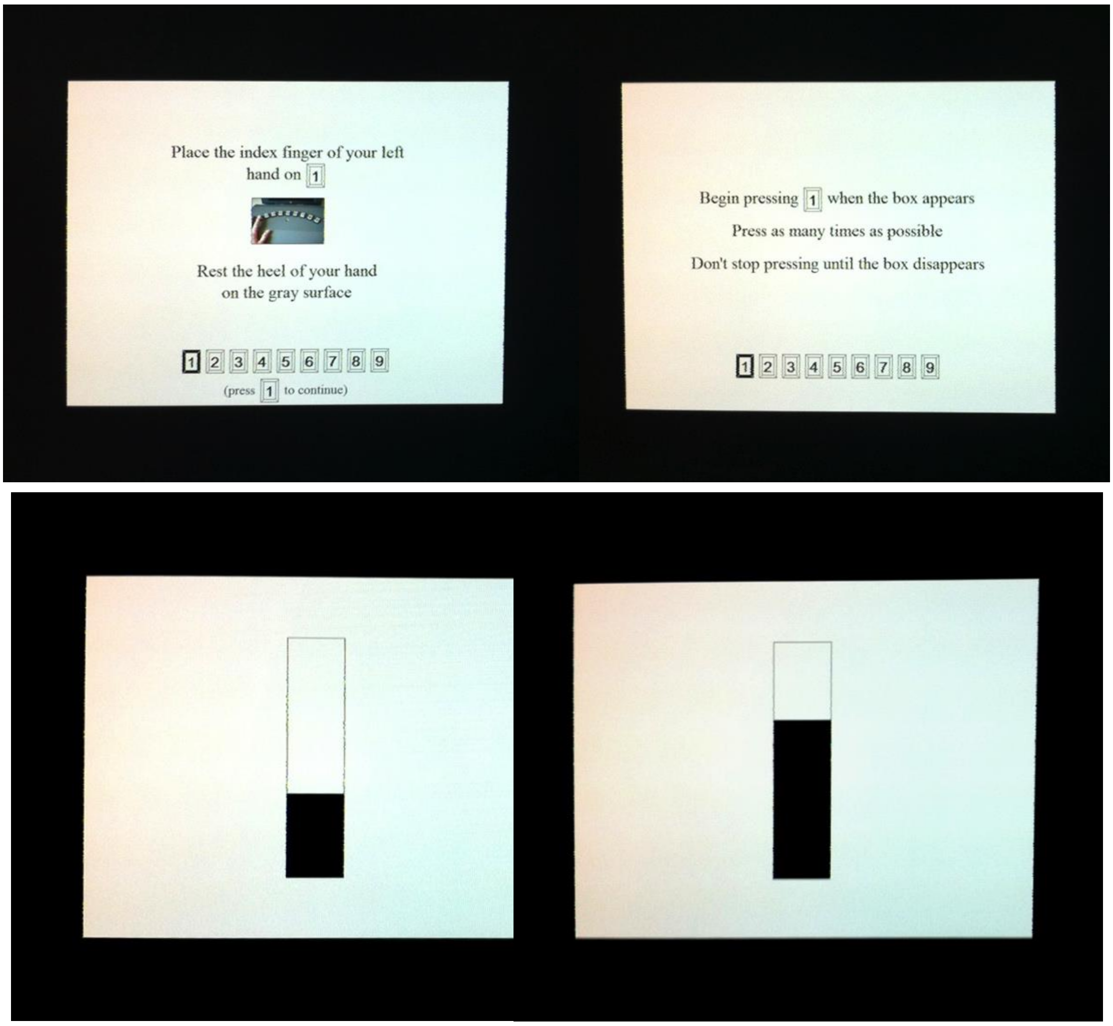


Figure 4.12: Typing task using alternative hands for measuring and also the coordination between right and left hemispheres of the brain by asking the participants to type using alternating hands.

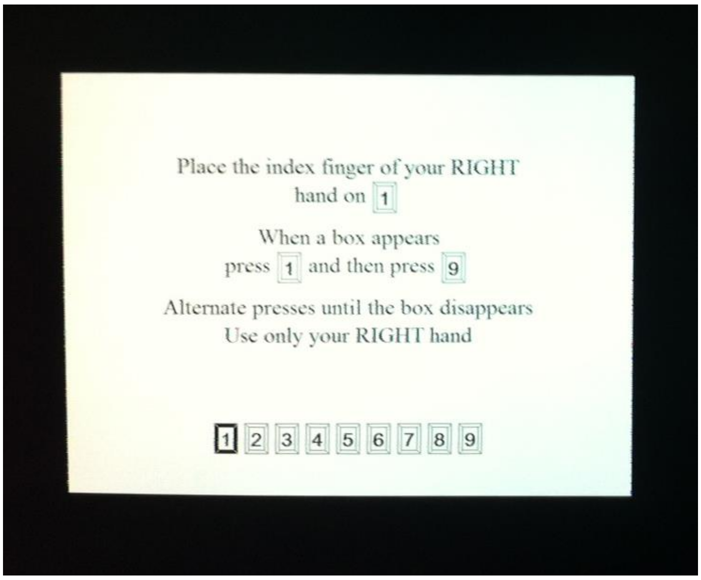


Table 4.6.2: Summary of the description of the cognitive tasks of BARS considered in this study.

Test	Symbol	Function measured
Continuous Performance	(CPT)	Sustained attention.
Match-to-Sample	(MST)	Learning, and visual-memory capacity.
Simple Reaction Time	(SRT)	Selective attention.
Reversal Learning	(RL)	Learning, coordination and working memory.
Serial Digit	(SDT)	Learning, and digital memory capacity.
Symbol Digit	(SDT)	Complex function of working memory.
Digit Span	(DST)	Learning, and complex function of working memory.
Alternative Tapping	(ALT TAP)	Alternating attention, and coordination between right and left hemispheres of the brain.

4.6.3 Advantages of Using BARS and its Validity

- Compared to the other available batteries like CANTAB® (Cambridge Neuropsychological Test Automated Battery), BARS has been reliably used in well-established neurobehavioral performance research, while CANTAB® is mainly designed for clinical research focusing on Alzheimer's, mood, schizophrenia and emotional testing purposes. In addition, CANTAB® is very costly compared to BARS. Similarly, compared to NES, SPES (Swedish performance evaluation system), CAT (Cognitive Abilities digital Test), and the CDR computerised assessment system (CDR system), these are mainly employed in clinical neuropsychology research (Iregren and Letz, 1992).
- BARS has large graphics, simple instructions integrated with the test during practice and a '9Button' response unit, which is a better alternative to a keyboard in which the inexpensive components are not designed for repeated testing.
- It is available with Arabic instructions (the mother tongue in Saudi Arabia), in addition to the English instructions.
- BARS tests have modifiable parameters (e.g. number of trials, stimulus shape, inter-stimulus intervals, instruction language, practice trials, test difficulty levels, delays).
- It effectively teaches test performance to the participants with minimal support from a human examiner (Rohlman et al., 2003).

4.7 A State-of-the-Art Methodology for Cognitive Performance Assessment in the Context of Built Environment Studies

The use of neurobehavioral tests to assess indoor environment exposure has continued to increase, and neurobehavioral tests have become the most efficient methods (in terms of cost and time) to investigate the effects of safe exposure levels on the nervous system in adults (Anger and Johnson, 1985; Anger, 1990; Anger et al., 1996). Relevant studies examining the effects on the indoor environment on learning in classrooms used mainly psychological and neurobehavioral tests to examine different skills needed for proper learning, such as the ability to concentrate and memorise (e.g. Myhrvold and Olesen, 1997; Bako-Biro et al., 2007).

The computer-administered tests are the most commonly used. Computerised measures have a number of further advantages over pencil and paper tests. First, the demands on the experimenter are restricted to the presentation of instructions and initiation of the task. Second, computerised measures allow for programming of complex task contingencies and automatic recording of objective data for accuracy and, in particular, reaction times. Computer-administered neuropsychological tests are dependent on subjects' reading written instructions on the computer screen (Kane and Kay, 1998), which can be improved by guidelines from computer interface design. These guidelines include breaking the instructions into component parts using multiple "screens" to allow opportunities for practice at each step, also designing the screen layout, and the timing of instructions to direct attention. The process incorporates training, which is achieved by dividing the tasks into a series of small steps and rewarding successive approximations of the final performance.

In relevant studies, the cognitive test batteries, which were used to assess various cognitive domains (including: attention, memory, speed of response, mathematics, categories of concepts, language and problem solving) are: CANTAB® (Cambridge Neuropsychological Test Automated Battery), VISCoPE (Ventilation in Schools and Cognitive Performance Evaluation), NES (neurobehavioral evaluation system), SPES (Swedish performance evaluation system), CAT (Cognitive Abilities digital Test), CDR computerised assessment system (CDR system), and BARS (Behavioral Assessment and Research System). Among these batteries, BARS was chosen for this study.

BARS tests focus primarily on working memory and attention. Working memory consists of a central executive that controls and coordinates the operation of two subsystems that process and store information: one for spoken and written material and one for visual or spatial information (Polkey et al., 2013). Also, the central executive is involved in other cognitive tasks like problem solving and mental arithmetic. Working memory becomes critical in any intervention designed to increase knowledge and change behaviour as it applies to real-life tasks. Specifically, working memory is essential to reading and understanding educational materials and navigation of daily activities requiring visual and spatial processing and problem solving central to self-care (Fan and Meek, 2014). BARS is integrated with a nine-button ('9Buttons') keyboard instead of the typical computer keyboard, which has the advantage of having only nine buttons for the purpose of the given tasks and thus helped to minimise distraction when selecting the buttons as quickly as possible and the chances of obtaining biased results. Description of BARS and its advantages will be discussed in detail in the next chapter.

4.8 Statistical Analysis

The analysis was based on multivariable multilevel analysis approach which takes into consideration the confounding factors' effect including: thermal comfort sensations, age, physical activity, clothing levels, stress, caffeine intake, sleeping hours, noise levels, set AC temperature at home, as well as the ethnic background and the number of years spent in the country for non-Saudi participants, as well as the detected symptoms related to the inability to focus. The order of exposure to the exposure conditions was accounted for as well. The confounding refers to magnitude of an association parameter estimation with respect to adjusting versus not adjusting for external variables (Kleinbaum et al. 1992; Greenland and Morgenstern, 2001). This is important to consider in the analysis for obtaining non-biased results since the presence of imbalance covariates (confounders) in the comparisons between the exposure conditions distorts the association of interest if one does not take it into account in design or analysis (Rothman, 1986).

Multivariable multilevel statistical modelling is considered an advanced quantitative method in health-related studies. Multilevel models recognise the existence of data hierarchies by allowing for residual components at each level in the hierarchy. In comparison to standard regression models, the traditional multiple regression techniques treat the units of analysis as independent observations. One consequence of failing to recognise hierarchical structures is that standard errors of regression coefficients will be underestimated, leading to an overstatement of statistical significance (Centre for Multilevel Modelling, University of Bristol).

Almost no relevant studies have adopted the multilevel modelling approach except for one recent study by Haverinen-Shaughnessy and Shaughnessy (2015), which employed the multilevel modelling approach to find the association between ventilation rates and indoor temperature with mathematics test scores. However, no statistically significant interactions were found because of the limited sample size.

First, descriptive analysis was performed to check the interesting patterns due to intra-individual differences by comparing an individuals' pattern of performances across measures. This type of comparison allows for identification of a pattern of strengths and weaknesses. If all performances fall within the mildly to moderately impaired range, the multilevel mixed effect models can be performed. However, if a significant variability in performances across domains is observed, then a specific pattern of impairment may be indicated. Accordingly, univariable multilevel mixed effect models were then performed to check whether any association is found between the confounders of this study with the outcomes of interest including: age, ethnicity, physical activity, number of years spent in Saudi Arabia (for non-Saudis), trend of use and temperature of ACs used at home, the effect of caffeine, sleeping hours, thermal comfort sensation votes, clothing levels, the effect of ambient noise, and the effect of stress owing to personal reasons not related to the exposure conditions, and/or any other reported symptoms by the participants which impaired their focusing ability including un-tolerable thermal stress sensation.

Finally, four multivariable multilevel mixed effect models were applied according to the results of the univariable multilevel mixed effect models, which adjusted for the confounders which were found associated with the accuracy and speed of performance. The first two models (model A for accuracy and model B for speed) were performed to determine the estimated effect sizes of the exposure conditions relative to the base-line condition (condition 1) on the percentages of errors and speeds of responses for all the cognitive tasks considered in the study after adding the confounders.

The second two models (model C for accuracy and model D for speed) were performed to determine whether temperature or CO_2 levels has the higher effect on cognitive performance of the tasks considered in this study. These models were better in predicting whether temperature or CO_2 levels has greater effect on the cognitive tasks considered in this study. Another advantage of this model is that it gives the interactions between the variables of interest. The presence of interactions can have important implications for the interpretation of statistical models, as they describe the simultaneous influence of two variables (temperature and CO_2) on the third one (cognitive performance). These models (C and D) show the effects of interactions between the investigated temperatures and CO_2 levels on accuracy and speed of performance, these interactions show how the effect of one independent variable may depend on the level of the other independent variable. STATA Data Analysis and Statistical Software was used for the analysis.

4.9 Summary of Setting the Experimental Approach Adopted

Stage 1: Gathering Information about the mean set classroom temperature in adult female University buildings and CO_2 levels. However; because of time and financial constraints, only the mean set classroom temperature in adult female University buildings were gathered and information about the CO_2 levels was obtained from 25 classrooms in the selected case study building.

Stage 2: Conducting a pilot study in the selected case study building, based on which the conditions of exposures were set as follows:

Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm (Base line condition)	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

Stage 3: Monitoring the physical environmental parameters of selected two identical classrooms: temperature, CO_2 levels, RH%, ambient sound levels, air speed. Light intensity was calculated

Stage 3: Gathering subjective data from the participants by asking questions on their actual mean votes thermal comfort sensations during the exposures, clothing levels, breakfast, caffeine intake and physical activity within two hours prior to participation, sleeping hours, age, ethnicity, trend of using ACs at home and temperature setting, detecting stress, inability to focus and/or other symptoms due to exposure conditions not personal reasons

Stage 3: Eight cognitive tasks were evaluated using BARS battery (namely: SRT, MTS, RL, CPT, SDL, DST, SDL, ALTTAP). Nine-button ('9Buttons') keyboard was used instead of the typical keyboard, to minimise distraction when selecting the right button.

Stage 4: Statistical analysis of data using a multivariable multilevel approach which accounted for the possible confounders of the study (namely: age, ethnicity, physical activity, number of years spent in Saudi Arabia for non-Saudis, trend of use and temperature of ACs used at home, the effect of caffeine, sleeping hours, thermal comfort sensation votes, clothing levels, the effect of ambient noise, and the effect of stress owing to personal reasons not related to the exposure conditions, and/or any other reported symptoms).

4.10 Ethics

Ethical approval was obtained for conducting this experiment in accordance with the regulations of the UCL, ensuring that no harm is caused to the participants. The participants became aware that they were taking part in an experiment in which classroom temperature and ventilation rate were being manipulated. All protocols were approved by UCL ethics committee (Project ID Number: 4158/002) and conformed to the guidelines contained within the declaration of the university. Overall, the research has progressed as scheduled with no risks or hazards to the participants and the protection of participants from physical and mental harm was greatly ensured. With regard to the written consent for research, no difficulty was encountered in obtaining the consent forms from the participants (samples are provided in Appendix F). Also, all data collected were given numbers and codes while names became anonymous.

4.11 Summary

This chapter discussed the methods proposed for the study. The study protocol was based on an intervention study conducted in the real classroom environments in a female university building in Saudi Arabia as a reference for the hot arid climatic context. The intervention lasted for almost 12 months, exclusive of semester breaks and examination periods.

First, the protocol of the study was described with a clear identification of the nine selected exposure conditions, combining temperatures 20°C, 23°C, 25°C, and CO_2 levels 600 ppm, 1000 ppm, and 1800 ppm. Classrooms' ambient temperature, CO_2 levels, air velocity and RH% were monitored, where the ambient room temperatures were the only variable while the ventilation rate was kept at a constant range and then the ventilation rate was manipulated while temperatures were kept at a constant range, thus yielding a 3 x 3 factorial experimental design. Following that, the case study building was described and its selection criteria, and the selected classrooms and their selection criteria as well. Afterwards, human participation, sample size and the protocol of recruitment were discussed in detail. The physical monitoring protocol and the equipment used, as well as the protocol for collection of subjective responses from the participants and the questionnaire survey used were discussed afterwards.

The BARS cognitive performance battery was chosen as the cognitive performance assessment tool for this study. Advantages of using this battery and the cognitive performance assessment protocol and also description of BARS were presented in detail afterwards. The chapter concluded with the multivariable multilevel statistical analysis approach, which was done using STATA software. Finally, the ethical approval which was obtained prior to the study was highlighted. Based on this methodology, a pilot study was conducted in the same case study to verify the methods proposed and tools for assessment. This study will be discussed in detail in the following chapter.

Chapter 5: Pilot Study

This chapter describes the pilot study conducted prior to the intervention study in the same case study building. The main purpose of this pilot study was to verify the methods proposed and help to identify the reference conditions prevalent in the context of study and thus to apply modifications when needed. The chapter begins with a description of the protocol of the study; including the physical monitoring protocol, as well as the subjective measurements collection and the assessment tool of cognitive performance and the tasks considered for this study. This is followed by the results. A preliminary discussion is provided accordingly, followed by the conclusions and the lessons learnt for application on the intervention study.

5.1 Introduction

Thirty female students aged 18–20 years have successfully participated to all of the experimental exposure conditions in the pilot study. Participants were recruited by circulating internal emails within the university seeking volunteers for the study. Participants were recruited on a simple random sample basis. Written consent forms and signed research information sheets were provided for identifying the research purpose to the participants. The nature of tasks and what was expected of them was explained prior to participation (samples of consent form and information sheet are provided in Appendix F). In addition, involvement in low-risk tasks and confidentiality of information were both ensured for the participants. Participants were offered community service hours as appreciation for their time.

Physical monitoring, collection subjective measurements and evaluating the cognitive performance for the tasks selected for the study all took place simultaneously. One classroom was selected based on its availability over the duration of the study, and also because it was a computer lab, and hence performing the computerised neurobehavioral battery tasks on the available computers was easier and more feasible compared to purchasing laptops. In addition, the classroom was located in a central location inside the building, which was not exposed to external heat radiation and thus the effect or radiant temperature was eliminated as well as the effect of sunlight.

Within-subject design was applied for this experiment (i.e., the same participants were tested in each condition). The experiment took place every day from Saturday to Wednesday from 8:00 AM to 3:00 PM to allow for flexibility for the participants for nine consecutive weeks (from the 1st May until 10th July 2012), and always at the same time of the day.

Each exposure condition lasted for 1 week. The participants were divided in to 5 groups, each consisted of eight participants. On each day of the week, two groups participated. However, the number of participants started to decrease during the last three weeks. At the end, 30 participants successfully completed their exposure to all of the experimental exposure conditions.

The exposures took place away from intervals directly before lunchtime since the participants are most likely to be hungry and thus distracted from focusing when performing the cognitive tasks. Participants were instructed to avoid caffeinated beverages (including forgoing their morning coffee), and to avoid taking diet pills before participation (as they have caffeine content), and to have enough sleep on the nights before participation. They were also asked not to skip breakfast on the days of participation. In addition, participants were asked not to participate if they were not feeling well and/or if they had an exam or course work submission, which by nature makes them more anxious and/or stressed for any personal reason. A week before the experiment, participants received training on the cognitive performance testing battery. They were also instructed on how to fill out the questionnaires used to obtain the subjective responses.

Cognitive performance assessment started after around 20 minutes from the time the participants entered the classroom in order to allow them enough time to become acclimatised to the classroom's adjusted exposure conditions. The participants were randomly seated at the computers available. All computers were equipped with BARS software. The 9Buttons keyboards were exchanged according to participants' locations. These keyboards have the advantage of having only nine buttons for the purpose of the given tasks. These buttons are larger compared to the numbers of the typical keyboards, and thus a distraction when selecting the right button as quickly as possible was minimised. While the classroom's ambient temperature and CO_2 concentration levels were monitored, the participants were performing the cognitive tasks selected for the study. The whole duration of the assessment on the cognitive tasks lasted for no longer than 35 min, varied according to participants' variations in performance and speed of response. The subjective questionnaire responses of the participants' perceptions of the classroom thermal environment were collected during the exposures directly after the participants finished performing the cognitive tasks. Filling of the questionnaire survey forms took around 10 minutes.

In order to overcome the carryover effect, known as the main disadvantage of the within-subject design, the parameters of the cognitive tasks were modified with each time of the exposure. The modifications made were in terms of the order of the tasks, sequence of the appearance of stimuli in each task, their shapes, their corresponding response keys, the sequence of digits in the tasks in which digits are used, and the patterns in the match-to-sample task. Number of trials, duration of tasks, stimulus durations, interval between presentation of sample stimulus and distractors, success/fail criteria, and the number of spans at each length presented in the tasks in which digits are used were all kept constant for the nine times of exposures. Hence, difficulty level and duration of the tasks were maintained while learning effect was offset for the accuracy of data analysis.

5.2 Classrooms’ Physical Environmental Conditions

Nine exposure conditions were investigated combining temperatures and CO_2 levels. As mentioned in the methodology chapter, the Building Management System (BMS) was primarily used to achieve the required measurements of temperatures and CO_2 concentration levels. During the exposures whilst eight participants were present in the classroom plus the investigator, the fresh air dampers, exhaust dampers and return dampers modulated together to reach the desired CO_2 set points to achieve CO_2 levels of 600 ppm and 1000 ppm; however, the BMS was not used for achieving 2000 ppm. The fresh air dampers were closed in the monitored classroom and the command of the dampers was put into manual mode, i.e. it was no longer controlled by the BMS automatic mode and therefore the dampers were not able to be opened automatically until the end of the exposure duration. After approximately 35-40 minutes, as the time taken for the participants to adapt to the environment and for the investigator to disseminate the consent sheets to the participants, and the questionnaire forms, and to instruct the participants to the tasks required, as well as preparing the BARS tasks on the participants’ screens, CO_2 levels of 600 ppm and 1000 ppm were achieved but CO_2 levels ~1800 ppm were the maximum levels that were achieved, and not 2000 ppm as required. The air-conditioning system used in the case study building is a central system supplying fixed ventilation flow rate (CAV system). The commissioning of AHU was set at 25% supply of outdoor fresh air.

With regard to achieving the indoor temperatures required, the BMS was used to achieve the temperatures required within constant ranges. After setting the desired temperature in the control room, the BMS compared the return air temperature with the temperature set point adjusted. In case the return air temperature was higher than the set point, the BMS commanded the compressors (two stages) to start in sequence as temperature increased. Compressor stages therefore kept on until the set point was reached. The BMS compares the supply air temperature through the sensor (SAT) and the set points. The cooling coil valve actuator (CCVA) opened the valve for more cooling or closed the valve for less cooling to maintain the required supply air temperature set point.

According to the information gathered about the base-line classroom temperature in educational buildings in Jeddah for adult students which was conducted prior to the intervention and prior to the pilot study, a temperature of 20°C was found to be the most common temperature set in more than 80% of educational buildings surveyed. Moreover, during the pilot study period, the prevailing temperature and CO_2 concentration levels were monitored in 25 classrooms in the selected case study building for the whole working day over a period of 5 weeks. It has been observed that the ambient temperatures of the classrooms were ~20–21°C and that CO_2 concentration levels ranges between 612 and 647 ppm. The reference exposure condition (baseline condition) was set at CO_2 ~ 600 ppm and temperature was set at ~20°C (referred to as condition 1).

Figure 5.1: The exposure conditions investigated in the study.

Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

Base line condition

The measurements were initiated at 8:00 AM to allow time for each unit to get adapted to their environment. This data was collected continuously from 8:00 AM until 3:00 PM. The equipment used for the physical measurements (discussed in the previous chapter, Table 4.4.2) were located in a central location in the classrooms since the outlets and inlets of the ACs are distributed equally in the ceiling. The equipment was placed at the head height of a seated person.

5.3 Subjective Measurements

5.3.1 Gathering Information on the Mean Classroom Temperature in Educational Buildings for Adult Students in Jeddah, Saudi Arabia.

Questionnaire forms used are described in the previous chapter and a sample is provided in Appendix A. The questionnaires were disseminated by physical visits to the buildings, or via emails, or via phone calls.

5.3.2 Questionnaire Responses from Participants

Questionnaire forms used are described in the previous chapter and a sample is provided in Appendix B.

5.4 Cognitive Performance Assessment

As discussed in the previous chapter, eight cognitive tasks were evaluated using BARS battery (http://www.nweta.com/bars/). Also, the description of the cognitive tasks is provided in the previous chapter, along with the parameters that were modified each time of the exposure. The parameters controlled and manipulated were: the number of trials, maximum number of timeouts and errors, trial sequence, stimulus shape, stimulus duration, success/fail criteria (e.g. 1 out of two chances), response buttons/keys, break duration between trials, number of digits in the sequence (e.g. 9 = maximum), and criterion for ending the test (e.g. 2 correct in a row), and assessment duration. Performance was measured in terms of speed and accuracy (expressed as a percentage of errors).

5.5 Results and Discussion

5.5.1 The Average Values of the Physical Environment Measurements of the Monitored Classrooms Collected during the Exposure Conditions

Table 5.5.1 shows the results of the continuous measurements of the monitored classroom's temperature, relative humidity, CO_2, air velocity, and ambient noise levels (in terms of the means of all relevant experiments ± SD). The calculated lighting intensity was 400 Lux.

Table 5.5.1: Measured environmental parameters during the exposure conditions (mean ± SD).

Condition	Classroom temperature (°C)	Classroom CO_2 levels (ppm)	Classroom relative humidity (%)	Air velocity from air-conditioners' diffusers (m/s)	Classroom noise levels (dB(A))
Condition 1	19.8 ± 0.2	596 ± 18	44.9 ± 0.32	0.15 ± 0.1	35 ± 2
Condition 2	20.3 ± 0.2	9989 ± 24	44.7 ± 0.43	0.14 ± 0.2	37 ± 3
Condition 3	20.5 ± 0.2	1807 ± 30	44.4 ± 0.29	0.11 ± 0.1	34 ± 2
Condition 4	22.9 ± 0.2	607 ± 22	42.7 ± 0.19	0.11 ± 0.1	38 ± 3
Condition 5	23.2 ± 0.2	1004 ± 27	42.2 ± 0.15	0.10 ± 0.1	35 ± 2
Condition 6	23.4 ± 0.2	1811 ± 35	42.2 ± 0.20	0.10 ± 0.1	36 ± 3
Condition 7	25.2 ± 0.2	612 ± 25	39.6 ± 0.31	0.09 ± 0.2	36 ± 3
Condition 8	25.2 ± 0.2	1013 ± 31	39.4 ± 0.27	0.09 ± 0.1	35 ± 3
Condition 9	25.4 ± 0.2	1817 ± 40	39.2 ± 0.40	0.08 ± 0.1	34 ± 2

5.5.2 Gathering Information on the Mean Classroom Temperature in Educational Buildings for Adult Students in Jeddah, Saudi Arabia.

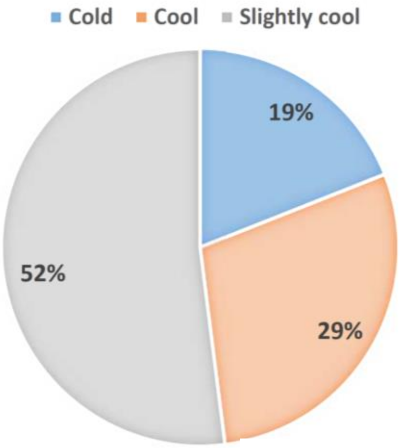
On the basis of the information gathered from 338 secondary schools out of the total number of ~450 schools in Jeddah for adult female students which were approached, and according to the responses from the surveyed seven universities in Jeddah, the mean AC temperature set in classrooms is 20°C. This was reported by slightly above 90% of the buildings as 'almost' constant during the academic year explained by the lack of 'tangible/ noticeable' variation in the outdoor climatic conditions.

5.5.3 Questionnaire Responses from Participants

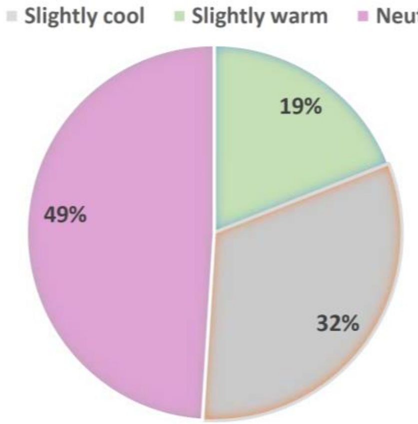
Firstly, all participants agreed that the duration of the cognitive tasks and difficulty level were reasonable. Secondly, according to the pie charts below (Figures 5.2 a, b, and c), exposures to the conditions when temperature was set at 23°C elevated the thermal comfort sensations of the participants from cold, cool, and slightly cool sensations at 20°C towards neutral sensation and/or close to it. Nevertheless, exposures to the conditions when temperature was set at 25°C shifted the neutral sensations (and/or close to it) to slightly warm, warm, and hot sensations.

Figure 5.2: Thermal sensation votes of the participants during the exposure conditions.

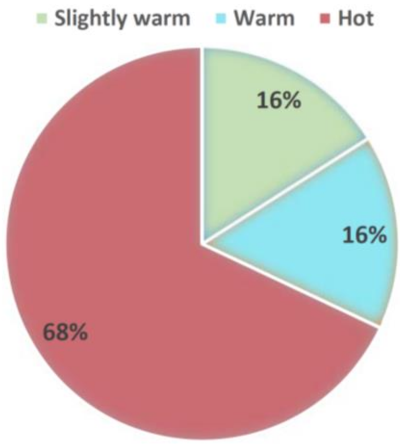
a-Thermal sensations votes during the three exposure conditions when temperature was set at 20°C.



b-Thermal sensations votes during the three exposure conditions when temperature was set at 23°C.



c-Thermal sensations votes during the three exposure conditions when temperature was set at 25°C.



Moreover, the questionnaire responses collected from the participants indicated that the majority of participants (84%) reported intolerable thermal condition during the three exposure conditions when the temperature was set at 25°C and CO_2 concentrations reached the average levels of 100 ppm and/or 1800 ppm (68% of participants reported hot thermal sensation, and 16% reported warm thermal sensation). In addition, the participants reported that they felt more tired and sleepy and had headaches and were unable to think clearly and focus during the three exposure conditions when the CO_2 levels reached ~1800 ppm (at temperatures 20°C, 23°C and 25°C). They reported also that the intensity of these symptoms became even worse at the exposure condition when the CO_2 levels were an average of 1800 ppm while temperature was set at 25°C, given that the participants were blind to the exposure conditions.

Also, the questionnaire responses gathered indicated that all participants normally keep ACs turned on during the whole day at home (in both summer and winter), during sleeping hours, and also on transportation. It was indicated that the mean AC temperature set at home by the Saudi participants was 18–20°C, which was found 2°C lower than that reported by the non-Saudi participants. Furthermore, it was found that, on average, the participants spent 88% of their day inside buildings, and 7% in a vehicle. Only 5% of participants' time was actually spent outdoors.

Moreover, it was observed, as expected according to Saudi cultures and norms of women's clothing, that all the participants wear a black silk loose dress with long sleeves on top of their clothes. It is called *Abaya*, which is the local custom for women in Saudi Arabia, and must be worn outdoors. It has as a value of 1.1 clo.

5.5.4 The Effects of the Exposure Conditions on the Cognitive Tasks

First, according to the descriptive analysis results, the most interesting observations were that the lowest percentage of errors occurred when temperature was set at ~20°C and CO_2 levels were set at levels within the range of ~600 ppm (which is during the baseline condition, condition 1). This was for vigilance tasks, namely the SRT, the CPT and the alternative tapping (ALT TAP) tasks. This was observed to be concurrent with the slowest speed of response. Also, the highest percentage of errors occurred when the temperature was set at ~25°C and CO_2 levels were set al levels within the range of ~1800 ppm (condition 9). This was observed to be simultaneous with the fastest speed of response. However, for the rest of tasks (memory and learning), the lowest percentage of errors occurred when temperature was set at ~23°C and CO_2 levels were set at levels within the range of ~600 ppm (condition 4). Whereas the highest percentage of errors occurred during condition 9 (temperature ~25°C, and CO_2~1800 ppm) with a simultaneous fastest speed of response. Furthermore, the percentages of errors for all tasks increased significantly during condition 6 when temperature was set at ~23°C and CO_2 levels were set at levels within the range of ~1800 ppm.

Overall, the results indicated that the percentages of errors for all the cognitive tasks considered in this study increased significantly during the conditions when CO_2 levels were set at the average range of ~1800 ppm and 1000 ppm relative to 600 ppm and that the speed of response decreased significantly for all tasks during the conditions when temperature was set at 20°C relative to 23°C and 25°C.

Figure 5.3: The estimated effects on the percentages of errors for all tasks during the exposure conditions (as the average of all percentages of errors calculated from all participants).

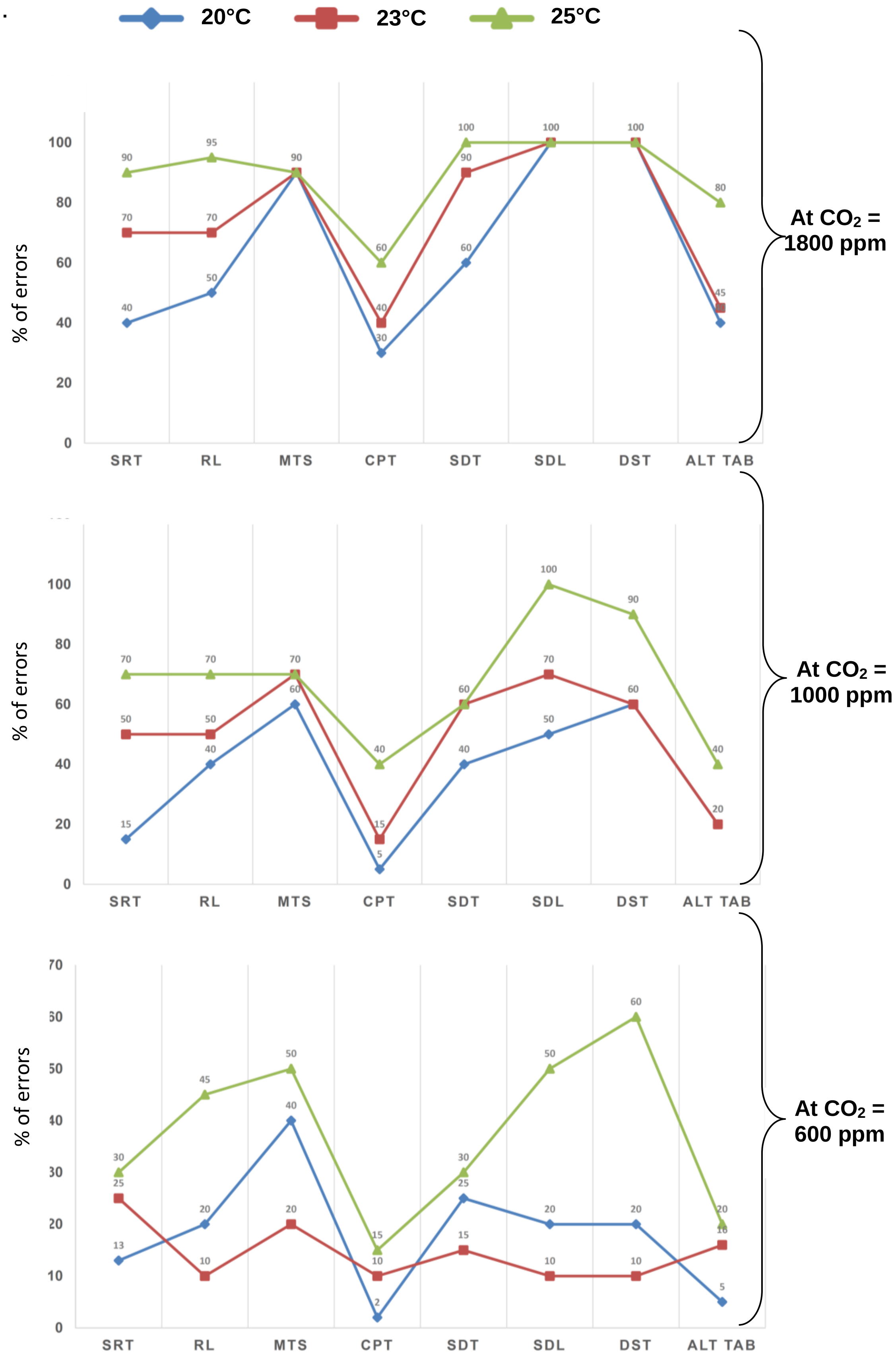
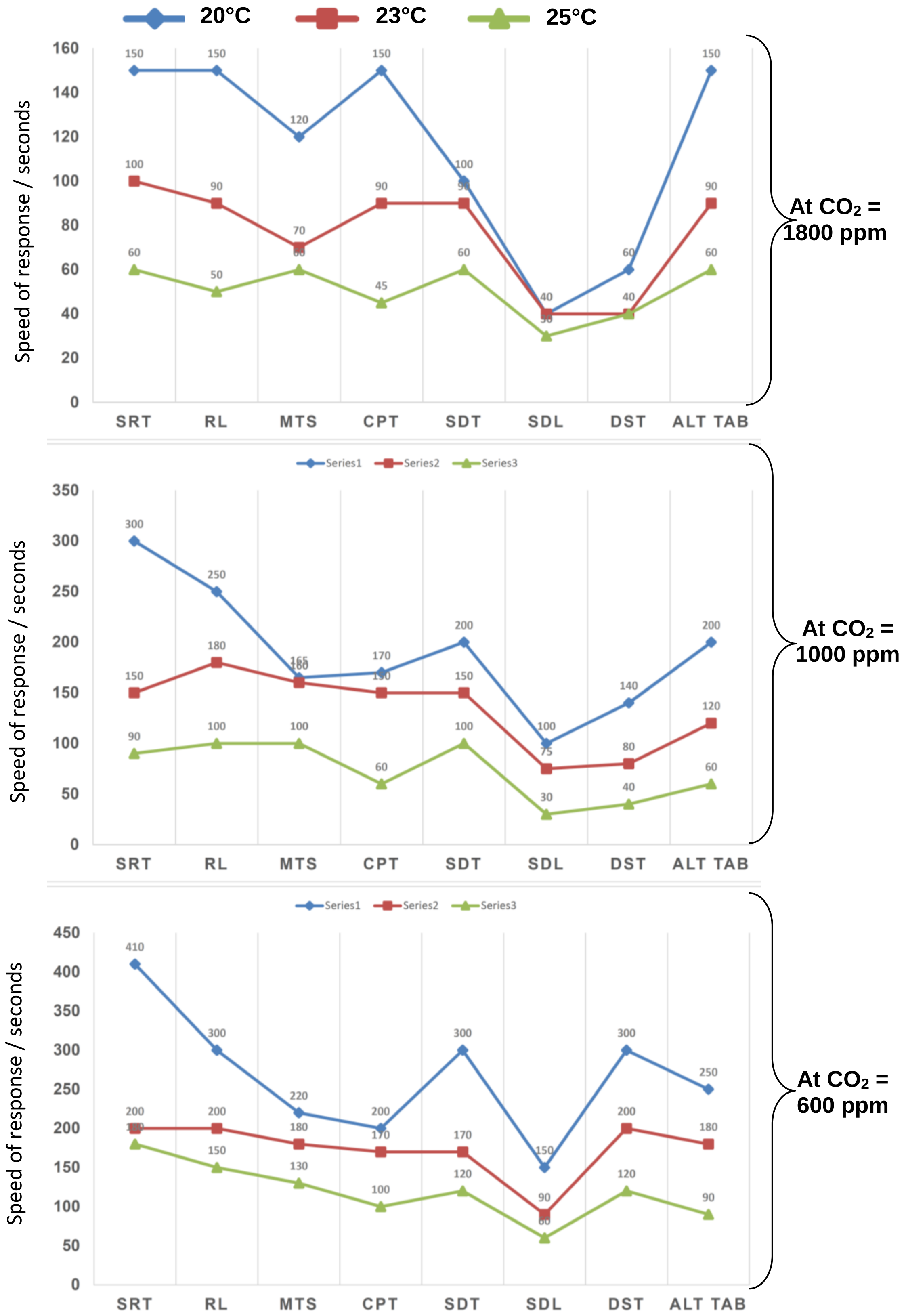


Figure 5.4: The estimated effects on the speeds of responses for all tasks during the exposure conditions per seconds (as the average of all speeds of responses calculated from all participants).



Results of the univariable multilevel analysis of the effects of exposure conditions on the cognitive tests are presented in Table 5.5.2 and Table 5.5.3. In Table 5.5.2, the estimated effect size for the effect of exposure conditions on the accuracy of tasks (percentages of errors) by the univariable multilevel analysis are presented. For instance, the percentages of errors of the SRT test has increased significantly (p=0.02) by an estimate of 2% due to the effect of exposure condition 2 vs. condition 1 (base line condition).

In Table 5.5.3, the estimated effect size for the effect of exposure conditions on the speed of reaction by the univariable multilevel analysis are presented. For instance, the speed of reaction decreased significantly (p=0.02) by an estimate of 15 seconds due to the effect of exposure condition 2 vs. condition 1 (base-line).

No significant associations were observed between both the accuracy and speed of performance for all the cognitive tasks with the confounding variables considered in the study namely: ambient noise levels, caffeine intake, physical activity, eating breakfast, sleeping hours, stress, AC temperature at home, ethnic background, number of years spent in the country for the non-Saudi participants, and clothing levels, mostly due to the small sample size of the study. Therefore, the multi-variable multi-level analysis was not performed for the results obtained.

Similar to the descriptive analysis, it was observed from the univariable multilevel analysis of the effects of exposure conditions on the cognitive tests that the tasks were affected differentially depending on their type. For the vigilance tasks, percentage of errors increased significantly during all exposure conditions relative to condition 1 (base-line condition), whereas for the rest of tasks, percentage of errors decreased significantly during exposure to condition 4 relative to the rest of exposure conditions. The highest significant percentage of errors occurred during exposure to condition 9 when the temperature reached ~25°C and CO_2 levels reached ~1800 ppm with a simultaneous highest speed of response relative to condition 1.

With regard to the different observed effects of the conditions of exposures on vigilance tasks relative to the memory and learning tasks, most relevant studies agreed that vigilance and memory tasks differ in terms of cognitive load, and are most likely carried out in different brain areas (e.g. Lan et al., 2009). Moreover, the overall significant slower performance observed during the exposure conditions when the temperature was set at 20°C relative to 23°C and 25°C is most likely attributable to the stiffness in hand joints when the participants were exposed to cool/cold exposures. This observation is in line with all relevant studies like Seppänen et al. (2004), Tanabe and Nishihara (2004) and Lan et al. (2009). Also, an explanation was provided for the high speed during the conditions when the temperature was set at 25°C, which could be that the rise in internal body temperature resulted in an increase in the rate of neural activity and a decrease in perceived time (Bruyn and Lamoureux, 2005). Therefore, accuracy and speed results obtained were valid and in line with the most relevant studies. Accordingly, the proposed cognitive assessment tool was found reliable for adoption in the intervention study.

With regard to the observed different effects of the conditions of exposures on vigilance tasks relative to the memory and learning tasks, this observation concurs with most of the relevant studies (e.g. Lan and Lian, 2009), especially that no extreme patterns have been observed. Overall, the results obtained were found to be valid and the proposed cognitive assessment tool was found to be reliable for adoption in the intervention study.

Table 5.5.2: Results of the estimated effects of exposure conditions relative to condition 1 (temperature=20°C, CO_2 ~600 ppm), the base-line condition, on the percentages of errors estimated by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%	
Condition	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**
2 vs. 1	2.00 (1.00, 3.00)	0.020	10.00 (6.00, 14.00)	0.001	20.00 (15.00, 25.00)	0.001	3.00 (2.00, 4.00)	0.010
3 vs. 1	27.00 (22.00, 32.00)	0.001	20.00 (15.00, 25.00)	0.001	50.00 (43.00, 57.00)	0.005	28.00 (23.00, 33.00)	0.020
4 vs. 1	12.00 (7.00, 17.00)	0.005	-10.00 (-14.00, -6.00)	<0.001	10.00 (8.00, 10.00)	0.002	8.00 (05.00, 11.00)	0.002
5 vs. 1	37.00 (32.00, 44.00)	0.002	20.00 (15.00, 25.00)	0.002	30.00 (26.00, 34.00)	0.005	13.00 (9.00, 17.00)	0.006
6 vs. 1	57.00 (47.00, 67.00)	<0.001	40.00 (33.00, 47.00)	<0.001	50.00 (45.00, 55.00)	0.025	38.00 (33.00, 43.00)	0.005
7 vs. 1	17.00 (9.00, 25.00)	0.001	15.00 (10.00, 20.00)	<0.001	10.00 (8.00, 12.00)	0.002	13.00 (9.00, 17.00)	0.020
8 vs. 1	57.00 (47.00, 67.00)	<0.001	40.00 (32.00, 48.00)	<0.001	30.00 (27.00, 33.00)	0.001	38.00 (30.00, 46.00)	0.002
9 vs. 1	77.00 (64.00, 90.00)	<0.001	65.00 (50.00, 80.00)	<0.001	50.00 (45.00, 55.00)	0.001	58.00 (46.00, 70.00)	0.001

	SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Condition	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**
2 vs. 1	15.00 (12.00, 18.00)	0.020	30.00 (27.00, 33.00)	<0.001	30.00 (25.00, 35.00)	0.020	4.00 (3.00, 5.00)	0.010
3 vs. 1	35.00 (30.00, 40.00)	0.030	60.00 (57.00, 63.00)	<0.001	70.00 (60.00, 80.00)	0.010	24.00 (20.00, 28.00)	0.001
4 vs. 1	0.00 (0.00, 0.00)	0.010	-20.00 (-23.00, -17.00)	<0.001	-10.00 (-12.00, -8.00)	0.050	-11.00 (-14.00, -8.00)	0.002
5 vs. 1	35.00 (30.00, 40.00)	0.050	10.00 (7.00, 13.00)	<0.001	30.00 (25.00, 35.00)	0.030	4.00 (3.00, 5.00)	0.001
6 vs. 1	65.00 (58.00, 72.00)	0.020	60.00 (55.00, 65.00)	<0.001	70.00 (60.00, 80.00)	0.010	29.00 (24.00, 34.00)	0.002
7 vs. 1	5.00 (3.00, 7.00)	<0.001	10.00 (5.00, 15.00)	<0.001	30.00 (25.00, 35.00)	<0.001	4.00 (1.00, 7.00)	0.005
8 vs. 1	35.00 (29.00, 41.00)	<0.001	60.00 (55.00, 65.00)	<0.001	60.00 (53.00, 67.00)	<0.001	24.00 (19.00, 29.00)	0.002
9 vs. 1	75.00 (65.00, 85.00)	<0.001	60.00 (55.00, 65.00)	<0.001	70.00 (60.00, 80.00)	<0.001	64.00 (59.00, 69.00)	0.001

SRT= Simple Reaction Time, measuring sustained attention

RL= Reversal Learning, measuring learning, coordination, and memory

MTS= Match to Sample, measuring learning and visual memory capacity

CPT= Continuous Performance, measuring sustained and selective attention

SDT= Symbol Digit Test, measuring complex memory capacity

SDL= Serial Digit, measuring learning and complex memory capacity

DST= Digit Span, measuring learning and digital memory capacity

ALTERNATIVE TAB= Alternative Tabbing, measuring coordination between brain hemispheres

Conditions of exposure	Ambient temperature	CO2 concentration level	
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm	Base line condition
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm	
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm	
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm	
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm	
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm	
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm	
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm	
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm	

Table 5.5.3: Results of the estimated effects of exposure conditions relative to condition 1 (temperature=20°C, CO_2 ~600 ppm), the base-line condition, on the speeds of response estimated by the univariable multilevel analysis.

Condition	SRT speed/sec estimate (95% CI)	p-value	RL speed/sec estimate (95% CI)	p-value	MTS speed/sec estimate (95% CI)	p-value	CPT speed/sec estimate (95% CI)	p-value
2 vs. 1	-110.00 (-150.00, -70.00)	0.002	-50.00 (-70.00, -30.00)	0.001	-70.00 (-90.00, -50.00)	<0.001	-30.00 (-35.00, -25.00)	0.070
3 vs. 1	-260.00 (-320.00, -200.00)	0.025	-210.00 (-260.00, -160.00)	<0.001	-160.00 (-210.00, -110.00)	0.010	-50.00 (-60.00, -40.00)	0.055
4 vs. 1	-210.00 (-260.00, -160.00)	0.005	-100.00 (-140.00, -60.00)	<0.001	-40.00 (-50.00, -30.00)	0.050	-30.00 (-40.00, -20.00)	0.040
5 vs. 1	-260.00 (-310.00, -210.00)	0.040	-120.00 (-170.00, -70.00)	0.001	-60.00 (-75.00, -45.00)	0.040	-50.00 (-60.00, -40.00)	0.020
6 vs. 1	-310.00 (-370.00, -250.00)	0.025	-150.00 (-200.00, -100.00)	0.001	-100.00 (-120.00, -80.00)	0.030	-110.00 (-140.00, -80.00)	0.020
7 vs. 1	-230.00 (-280.00, -180.00)	0.060	-150.00 (-200.00, -100.00)	0.001	-90.00 (-110.00, -70.00)	0.020	-100.00 (-130.00, -70.00)	0.050
8 vs. 1	-320.00 (-390.00, -250.00)	0.050	-200.00 (-260.00, -140.00)	0.001	-120.00 (-170.00, -70.00)	0.010	-140.00 (-170.00, -110.00)	0.040
9 vs. 1	-350.00 (-420.00, -280.00)	0.050	-250.00 (-310.00, -190.00)	0.001	-130.00 (-180.00, -80.400)	0.010	-155.00 (-185.00, -125.00)	0.010

Condition	SDT speed/sec estimate (95% CI)	p-value	SDL speed/sec estimate (95% CI)	p-value	DST speed/sec estimate (95% CI)	p-value	ALTERNATIVE TAB speed/sec estimate (95% CI)	p-value
2 vs. 1	-100.00 (-120.00, -80.00)	0.010	-50.00 (-60.00, -40.00)	0.020	-160.00 (-210.00, -110.00)	0.020	-50.00 (-60.00, -40.00)	0.001
3 vs. 1	-200.00 (-250.00, -150.00)	0.050	-110.00 (-140.00, -80.00)	0.030	-240.00 (-290.00, -190.00)	0.010	-100.00 (-130.00, -70.00)	0.020
4 vs. 1	-130.00 (-160.00, -100.00)	0.030	-60.00 (-80.00, -40.00)	0.010	-100.00 (-130.00, -70.00)	0.030	-70.00 (-90.00, -50.00)	0.050
5 vs. 1	-150.00 (-180.00, -120.00)	0.020	-75.00 (-95.00, -55.00)	0.005	-220.00 (-270.00, -170.00)	0.005	-130.00 (-170.00, -90.00)	0.001
6 vs. 1	-200.00 (-250.00, -150.00)	0.025	-110.00 (-135.00, -85.00)	0.001	-260.00 (-320.00, -200.00)	0.001	-160.00 (-210.00, -110.00)	0.001
7 vs. 1	-180.00 (-215.00, -145.00)	0.010	-90.00 (-110.00, -70.00)	0.020	-180.00 (-230.00, -130.00)	0.020	-160.00 (-210.00, -110.00)	0.005
8 vs. 1	-200.00 (-250.00, -150.00)	0.030	-120.00 (-150.00, -90.00)	0.001	-260.00 (-310.00, -210.00)	0.030	-190.00 (-240.00, -140.00)	0.002
9 vs. 1	-240.00 (-290.00, -190.00)	0.010	-120.00 (-150.00, -90.00)	0.001	-260.00 (-310.00, -210.00)	0.050	-190.00 (-240.00, -140.00)	0.001

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Conditions of exposure	Ambient temperature	CO2 concentration level	
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm	Base line condition
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm	
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm	
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm	
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm	
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm	
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm	
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm	
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm	

5.6 Summary

1. First, the information gathered from the facility management survey indicated that more than 80% of the educational buildings surveyed in Jeddah for adult female students (in addition to the case study building) set the classrooms' temperature at ~20°C throughout the whole academic year, justified by the lack of variation in the outdoor temperature between late September and June. Therefore, with regard to the scarce data available from this context, it could be considered a novel contribution to the knowledge that the base-line temperature in the educational buildings for adult female students in Jeddah, Saudi Arabia is 20°C.
2. Second, with regard to the settings of the conditions of exposures for the intervention, CO_2 levels of ~1800 ppm were found to be the maximum that could have been reached, and the temperature of 25°C was found to be the maximum that could be tolerated by the participants. The exposure conditions were set accordingly as shown in Figure 5.1.
3. Furthermore, comprehensive feedback and responses were obtained from the participants using the disseminated questionnaire forms and thus the same questionnaires were used for the intervention study. In addition, the duration of the cognitive tests, difficulty level and the tasks chosen for the investigation were perceived to be acceptable by all participants.
4. In addition, offering community service hours to motivate the participants and encourage them to come back to complete their participation for the nine exposure conditions was found successful and actually worked as an alternative to the commonly used method of recruiting subjects by offering bursary payments, as the payment method could not have been applied owing to cultural and social considerations.
5. Moreover, because of the lack of associations which were found between both the accuracy and speed of performance with any of the confounding variables considered in the study, multilevel modelling was not performed. This was primarily attributed to the low number of participants. This could be also due to the well-controlled study design, which aimed at minimising the confounding effect. Thus, it was concluded that the proposed methodology for the study achieved the target of minimising the

confounding; therefore, the same methodological approach was applied for the intervention.

6. Nevertheless, the univariable multilevel analysis showed that the exposure conditions affected the performance of the tasks considered in the study differentially depending on the type of tasks. For the vigilance tasks, percentage of errors increased significantly during all exposure conditions relative to condition 1 (base-line condition), whereas for the rest of tasks, percentage of errors decreased significantly during exposure to condition 4 relative to the rest of exposure conditions. The highest significant percentage of errors occurred during exposure to condition 9 when the temperature reached ~25°C and CO_2 levels reached ~1800 ppm with a simultaneous highest speed of response relative to condition 1.
7. Also, it was found that the participants who were seated under the HVAC diffusers reported 'heaviness on head' and headache and inability to focus. Therefore, during the intervention, participants were not seated randomly, as they were allocated seats away from the HVAC diffusers.
8. In addition, it was indicated from the questionnaire responses with regard to the AC habits and norms at home, and also their TSVs, that individuals are more sensitive to the effect of temperature indoors and most likely influenced by the acclimation effect to indoor ACs' set temperatures. Accordingly, the importance of the acclimation effect considered for the study has yet become crucial for consideration, and the influence of ACs' set temperature at home was added to the confounding variables for the analysis of data of the intervention.

Accordingly, the intervention study was conducted using the same methodological approach after a few adjustments, as mentioned in the chapter. The results of this intervention study are presented in the following chapter.

Chapter 6: Results of the Intervention Study

The previous chapter described the pilot study conducted prior to the intervention in order to validate the methodology, the equipment, and assessment tools proposed for this study. Based on the results obtained and the conclusions drawn from the pilot study, the intervention study was conducted and the results are presented in this chapter. The results presented in this chapter are based on complete design analyses, i.e. analysis for each intervention only with the results obtained from those who had participated in all nine exposure conditions. The chapter begins with a summary of the sociodemographic characteristics of the study. Afterwards, the average values of the monitored physical environmental parameters collected during the intervention will be presented, followed by the subjective measurements gathered during the exposures. Following this, the results of both the univariable multilevel models and the multilevel models analyses are presented.

6.1 Sociodemographic Characteristics of the Study Population

Table 6.1 summarises the sociodemographic characteristics of the participants in this study. All participants were females, aged between 15 and 22 years old with a mean and also median age of 19 years old. The majority of the recruited participants are Saudis (64%). According to Saudi Arabia's Central Department of Statistics and Information, the estimated foreign population at the end of 2014 was almost 33% (KSA population, 2017). According to the questionnaire responses reported by participants, all of them were non-smokers, non-alcoholic, non-diabetic and had no chronic diseases. Generally, the information gathered indicated that the study population can be considered as sufficiently homogeneous.

Table 6.1: A summary of the sociodemographic characteristics of the participants in this study.

Variable	Frequency	Percentage
Age:		
15	60	12.0%
16	64	12.8%
17	66	13.2%
18	68	13.6%
19	62	12.4%
20	59	11.8%
21	65	13.0%
22	55	11.2%
Gender:		
Females	499	100%
Marital Status:		
Single	480	96.2%
Married	19	3.8%
Ethnicity:		
Bangladeshi	13	2.6%
Egyptian	15	3.0%
Indian	71	14.2%
Iraqi	1	0.2%
Lebanese	10	2.0%
Libyan	1	0.2%
Pakestani	49	9.8%
Palestanian	19	3.8%
Saudi	320	64.2%
Number of years spent in KSA for non-Saudis		
1, or less	10	5.6%
2	11	6.1%
3	7	3.9%
4	7	3.9%
5	9	5.0%
6	11	6.1%
7	13	7.3%
8	10	5.6%
9	8	4.5%
10	11	6.1%
11	9	5.0%
12	12	6.7%
13	10	5.6%
14	11	6.1%
15	10	5.6%
16	9	5.0%
17	10	5.6%
18	11	6.1%
Smoking and drinking alcohol profile		
non-smokers	499	100%
not drinking alcohol	499	100%
General fitness status		
regularly physically active	14	2.8%
not physically active	485	97.2%
General health status		
diabetic	0	0%
having any health issue or coronic disease	0	0%

6.2 The Average Values of the Physical Measurements

Table 6.2 presents the measured phusical paramters during the different exposure conditions investigated in the study in both classrooms. The calculated lighting intensity was 400 Lux.

Table 6.2: Measured environmental parameters (mean ± SD) during the different exposure conditions investigated in the study.

Condition	Classroom temperature (°C)		Classroom CO_2 concentration (ppm)		Classroom relative humidity (%)		Air velocity from air-conditioners' diffusers (m/s)		Classroom noise levels (dB(A))	
	Classroom 1	Classroom 2	Classroom 1	Classroom 2	Classroom 1	Classroom 2	Classroom 1	Classroom 2	Classroom 1	Classroom 2
Condition 1	19.8 ± 0.2	19.9 ± 0.2	592 ± 15	596 ± 18	45.11 ± 0.32	45.13 ± 0.35	0.15 ± 0.1	0.16 ± 0.1	38 ± 3	36 ± 3
Condition 2	20.2 ± 0.2	20.1 ± 0.2	1007 ± 24	1010 ± 27	45.07 ± 0.24	45.05 ± 0.22	0.16 ± 0.1	0.15 ± 0.2	36 ± 3	35 ± 3
Condition 3	20.4 ± 0.1	20.3 ± 0.2	1816 ± 36	1812 ± 30	44.66 ± 0.18	44.82 ± 0.20	0.14 ± 0.1	0.15 ± 0.1	33 ± 2	34 ± 3
Condition 4	23.1 ± 0.2	23.2 ± 0.1	609 ± 21	612 ± 22	43.18 ± 0.19	43.15 ± 0.15	0.12 ± 0.2	0.13 ± 0.1	35 ± 3	36 ± 3
Condition 5	23.3 ± 0.1	23.3± 0.1	1005 ± 25	1011 ± 29	43.10 ± 0.15	43.12 ± 0.15	0.11 ± 0.1	0.11 ± 0.1	35 ± 3	35 ± 3
Condition 6	23.3 ± 0.1	23.3± 0.2	1821 ± 43	1817 ± 36	42.97 ± 0.10	43.08 ± 0.10	0.11 ± 0.1	0.10 ± 0.1	35 ± 2	35 ± 3
Condition 7	24.9± 0.1	25.1± 0.2	614 ± 26	602 ± 15	41.22 ± 0.11	41.28 ± 0.13	0.09 ± 0.1	0.09 ± 0.1	36 ± 3	37 ± 3
Condition 8	25.1 ± 0.2	25.1 ± 0.2	1016 ± 35	1009 ± 31	39.87 ± 0.13	39.84 ± 0.15	0.10 ± 0.1	0.09 ± 0.1	33 ± 2	32 ± 2
Condition 9	25.3 ± 0.1	25.2 ± 0.2	1823 ± 45	1820 ± 40	39.76 ± 0.17	39.80 ± 0.15	0.08 ± 0.1	0.08 ± 0.1	34 ± 2	33 ± 2

6.3 Subjective Measurements: Questionnaire Responses from Participants

A total of 499 completed questionnaires were collected. Summary of the questionnaire responses and participants' TSVs are presented in Tables 6.3 and 6.4. It was indicated that:

- The overall average number of sleeping hours by participants during the night before participation was 7 hours or more for 99% of the participants. As discussed in the literature, sleep quantity is one of the influential factors affecting cognitive performance and therefore having adequate amounts of sleep before participation for almost all participants minimises the likeliness that the data could be biased by the effect of inadequate sleep.
- All participants ate breakfast on all days of participation, and 99% of the participants did not drink coffee, tea or coke or eat chocolate within two hours before participation which, again minimises the likeliness that the data could be biased by the effect of breakfast and/or caffeine.
- Less than 1% of the participants reported being stressed for personal reasons, which are not related to the exposure conditions. Only 2% of the participants were dissatisfied with the ambient noise levels during all conditions of exposure.
- Only 5% of the participants reported symptoms of dizziness, headache and heaviness on their head, leading to the inability to focus during the exposure conditions when CO_2 levels were an average of ~600 ppm and/or ~1000 ppm, while 95% reported these symptoms in the exposure conditions when CO_2 levels reached ~1800 ppm.
- 99% of the participants reported these symptoms during the exposure condition when the CO_2 levels were an average of ~1800 ppm while temperature was set at 25°C (condition 9).
- 98% of the participants reported wearing clothes equivalent to 0.8 clo and 0.9 clo (49% for each) under the *Abaya*. Only 2% of the participants were wearing clothes equivalent to 1.0 clo and/or 1.1 clo under the *Abaya*.
- 82% of the participants reported numbness in their fingers during the exposure conditions when the temperature was set at 20°C, and less than 1% reported numbness in fingers when the temperature was set at 23°C.

- There were no reports of numbness in fingers in any exposure conditions when the temperature was set at 25°C.

Table 6.3: Summary of the questionnaire responses gathered during the investigated exposure conditions.

	Sleeping hours (More than 7 hours)	Caffeine intake (drinking coffee or coke within 2 hrs before participating)	Having breakfast on the same day of the participation	Reported dissatisfaction with the ambient noise leading to inability to focus	Reported symptoms of dizziness, headache and heaviness on head leading to inability to focus	Reported other symptoms leading to inability to focus
	Percantage	Percantage	Percantage	Percantage	Percantage	Percantage
Condition 1	99.4	0.4	99.6	2.8	3.0	3.4
Condition 2	99.6	0.8	100	0.8	9.6	9.9
Condition 3	98.4	1.0	100	3.0	93	94.2
Condition 4	99.0	0.6	100	2.0	2.8	2.0
Condition 5	98.2	0.4	99.4	2.6	5.0	4.6
Condition 6	99.2	0.8	100	2.8	93.4	97.2
Condition 7	98.8	0.8	100	1.2	89.0	84.2
Condition 8	99.4	0.4	100	0.6	98.6	98.6
Condition 9	99.2	0.4	100	2.8	99.4	99.4

	Reported numbness in fingers/ stiffness in joints which impairs the speed of hands	Reported inability to focus owing to being stressed or feeling unwell due to personal reasons not related to the experimental exposure	Reported overall speedy performance and lack of concentration due to the willing to leave the room ASAP and intolerable thermal discomfort	Clothing levels			
				0.8	0.9	1.0	1.1
	Percantage	Percantage	Percantage	%	%	%	%
Condition 1	77.8	0.8	42.3	64.0	34.0	1.0	1.0
Condition 2	83.0	0.4	46.3	42.0	56.0	1.0	1.0
Condition 3	86.6	1.4	79.2	64.0	34.0	0.8	0.2
Condition 4	1.4	0.8	65.0	63.0	34.0	2.0	1.0
Condition 5	0.4	0.2	94.2	66.0	31.6	1.6	0.8
Condition 6	0.0	0.4	98.6	66.5	30.1	1.6	1.8
Condition 7	0.0	0.6	73.1	65.3	33.0	1.0	1.0
Condition 8	0.0	0.8	100	39.8	58.0	1.2	1.0
Condition 9	0.0	0.4	100	39.1	58.5	1.4	1.0

Table 6.4: Thermal comfort sensation votes segregated by ethnicity.

	Thermal Sensation Votes (TSV) for Saudi participants						
	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
	%	%	%	%	%	%	%
Condition 1	6	17	53	24	0	0	0
Condition 2	5	14	55	27	0	0	0
Condition 3	4	13	52	31	0	0	0
Condition 4	0	0	0	53	31	15	1
Condition 5	0	0	0	5	70	20	5
Condition 6	0	0	0	0	0	25	75
Condition 7	0	0	0	0	1	6	93
Condition 8	0	0	0	0	0	0	100
Condition 9	0	0	0	0	0	0	100

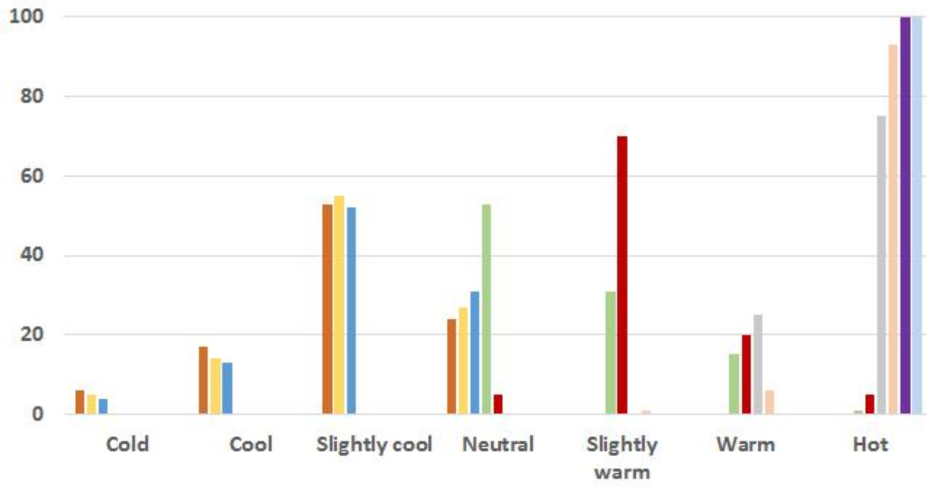
	Thermal Sensation Votes (TSV) for non-Saudi participants						
	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
	%	%	%	%	%	%	%
Condition 1	38	36	20	6	0	0	0
Condition 2	34	31	27	9	0	0	0
Condition 3	18	18	47	17	0	0	0
Condition 4	0	3	47	50	0	0	0
Condition 5	0	0	0	54	34	12	0
Condition 6	0	0	0	9	47	32	12
Condition 7	0	0	0	0	10	80	10
Condition 8	0	0	0	0	0	0	100
Condition 9	0	0	0	0	0	0	100

Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

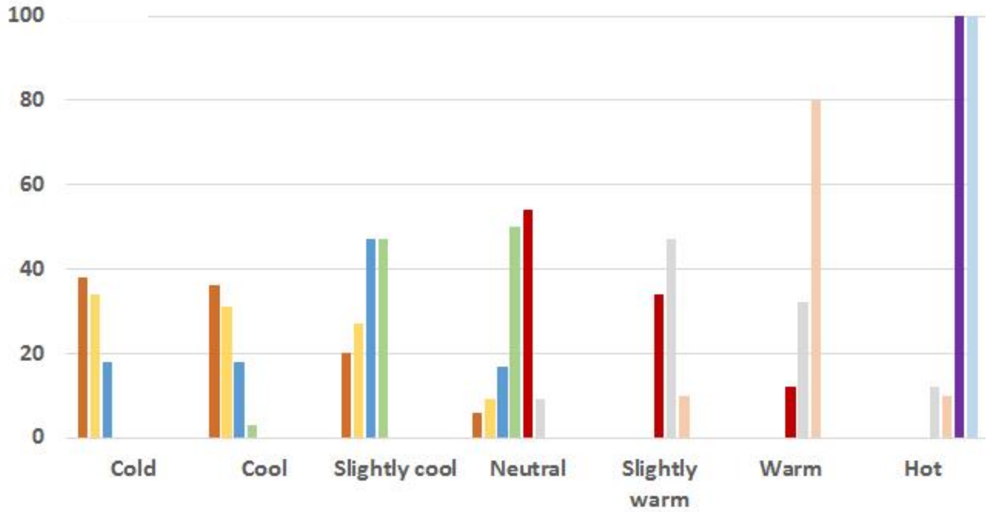
Base line condition

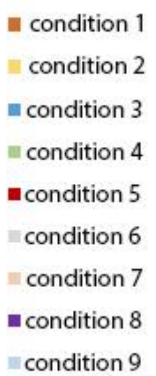
Figure 6.1: Frequencies of the thermal sensation votes of the Saudi participants (a) vs. frequencies of the thermal sensation votes of the non-Saudi participants (b), during the different exposure conditions investigated in the study.

(a)



(b)





Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

Base line condition

6.4 Descriptive Statistical Analysis

As a first stage, a descriptive analysis was performed for effects of the exposure conditions investigated in this study on participants' cognitive performance, to check whether there is significant variability in performances across domains in order to indicate a specific pattern of impairment. Error bar charts were plotted with the aim to show any extreme observations, as well as any interesting pattern of strength and/or weakness, provided in Appendix C.

An interesting pattern observed was that the percentage of errors for all the cognitive tasks peaked during exposure condition 3 (temperature=20°C, CO_2 levels ~1800 ppm), also during condition 6 (temperature=23°C, CO_2 levels ~1800 ppm), and during condition 9 (temperature=25°C, CO_2 levels ~1800 ppm). On the other hand, the minimum percentage of errors for all cognitive tasks was observed during exposure condition 1 (temperature=20°C, CO_2 levels ~600 ppm), and condition 4 (temperature=23°C, CO_2 levels ~600 ppm), and condition 7 (temperature=25°C, CO_2 levels ~600 ppm). It was also observed that the speed of response increases as the temperature increases.

It was observed that all performances fall within the moderately impaired range, thus it was possible to perform the univariable multilevel mixed effect analysis.

6.5 Univariable Multilevel Analysis

The univariable multilevel analysis results obtained for all the confounders considered in the study are presented in Appendix D.

The estimated effect size for the effect of exposure conditions on the accuracy of tasks (percentages of errors) and speed of reaction obtained by the univariable multilevel analysis are highlighted below and referred to the so-called 'zero models' (Table 6.5 and Table 6.6). This is because none of the confounding variables was added to these models at this stage. Nevertheless, the associated confounders will be added to these models in particular for the multivariable multilevel analysis.

Table 6.5: The estimated effect size for the effects of exposure conditions on the accuracy (percentages of errors) obtained by the univariable multilevel analysis (zero model).

	SRT error%		RL error%		MTS error%		CPT error%	
Condition	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
2 vs. 1	2.41 (1.39, 3.42)	<0.001	3.99 (2.61, 5.37)	<0.001	2.33 (1.82, 2.85)	<0.001	2.74 (1.05, 3.43)	<0.001
3 vs. 1	5.37 (4.96, 6.78)	<0.001	8.93 (7.55, 9.31)	<0.001	5.87 (5.35, 5.38)	<0.001	6.42 (5.05, 7.79)	<0.001
4 vs. 1	3.87 (3.50, 4.24)	<0.001	-1.87 (-2.42, -1.33)	<0.001	-1.19 (-1.71, -1.50)	<0.001	4.19 (3.77, 4.60)	<0.001
5 vs. 1	9.71 (9.34, 10.08)	<0.001	9.71 (9.34, 10.08)	<0.001	9.95 (9.57, 10.33)	<0.001	11.61 (10.20, 12.02)	<0.001
6 vs. 1	12.06 (11.69, 12.43)	<0.001	15.12 (14.71, 16.53)	<0.001	10.80 (10.28, 11.31)	<0.001	14.79 (13.41, 15.17)	<0.001
7 vs. 1	4.41 (3.04, 5.78)	<0.001	8.81 (8.43, 9.19)	<0.001	7.85 (6.34, 8.37)	<0.001	5.96 (4.55, 6.37)	<0.001
8 vs. 1	13.87 (13.50, 14.24)	<0.001	17.33 (16.95, 17.71)	<0.001	14.42 (13.90, 15.93)	<0.001	14.75 (13.34, 15.17)	<0.001
9 vs. 1	22.13 (21.75, 22.51)	<0.001	21.55 (20.03, 22.06)	<0.001	21.71 (20.34, 22.08)	<0.001	22.70 (21.28, 23.11)	<0.001

	SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Condition	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
2 vs. 1	3.38 (2.84, 3.93)	<0.001	5.54 (4.51, 6.57)	<0.001	5.65 (4.41, 6.90)	<0.001	2.66 (1.92, 3.40)	<0.001
3 vs. 1	5.49 (3.46, 7.52)	<0.001	9.42 (8.05, 10.79)	<0.001	9.76 (8.53, 10.99)	<0.001	4.62 (3.87, 5.36)	<0.001
4 vs. 1	-1.38 (-2.06, -0.30)	<0.001	-2.03 (-3.39, -1.33)	<0.001	-2.78 (-3.01, -1.55)	<0.001	3.52 (2.77, 4.26)	<0.001
5 vs. 1	9.12 (8.61, 10.64)	<0.001	10.49 (9.46, 11.52)	<0.001	12.01 (11.78, 13.24)	<0.001	8.66 (7.91, 9.40)	<0.001
6 vs. 1	14.06 (13.69, 15.43)	<0.001	15.45 (14.40, 16.50)	<0.001	18.10 (17.00, 19.10)	<0.001	13.50 (12.76, 14.24)	<0.001
7 vs. 1	5.41 (4.04, 6.78)	<0.001	9.40 (8.40, 10.50)	<0.001	10.50 (9.75, 11.50)	<0.001	6.54 (5.80, 7.28)	<0.001
8 vs. 1	12.87 (11.50, 13.24)	<0.001	20.20 (19.10, 21.40)	<0.001	20.50 (19.40, 21.90)	<0.001	10.89 (10.15, 11.63)	<0.001
9 vs. 1	20.71 (19.34, 21.08)	<0.001	20.20 (19.10, 21.40)	<0.001	20.50 (19.40, 21.90)	<0.001	21.71 (20.97, 22.46)	<0.001

Conditions of exposure	Ambient temperature	CO2 concentration level	
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm	Base line condition
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm	
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm	
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm	
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm	
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm	
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm	
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm	
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm	

Table 6.6: The estimated effect size for the effects of exposure conditions on the speed of response obtained by the uni-variable multilevel analysis (zero model).

Condition	SRT speed/seconds estimate (95% CI)	p-value	RL speed/seconds estimate (95% CI)	p-value	MTS speed/seconds estimate (95% CI)	p-value	CPT speed/seconds estimate (95% CI)	p-value
2 vs. 1	-143.62 (-145.63, -141.62)	<0.001	-20.24 (-21.02, -19.47)	<0.001	-8.92 (-10.07, -7.78)	<0.001	-29.17 (-30.45, -27.89)	<0.001
3 vs. 1	-160.93 (-162.93, -158.92)	<0.001	-50.00 (-50.77, -49.22)	<0.001	-17.28 (-18.43, -16.14)	<0.001	-39.63 (-40.91, -38.35)	<0.001
4 vs. 1	-172.20 (-174.21, -170.20)	<0.001	-66.29 (-67.07, -65.52)	<0.001	-23.94 (-25.08, -22.79)	<0.001	-45.01 (-46.29, -43.73)	<0.001
5 vs. 1	-177.18 (-179.19, -175.18)	<0.001	-79.66 (-80.43, -78.88)	<0.001	-27.59 (-28.73, -26.44)	<0.001	-52.45 (-53.73, -51.17)	<0.001
6 vs. 1	-178.89 (-180.90, -176.89)	<0.001	-96.57 (-97.35, -95.80)	<0.001	-45.56 (-46.70, -44.41)	<0.001	-54.08 (-55.36, -52.80)	<0.001
7 vs. 1	-181.45 (-183.45, -179.44)	<0.001	-117.81 (-118.59, -117.04)	<0.001	-58.97 (-60.12, -57.83)	<0.001	-62.46 (-63.74, -61.18)	<0.001
8 vs. 1	-187.94 (-189.95, -185.94)	<0.001	-130.27 (-131.04, -129.49)	<0.001	-71.57 (-72.716, -70.43)	<0.001	-73.38 (-74.66, -72.10)	<0.001
9 vs. 1	-199.05 (-201.30, -198.40)	<0.001	-139.19 (-139.96, -138.42)	<0.001	-117.77 (-118.91, -116.62)	<0.001	-82.03 (-83.31, -80.74)	<0.001

Condition	SDT speed/seconds estimate (95% CI)	p-value	SDL speed/seconds estimate (95% CI)	p-value	DST speed/seconds estimate (95% CI)	p-value	ALTERNATIVE TAB speed/seconds estimate (95% CI)	p-value
2 vs. 1	-9.04 (-11.12, -6.75)	<0.001	-74.60 (-81.95, -67.24)	<0.001	-28.60 (-31.37, -25.83)	<0.001	-25.20 (-26.59, -23.82)	<0.001
3 vs. 1	-26.50 (-30.20, -24.90)	<0.001	-130.00 (-138.45, -124.00)	<0.001	-30.43 (-33.26, -27.80)	<0.001	-55.30 (-56.78, -53.98)	<0.001
4 vs. 1	-63.34 (-67.70, -62.99)	<0.001	-131.77 (-139.95, -125.58)	<0.001	-61.40 (-64.23, -58.77)	<0.001	-31.60 (-33.24, -30.54)	<0.001
5 vs. 1	-65.05 (-75.40, -60.69)	<0.001	-155.90 (-164.10, -149.73)	<0.001	-95.16 (-97.89, -92.43)	<0.001	-76.41 (-77.87, -75.15)	<0.001
6 vs. 1	-75.06 (-37.71, -32.42)	<0.001	-169.65 (-176.83,-152.47)	<0.001	-120.20 (-128.93, -113.47)	<0.001	-118.34 (-119.70, -116.97)	<0.001
7 vs. 1	-89.41 (-72.06, -66.77)	<0.001	-178.36 (-171.54,-181.18)	<0.001	-130.70 (-140.42, -120.97)	<0.001	-121.86 (-123.23, -120.50)	<0.001
8 vs. 1	-96.68 (-119.33, -84.04)	<0.001	-185.83 (-193.01,-178.65)	<0.001	-134.69 (-147.42, -125.96)	<0.001	-126.90 (-128.26, -125.54)	<0.001
9 vs. 1	-113.93 (-126.57, -91.28)	<0.001	-195.61 (-112.79,-188.42)	<0.001	-140.78 (-150.51, -127.05)	<0.001	-135.90 (-139.27, -128.54)	<0.001

Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

Base line condition

With regards to the main findings obtained from the univariable multilevel analyses presented in Appendix D. A summary of the effects of the confounding factors observed on the accuracy of tasks performed and speeds of responses is provided in Table 6.7. For instance, it was found that the performance of students in all the tasks assessed was not associated with age (Tables D.1 and D.2).

Table 6.7: Summary of the main findings obtained from the univariable multilevel analyses presented in Appendix D.

Confounding factor	**Effect**	**Reference in Appendix D**
Age	No association.	Tables D.1 and D.2, page 221.
Level of activity	No association.	Tables D.7 and D.8, page 223.
Sleeping hours	No association.	Tables D.9 and D.10, page 223.
Caffeine	No association.	Tables D.11 and D.12, page 224.
Stress owing to personal reasons not related to the exposure conditions	No association.	Tables D.13 and D.14, page 224.
Ambient noise	No association.	Tables D.15 and D.16, page 225.
Clothing levels	No association.	Tables D.23 and D.24, page 227.
Ethnicity	The percentages of errors by the Saudi participants were significantly lower and the speed of response was significantly faster for all tasks during all exposure conditions investigated compared to the non-Saudi participants.	Tables D.3 and D.4, page 221.

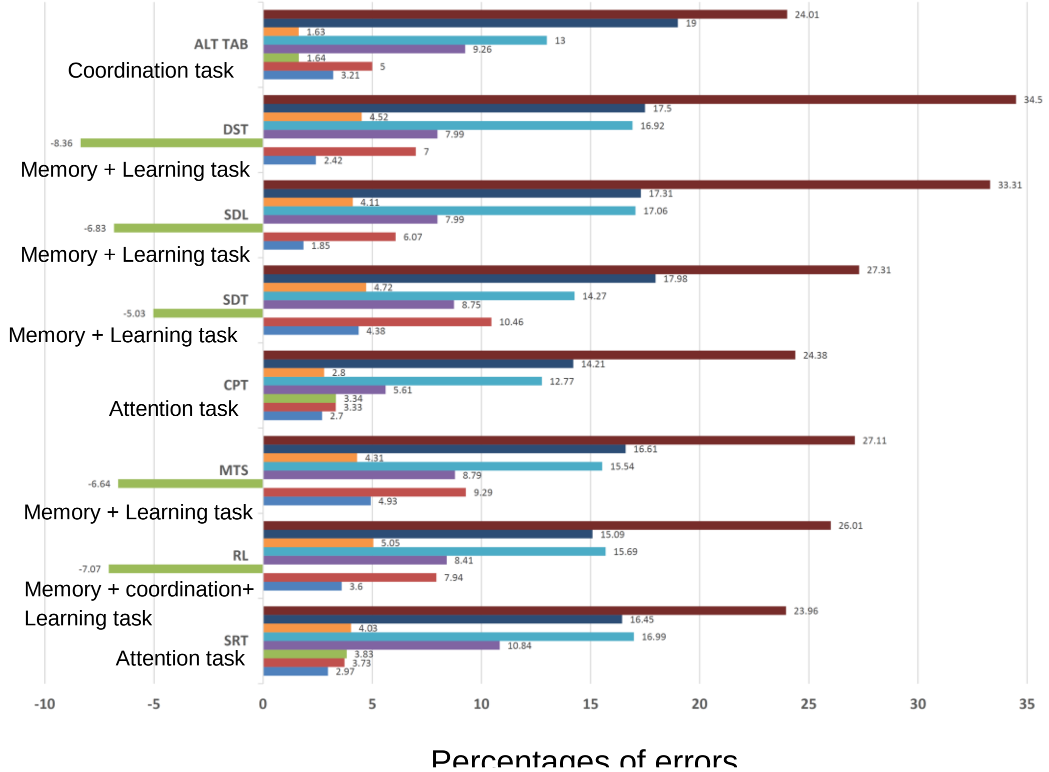
Number of years spent in the country for the non-Saudi participants	The percentages of errors decreased significantly for the non-Saudi participants who stayed in the country for five years or more relative to those who spent less than five years in the country, but no effect on the speed.	Tables D.5 and D.6, page 222.
AC set temperature at home	The percentages of errors decreased significantly for each 1°C increase in the AC set temperature at home in the range between 18-24°C. The speed of response increased significantly for each 1°C increase in the AC set temperature at home in the range between 18-24°C.	Tables D.25 and D.26, page 227.
Symptoms of headache, dizziness, heaviness on head, confusion, difficulty thinking, difficulty concentrating and fatigue	The percentage of errors increased significantly by the participants who detected these symptoms, and the speed of response decreased significantly for all tasks for those who detected the symptoms relative to those who didn't detect these symptoms.	Tables D.17 and D.18, page 225.
Symptoms of intolerable thermal discomfort that attributes to inability to focus and numbness in fingers	The percentage of errors increased significantly by the participants who detected these symptoms, and the speed of response of these participants increased significantly compared to the participants who didn't detect these symptoms.	Tables D.19 and D.20, D.21 and D.22, page 226.
Thermal comfort sensations	-The percentage of errors increased significantly for all tasks considered in this study when the participants perceived the thermal environment during the time of exposure as cold compared to the neutral comfortable sensation.	Tables D.27 and D.28, page 230.

	-The percentage of errors increased significantly for all tasks when the participants perceived the thermal environment as warm and hot compared to the neutral comfortable sensation, except for the alternative tapping test. -On the contrary, the percentage of errors decreased significantly for all tasks when the participants perceived the thermal environment as slightly warm compared to neutral. -Similarly, the percentage of errors decreased significantly for all tasks when the participants perceived the thermal environment during the time of exposure as cool and slightly cool compared to the neutral comfortable sensation.	

6.6 Multivariable Multilevel Analysis

According to the results obtained from the univariable multilevel models mentioned in the previous section, the confounders which were added to the zero model in the final multivariable multilevel model are ethnicity, number of years spent in the country (for the non-Saudi participants), thermal comfort sensations, AC's set temperature at home, symptoms of headache, dizziness, heaviness on head, confusion, difficulty thinking, difficulty concentrating and fatigue, and intolerable thermal discomfort attributable to an inability to focus. After adding these confounders to the zero models (models A, and B) of the effects of conditions of exposures on the accuracy and the speed of performance of the cognitive tasks, the estimated effect sizes obtained are presented in Tables 6.8 and 6.9. After adding the confounders in the final models, the changes observed in the percentages of errors and speeds of responses for all the cognitive tasks considered in the study and attributed to the exposure conditions relative to the baseline condition (condition 1) were plotted in Figure 6.2 and Figure 6.3 below.

Figure 6.2: The arithmetic difference between the estimated effect sizes attributed to the effects of confounding variables on the percentages of errors during all exposure conditions for all cognitive tasks considered in this study and the baseline condition (condition 1: temperature=20ºC, CO_2 levels ~600 ppm), derived from model A.



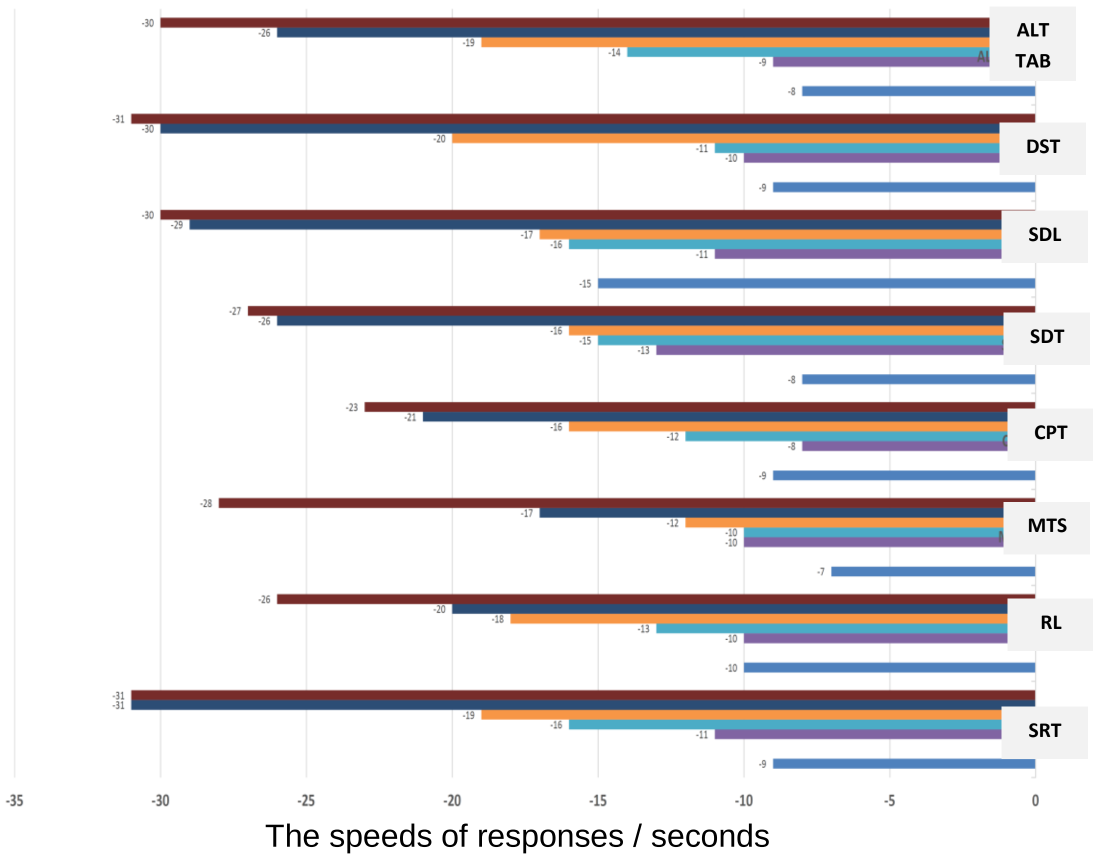
Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

Base line condition

- condition 9 (T= 25°C, CO_2= 1800 ppm)
- condition 8 (T= 25°C, CO_2= 1000 ppm)
- condition 7 (T= 25°C, CO_2= 600 ppm)
- condition 6 (T= 23°C, CO_2= 1800 ppm)
- condition 5 (T= 23°C, CO_2= 1000 ppm)
- condition 4 (T= 23°C, CO_2= 600 ppm)
- condition 3 (T= 20°C, CO_2= 1800 ppm)
- condition 2 (T= 20°C, CO_2= 1000 ppm)

It can be noted from Figure 6.2, that the accuracy (percentages of errors) of the cognitive tasks increased at the different exposure conditions, relative to the baseline condition (condition 1), after adding the estimated effect sizes of the confounding variables to the original and the estimated effect sizes derived from the multivariable multilevel statistical model. This was true for all conditions, except for condition 4 (temperature=20°C, CO_2 levels ~600 ppm), at which the percentages of errors decreased significantly from the baseline condition (condition 1) for the memory and learning tasks. This diagram was useful to highlight the direction of change in accuracy which occurred after adding the confounding variables to the model. Also, it could be noted that a higher magnitude of the effect occurred particularly during exposure to condition 9 for all tasks.

Figure 6.3: The arithmetic differences between the estimated effect sizes attributed to the effects of the confounding variables on the percentages of errors during all exposure conditions for all cognitive tasks considered in this study and the baseline condition (condition 1: temperature=20ºC, CO_2 levels ~600 ppm), derived from model B.



Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

With regard to the speed of performance, Figure 6.3 shows that the speed of reaction increased significantly during exposure to all the investigated conditions relative to condition 1. No effect was observed in any tasks on the speed of response during exposures to conditions 3 (temperature=20°C, CO_2 levels ~1800 ppm) and 4 (temperature=23°C, CO_2 levels ~600 ppm) relative to condition 1 (temperature=20°C, CO_2 levels ~600 ppm).

Table 6.8 (a): The estimated effect size for the effects of the exposure conditions on the accuracy (percentages of errors) of the cognitive tasks after adding the confounders' estimated effect sizes to the final model, obtained by the multivariable multilevel analysis (model A).*

Variable	SRT accuracy (error%) zero model estimate (95% CI)	p-value	SRT accuracy (error%) estimate (95% CI)	p-value	RL accuracy (error%) zero model estimate (95% CI)	p-value	RL accuracy (error%) estimate (95% CI)	p-value
Conditions								
2(20°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	2.41 (1.39, 3.42)	<0.001	5.38 (3.63, 7.13)	<0.001	3.99 (2.61, 5.37)	<0.001	7.59 (5.83, 10.35)	<0.001
3(20°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	5.37 (4.96, 6.78)	<0.001	9.10 (7.45, 11.75)	<0.001	8.93 (7.55, 9.31)	<0.001	16.87 (14.35, 19.38)	<0.001
4(23°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	3.87 (3.50, 4.24)	<0.001	7.70 (5.94, 9.46)	<0.001	-1.87 (-2.42, -1.33)	<0.001	-5.20 (-6.72, -4.69)	<0.001
5(23°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	9.71 (9.34, 10.08)	<0.001	20.55 (15.53, 19.57)	<0.001	9.71 (9.34, 10.08)	<0.001	18.12 (15.60, 19.63)	<0.001
6(23°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	12.06 (11.69, 12.43)	<0.001	29.05 (26.32, 32.56)	<0.001	15.12 (14.71, 16.53)	<0.001	30.81 (27.29, 33.32)	<0.001
7(25°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	4.41 (3.04, 5.78)	<0.001	8.44 (6.41, 10.46)	<0.001	8.81 (8.43, 9.19)	<0.001	13.86 (11.35, 15.38)	<0.001
8(25°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	13.87 (13.50, 14.24)	<0.001	30.32 (27.04, 32.59)	<0.001	17.33 (16.95, 17.71)	<0.001	32.42 (29.91, 35.94)	<0.001
9(25°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	22.13 (21.75, 22.51)	<0.001	46.09 (43.74, 47.44)	<0.001	21.55 (20.03, 22.06)	<0.001	47.56 (43.04, 49.07)	<0.001
Ethnicity (Saudi vs. other)	-	-	-1.57 (-2.51, -0.63)	0.003	-	-	-1.87 (-2.63, -0.12)	<0.001
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years)	-	-	-2.22 (-3.35, -1.38)	0.001	-	-	-2.25 (-3.50, -1.40)	0.001
Thermal comfort perception								
cold vs. neutral	-	-	10.56 (5.10, 7.02)	<0.001	-	-	10.72 (9.06, 11.37)	<0.001
cool vs. neutral	-	-	-1.45 (-2.17, -0.26)	<0.001	-	-	-0.96 (-1.53, -0.39)	<0.001
slightly cool vs. neutral	-	-	-2.53 (-3.59, -1.02)	0.001	-	-	-1.83 (-2.56, -0.10)	0.003
slightly warm vs. neutral	-	-	7.04 (4.52, 6.60)	0.005	-	-	-0.54 (-0.26, -0.81)	<0.001
warm vs. neutral	-	-	9.13 (5.46, 7.72)	0.004	-	-	12.15 (7.07, 9.98)	<0.001
hot vs. neutral	-	-	14.50 (8.27, 10.28)	<0.001	-	-	18.00 (13.03, 15.98)	<0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C)	-	-	-0.90 (-1.09, -0.71)	<0.001	-	-	-0.91 (-1.10, -0.73)	<0.001
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not)	-	-	15.03 (16.19, 13.25)	<0.001	-	<0.001	15.13 (16.08, 14.33)	<0.001
Other symptoms reported vs. not	-	-	15.74 (16.07, 14.54)	<0.001	-	<0.001	16.67 (18.25, 14.60)	<0.001

Variable	MTS accuracy (error%) zero model estimate (95% CI)	p-value	MTS accuracy (error%) estimate (95% CI)	p-value	CPT accuracy (error%) zero model estimate (95% CI)	p-value	CPT accuracy (error%) estimate (95% CI)	p-value
Conditions								
2(20°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	2.33 (1.82, 2.85)	<0.001	7.26 (5.72, 10.79)	<0.001	2.74 (1.05, 3.43)	<0.001	5.44 (3.03, 7.85)	<0.001
3(20°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	5.87 (5.35, 5.38)	<0.001	15.16 (12.18, 17.15)	<0.001	6.42 (5.05, 7.79)	<0.001	9.75 (7.38, 11.12)	<0.001
4(23°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-1.19 (-1.71, -1.50)	<0.001	-5.45 (-6.72, -4.58)	<0.001	4.19 (3.77, 4.60)	<0.001	7.53 (5.81, 9.25)	<0.001
5(23°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	9.95 (9.57, 10.33)	<0.001	18.74 (15.80, 20.68)	<0.001	11.61 (10.20, 12.02)	<0.001	17.22 (14.86, 19.59)	<0.001
6(23°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	10.80 (10.28, 11.31)	<0.001	26.34 (24.88, 28.81)	<0.001	14.79 (13.41, 15.17)	<0.001	27.56 (24.27, 29.86)	<0.001
7(25°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	7.85 (6.34, 8.37)	<0.001	12.16 (11.34, 12.98)	<0.001	5.96 (4.55, 6.37)	<0.001	8.76 (6.67, 10.87)	<0.001
8(25°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	14.42 (13.90, 15.93)	<0.001	31.03 (29.53, 33.54)	<0.001	14.75 (13.34, 15.17)	<0.001	28.96 (26.61, 30.30)	<0.001
9(25°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	21.71 (20.34, 22.08)	<0.001	48.82 (45.31, 50.33)	<0.001	22.70 (21.28, 23.11)	<0.001	47.08 (44.20, 49.77)	<0.001
Ethnicity (Saudi vs. other)	-	-	-1.71 (-2.53, -0.88)	<0.001	-	-	-1.63 (-2.30, -0.95)	0.001
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years)	-	-	-2.85 (-3.71, -1.60)	0.001	-	-	-2.10 (-3.20, -1.40)	0.001
Thermal comfort perception								
cold vs. neutral	-	-	13.06 (12.19, 14.94)	<0.001	-	-	8.67 (4.10, 6.33)	0.003
cool vs. neutral	-	-	-1.09 (-1.46, -0.37)	<0.001	-	-	-1.71 (-2.25, -0.17)	0.002
slightly cool vs. neutral	-	-	-2.47 (-3.44, -1.49)	0.001	-	-	-2.09 (-3.15, -1.03)	0.008
slightly warm vs. neutral	-	-	-0.60 (-1.06, -0.21)	<0.001	-	-	10.22 (4.52, 6.90)	0.003
warm vs. neutral	-	-	13.82 (7.33, 9.97)	<0.001	-	-	12.52 (6.01, 8.05)	0.007
hot vs. neutral	-	-	19.06 (15.58, 17.55)	<0.001	-	-	17.90 (9.99, 11.81)	0.003
Temperature at home (per unit increase in temperature in the range between 18°C-24°C)	-	-	-1.01 (-1.11,-1.90)	<0.001	-	-	-0.80 (-0.97, -0.62)	0.008
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not)	-	<0.001	15.65 (13.38, 17.92)	<0.001	-	<0.001	14.10 (16.05, 16.15)	<0.001
Other symptoms reported vs. not	-	<0.001	15.50 (16.56, 13.95)	<0.001	-	<0.001	15.04 (16.48, 13.57)	<0.001

Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9:	T3: 25°C	CO2: 1800 ppm

Base line condition

*: The orange colour columns show the estimated effects on percentages of errors derived by the univariable multilevel model displayed (Zero-model), and the grey column the arithmetic difference between the 'Zero-model' and estimated effects on percentages of errors after accounting for the confounders.

Table 6.8 (b): The estimated effect size for the effects of the exposure conditions on the accuracy (percentages of errors) of the cognitive tasks after adding the confounders' estimated effect sizes to the final model, obtained by the multivariable multilevel analysis (model A)*.

Variable	SDT accuracy (error%) zero model estimate (95% CI)	p-value	SDT accuracy (error%) estimate (95% CI)	p-value	SDL accuracy (error%) zero model estimate (95% CI)	p-value	SDL accuracy (error%) estimate (95% CI)	p-value
Conditions								
2(20°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	3.38 (2.84, 3.93)	<0.001	7.75 (5.37, 9.13)	<0.001	5.54 (4.51, 6.57)	<0.001	7.39 (6.33, 8.45)	<0.001
3(20°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	5.49 (3.46, 7.52)	<0.001	15.95 (13.40, 17.49)	<0.001	9.42 (8.05, 10.79)	<0.001	15.49 (14.46, 16.53)	<0.001
4(23°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-0.38 (-2.06, -0.30)	<0.001	-4.65 (-5.24, -3.50)	<0.001	-1.03 (-3.39, -1.33)	<0.001	-5.80 (-6.81, -4.34)	<0.001
5(23°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	9.12 (8.61, 10.64)	<0.001	17.87 (15.33, 19.40)	<0.001	10.49 (9.46, 11.52)	<0.001	18.48 (17.45, 16.52)	<0.001
6(23°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	14.06 (13.69, 15.43)	<0.001	28.33 (27.78, 31.87)	<0.001	15.45 (14.40, 16.50)	<0.001	32.51 (30.40, 35.54)	<0.001
7(25°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	5.41 (4.04, 6.78)	<0.001	10.13 (8.58, 12.67)	<0.001	9.40 (8.40, 10.50)	<0.001	13.51 (12.48, 14.54)	<0.001
8(25°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	12.87 (11.50, 13.24)	<0.001	30.85 (28.30, 32.39)	<0.001	20.20 (19.10, 21.40)	<0.001	37.51 (35.48, 39.54)	<0.001
9(25°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	20.71 (19.34, 21.08)	<0.001	48.02 (45.47, 51.56)	<0.001	20.20 (19.10, 21.40)	<0.001	53.51 (51.48, 55.54)	<0.001
Ethnicity (Saudi vs. other)	-	-	-1.62 (-2.94, -0.49)	<0.001	-	-	-1.76 (-2.16, -0.36)	0.001
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years)	-	-	-2.50 (-3.64, -1.25)	0.001	-	-	-2.87 (-3.70, -1.45)	0.001
Thermal comfort perception								
cold vs. neutral	-	-	10.37 (9.68, 11.06)	<0.001	-	-	14.28 (13.57, 15.99)	<0.001
cool vs. neutral	-	-	-0.98 (-0.38, -0.30)	<0.001	-	-	-1.39 (-2.64, -0.13)	<0.001
slightly cool vs. neutral	-	-	-2.80 (-3.61, -1.00)	0.002	-	-	-2.28 (-3.39, -1.17)	0.004
slightly warm vs. neutral	-	-	-0.50 (-0.53, -0.57)	<0.001	-	-	-0.18 (-0.09, -0.46)	<0.001
warm vs. neutral	-	-	12.43 (7.06, 9.88)	0.001	-	-	18.92 (12.19, 14.34)	0.009
hot vs. neutral	-	-	16.72 (11.31, 13.12)	<0.001	-	-	26.09 (19.79, 21.38)	0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C)	-	-	-0.84 (-1.64, -0.23)	<0.001	-	-	-0.97 (-1.35, -0.28)	<0.001
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not)	-	<0.001	14.25 (15.63, 13.88)	0.001	-	-	15.78 (16.58, 13.97)	0.003
Other symptoms reported vs. not	-	<0.001	15.22 (16.75, 13.79)	0.003	-	-	16.55 (17.98, 13.13)	0.002

Variable	DST accuracy (error%) zero model estimate (95% CI)	p-value	DST accuracy (error%) estimate (95% CI)	p-value	ALTERNATIVE TAB accuracy (error%) zero model estimate (95% CI)	p-value	ALTERNATIVE TAB accuracy (error%) estimate (95% CI)	p-value
Conditions								
2(20°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	5.65 (4.41, 6.90)	<0.001	8.07 (7.34, 8.80)	<0.001	2.66 (1.92, 3.40)	<0.001	5.87 (3.11, 7.64)	<0.001
3(20°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	9.76 (8.53, 10.99)	<0.001	16.76 (15.53, 17.99)	<0.001	4.62 (3.87, 5.36)	<0.001	9.62 (7.87, 11.36)	<0.001
4(23°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-1.78 (-3.01, -1.55)	<0.001	-6.58 (-7.81, -5.35)	<0.001	3.52 (2.77, 4.26)	<0.001	5.16 (3.91, 7.42)	<0.001
5(23°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	12.01 (11.78, 13.24)	<0.001	20.00 (19.77, 21.23)	<0.001	8.66 (7.91, 9.40)	<0.001	17.92 (15.18, 19.66)	<0.001
6(23°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	18.10 (17.00, 19.10)	<0.001	35.02 (32.79, 37.25)	<0.001	13.50 (12.76, 14.24)	<0.001	26.50 (24.76, 28.24)	<0.001
7(25°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	10.50 (9.75, 11.50)	<0.001	15.02 (14.79, 16.25)	<0.001	6.54 (5.80, 7.28)	<0.001	8.17 (6.43, 9.91)	<0.001
8(25°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	20.50 (19.40, 21.90)	<0.001	38.00 (36.79, 40.24)	<0.001	10.89 (10.15, 11.63)	<0.001	29.89 (27.15, 31.64)	<0.001
9(25°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	20.50 (19.40, 21.90)	<0.001	55.00 (52.79, 58.24)	<0.001	21.71 (20.97, 22.46)	<0.001	45.72 (43.98, 47.46)	<0.001
Ethnicity (Saudi vs. other)	-	-	-1.38 (-2.53, -0.77)	0.007	-	-	-1.27 (-2.22, -0.33)	0.003
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years)	-	-	-2.93 (-3.80, -1.62)	0.001	-	-	-2.15 (-3.20, -1.28)	0.001
Thermal comfort perception								
cold vs. neutral	-	-	14.30 (13.67, 15.92)	<0.001	-	-	8.39 (6.39, 8.39)	<0.001
cool vs. neutral	-	-	-2.51 (-6.03, 1.01)	<0.001	-	-	6.67 (5.48, 7.15)	0.002
slightly cool vs. neutral	-	-	-3.32 (-4.87, -2.22)	<0.001	-	-	-1.68 (-2.72, -0.63)	0.001
slightly warm vs. neutral	-	-	-0.20 (-0.38, -0.77)	0.003	-	-	-4.84 (-5.65, -4.04)	<0.001
warm vs. neutral	-	-	18.96 (12.39, 14.52)	0.006	-	-	9.14 (4.53, 6.74)	<0.001
hot vs. neutral	-	-	27.76 (19.63, 21.89)	0.008	-	-	15.75 (8.37, 10.13)	<0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C)	-	-	-0.95 (-1.13, -0.77)	<0.001	-	-	-0.88 (-1.13, -0.62)	<0.001
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not)	-	-	15.15 (17.42, 13.87)	0.001	-	-	14.40 (15.01, 12.79)	0.002
Other symptoms reported vs. not	-	-	16.70 (17.43, 14.98)	0.002	-	-	15.50 (13.59, 16.60)	0.002

Conditions of exposure	Ambient temperature	CO2 concentration level	
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm	Base line condition
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm	
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm	
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm	
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm	
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm	
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm	
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm	
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm	

*: The orange colour columns show the estimated effects on percentages of errors derived by the univariable multilevel model displayed (Zero-model), and the grey column the arithmetic difference between the 'Zero-model' and estimated effects on percentages of errors after accounting for the confounders.

Table 6.9 (a): The estimated effect size for the effects of the exposure conditions on the speed of response of the cognitive tasks after adding the confounders estimated effect sizes to the final model, obtained by the multivariable multilevel analysis (model B).*

Variable	SRT speed/seconds zero model estimate (95% CI)	p-value	SRT speed/seconds estimate (95% CI)	p-value	RL speed/seconds zero model estimate (95% CI)	p-value	RL speed/seconds estimate (95% CI)	p-value
Conditions								
2(20°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	-143.62 (-145.63, -141.62)	<0.001	-155.41 (-163.47, -138.34)	0.005	-20.24 (-21.02, -19.47)	<0.001	-30.25 (-40.05, -15.44)	0.080
3(20°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	-160.93 (-162.93, -158.92)	<0.001	-161.90 (-162.96, -159.94)	0.100	-50.00 (-50.77, -49.22)	<0.001	-51.08 (-50.63, -49.05)	0.100
4(23°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-172.20 (-174.21, -170.20)	<0.001	-173.10 (-174.50, -172.60)	0.100	-66.29 (-67.07, -65.52)	<0.001	-67.15 (-68.77, -65.02)	0.100
5(23°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	-177.18 (-179.19, -175.18)	<0.001	-188.20 (-190.10, -186.30)	<0.001	-79.66 (-80.43, -78.88)	<0.001	-87.06 (-90.40, -82.90)	<0.001
6(23°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	-178.89 (-180.90, -176.89)	<0.001	-195.42 (-197.40, -193.44)	<0.001	-96.57 (-97.35, -95.80)	<0.001	-116.17 (-120.30, -110.03)	<0.001
7(25°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-181.45 (-183.45, -179.44)	<0.001	-200.23 (-202.23, -198.22)	<0.001	-117.81 (-118.59, -117.04)	<0.001	-135.20 (-143.60, -127.20)	<0.001
8(25°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	-187.94 (-189.95, -185.94)	<0.001	-218.90 (-220.90, -216.00)	<0.001	-130.27 (-131.04, -129.49)	<0.001	-150.45 (-157.40, -143.85)	<0.001
9(25°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	-199.05 (-201.30, -198.40)	<0.001	-229.97 (-229.90, -225.47)	<0.001	-139.19 (-139.96, -138.42)	<0.001	-165.10 (-153.25, -158.35)	<0.001
Ethnicity (Saudi vs. other**)**	-	-	-15.75 (-23.73, -10.78)	0.008	-	-	-15.97 (-22.60, -10.66)	0.007
Number of years spent in the country by the non-Saudi participants (5 years or more vs. 5 year or less**)**	-	-	-10.74 (-17.70, -7.43)	0.850	-	-	-12.62 (-15.50, -8.23)	0.800
Thermal comfort perception								
cold vs. neutral	-	-	12.50 (8.18, 15.17)	0.005	-	-	12.60 (8.08, 17.07)	0.005
cool vs. neutral	-	-	1.02 (0.64, 3.68)	0.100	-	-	1.57 (0.28, 2.43)	0.100
slightly cool vs. neutral	-	-	0.45 (0.19, 2.60)	0.100	-	-	1.48 (0.05, 2.55)	0.100
slightly warm vs. neutral	-	-	-8.04 (-12.32, -6.76)	0.500	-	-	-7.05 (-11.16, -5.06)	0.500
warm vs. neutral	-	-	-20.50 (-22.28, -18.72)	0.001	-	-	-15.89 (-17.76, -13.02)	0.001
hot vs. neutral	-	-	-27.47 (-29.66, -25.28)	0.001	-	-	-20.42 (-21.13, -19.29)	0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C)	-	-	-12.10 (-18.68, -7.51)	0.005	-	-	-11.15 (-17.51, -6.22)	0.005
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	-	-	16.62 (12.56, 20.79)	0.003	-	-	17.01 (14.73, 21.75)	0.006
Other symptoms reported vs. not	-	-	15.01 (12.18, 18.19)	0.005	-	-	14.38 (10.50, 18.25)	0.003

Variable	MTS speed/seconds zero model estimate (95% CI)	p-value	MTS speed/seconds estimate (95% CI)	p-value	CPT speed/seconds zero model estimate (95% CI)	p-value	CPT speed/seconds estimate (95% CI)	p-value
Conditions								
2(20°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	-8.92 (-10.07, -7.78)	<0.001	-18.91 (-25.09, -10.73)	0.060	-29.17 (-30.45, -27.89)	<0.001	-40.32 (-47.65, -33.99)	0.005
3(20°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	-17.28 (-18.43, -16.14)	<0.001	-18.88 (-19.40, -17.20)	0.100	-39.63 (-40.91, -38.35)	<0.001	-40.61 (-42.90, -38.33)	0.100
4(23°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-23.94 (-25.08, -22.79)	<0.001	-24.94 (-25.08, -23.79)	0.100	-45.01 (-46.29, -43.73)	<0.001	-46.01 (-47.29, -45.73)	0.100
5(23°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	-27.59 (-28.73, -26.44)	<0.001	-38.56 (-40.50, -30.11)	<0.001	-52.45 (-53.73, -51.17)	<0.001	-60.46 (-65.74, -52.18)	<0.001
6(23°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	-45.56 (-46.70, -44.41)	<0.001	-55.78 (-57.58, -53.98)	<0.001	-54.08 (-55.36, -52.80)	<0.001	-70.44 (-83.72, -61.16)	<0.001
7(25°C, CO2=600 ppm) vs. **1**(20°C, CO2=600 ppm)	-58.97 (-60.12, -57.83)	<0.001	-70.57 (-72.72, -68.43)	<0.001	-62.46 (-63.74, -61.18)	<0.001	-70.06 (-78.34, -62.78)	<0.001
8(25°C, CO2=1000 ppm) vs. **1**(20°C, CO2=600 ppm)	-71.57 (-72.716, -70.43)	<0.001	-88.97 (-90.12, -85.83)	<0.001	-73.38 (-74.66, -72.10)	<0.001	-94.37 (-107.66, -82.09)	<0.001
9(25°C, CO2=1800 ppm) vs. **1**(20°C, CO2=600 ppm)	-117.77 (-118.91, -116.62)	<0.001	-145.77 (-148.91, -143.62)	<0.001	-82.03 (-83.31, -80.74)	<0.001	-105.01 (-123.29, -85.73)	<0.001
Ethnicity (Saudi vs. other**)**	-	-	-14.83 (-18.81, -11.14)	0.008	-	-	-15.90 (-24.82, -9.02)	0.006
Number of years spent in the country by the non-Saudi participants (5 years or more vs. 5 year or less**)**	-	-	-8.45 (-12.60, -5.60)	0.910	-	-	-9.78 (-12.82, -8.54)	0.870
Thermal comfort perception								
cold vs. neutral	-	-	12.15 (7.58, 19.72)	0.005	-	-	13.48 (10.66, 16.30)	0.005
cool vs. neutral	-	-	1.13 (-1.03, 3.30)	0.100	-	-	1.46 (-0.30, 3.22)	0.100
slightly cool vs. neutral	-	-	0.95 (-0.69, 2.59)	0.100	-	-	1.24 (-1.19, 3.67)	0.100
slightly warm vs. neutral	-	-	-6.24 (-9.50, -2.02)	0.500	-	-	-5.04 (-8.45, -2.37)	0.500
warm vs. neutral	-	-	-15.05 (-17.56, -12.47)	0.001	-	-	-13.22 (-15.65, -11.03)	0.001
hot vs. neutral	-	-	-25.52 (-27.80, -22.77)	0.001	-	-	-15.77 (-17.61, -13.06)	0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C)	-	-	-12.21 (-17.60, -7.17)	0.050	-	-	-11.12 (-17.63, -6.40)	0.050
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	-	-	15.21 (10.57, 20.99)	0.005	-	-	16.19 (12.23, 20.85)	0.007
Other symptoms reported vs. not	-	-	17.68 (14.60, 20.97)	0.002	-	-	13.71 (10.26, 17.15)	0.007

Conditions of exposure	Ambient temperature	CO2 concentration level
Condtion 1: Temp: 20°C, CO2: 600 ppm	T1: 20°C	CO2: 600 ppm
Condtion 2: Temp: 20°C, CO2: 1000 ppm	T2: 20°C	CO2: 1000 ppm
Condtion 3: Temp: 20°C, CO2: 1800 ppm	T3: 20°C	CO2: 1800 ppm
Condtion 4: Temp: 23°C, CO2: 600 ppm	T1: 23°C	CO2: 600 ppm
Condtion 5: Temp: 23°C, CO2: 1000 ppm	T2: 23°C	CO2: 1000 ppm
Condtion 6: Temp: 25°C, CO2: 1800 ppm	T3: 23°C	CO2: 1800 ppm
Condtion 7: Temp: 25°C, CO2: 600 ppm	T1: 25°C	CO2: 600 ppm
Condtion 8: Temp: 25°C, CO2: 1000 ppm	T2: 25°C	CO2: 1000 ppm
Condtion 9: Temp: 25°C, CO2: 1800 ppm	T3: 25°C	CO2: 1800 ppm

Base line condition

*: The orange colour columns show the estimated effects on speeds of responses derived by the univariable multilevel model displayed (Zero-model), and the grey column the arithmetic difference between the 'Zero-model' and estimated effects on the speeds of responses after accounting for the confounders.

Table 6.9 (b): The estimated effect size for the effects of the exposure conditions on the speed of response of the cognitive tasks after adding the confounders estimated effect sizes to the final model, obtained by the multivariable multilevel analysis (model B).*

Variable	SDT speed/seconds zero model estimate (95% CI)	p-value	SDT speed/seconds estimate (95% CI)	p-value	SDL speed/seconds zero model estimate (95% CI)	p-value	SDL speed/seconds estimate (95% CI)	p-value
Conditions								
2(20°C, CO_2=1000 ppm) vs. **1**(20°C, CO_2=600 ppm)	-9.04 (-11.12, -6.75)	<0.001	-17.16 (-26.81, -10.52)	0.070	-74.60 (-81.95, -67.24)	<0.001	-90.28 (-104.47,-75.10)	0.060
3(20°C, CO_2=1800 ppm) vs. **1**(20°C, CO_2=600 ppm)	-26.50 (-30.20, -24.90)	<0.001	-27.57 (-30.21, -24.92)	0.100	-130.00 (-138.45, -124.00)	<0.001	-131.30 (-138.48,-124.11)	0.100
4(23°C, CO_2=600 ppm) vs. **1**(20°C, CO_2=600 ppm)	-63.34 (-67.70, -62.99)	<0.001	-65.31 (-67.96, -62.67)	0.100	-131.77 (-139.95, -125.58)	<0.001	-132.69 (-139.88,-125.51)	0.100
5(23°C, CO_2=1000 ppm) vs. **1**(20°C, CO_2=600 ppm)	-65.05 (-75.40, -60.69)	<0.001	-78.22 (-82.86, -65.57)	<0.001	-155.90 (-164.10, -149.73)	<0.001	-166.95 (-174.13,-149.77)	<0.001
6(23°C, CO_2=1800 ppm) vs. **1**(20°C, CO_2=600 ppm)	-75.06 (-37.71, -32.42)	<0.001	-90.19 (-115.83, -75.54)	<0.001	-169.65 (-176.83,-152.47)	<0.001	-185.73 (-195.91, -175.54)	<0.001
7(25°C, CO_2=600 ppm) vs. **1**(20°C, CO_2=600 ppm)	-89.41 (-72.06, -66.77)	<0.001	-105.39 (-111.03, -96.74)	<0.001	-178.36 (-171.54,-181.18)	<0.001	-195.43 (-205.62, -175.25)	<0.001
8(25°C, CO_2=1000 ppm) vs. **1**(20°C, CO_2=600 ppm)	-96.68 (-119.33, -84.04)	<0.001	-122.67 (-130.31, -104.02)	<0.001	-185.83 (-193.01,-178.65)	<0.001	-215.87 (-223.05, -188.69)	<0.001
9(25°C, CO_2=1800 ppm) vs. **1**(20°C, CO_2=600 ppm)	-113.93 (-126.57, -91.28)	<0.001	-140.90 (-156.54, -121.25)	<0.001	-195.61 (-112.79,-188.42)	<0.001	-225.68 (-232.86, -205.50)	<0.001
Ethnicity (Saudi vs. other**)**	-	-	-13.77 (-19.10, -9.43)	0.005	-	-	-13.69 (-18.24, -8.14)	0.005
Number of years spent in the country by the non-Saudi participants (5 years or more vs. 5 year or less**)**	-	-	-10.19 (-15.80, -7.76)	0.750	-	-	-9.25 (-14.16, -7.05)	0.850
Thermal comfort perception								
cold vs. neutral	-	-	14.64 (11.16, 18.12)	0.005	-	-	15.97 (11.23, 20.71)	0.005
cool vs. neutral	-	-	2.34 (1.76, 3.91)	0.100	-	-	2.90 (1.67, 3.14)	0.100
slightly cool vs. neutral	-	-	1.47 (0.35, 2.97)	0.100	-	-	1.35 (2.25, 0.94)	0.100
slightly warm vs. neutral	-	-	-5.48 (-7.16, -2.79)	0.500	-	-	-7.35 (-10.81, -2.89)	0.500
warm vs. neutral	-	-	-15.18 (-18.96, -12.41)	0.001	-	-	-28.77 (-31.43, -25.11)	<0.001
hot vs. neutral	-	-	-20.47 (-22.88, -18.06)	0.001	-	-	-37.78 (-42.62, -32.94)	<0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C**)**	-	-	-12.13 (-17.61, -7.66)	0.050	-	-	-11.87 (-17.66, -6.08)	0.050
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	-	-	17.94 (11.90, 23.02)	0.001	-	-	15.07 (10.55, 20.68)	0.003
Other symptoms reported vs. not	-	-	15.41 (11.23, 20.60)	0.003	-	-	14.39 (9.21, 19.99)	0.002

Variable	DST speed/seconds zero model estimate (95% CI)	p-value	DST speed/seconds estimate (95% CI)	p-value	ALTERNATIVE TAB speed/sec zero model estimate (95% CI)	p-value	ALTERNATIVE TAB speed/seconds estimate (95% CI)	p-value
Conditions								
2(20°C, CO_2=1000 ppm) vs. **1**(20°C, CO_2=600 ppm)	-28.60 (-31.37, -25.83)	<0.001	-39.89 (-47.62,-25.16)	0.060	-25.20 (-26.59, -23.82)	<0.001	-37.30 (-45.67,-20.94)	0.070
3(20°C, CO_2=1800 ppm) vs. **1**(20°C, CO_2=600 ppm)	-30.43 (-33.26, -27.80)	<0.001	-30.50 (-33.23,-27.77)	0.100	-55.30 (-56.78, -53.98)	<0.001	-55.34 (-56.71,-53.98)	0.100
4(23°C, CO_2=600 ppm) vs. **1**(20°C, CO_2=600 ppm)	-61.40 (-64.23, -58.77)	<0.001	-61.49 (-64.22,-58.77)	0.100	-31.60 (-33.24, -30.54)	<0.001	-31.89 (-33.25,-30.53)	0.100
5(23°C, CO_2=1000 ppm) vs. **1**(20°C, CO_2=600 ppm)	-95.16 (-97.89, -92.43)	<0.001	-105.17 (-117.90,-92.44)	<0.001	-76.41 (-77.87, -75.15)	<0.001	-85.52 (-90.88,-75.15)	<0.001
6(23°C, CO_2=1800 ppm) vs. **1**(20°C, CO_2=600 ppm)	-120.20 (-128.93, -113.47)	<0.001	-131.17 (-133.90,-128.44)	<0.001	-118.34 (-119.70, -116.97)	<0.001	-132.32 (-144.67, -119.95)	<0.001
7(25°C, CO_2=600 ppm) vs. **1**(20°C, CO_2=600 ppm)	-130.70 (-140.42, -120.97)	<0.001	-150.75 (-153.48,-148.02)	<0.001	-121.86 (-123.23, -120.50)	<0.001	-140.85 (-148.20, -130.45)	<0.001
8(25°C, CO_2=1000 ppm) vs. **1**(20°C, CO_2=600 ppm)	-134.69 (-147.42, -125.96)	<0.001	-164.67 (-177.40,-151.94)	<0.001	-126.90 (-128.26, -125.54)	<0.001	-152.88 (-166.25, -137.53)	<0.001
9(25°C, CO_2=1800 ppm) vs. **1**(20°C, CO_2=600 ppm)	-140.78 (-150.51, -127.05)	<0.001	-170.67 (-180.40,-160.94)	<0.001	-135.90 (-139.27, -128.54)	<0.001	-165.89 (-172.20, -149.50)	<0.001
Ethnicity (Saudi vs. other**)**	-	-	-16.87 (-23.56, -11.83)	0.008	-	-	-2.57 (-3.58, -1.44)	0.009
Number of years spent in the country by the non-Saudi participants (5 years or more vs. 5 year or less**)**	-	-	-6.75 (-13.10, -4.55)	0.900	-	-	-14.12 (-18.56, -9.70)	0.700
Thermal comfort perception								
cold vs. neutral	-	-	16.77 (12.30, 21.24)	0.005	-	-	14.21 (10.44, 19.97)	0.005
cool vs. neutral	-	-	6.04 (3.22, 8.86)	0.100	-	-	3.16 (1.73, 4.59)	0.100
slightly cool vs. neutral	-	-	4.46 (0.30, 9.21)	0.100	-	-	1.23 (1.19, 3.65)	0.100
slightly warm vs. neutral	-	-	-6.97 (-9.85, -2.10)	0.500	-	-	-6.40 (-7.85, -4.95)	0.500
warm vs. neutral	-	-	-31.69 (-35.33, -28.05)	<0.001	-	-	-14.35 (-16.19, -12.51)	0.001
hot vs. neutral	-	-	-40.80 (-46.36, -35.23)	0.006	-	-	-19.26 (-22.09, -16.44)	0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C**)**	-	-	-12.71 (-19.14, -6.28)	0.050	-	-	-12.36 (-16.62, 8.10)	0.050
Detected and reported intolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	-	-	16.71 (10.17, 21.58)	0.001	-	-	14.22 (10.31, 18.75)	0.002
Other symptoms reported vs. not	-	-	16.62 (12.24, 22.49)	0.002	-	-	10.83 (7.62, 14.28)	0.002

Conditions of exposure	Ambient temperature	CO_2 concentration level
Condtion 1: Temp: 20°C, CO_2: 600 ppm [Base line condition]	T1: 20°C	CO_2: 600 ppm
Condtion 2: Temp: 20°C, CO_2: 1000 ppm	T2: 20°C	CO_2: 1000 ppm
Condtion 3: Temp: 20°C, CO_2: 1800 ppm	T3: 20°C	CO_2: 1800 ppm
Condtion 4: Temp: 23°C, CO_2: 600 ppm	T1: 23°C	CO_2: 600 ppm
Condtion 5: Temp: 23°C, CO_2: 1000 ppm	T2: 23°C	CO_2: 1000 ppm
Condtion 6: Temp: 25°C, CO_2: 1800 ppm	T3: 23°C	CO_2: 1800 ppm
Condtion 7: Temp: 25°C, CO_2: 600 ppm	T1: 25°C	CO_2: 600 ppm
Condtion 8: Temp: 25°C, CO_2: 1000 ppm	T2: 25°C	CO_2: 1000 ppm
Condtion 9: Temp: 25°C, CO_2: 1800 ppm	T3: 25°C	CO_2: 1800 ppm

*: The orange colour columns show the estimated effects on speeds of responses derived by the univariable multilevel model displayed (Zero-model), and the grey column the arithmetic difference between the 'Zero-model' and estimated effects on the speeds of responses after accounting for the confounders.

It is indicated in Table 6.7 that significant effects occurred when the variables of ethnicity, number of years spent in the country for the non-Saudi participants, AC temperature set at home in the range between 18 and 24°C, thermal comfort sensations, the reported intolerable thermal discomfort which leads to inability to focus, and other symptoms reported that impaired the focusing ability, were added to the model.

A summary of the effects of the confounding variables' effects on the percentages of errors indicated in Table 6.7 when the variables were added to the zero model (model A) is provided below in Table 6.10. For instance, a significant decrease in the percentages of errors was observed for the Saudi participants relative to the non-Saudi participants by an average estimate of ~2% when the confounding variable of ethnicity was added to the model.

Table 6.10: Summary of the estimated effects of the confounding variables on the accuracy of tasks (percentages of errors) when added to the zero model (model A, Table 6.8), expressed as averages from all tasks.

The confounding factor	Magnitude of effect
Ethnicity	~2%* ↓ for all tasks for the Saudi relative to the non-Saudi participants.
Number of years spent in the country for the non-Saudi participants	~2%** ↓ for all tasks for the non-Saudi participants who spent 5 years or more in the country relative to those who spent less than 5 years.
AC temperature set at home	~1%* ↓ for all tasks for every 1°C increase in temperature in the range between 18-24°C.
Reported symptoms that impaired the focusing ability	~15%*** ↑ for those who reported the symptoms versus those who did not.
Reported intolerable thermal discomfort, which lead to inability to focus	~15%*** ↑ for those who reported the symptoms versus those who did not.

Effects of thermal comfort sensations:	**For the vigilance tasks:**
Cold versus neutral	~10%* ↑ .
Slightly warm versus neutral	~7%*** ↑.
Warm versus neutral	~12%** ↑ .
Hot versus neutral	~16%* ↑.
Cool versus neutral	~1.5%* ↓ .
Slightly cool versus neutral	~2%** ↓ .
	For memory and learning tasks:
Cold versus neutral	~11%* ↑ .
Warm versus neutral	~14%** ↑.
Hot versus neutral	~22%* ↑ .
Cool versus neutral	~1%* ↓ .
Slightly cool versus neutral	~2%*** ↓ .
Slightly warm versus neutral	~0.5%* ↓.

* : $p< 0.001$, ** : $p= 0.001$, *** : $p= 0.002-0.009$.

From the summary of Table 6.10, by doing simple arithmetic calculations of adding all estimated effect sizes caused by the confounding variables and dividing them in portions out of 100%, it was found that the estimated effect size caused by the effects of thermal sensations are the ones responsible for over half of the magnitude of the size of increase which occurred in the percentages of errors for all tasks (~60%).

With regard to the speeds of responses, Table 6.9 indicated that significant effects occurred on the speeds of responses when the variables of ethnicity, number of years spent in the country for the non-Saudi participants, AC temperature set at home in the range between 18 and 24°C, thermal comfort sensations, the reported intolerable thermal discomfort which leads to inability to focus, and other symptoms reported that impaired the focusing ability, were added to the model. All observed effects were significantly associated with the speeds of responses. A summary of the effects of the confounding variables' effects on the speeds of responses indicated in Table 6.8 when the variables were added to the zero model is provided below in Table 6.11. For instance, a significant decrease in the percentages of errors was observed for the Saudi participants, relative to the non-Saudi participants, by an average estimate of ~15 seconds when the confounding variable of ethnicity was added to the model.

Table 6.11: Summary of the estimated effects of the confounding variables on the speeds of responses when added to the zero model (model B, Table 6.9), expressed as averages from all tasks.

The confounding factor	**Magnitude of effect**
Ethnicity	~15 seconds***↑ for all tasks for the Saudi participants relative to the non-Saudi participants (i.e. the Saudi participants were faster).
Number of years spent in the country for the non-Saudi participants	No association.
AC temperature set at home	~12 seconds***↑ for all tasks for every 1°C increase in temperature in the range between 18-24°C.
Reported symptoms that impaired the focusing ability	~17 seconds*** ↓ for those who reported the symptoms versus those who did not.
Reported intolerable thermal discomfort, which lead to inability to focus	~15 seconds*** ↓ for those who reported the symptoms versus those who did not.

Effects of thermal comfort sensations:	**For all tasks:**
Cold versus neutral	~14 seconds***↓.
Warm versus neutral	~19 seconds**↑.
Hot versus neutral	~26 seconds**↑.
Slightly warm versus neutral	No association.
Cool versus neutral	No association.
Slightly cool versus neutral	No association.

**: p=0.001, ***: p=0.002-0.007.

6.7 Estimating the Relative Effect of Temperature vs. CO_2

As mentioned in the methodology chapter, another multivariable multilevel models were applied for the effects on accuracy and speeds of responses to determine whether temperature or CO_2 levels have the higher effect on cognitive performance of the tasks considered in this study. These models were better in predicting whether temperature or CO_2 levels have greater effect on the cognitive tasks considered in this study. Another advantage of this model is that it gives the interactions between the variables of interest. The presence of interactions can have important implications for the interpretation of statistical models, as they describe the simultaneous influence of two variables (temperature and CO_2) on the third one (cognitive performance).

The multivariable multilevel models of the non-additive effects of temperature and CO_2 included the same confounding variables used in the previous models (Tables 6.8 and 6.9), namely: ethnicity, thermal comfort sensations, number of years spent in the country for the non-Saudi participants, AC set temperature at home, symptoms of headache, dizziness, heaviness on head, confusion, difficulty thinking, difficulty concentrating and fatigue, and intolerable thermal discomfort that attributes to inability to focus. After adding these confounders, the estimated effect sizes obtained are presented in Table 6.12 (a, b) (model C), and Table 6.13 (a, b) (model D).

According to these models (for instance, model C, Table 6.12 (a)), when temperature increased to 23°C vs. 20°C, the percentages of errors for the SRT increased by 8.62%. When the CO_2 levels increased to 1000 ppm vs. 600 ppm, the percentages of errors for the SRT increased by 7.31%. When both; temperature and CO_2 levels increased together (interaction: 23°C vs. 20°C * 1000 ppm vs. 600 ppm), an additional increase in the percentages of errors with an estimate of 4.62% occurred for the SRT. Thus, a total for this combination of 8.62+7.31+4.62=20.55% occurred. It is worth noting that this is the same estimated effect size which occurred in model A at condition 5 (temperature= 23°C, CO_2 levels ~ 1000 ppm) vs. condition 1 (temperature= 20°C, CO_2 levels ~ 600 ppm).

Table 6.12 (a): Estimates for the effects of the investigated CO_2 levels and indoor temperatures on the accuracy (% of errors) obtained by the multivariable multilevel analysis (model C).

Variable	SRT accuracy (error%) estimate (95% CI)	p-value	RL accuracy (error%) estimate (95% CI)	p-value	MTS accuracy (error%) estimate (95% CI)	p-value	CPT accuracy (error%) estimate (95% CI)	p-value
Temprature/°C								
23°C vs. 20°C	8.62 (5.59, 9.97)	<0.001	-2.34 (-3.84, -1.83)	<0.001	-2.87 (-3.42, -1.33)	<0.001	6.97 (4.77, 8.60)	<0.001
25°C vs. 20°C	12.24 (10.83, 14.21)	<0.001	10.93 (8.61, 13.37)	<0.001	8.48 (6.82, 10.84)	<0.001	11.12 (9.03, 14.86)	<0.001
CO2 level/ ppm								
1000 ppm vs. 600 ppm	7.31 (5.54, 9.37)	<0.001	12.73 (10.16, 14.18)	<0.001	13.68 (11.42, 15.18)	<0.001	4.98 (2.24, 5.62)	<0.001
1800 ppm vs. 600 ppm	12.43 (9.96, 14.78)	<0.001	24.56 (22.55, 27.31)	<0.001	20.21 (18.37, 22.38)	<0.001	10.62 (8.59, 12.97)	<0.001
Ethnicity (Saudi vs. other**)**	-1.55 (-2.92, -0.18)	<0.001	-2.86 (-3.70, -1.01)	<0.001	-2.13 (-3.86, -1.41)	<0.001	-1.40 (-2.82, -0.99)	<0.001
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years**)**	-2.16 (-3.10, -1.20)	0.001	-2.24 (-3.20, -1.50)	0.001	-2.35 (-3.40, -1.35)	0.001	-1.85 (-2.75, -1.05)	0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C**)**	-0.80 (-1.07, -0.11)	0.008	-3.33 (-4.70, -2.05)	0.009	-3.21 (-4.56, -2.15)	0.003	-1.08 (-2.28, -0.13)	0.004
Detected and reported un-tolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	15.03 (16.19, 13.25)	<0.001	15.13 (16.08, 14.33)	<0.001	15.65 (13.38, 17.92)	<0.001	14.10 (16.05, 16.15)	<0.001
Detected other symptoms that impairs focusing ability vs. not	15.74 (16.07, 14.54)	<0.001	16.67 (18.25, 14.60)	<0.001	15.50 (16.56, 13.95)	<0.001	15.04 (16.48, 13.57)	<0.001
Interactions								
1000 ppm vs. 600 ppm, T=23°C vs. 20°C	4.62 (3.81, 5.50)	<0.001	7.63 (5.26, 9.82)	<0.001	7.93 (5.83, 10.26)	<0.001	5.26 (2.77, 7.94)	<0.001
1000 ppm vs. 600 ppm, T=25°C vs. 20°C	10.77 (9.13, 13.20)	<0.001	8.76 (6.30, 10.38)	<0.001	8.87 (6.24, 10.68)	<0.001	9.87 (7.40, 12.56)	<0.001
1800 ppm vs. 600 ppm, T=23°C vs. 20°C	8.00 (6.10, 10.75)	<0.001	8.59 (6.81, 10.89)	<0.001	9.00 (5.70, 11.10)	<0.001	8.97 (6.02, 11.19)	<0.001
1800 ppm vs. 600 ppm, T=25°C vs. 20°C	21.42 (19.07, 23.60)	<0.001	12.07 (9.97, 15.47)	<0.001	20.13 (17.52, 24.96)	<0.001	25.34 (22.72, 27.88)	<0.001

Table 6.12 (b): Estimates for the effects of the investigated CO_2 levels and indoor temperatures on the accuracy (% of errors) obtained by the multivariable multilevel analysis (model C).

Variable	SDT accuracy (error%) estimate (95% CI)	p-value	SDL accuracy (error%) estimate (95% CI)	p-value	DST accuracy (error%) estimate (95% CI)	p-value	ALTERNATIVE TAB accuracy (error%) estimate (95% CI)	p-value
Temprature/°C								
23°C vs. 20°C	-2.50 (-3.86, -1.13)	<0.001	-2.69 (-3.07, -1.31)	<0.001	-2.73 (-3.39, -1.33)	<0.001	7.69 (5.95, 9.43)	<0.001
25°C vs. 20°C	8.04 (6.57, 10.31)	<0.001	11.94 (9.71, 19.71)	<0.001	11.41 (9.58, 13.67)	<0.001	10.91 (8.87, 12.35)	<0.001
CO2 level/ ppm								
1000 ppm vs. 600 ppm	13.12 (11.38, 15.11)	<0.001	13.32 (11.55, 15.54)	<0.001	15.04 (13.40, 17.49)	<0.001	5.62 (3.18, 7.66)	<0.001
1800 ppm vs. 600 ppm	21.91 (19.05, 24.79)	<0.001	26.34 (24.53, 28.52)	<0.001	29.10 (27.84, 32.93)	<0.001	11.56 (8.55, 13.03)	<0.001
Ethnicity (Saudi vs. other**)**	-2.16 (-3.54, -1.79)	<0.001	-2.22 (-3.52, -1.92)	0.001	-2.50 (-3.84, -1.15)	<0.001	-0.76 (-2.63, -0.90)	<0.001
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years**)**	-2.10 (-3.17, -1.15)	0.001	-2.50 (-3.45, -1.56)	0.001	-2.62 (-3.65, -1.60)	0.001	-1.74 (-2.40, -0.90)	0.001
Temperature at home (per unit increase in temperature in the range between 18°C-24°C**)**	-3.37 (-4.73, -2.01)	0.009	-3.38 (-4.96, -2.20)	0.002	-3.05 (-4.43, -2.34)	0.001	-1.19 (-2.72, -0.34)	0.004
Detected and reported un-tolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	14.25 (15.63, 13.88)	<0.001	15.78 (16.58, 13.97)	<0.001	15.15 (17.42, 13.87)	<0.001	14.40 (15.01, 12.79)	<0.001
Detected other symptoms that impairs focusing ability vs. not	15.22 (16.75, 13.79)	<0.001	16.55 (17.98, 13.13)	<0.001	16.70 (17.43, 14.98)	<0.001	15.50 (13.59, 16.60)	<0.001
Interactions								
1000 ppm vs. 600 ppm, T=23°C vs. 20°C	7.25 (6.33, 9.37)	<0.001	7.85 (5.43, 9.21)	<0.001	7.69 (5.98,099.43)	<0.001	4.61 (2.01, 6.10)	<0.001
1000 ppm vs. 600 ppm, T=25°C vs. 20°C	9.69 (8.13, 11.17)	<0.001	12.25 (10.88, 14.54)	<0.001	11.55 (9.85, 13.39)	<0.001	13.36 (11.29, 15.38)	<0.001
1800 ppm vs. 600 ppm, T=23°C vs. 20°C	8.92 (6.31, 10.35)	<0.001	8.86 (6.88, 10.53)	<0.001	8.65 (6.33, 10.79)	<0.001	8.90 (6.60, 10.70)	<0.001
1800 ppm vs. 600 ppm, T=25°C vs. 20°C	18.07 (16.63, 20.68)	<0.001	15.23 (12.18, 17.87)	<0.001	14.49 (11.64, 16.09)	<0.001	21.25 (19.80, 23.20)	<0.001

Table 6.13 (a): Estimates for the effects of the investigated CO_2 levels and indoor temperatures on the speed of response obtained by the multivariable multilevel analysis (model D).

Variable	SRT speed/seconds estimate (95% CI)	p-value	RL speed/seconds estimate (95% CI)	p-value	MTS speed/seconds estimate (95% CI)	p-value	CPT speed/seconds estimate (95% CI)	p-value
Temprature/°C								
23°C vs. 20°C	-172.54 (-174.54, -170.55)	<0.001	-149.99 (-160.77, -129.22)	<0.001	-133.94 (-145.08, -122.79)	<0.001	-145.01 (-166.29, -123.73)	<0.001
25°C vs. 20°C	-200.24 (-202.24, -198.25)	<0.001	-166.25 (177.02, -155.47)	<0.001	-171.63 (-192.77, -117.48)	<0.001	-154.10 (-185.38, -122.82)	<0.001
CO2 level/ ppm								
1000 ppm vs. 600 ppm	-143.62 (-145.61, -141.63)	<0.001	-117.87 (-118.64, -117.09)	<0.001	-117.24 (-180.38, -106.09)	<0.001	-129.17 (-136.45, -117.89)	<0.001
1800 ppm vs. 600 ppm	-160.50 (-162.49, -158.50)	<0.001	-120.24 (-141.02, -109.47)	<0.001	-128.92 (-140.06, -107.78)	<0.001	-131.69 (-140.90, -98.33)	<0.001
Ethnicity (Saudi vs. other**)**	-17.71 (-21.93, -13.49)	<0.001	-17.36 (-16.50, -4.76)	0.002	-13.77 (-16.44, -1.07)	0.006	-11.89 (-19.80, -6.03)	0.007
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years**)**	-12.11 (-18.40, -8.50)	0.850	-10.32 (-15.55, -6.78)	0.875	-8.97 (-11.32, -6.05)	0.900	-10.90 (-15.77, -8.14)	0.800
Temperature at home (per unit increase in temperature in the range between 18°C-24°C**)**	-12.38 (-17.81, -3.04)	0.003	-12.20 (-18.98, -4.58)	0.009	-12.00 (-18.77, -4.77)	0.007	-12.47 (-17.76, -2.81)	0.008
Detected and reported un-tolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	13.90 (10.84, 15.96)	<0.001	15.51 (18.10, 10.92)	0.015	13.65 (10.54, 16.83)	0.007	15.68 (8.49, 20.87)	0.005
Detected other symptoms that impairs focusing ability vs. not	17.55 (6.98, 28.13)	0.002	17.09 (10.25, 23.94)	0.001	12.76 (5.00, 20.51)	0.005	15.01 (10.16, 20.19)	0.003
Interactions								
1000 ppm vs. 600 ppm, T=23°C vs. 20°C	-151.72 (-174.55, -138.90)	<0.001	-134.86 (-147.96, -125.77)	<0.001	-125.54 (-135.16, -111.92)	<0.001	-137.35 (-148.16, -124.53)	<0.001
1000 ppm vs. 600 ppm, T=25°C vs. 20°C	-166.60 (-177.447, -151.76)	<0.001	-142.70 (-158.80, -126.61)	<0.001	-145.37 (-160.99, -127.75)	<0.001	-141.83 (-151.65, -130.02)	<0.001
1800 ppm vs. 600 ppm, T=23°C vs. 20°C	-166.30 (-189.12, -143.47)	<0.001	-139.62 (- 150.72, -118.52)	<0.001	-135.44 (-147.06, -129.82)	<0.001	-138.15 (-145.97, -120.33)	<0.001
1800 ppm vs. 600 ppm, T=25°C vs. 20°C	-178.75 (-191.57, -135.93)	<0.001	-143.44 (-159.54, -127.33)	<0.001	-150.43 (-164.07, -140.80)	<0.001	-143.00 (-158.82, -125.17)	<0.001

Table 6.13 (b): Estimates for the effects of the investigated CO_2 levels and indoor temperatures on the speed of response obtained by the multivariable multilevel analysis (model D).

Variable	SDT speed/seconds estimate (95% CI)	p-value	SDL speed/seconds estimate (95% CI)	p-value	DST speed/seconds estimate (95% CI)	p-value	ALTERNATIVE TAB speed/seconds estimate (95% CI)	p-value
Temprature/°C								
23°C vs. 20°C	-166.19 (-188.78, -133.61)	<0.001	-151.39 (-178.45, -124.34)	<0.001	-149.69 (-162.37, -137.01)	<0.001	-151.40 (-172.74, -120.06)	<0.001
25°C vs. 20°C	-170.54 (-183.12, -117.95)	<0.001	-185.70 (-192.77, -178.63)	<0.001	-161.53 (-174.21,-148.86)	<0.001	-155.36 (-176.70, -134.02)	<0.001
CO2 level/ ppm								
1000 ppm vs. 600 ppm	-139.16 (-151.74, -126.58)	<0.001	-134.77 (-141.83, -127.71)	<0.001	-128.89 (-141.56, -116.22)	<0.001	-125.30 (-136.65, -113.96)	<0.001
1800 ppm vs. 600 ppm	-147.53 (-130.11, -124.95)	<0.001	-145.28 (-162.34, -128.23)	<0.001	-131.33 (-144.00, -118.65)	<0.001	-132.24 (-143.59, -120.90)	<0.001
Ethnicity (Saudi vs. other**)**	-16.97 (-24.20, -9.73)	<0.001	-11.77 (-18.90, -4.64)	<0.001	-16.49 (-19.50, -13.48)	<0.001	-13.19 (-15.00, -11.38)	0.001
Number of years spent in the country by the non-Saudi participants (5 years or more vs. less than 5 years**)**	-11.57 (-15.80, -7.64)	0.850	-9.45 (-12.15, -7.05)	0.950	-9.10 (-12.00, -5.55)	0.950	-12.43 (-16.52, -8.19)	0.950
Temperature at home (per unit increase in temperature in the range between 18°C-24°C**)**	-12.75 (-19.61, -4.11)	0.001	-11.77 (-16.26, -2.73)	0.005	-11.37 (-19.28, -6.55)	0.005	-13.30 (-18.21, -1.60)	0.004
Detected and reported un-tolerable thermal discomfort that impairs focusing ability (Detected vs. not**)**	19.63 (8.22, 21.04)	<0.001	14.20 (3.43, 24.98)	<0.001	10.20 (8.83, 15.56)	<0.001	14.10 (7.39, 20.81)	<0.001
Detected other symptoms that impairs focusing ability vs. not	18.12 (12.14, 24.11)	0.001	11.93 (7.74, 22.12)	0.001	10.00 (3.35, 16.65)	0.001	14.56 (10.15, 18.97)	0.002
Interactions								
1000 ppm vs. 600 ppm, T=23°C vs. 20°C	-153.78 (-163.44, -146.13)	<0.001	-143.77 (-151.77, -131.78)	<0.001	-135.55 (-145.33, -122.76)	<0.001	-138.21 (-151.10, -117.31)	<0.001
1000 ppm vs. 600 ppm, T=25°C vs. 20°C	-157.68 (-174.26, -143.10)	<0.001	-160.70 (-171.68, -141.72)	<0.001	-140.35 (-151.14, -123.56)	<0.001	-142.31 (-162.21, -128.41)	<0.001
1800 ppm vs. 600 ppm, T=23°C vs. 20°C	-155.37 (-165.02, -137.72)	<0.001	-152.65 (-162.72, -132.58)	<0.001	-137.52 (-149.30, -121.74)	<0.001	-140.94 (-154.04, -122.84)	<0.001
1800 ppm vs. 600 ppm, T=25°C vs. 20°C	-159.90 (-183.56, -146.24)	<0.001	-166.93 (-178.93, -148.92)	<0.001	-146.01 (-164.82, -137.19)	<0.001	-143.77 (-153.68, -139.85)	<0.001

Table 6.12 (a and b) (model C) indicated that significant changes occurred in the effects on the percentages of errors when the variables of ethnicity, number of years spent in the country for the non-Saudi participants, AC temperature set at home in the range between 18 and 24°C, the reported intolerable thermal discomfort which lead to inability to focus, and other symptoms reported that impaired the focusing ability, were added to the model. All observed effects were significantly associated with the accuracy of tasks (percentages of errors), where the results were matching the results obtained from model A. For instance, when the confounding variable of ethnicity was added to the model, a significant decrease in the percentages of errors was observed for the Saudi participants relative to the non-Saudi participants by an average estimate of ~2%. A summary of these effects of the confounding variables is provided in Table 6.14 below. It is worth noting that the thermal comfort sensations variables are not included among the confounding factors, since they interfered with the effects of temperature and thus a collinearity problem occurred.

Table 6.14: Summary of the estimated effects of the confounding variables on the percentages of errors presented in Tables 6.12 (a) and (b), expressed as averages from all tasks.

The confounding factor	**Magnitude of effect**
Ethnicity	~2%* ↓ for all tasks for the Saudi participants relative to the non-Saudi participants.
Number of years spent in the country for the non-Saudi participants	~2%** ↓ for all tasks for those who spent 5 years or more in the country relative to the non-Saudi participants who spent less than 5 years in the country.
AC temperature set at home	~2%*** ↓ for all tasks for every 1°C increase in temperature in the range between 18-24°C.

Reported symptoms that impaired the focusing ability	~15%* ↑ for those who reported the symptoms versus those who did not.
Reported intolerable thermal discomfort, which lead to inability to focus	~15%* ↑ for those who reported the symptoms versus those who did not.

*: P<0.001, **: P=0.001, ***: P=0.002-0.009.

With regard to the speed of response, Table 6.13 (a and b) indicated that significant effects occurred in the speeds of responses when the variables of ethnicity, AC temperature set at home in the range between 18 and 24°C, the reported intolerable thermal discomfort which leads to inability to focus, and other symptoms reported that impaired the focusing ability, were added to the model. All observed effects were significantly associated with the speeds of responses. However, the number of years spent in the country for the non-Saudi participants was found not to be associated with the speed of response. A summary of the effects of the confounding variables' effects on the speeds of responses indicated in Table 6.13 when the variables were added to the zero model is provided below in Table 6.15.

Table 6.15 shows for instance, a significant decrease in the speed of responses was observed for the Saudi participants relative to the non-Saudi participants by an average estimate of 15 seconds when the confounding variable of ethnicity was added to the model, which is matching the estimated effect size obtained from model A.

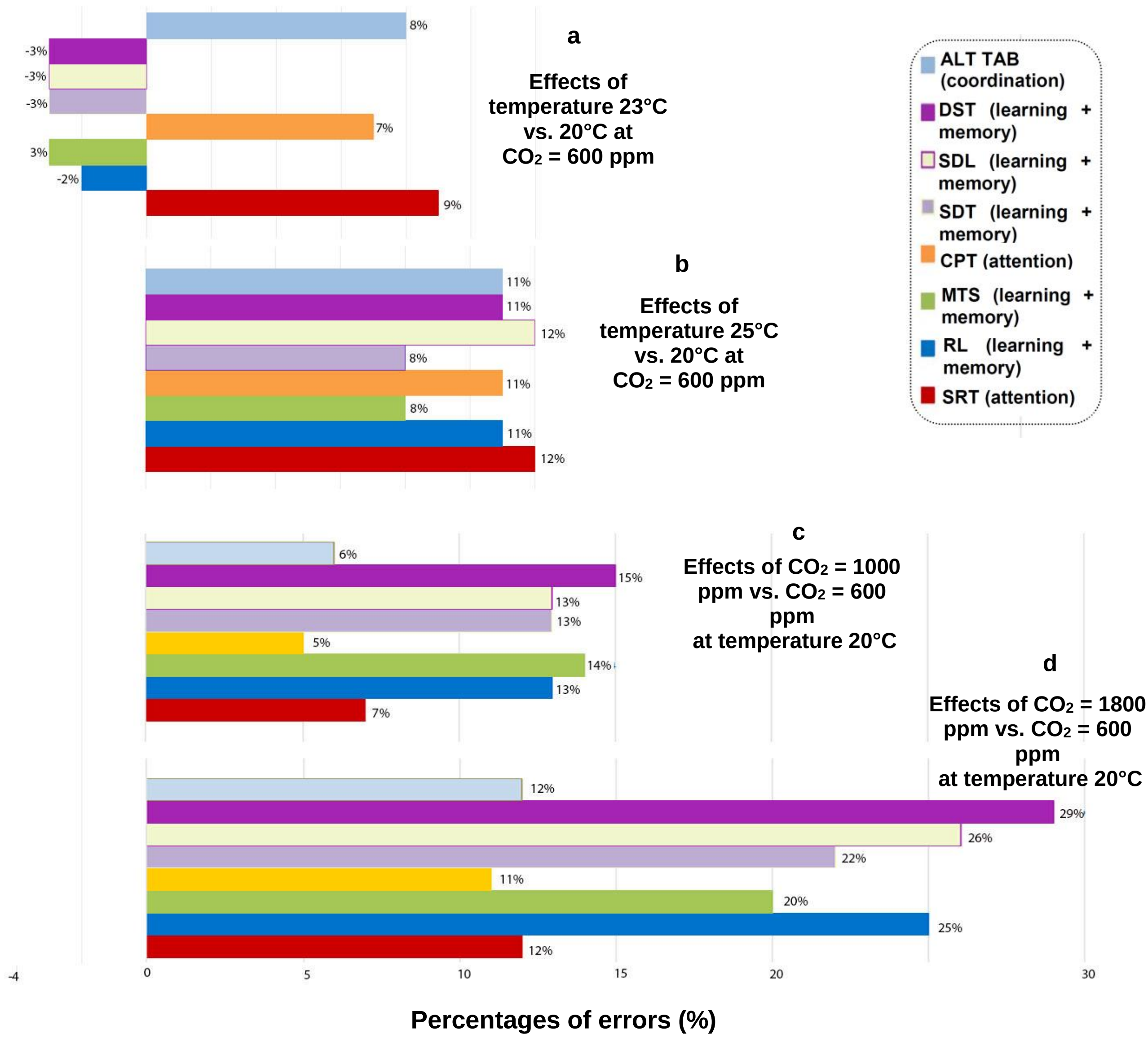
Table 6.15: Summary of the estimated effects of the confounding variables on the speeds of responses presented in Tables 6.12 (a) and (b), expressed as averages from all tasks.

The confounding factor	**Magnitude of effect**
Ethnicity	~15 seconds* ↓ for all tasks for the Saudi participants relative to the non-Saudi participants (significantly).
Number of years spent in the country for the non-Saudi participants	No association.
AC temperature set at home	~10 seconds** ↓ for all tasks for every 1°C increase in temperature in the range between 18-24°C (significantly).
Reported symptoms that impaired the focusing ability	~15 seconds* ↑ for those who reported the symptoms versus those who did not (significantly).
Reported intolerable thermal discomfort, leading to inability to focus	~15 seconds* ↑ for those who reported the symptoms versus those who did not (significantly).

*: P<0.001, **: P=0.001.

The estimated effect sizes of increase/decrease in the percentages of errors attributed to the effects of the investigated temperatures and CO_2 levels presented in Table 6.12 (a) and (b) (model C) are summarised in Figure 6.4 below. Figure 6.4 (a) shows, for instance, that the percentages of errors increased significantly when temperature increased from 20°C to 23°C while CO_2 levels were at constant ranges of 600 ppm, but only for the attention and coordination tasks by ~8%, whereas the percentages of errors decreased significantly under this condition for the learning and memory tasks by ~3%.

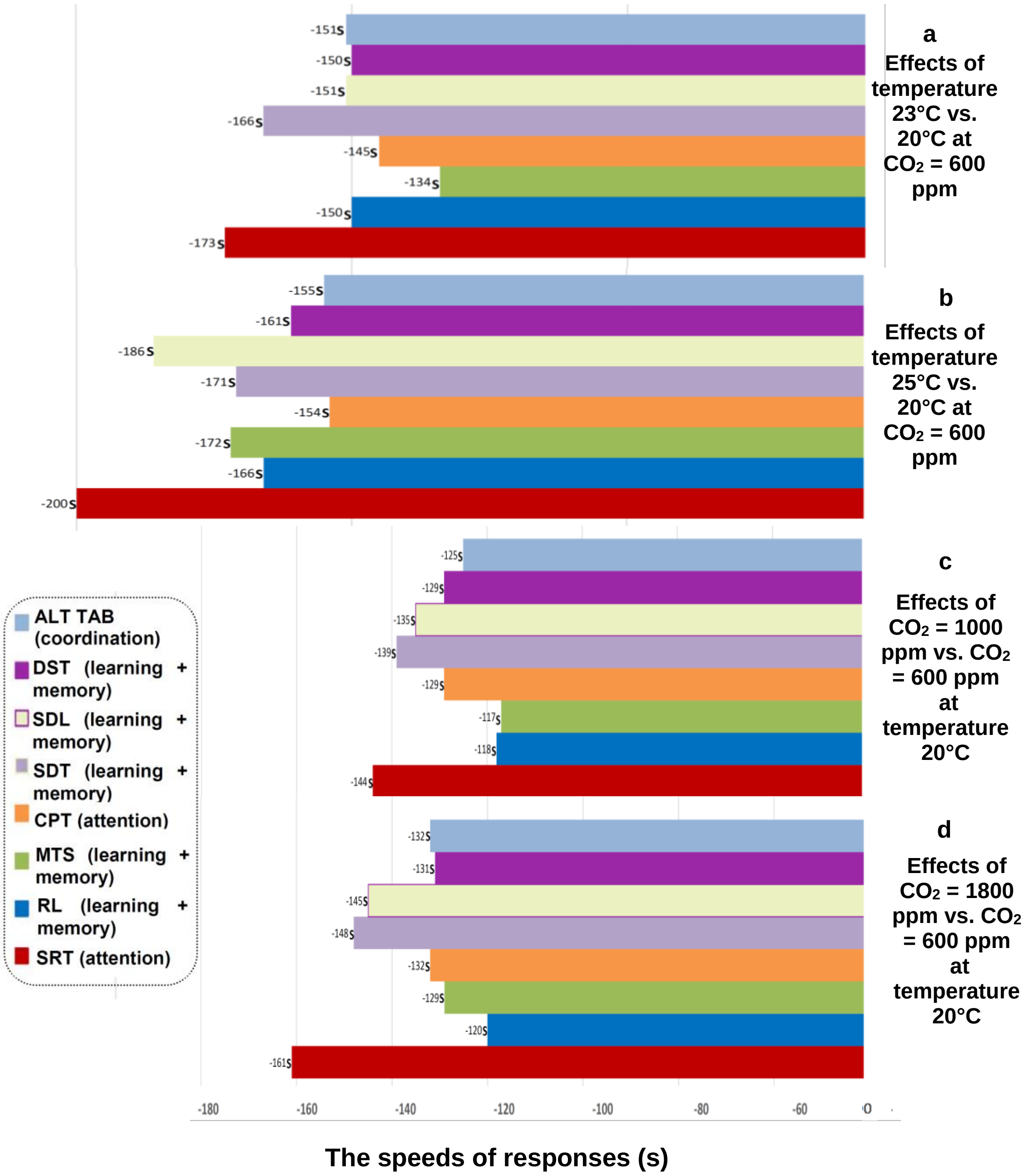
Figure 6.4: The estimated effects on the percentages of errors for the cognitive tasks attributed to the investigated temperatures and CO_2 levels (model C).



The estimated effect sizes of increase/decrease in the speeds of responses attributed to the effects of the investigated temperatures and CO_2 levels presented in Table 6.13 (a) and (b) (model D) are summarised in Figure 6.5 below. For instance, Figure 6.5 (a and b) show that the time of response decreased significantly (became faster) when temperature increased from 20°C to 23°C and to 25°C, respectively, while CO_2 levels were at constant ranges of 600 ppm for all tasks by an average estimate of ~180 seconds.

Nevertheless, Figure 6.6 (c and d) show that the time of response decreased when CO_2 levels increased from 600 ppm to 1000 ppm and 1800 ppm, respectively, while temperature remained constant at 20°C for all tasks, but the estimated average decrease in speed is ~140 seconds. Thus, it was indicated that effect of temperature effect had a greater influence on speed of response than CO_2 levels did.

Figure 6.5: The estimated effects on speeds of responses for the cognitive tasks attributed to the investigated temperatures and CO_2 levels (model D).



In Tables 6.12 (a) and (b) and Figure 6.4, it was indicated that the effects on accuracy (percentages of errors) attributed to CO_2 levels ~1000 ppm was close in size for most of the tasks relative to the effects attributed to temperature of 25°C. Nevertheless, when the CO_2 levels reached ~1800 ppm, the estimated sizes of the effects were almost doubled for all tasks, relative to the estimated sizes of effects attributed to CO_2 levels ~1000, and temperature of 25°C. Therefore, it could be concluded that the effect on the accuracy of the cognitive tasks by CO_2 levels was larger compared to the effect of temperature, and particularly at CO_2 levels ~1800 ppm.

However, with regard to speed of performance, it was indicated from the results obtained from model D, that temperature have the greatest influence on the speed of performance relative to CO_2 levels and particularly at 25°C.

Discussion of these results will be provided in the following chapter.

6.8 Summary

According to the multivariable multilevel models performed, it was indicated that:

1. The univariable multilevel modelling analysis revealed that the performance of the participants in the tasks considered for this study (in terms of accuracy and speed) for all the cognitive tasks examined here were independent of the effects of age, physical activity, sleeping hours, caffeine intake, anxiety, ambient noise, clothing levels, and the order of cognitive tests. However, thermal comfort sensations, ethnicity (Saudi versus non-Saudi), number of years spent in the country for the non-Saudi participants, and AC temperature set at home were found to have significant associations with performance in terms of accuracy and speed for all the cognitive tasks considered. Also, the detected symptoms of intolerable thermal discomfort that impairs focusing ability and symptoms of headache, confusion, difficulty thinking, difficulty concentrating, or fatigue were found to have significant associations with performance in terms of accuracy and speed.

2. It was found that the estimated effect size caused by the effects of thermal sensations are the ones responsible for over half of the magnitude of the size of increase which occurred in the percentages of errors for all tasks (~60%). Moreover, thermal comfort sensations' effects on the accuracy and speed of performance varied according to the type of task performed. A significant increase in the percentages of errors was observed when the participants perceived the ambient thermal environment as slightly warm, warm, hot, and cold versus neutral. However, a significant decrease in the percentages of errors was observed when the participants perceived the ambient thermal environment as cool and slightly cool versus neutral.
3. The conditions of exposures affected the cognitive tasks differentially according to the type of task. A significant decrease in the percentages of errors occurred for the learning and memory tasks during exposure condition 4 (temperature=23°C, CO_2 levels ~600 ppm) relative to the baseline condition 1 (temperature=20°C, CO_2 levels ~600 ppm). However, the lowest percentages of errors for the vigilance tasks were observed at the baseline condition relative to the rest of conditions.
4. When another models (models C, and D) were performed for the effects of the CO_2 levels and the temperatures investigated in the study (in order to predict whether CO_2 levels or temperature is having the higher effect on cognitive performance tasks conducive to learning), it was indicated that the effect on the accuracy of the cognitive tasks by CO_2 levels was larger compared to the effect of temperature. However, it was indicated that effect of temperature effect had a greater influence on speed of response than CO_2 levels did.

Chapter 7: Discussion

In this chapter, a discussion of the results reported in the previous chapter is provided. The chapter begins by discussing the results of the univariable multilevel analysis showing the associations of the confounding variables with the accuracy and speed of participants' cognitive performance. Following that, a discussion is provided on the associated confounders, which were found to have significantly influenced the cognitive performance of participants. The results of the estimated effect sizes of these confounders is discussed after including them in the final multivariable multilevel model. Accordingly, a discussion will be provided afterwards on the implications of educational buildings' design in the context of female university/college buildings located in the hot climates relying on ACs for cooling and ventilation. The chapter concludes with the limitations of the study. Conclusions accordingly are drawn, and the findings of the study together with suggestions for future work will be presented in the following chapter.

7.1 The Associations of the Exposure Conditions and the Investigated Temperatures and CO_2 Levels with the Cognitive Performance Tasks

Firstly, the results presented in the previous chapter revealed statistically significant associations, not only between the conditions of exposures combining the temperatures and CO_2 levels investigated in the study with all cognitive tasks considered in the study, but also between the investigated temperatures separately with all cognitive tasks and between the investigated CO_2 levels separately with all cognitive tasks.

Nevertheless, according to the univariable multilevel analysis, there were statistically significant associations between all exposure conditions with ethnicity, number of years spent in the country for the non-Saudi participants, thermal comfort sensations, AC's set temperature at home, the symptoms of intolerable thermal discomfort that impairs focusing ability, and symptoms such as headache, fatigue and dizziness, with the percentages of errors for both cognitive tasks.

After adding these confounders to the original univariable multilevel model of the effects of conditions (Zero model, models A, and B) (Table 6.8 and Table 6.9 on pages 126-129), statistically significant associations have been observed. The effect sizes estimated from model A for the associations between the investigated exposure conditions and the accuracy of the cognitive tasks performed indicated that the percentages of errors were almost doubled, as an overall average estimate during all the exposure conditions investigated, relative to the baseline condition (condition 1) for the vigilance tasks ($p<0.001$). Similarly, for memory and learning tasks, the percentages of errors were almost doubled ($p<0.001$) during all exposure conditions investigated relative to the baseline condition, except during exposure condition 4, where the percentages of errors decreased significantly by around five times ($p<0.001$). During exposure condition 4, temperature was set at 23°C, while at the baseline exposure condition temperature was set at 20°C. CO_2 levels were set at 600 ppm during both exposures.

This result could be explained by the following reason. First, some studies supported the hypothesis that temperature affects task performance differentially depending on the type of task (e.g., Lan et al., 2009; Hancock and Vasmatzidis, 1998). This discrepancy might result from the fact that different cognitive tasks are accomplished by different dominant hemispheres and different brain cortexes (Lezak et al., 2006; Baddeley, 1986). These tasks include memory, reasoning, planning, etc.; however, attention functions differ from these functions in that they underlie and maintain the activity of the cognitive functions. Tham and Willem (2010) provided an explanation based on the Tsai–Partington test results, i.e. that higher arousal occurs at lower air temperature particularly at 20°C, and concluded that cooling sensation activates the brain and excites the nervous system controlling thermoregulation, and that the activation of the sympathetic nervous system elevates mental alertness or arousal, a mental state preferred in performing tasks that requires attention, endurance and stamina.

Furthermore, with regard to the significant increase of effect size on the percentage of errors which occurred after adding the associated confounders to the model (model A), it was indicated that the estimated effect size caused by the effects of thermal sensations are the ones responsible for over half of the magnitude of the size of increase which occurred in the percentages of errors for all tasks (~60%). The remaining increase in the percentage of errors is divided between the effects of ethnicity, number of years spent in the country for the non-Saudi participants, AC temperature at home, and the reported symptoms which were associated with the inability to focus. This is not surprising since over 100 published studies reported significant effects on human performance attributed to human thermal comfort. For instance, Cui et al. (2013) carried out chamber room studies, using 36 subjects completing questionnaires and memory typing tasks, on the influence of human thermal comfort on motivation and performance. They concluded that learning was affected by temperature especially when it changed frequently; warm discomfort was more detrimental to performance and motivation than cold discomfort and so recommended a slightly cool to neutral.

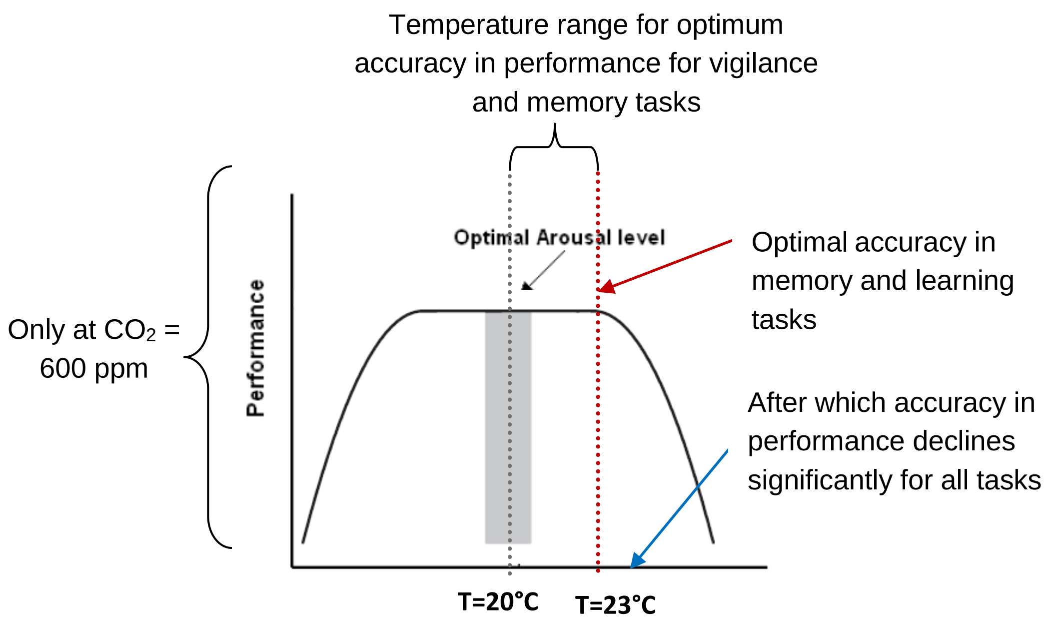
Regarding the temperature and CO_2 models (Table 6.12 (a, b) and Table 6.13 (a, b)) on pages 135-138), when the exposure conditions were broken down into interactions between the temperatures and CO_2 levels investigated, this approach allowed the control of all the possible permutations separately for the effects of the temperatures and those of the CO_2 levels, and also the effects of all possible combinations. Therefore, it was possible to answer the research question whether temperature or CO_2 levels had more effect on cognitive performance. Same confounders were added to these models, namely ethnicity, number of years spent in the country for the non-Saudi participants, thermal comfort sensations, AC's set temperature at home, and the symptoms of intolerable thermal discomfort that impairs focusing ability and symptoms like headache, fatigue and dizziness with the percentages of errors for both cognitive tasks. After adding these confounders to the temperature and CO_2 models, statistically significant associations were observed. Furthermore, the temperature and CO_2 models C and D indicated that all interactions' temperature * CO_2 levels were statistically significant in terms of both accuracy and speed of response, i.e.: giving an indication that the estimated effects from the investigated temperature and CO_2 levels depend on each other's/ associated with each other's (Finding Interactions [online]).

7.1.1 The Effects of Temperature

The estimated effect of temperature on accuracy on the cognitive tasks showed that the percentage of errors increased significantly by an average estimate of ~8% at 23°C, relative to 20°C, for vigilance tasks but decreased significantly by an average estimate of ~3% at 23°C, relative to 20°C, for memory tasks. At 25°C, the percentage of errors increased significantly by an average estimate of ~12%, relative to 20°C, for memory and complex tasks. It could be seen from these results that the effect of temperature on performance is most likely task dependent.

According to the maximal adaptability model by Hancock and Vasmatzidis (1998), the estimated effect of temperature on vigilance and memory tasks can be expressed by an extended inverted U-shaped curve. A modification to this curve is proposed on Figure 7.1, showing that the optimal arousal in this study is achieved at 20°C. The model by Hancock and Vasmatzidis provided an explanation that mental resources can be used to compensate for the stress effects of temperature outside the range of optimal temperature for the memory tasks, which can explain the occurrence of optimal performance for the memory tasks to some extent after 20°C. Nevertheless, the model suggests that adaptation is possible up to a certain point, which depends on the temperature, and that performance (or actually the tolerance) collapses beyond this point. From the results of this study, it could be suggested that participants' tolerance and adaptability went up to 23°C, after which accuracy in performance declined significantly for all tasks at 25°C. Accordingly, the temperature range for optimum accuracy in performance for both vigilance and memory tasks could be 20–23°C. Moreover, adaptation of occupants also depends on the exposure time. In this study exposure time lasted for approximately 45 minutes, which is the average duration of lectures in universities in Saudi Arabia (based on the field observation while intervening). Another suggestion that could be made according to Yerkes and Dodson (1908), who stated that tasks which demand thinking abilities are better performed under lower arousal state to facilitate concentration, is that setting classrooms' temperature at 23°C would result in higher accuracy even if students' optimum arousal was not achieved.

Figure 7.1 : A proposed temperature range for optimal arousal levels and optimal accuracy for memory and learning tasks with reference to the maximal adaptability model (modified from the relation derived by Hancock and Vasmatzidis (1998), and Yerkes and Dodson (1908)).



However, the Yerkes–Dodson Law also considered task difficulty, which resulted in different shapes of the U-curve relationships. This may imply that the effect of temperature on cognitive tasks is not only dependent on the type of task, but also on the difficulty level. In pedagogy, difficulty level of the taught subjects differs considerably among the courses and between the academic years, and also across different syllabi in the same academic year. Thus, suggesting a range of temperatures for optimum performance seems to be more comprehensive rather than an absolute temperature for optimum performance. Nevertheless, McCartney and Humphreys (2002) postulated that perceived productivity was not influenced by actual temperature itself but could be influenced by human thermal sensation and thermal comfort. Also, according to Tham and Willem (2010), the significant reductions in comfort levels were those responsible for and associated with the higher mental arousal which occurred, and not absolute temperatures.

Overall, the findings agree well with the findings reported by Seppanen et al. (2006) who meta-analysed various studies and reported that increasing room air temperature within 20–23°C may improve work performance, while any increase beyond this range may lead to negative productivity. This study's findings also concurred with the previous studies which showed that the relationship between arousal/alertness improves with arousal/alertness up to an optimal temperature and/or a range of temperature beyond which the work performance decreases. Nevertheless, Seppanen et al. (2003) suggested that work performance is unaffected by temperatures in the range 21–25°C. The discrepancy in results could be explained by the reason that their model is based on data from various work environments and different types of performance measures. It includes studies from call centres, an apparel factory, and climate chambers. It also included performance measures such as customer service in call centres, factory work, learning, addition, multiplication, and memory tests. Thus, the data behind the model are based on very heterogeneous research methods.

Witterseh (2001) investigated the effect of temperature on mental work by performing simulated office work (including multiplication, typing and addition tests) and found that there was no significant effect of temperature on the performance from thermal neutral temperature (22°C) to slightly warm discomfort temperature (25°C). A possible reason for the discrepancy in results compared to this study could be that the thermal neutral perception of participants differed from Witterseh's study. Moreover, Maula et al. (2016) reported that temperature had no effect on psychomotor performance, attention, or long-term memory. However, the performance results for working memory tasks were contradictory. A possible reason for the discrepancy could be that the study by Maula et al. (2016) was an office-work study. Also, the temperatures investigated were 29°C and 23°C; 29°C is quite a bit higher than the temperatures investigated in this study. In addition, ventilation was kept constant in this study, unlike in their study. Furthermore, possible reasons for the discrepancies could be the sample size of the study (and thus power), minimal contrasts of exposure, and different or inadequate use of methods/metrics for measurements with different sensitivity, including different measurement strategies.

7.1.2 The Effects of CO_2 Levels

With regard to the effects of CO_2 levels on accuracy of the cognitive tasks, the estimated effect sizes (Table 6.12) showed that the percentage of errors increased significantly by an average estimate of ~13% at CO_2 levels of 1000 ppm relative to 600 ppm for memory and complex tasks, and by ~6% for vigilance tasks. The percentages of errors increased significantly by an average of ~24% at CO_2 levels of 1800 ppm relative to 600 ppm for memory and complex tasks, and by ~12% for vigilance tasks. These results agree with Twardella et al. (2012) who reported a significant increase in the percentage of errors when CO_2 levels were 2000 ppm, relative to 1000 ppm in their field study, in assessing the effect of IAQ as indicated by the median CO_2 level effect on the concentration performance of students. Satish et al. (2011, 2012) describe research evidence showing that CO_2 affects decision-making even at levels as low as 600 ppm, which is below the normally accepted level of 1000 ppm. Allen et al. (2015) obtained similar results pertaining to performance on a decision-making test, as in the study by Satish et al. (2012). They observed that several domains of the decision-making tests decreased significantly and by a very high degree during exposure to CO_2 at 945 and 1400 ppm compared with the levels of 550 ppm. It is worth noting that in these aforenoted experiments, CO_2 was considered a pollutant in itself, however; in the present study CO_2 is not considered to be a pollutant but an indicator of the efficiency of ventilation.

Nonetheless, using a similar approach to this present study that CO_2 is not considered to be a pollutant but an indicator of the efficiency of ventilation when the main sources of CO_2 is the humans, Myhrvold et al. (1996), Coley et al. (2007), Ribic (2008), Bako-Baro et al. (2012), and Sarbu and Parurar (2015) used psychological and neurobehavioral tests to examine the effects of indoor air quality and outdoor air supply on the performance of school work and learning. Myhrvold et al. (1996) found a weak association between CO_2 levels and simple reaction time that suggested a positive effect of increased ventilation on performance, where CO_2 levels were reduced from 1500 ppm to 1000 ppm. Ribic (2008) observed improved performance on a d2 test, which is a standard test measuring concentration and attention, when CO_2 levels were reduced from 3800 ppm to 870 ppm. Sarbu and Parurar (2015) found that the performance of students on two psychological tests requiring concentration and cue-utilisation (namely: the Kraepelin test and the Prague test) improved literarily when CO_2 levels were reduced from 2000 ppm to 500 ppm. Coley et al. (2007) found a significant and positive effect on tests measuring reaction time when CO_2 levels were reduced from 2900 ppm to 690 ppm, and it was concluded that the power of attention was improved.

Furthermore, the study by Bako-Baro et al. (2012) strengthens the evidence provided by Coley et al. (2007) that poor ventilation rates in classrooms significantly impair children’s attention and vigilance. They found faster and more accurate responses in Choice RT and Colour Word Vigilance tasks, which reflects higher level of focused attention at higher ventilation rates compared to low rates with natural ventilation. It was concluded accordingly that in poorly ventilated classrooms, students are likely to be less attentive and to concentrate less well on instructions given by teachers. The magnitude of the negative effects with inadequate ventilation was even higher for tasks that require more complex skills such as spatial working memory and verbal ability to recognize words and non-words. Also, it was concluded that CO_2 levels in the range of 1000 ppm are recommended in all teaching facilities.

The present results obtained seem to agree well with the findings of the aforementioned studies. However, the present results can add to the conclusion made by Bako-Baro et al. (2012) that CO_2 levels in the range of 1000 ppm (correspond to ventilation rates in the order of 8 l/s per person) are recommended in all teaching facilities to prevent any impairment of pupils' performance due to inadequate ventilation, so that CO_2 levels in the range of 600 ppm can contribute to significant lower percentages of errors in the tasks conducive to learning investigated in this study relative to 1000 ppm.

Seppänen et al. (1999) and Wargocki et al. (2006) have made a comprehensive review of over 20 studies with over 30,000 persons and found that ventilation rates below 10 1/s per person results in lower air quality and worsening health problems. Risk of the sick building syndrome is reduced, and perceived air quality is improved, when the ventilation rates increase from 10 l/s to about 20 l/s per person. The work can support the findings of this present study as it indicated that carbon dioxide concentrations below 800 ppm are preferable (cited from a review by Clements-Croome, 2008).

Moreover, according to the studies which investigated the effects of efficiency of ventilation on standardized tests and learning (e.g.: Haverinen-Shaughnessy et al., 2011), who measured CO_2 levels in 100 schools. It was found poor ventilation reduced the number of pupils managing to pass language and mathematics tests, and that 3% more pupils passed the tests for every 1 l/s per person increase in ventilation up to 7 l/s per person. Later, Haverinen-Shaughnessy and Shaughnessy (2015) showed that mathematics scores improved by about 0.5% for every 1 l/s per person increase in ventilation from 0.9 to 7 l/s per person. Toftum et al. (2015) evaluated academic achievement by using the scores from a standardized Danish test battery, adjusted for a socio-economic reference score, that includes mainly language-based and mathematics tests. It was found that the lower the national score for pupils in classes with CO_2 levels above 2000 ppm, however; the association was not significant. Wargocki et al. (2000) provided an explanation that in the absence of fresh air in the room, the rate of metabolic CO_2 production of participants becomes higher and thus people are more likely to exert less effort.

Clements-Croome (2008) provided an explanation in his review about work performance, productivity and indoor air, on the health negative effects of elevated CO_2 levels higher than the 1000 ppm currently recommended by ASHRAE, which is equivalent to a concentration of 0.1%. It was mentioned that health effects can become acute at higher exposure levels, than 1000 ppm/ 0.1% of air concentration. Carbon dioxide concentrations of 7.5% lead to headaches, dizziness, restlessness, the feeling of an inability to breathe, sweating, malaise, increased heart rate, and increased blood pressure, and visual distortion can become apparent. At 10% concentration levels, hearing can be impaired, accompanied by nausea and a loss of consciousness (Canadian Centre for Occupational Health and Safety (2002), also the ASHRAE standard (2013). In relevance to the effects of CO_2 levels on health and sick absence, Gaihre et al. (2014) found 0.2% increase in sick absence for each 100 ppm increase in CO_2 levels in 60 Scottish classrooms.

Nevertheless, contradictory to the findings of subsequent experiments by Zhang et al. (2016a; 2016b; 2016c), who exposed subjects to elevated CO_2 levels at 1000 ppm and 3000 ppm with reference to 500 ppm. It was not found that adding CO_2 levels had any effect on performance. The subjects performed multiple tasks resembling office work including text typing, arithmetical calculations, and proofreading. Also, they performed basic cognitive functions, such as attention level, memory capacity, and reaction time, and neurobehavioural tests comprising of the redirection test, Stroop test, grammatical reasoning test, and Tsai–Partington test, which was used to predict arousal/stress level. A possible reason for the non-significant results obtained could be the level of task difficulty as they did not used strategic management simulation (SMS) decision making test when comparing the results to the significant results obtained from the very similar studies by Satish et al. (2012) and Allen et al. (2015).

In the premise of this study and based on the results obtained, both effects of temperature and CO_2 levels are of vital importance when considering the effects on learning, supported by significant scholars (e.g. Clements-Croome, 2008; Fanger, 2002). Nevertheless, the present results suggested that the effect on the accuracy of the cognitive tasks by CO_2 levels was larger compared to the effect of temperature, and particularly at CO_2 levels ~1800 ppm, but temperature effect had a greater influence on speed of response than CO_2 levels did.

7.1.3 The Effects of Confounders

With regard to the effect of the confounders, according to exposure conditions models (models A and B), the estimated effect size for the percentage of errors for all tasks decreased by ~1.6% and speed increased significantly by ~16 seconds for the Saudi participants relative to the non-Saudis after adding the variable of ethnicity in the final model, where this relation was statistically significant ($p<0.001$). The temperature and CO_2 models (models C and D) revealed negative associations as well: Saudi participants had significant lower percentages of errors by ~1.5% for the vigilance tasks and ~2.5% for memory and learning tasks relative to the non-Saudis. With respect to the speed of performance, Saudi participants were significantly faster relative to the non-Saudis by ~15 seconds ($p<0.001$). Ewing and Lan Yong (1992), and Rivkin et al. (2005) observed differences between ethnic groups in terms of temperature preference while learning, which may support the effect of ethnic background. Haverinen-Shaughnessy and Shaughnessy (2015) found in their study that ethnic background is associated with the test scores; however, it is not statistically significant. They justified the non-significant results by the limited sample size in their study.

Furthermore, the inclusion of the confounder of set AC temperature at home in the final model resulted in a significant decrease in the percentages of errors for every unit increase in temperature in the range between 18 and 24°C. Given that according to participants' subjective questionnaire responses, the mean AC temperature set by the Saudi participants at home was lower by 2°C, relative to that reported by the non-Saudi participants. Acclimation studies agreed that the people who have AC acclimation behaviour at home are perceiving thermal neutrality with lower temperatures compared to the non-acclimatised people within the same climatic context.

Correspondingly, it was found that the subjective ratings of the TSVs of the participants varied considerably by ethnicity. For the Saudi participants, exposure to 23°C reduced their thermal sensations to slightly warm from cool and/or slightly cool at 20°C, while at 25°C almost all participants perceived the ambient thermal environment as uncomfortably hot. However, the non-Saudi participants perceived the thermal environment as slightly cool and/or neutral at 23°C while more participants reported feeling cold, cool and slightly cool at 20°C. Fewer participants reported feeling hot at 25°C relative to the Saudi participants. Therefore, a stratified univariable thermal comfort analysis by ethnicity was performed for participants' TSVs (Appendix E). According to this analysis, during exposure conditions 1 and 2, when the temperature was set at 20°C and CO_2 levels were set at 600 ppm and 1000 ppm, respectively, the non-Saudi participants reported a cold thermal sensation while the Saudi participants did not. Based on model A, the cold sensation was attributed to ~10% increase in the percentage of errors as an average estimate size from all tasks.

However, during conditions 4 and 5, when the temperature was set at 23°C and CO_2 levels were set at 600 ppm and 1000 ppm, respectively, the Saudi participants reported slightly warm, warm and hot thermal sensations which was attributed to a significant increase in the percentage of errors, whereas the non-Saudi participants reported cool, slightly cool, slightly warm thermal sensations which were attributed to a significant decrease in the percentage of errors.

According to de-Dear and Brager (1998), human adaptation to the thermal environment, physiological and one’s past thermal exposure experience plays a crucial role in human's thermal comfort sensation. Thus, this could be interpreted as the effect of home acclimatisation of the most prevailing set AC temperature on mean comfort sensations. Yamtraipat et al. (2005) supports this suggestion, since they indicated that acclimatisation to using home ACs could affect thermal comfort sensation considerably.

Moreover, the final model estimates for the associations between the exposure conditions and accuracy on the cognitive tasks indicated negative associations for the thermal sensations of cool, slightly cool and slightly warm, relative to neutral, with the percentages of errors for all tasks. However, positive associations with the percentages of errors were observed for perceiving the thermal environment as cold, warm and hot relative to neutral. With regard to the higher percentages of errors associated with the thermal sensation of feeling cold, warm and hot versus neutral with the percentage of errors, Gunstad et al. (2009) suggested that cognitive functions are reduced during exposure to acute coldness and also for a short period of time afterwards. Hancock and Vasmatzidis (1998; 2000) provided the explanation that cognitive performance can decrease because of the disturbance to the physiological stability when the body gets outside the psychological zone of maximal adaptability. Maula et al. (2016), provided evidence that heat exposure can be the primary environmental factor that impairs performance. Lan et al. (2009) provided an explanation that in the case of a warm thermal environment, the blood vessels would normally become wider and thus increase the blood flow through the skin and that at higher thermal load one begins to perspire. In the absence of conscious effort, the human body might tend to adapt by lowering the internal heat production, and this reduces or even prevents perspiration, which could be linked to the common experience that warmth makes one feel drowsy and relaxed and therefore work less efficiently. With particular respect to the vigilance tasks (namely SRT, CPT and ALT TAB), significant higher percentages of errors were observed during all exposure conditions when the temperature increased from 20°C to 23°C and 25°C.

This concurs with the results of Kershaw and Lash (2013), who explained that attempting to maintain high arousal levels in unfavourable thermal environments can lead to user fatigue and diminishing performance. Tham et al. (2010) also reported lower arousal of the participants in their study during moderate warm exposure. Moreover, Roelofsen (2001), Jensen et al. (2009) and Lan et al. (2011) found that in a warm or cold discomfort environment, the learning rate was slowed down. Motivation generally improves when people become more comfortable, and thus performance decreased when participants lacked motivation. Furthermore, Tham and Willem (2010) found that the Tsai–Partington test results suggested a higher arousal at lower air temperature, particularly at 20°C. It was concluded from their study that cooling sensation activates the brain and excites the nervous system controlling thermoregulation and that the activation of the sympathetic nervous system elevates mental alertness or arousal, a mental state preferred in performing tasks that require attention, endurance and stamina. Nevertheless, the results from this study agree with Cui et al. (2013) in that warm discomfort environments were more harmful to human performance than cold discomfort environments. Significant higher estimated effect sizes of percentages of errors were observed for the hot sensations relative to the cold sensations.

Based on the results obtained, model A indicated significantly lower percentages of errors caused by the effects of the thermal comfort sensation of cool, slightly cool and/or slightly warm versus neutral. This result is in line with Watanuki and Kim (2005) who revealed that exposure to moderate cold resulting in reduced comfort is believed to have the potential to activate the amygdala and can result in higher arousal. Also, this result is in line with

Maula et al. (2016), who found that task-specific effort was significantly higher at a slightly warm temperature for a long-term memory task. Nevertheless, results from relevant studies to date about the effect of slightly warm temperatures on thermal comfort and cognitive performance are still unclear. Heaggblom et al. (2011) pointed to the need for more detailed experiments on the effect of slightly warm temperatures involving cognitive performance of varying cognitive demands.

Moreover, positive associations with the percentages of errors were observed for the detected symptoms like headache, heaviness on head, confusion, difficulty thinking, difficulty concentrating, or fatigue and the intolerable thermal discomfort which distracts focusing ability (detected symptoms corresponded with higher percentage of errors). All associations were found to be statistically significant. In the study by Maula et al. (2016), subjects reported significantly more difficulties with concentration, while symptoms of headache, throat symptoms, nose symptoms, and eye symptoms increased significantly at 29°C relative to 23°C. Subjects reported that the heat at 29°C was more disturbing than the coldness at 23°C. Moreover, Zhang et al. (2016) indicated that the increase in the intensity of several neurobehavioural symptoms such as headache and difficulty in thinking clearly can cause subjects to feel more tired and more sleepy. Several studies agreed that with increased CO_2 levels significant associations were observed with headache, fatigue, eye, nose, and respiratory tract symptoms (e.g. Apte et al., 2000; Erdmann et al., 2002; Seppanen et al., 1999). It was reported that when individuals experience just two symptoms like dry eyes, itchy or watery eyes, dry throat, lethargy, headache, chest tightness, they begin to perceive a reduction in their own performance. That perceived reduction in performance increases as the number of symptoms increases, averaging a 3% loss when experiencing three symptoms and an 8% loss when experiencing five symptoms (Raw et al., 1990).

In addition, with regard to the CO_2 and temperature model and the significant increase in the percentages of errors associated with the reported symptoms, Nishihara et al. (2014) explained that when CO_2 levels increase, cerebral blood flow decreases, which in turn decreases O_2 and glucose supply to support mental function. In addition, according to a number of studies, CO_2 is proposed as a potential mechanism to explain negative effects on performance because it may result in mild acidosis, leading to headaches as well as difficulty thinking clearly and concentrating (Wyon and Wargocki, 2013; Cometto-Muñiz et al., 1997; Wargocki et al., 2002; Lumb, 2002). Building-related illnesses and SBS were associated with decreased ventilation rates since the 1980s (Riesenberg and Arehart-Treichel 1986). Significant associations were observed with headache, fatigue, eye, nose, and respiratory tract symptoms even in buildings where CO_2 levels were below 5000 ppm; the prevalence of symptoms continued to decrease with the CO_2 level even below 800 ppm (e.g. Myhrvold et al., 1996; Norback et al., 2013; Seppanen et al., 1999; Tsai et al., 2012).

Epidemiologic and intervention studies showed that higher levels of CO_2 within the range found in normal indoor settings are associated with increased prevalence of acute health symptoms like headache and mucosal irritation (Erdmann and Apte, 2004; Federspiel et al., 2004; Milton et al., 2000; Seppanen et al., 1999; Shendell et al., 2004; Wargocki et al., 2000). The significant increase in percentages of errors which occurred after including the symptoms of fatigue could be explained by the mental fatigue which would consume more cognitive resources to activate more effort to maintain optimal engagement through attention (Mackworth, 1968). Boksem et al. (2005) found that goal-directed attention is negatively affected by mental fatigue, known as an inability to maintain optimal cognitive performance. In addition, Seppänen at al. (1999), Fisk (2000) and Wargocki et al. (2002) showed that the prevalence of some types of communicable respiratory diseases is higher under conditions with lower ventilation rates.

With respect to the speed of reaction, significant fast performance was observed during the conditions when temperature was set at 25°C, relative to 23°C and 20°C, for all tests considered in the study. Lan and Lian (2009) provided the explanation that when participants felt uncomfortably hot, they tried to complete the tests as soon as possible to escape from the environment. Therefore, this is more linked to thermal perception than an absolute temperature. An explanation was provided by Grether (1973), who said that time estimation and reaction time is sped up upon exposure to the heat due to an increased speed of neural conduction associated with elevated body temperature. Moreover, the results indicated that the speeds of reaction in all tasks were slowed down significantly when the participants perceived the thermal environment during the time of exposure to be cold, cool and slightly cool versus a neutral comfortable sensation. Bruyn and Lamoureux (2005) provided the explanation for the high speed by stating that rise in internal body temperature resulted in an increase in the rate of neural activity and a decrease in perceived time. A study by Hocking et al. (2001) supported the theory of increased neural activity. In their study, brain imaging showed changes in electrical activity in response to thermal stress during cognitive performance. Complimentary to this finding, the speed of reaction in all tasks was found to increase significantly when the participants perceived the thermal environment during the time of exposure to be slightly warm, warm and hot compared to a neutral comfortable sensation.

On the other hand, significant slowed performance was observed during the conditions when temperature was set at 20°C, relative to 23°C and 25°C, for all tests considered in the study. Lan et al. (2009) suggested that the slowing speed at low temperature can be attributed to the deterioration of dexterity of hands, due to stiffening of joints and slow muscular reaction, numbness, and a loss in strength. Statistically significant fast responses were observed in the Saudi participants, relative to participants of other ethnicities, under the conditions of exposure when the temperature was set at 25°C. A possible explanation could be that the Saudis felt uncomfortably hot, thus they hoped to complete tasks as soon as possible to escape from the stressful thermal environment, especially because the observed quick reaction time has been associated with an increased percentage of errors.

With regard to the significant increase observed for the speed of reactions, which was concurrent with a significant increase in the percentages of errors, Nishihara et al. (2014) provided the explanation that when the tasks were performed at maximum pace, the subjects made more typing errors than when performing tasks at a normal pace. This is concordant with the postulation that people tend to reduce their speed of work to maintain a low and/or acceptable error rate (Wyon and Wargocki, 2013; Wickelgren, 1977).

The speed of performance is another important aspect of performance. Wargocki and Wyon (2013) argued that the speed of performance is an important aspect, since it is likely that if students in classrooms with poor indoor environmental quality work slower, teachers will have to spend more time and effort, so the costs can be quantified in terms of the extra time for which teachers must be paid.

7.2 Implications for Educational Buildings Design in Saudi Arabia

As indicated in the literature discussed, memory, language and reasoning abilities are the most important factors for learning and concentration. For information processing, information has to pass across billions of neurons' axons, which transmit signals to the next neuron via synapse, where some degradation is common (Ford, 2011). Therefore, neuroscientists have long believed that learning and memory formation are made by the strengthening and weakening of connections among brain cells to avoid or minimise the degradation that may happen while learning. For instance, strengthening memory formation when learning a new language is crucial for learning new vocabularies. Moreover, for solving arithmetic problems, brain imaging studies have shown that the right parietal region is primarily involved in basic quantity processing, while the left parietal region is involved in more precise numerical operations like addition and subtraction (Park, 2013). Thus, it was suggested that maths abilities are linked to left-right brain communication, and proficiency in calculation requires efficient neural signals between separate cortex areas (Marathe, 2012), hence it is implied that for processing the information across both brain hemispheres and the efficient yet fast coordination is crucial. Nevertheless, coordination between both brain hemispheres has also been linked to motor functioning and attention (e.g. McLeod et al., 2014; Goulardins et al., 2016). Hence, an efficient neural network with high attentiveness is a key requirement for enhancing memory, language, and reasoning abilities for the tasks conducive to learning.

Interestingly enough, evidence was provided that activation of the brain cells is significantly correlated with mild hot and cold ambient exposures (Kiyohara et al., 1995). However, the numbers of neurons in some nuclei were found to be significantly different between cold and warm ambient exposures, as the number of neurons were significantly larger, which were found to be activated in the brain regions after mild cold ambient exposure compared to mild hot ambient exposure. It was concluded also that thermoregulatory responses are associated with cold and warm ambient exposures (Kiyohara et al., 1995).

Accordingly, and also on the basis of the results obtained from the study, one can suggest that for activating more brain regions and processing the information with minimal degradations while learning, exposures to ambient mild cold and/or mild warm conditions would be favoured. Based on the associations obtained from the results of this study, this would be highly correlated with students' thermal comfort perceptions and acclimatisation and their ability to tolerate the ambient classroom thermal environmental. The results obtained and discussed earlier suggest that this could be achieved by exposure to classrooms' temperature in the air-conditioned educational buildings for adult female students in Jeddah, Saudi Arabia is in the range between 20 and 23°C for all taught subjects, while considering thermal comfort of students along with the provision of adequate ventilation rates of ~15 l/s per person (equivalent to CO_2 levels of ~600 ppm). The results also revealed that thermal comfort perceptions are linked in the first place to occupants' habits and ability of acclimatisation.

The results obtained from the study showed that by increasing classrooms' AC set points from 20°C, which is the mean temperature currently set in classrooms of the educational buildings for adult students in Jeddah, to become 23°C, the percentages of errors would significantly decrease by an average of ~3% for memory and learning tasks. Most importantly, according the estimates effect sizes derived from model A, during exposure condition 4 (at which the temperature was set at 23°C), the percentages of errors decreased significantly by around five times ($p<0.001$), relative to the baseline condition (at which the temperature was set at 20°C). Therefore, this estimates of effect sizes might be a relatively big effect in practice that cannot be ignored.

Also, increasing classrooms' ventilation rates so that indoor CO_2 levels are kept in the ranges of ~600 ppm, relative to recommended levels by ASHRAE of 1000 ppm, would significantly decrease the percentages of errors by an average estimate of ~12% for memory and complex tasks considered in the study, and by ~7% for vigilance tasks considered in the study. Furthermore, an average estimated decrease in the percentages of errors of ~24% for memory and complex tasks, and by ~12% for vigilance tasks is expected when keeping CO_2 levels in the range of 600 ppm relative to 1800 ppm, which is the mean level in educational buildings in Saudi Arabia based on the very limited published research to date (e.g. Al-Subaie, 2014). As suggested above, these estimates of effect sizes might be a relatively big effect in practice that cannot be ignored.

Rosbach et al. (2013) showed that classroom CO_2 levels can be reduced using a CO_2 controlled mechanical ventilation system. Also, Twardella et al. (2012) and Wargocki and Wyon (2013) suggested that classrooms' CO_2 levels can be significantly reduced by installing a CO_2 controlled mechanical ventilation system. Nevertheless, good environmental practice usually goes with good economic practice. Therefore, from both an economic and environmental point of view, educational buildings located in hot regions relying on HVAC for ventilation should strive for optimal HVAC operation to keep energy consumption in check. With regard to ventilation, US EPA (2013) has estimated that upgrading the HVAC systems with inclusion of a modern energy recovery ventilation system can increase ventilation rate from 2.4 l/s per person to 7.1 l/s per person, with no negative implications in terms of capital cost, energy costs, and moisture control. As for temperature, according to a number of studies, only 1°C rise in the AC's set temperature could significantly reduce energy consumption by ~6% (e.g. Tham, 1993; Yang and Su, 1997; Yamtraipat et al., 2004). With particular focus on the hot climatic region of the Arabian Peninsula, a study conducted in Kuwait by Al-Ajmi et al. (2009) indicated that in terms of energy conservation increasing the thermostat temperature by 1°C could save about 10% of space cooling energy, as supported by Sekhar et al. (2002) and Cena and deDear (2001). In support of this premise, results from this study revealed that increasing classrooms' temperature from 20°C to 23°C could improve performance for memory and learning tasks significantly. Therefore, no negative implications from an economic perspective; nevertheless, energy savings could be achieved by this application relative to the current norms of AC operation in educational buildings in Jeddah, Saudi Arabia.

7.3 Limitations of the Study

From a theoretical point of view, it would have been more accurate to conduct the experiment at all temperatures between 20°C and 25°C, keeping a difference of 1°C, especially because it was revealed that a 1.8–2.4% performance decrement is expected per 1°C below 25°C (Niemelä et al. 2001; 2002). However, from a practical point of view, a maximum of three conditions was manageable in terms of the fieldwork time schedule and also for minimising the carryover effect, which is the main disadvantage of within-subjects comparisons.

Furthermore, due to the segregation of female students from male students in educational buildings in Saudi Arabia, it was not possible to allow participation by both males and females and thus to investigate the effect of gender in the study. Therefore, generalisation of results to males will not be possible.

Although numerous studies have investigated the effect of gender in thermal comfort studies, the majority of relevant studies did not find significant effects attributed to gender. For instance, no statistically significant differences in thermal sensation were observed between residents of different gender in a study by Becker and Paciuk (2009) which was considered to have a strong design. Similarly, in a study which was conducted in air-conditioned buildings in Australia, gender was found to have no significant effect on thermal sensation (Erlandson et al., 2003). Likewise, in an early climate chamber study conducted in a Danish college, no significant differences in thermal comfort responses were found between people of different gender (Fanger, 1970). Also, in a study conducted in primary schools in Sweden gender did not affect the perception of room temperature (Norbäck, 1995). In another study conducted in an air-conditioned office building in Japan, a significant difference in neutral temperature between Japanese males and Japanese females was noted, $p<0.05$, (Nakano et al., 2002). It was also revealed by Tham and Willem (2010) that effects of air temperature were not influenced by gender differences, although between-subjects analysis indicated that the skin temperature of male subjects was slightly lower than that of the females. Also, Maula et al. (2016) found that gender had no main effect on the mean thermal sensation ($P>0.05$) or thermal satisfaction ($P>0.05$) in their study about the effect of temperature on thermal comfort and cognitive performance.

Another limitation to the study was that it was not possible to disentangle the effects of pure CO_2 from ventilation rates, since the CO_2 measured was a result of adjusting the dampers.

Also, another limitation is that it is not easy to understand how battery tests relate to real learning and whether students may develop coping strategy in real environments. Therefore, it could be a limitation to the study, regarding whether there are any compensation mechanisms which may affect performance in real life (e.g. the effect if the participants haven't foregone their morning coffee).

7.4 Summary

According to the results obtained from the intervention study, this chapter highlighted the following points of discussion:

1. First, it was revealed that the percentages of errors increased significantly by almost double the estimated size of effect during all the exposure conditions investigated relative to the baseline condition (condition 1) for the vigilance tasks ($p<0.001$), as an overall average estimate. However, for memory and learning tasks, the percentages of errors were almost doubled ($p<0.001$) during all exposure conditions investigated relative to the baseline condition, except during exposure condition 4, where the percentages of errors decreased significantly by around five times ($p<0.001$), estimated from model A. In exposure condition 4, temperature was set at 23°C, while in the baseline exposure condition the temperature was set at 20°C. CO_2 levels were set at 600 ppm during both exposures. The explanation provided was that temperature affects cognitive tasks differentially depending on the type of task.
2. Furthermore, a significant increase in the percentage of errors occurred after adding the associated confounders to the model. It was indicated that the estimated effect size caused by the effects of thermal sensations are the ones responsible for over half of the magnitude of the size of increase which occurred in the percentages of errors for all tasks (~60%). The remaining increase in the percentage of errors is divided between the effects of ethnicity, AC temperature at home, and the reported symptoms which were associated with the inability to focus.
3. Following that, the associations obtained from the investigated temperatures and CO_2 levels model were discussed. This model was applied to predict whether temperature or CO_2 levels have a higher effect on the cognitive performance of tasks conducive to learning. When the exposure conditions were broken down into interactions between the temperatures and CO_2 levels investigated, this approach gave control over all the possible permutations separately for the effects of the temperatures and those of the CO_2 levels and also the effects of all possible combinations. Therefore, it was possible to answer the research question

whether temperature or CO_2 levels have more effect on cognitive performance. On the basis of the results obtained from this, it was suggested that increasing room air temperature to within 20–23°C may improve work performance, while any increase beyond this range may lead to negative productivity which concurs with the results of the most relevant studies. With regard to the effect of the confounders, it was also indicated that ethnicity, AC temperature at home, and the reported symptoms which were associated with the inability to focus were all associated with the performance of the cognitive tasks and were responsible for a significant increase in the percentage of errors.

4. Moreover, the relevance of thermal comfort sensations and their effects as well as the effects of the confounders of the study were discussed in detail, with specific regard to the AC acclimatisation effect and its influence in the study. Implications for building design and cognitive performance were discussed afterwards. The chapter concludes with the limitations encountered. Accordingly, the conclusions drawn from the findings, and the suggested future work, as well as the application/generalisation of results to other contexts and climates are presented in the following chapter.

Chapter 8: Conclusions and Future Work

8.1 Main Findings and Contribution to Knowledge

In relation to the research main aim and specific questions, it could be concluded that:

- The current prevalent classrooms' temperatures in the educational buildings of adult of adult female students in Jeddah, Saudi Arabia relying solely on air-conditioners for cooling and ventilation is 20°C.
- Regarding the prevailing CO_2 levels levels (as an indicator for indoor ventilation rates) in the educational buildings of adult of adult female students in Jeddah, Saudi Arabia, due to time and financial constraints, the information about the prevalent CO_2 levels was not gathered.
- After considering the possible confounders of the study, the current temperature setting (namely 20°C) contributed to higher percentage of errors by ~3% for memory and learning tasks. In addition, the results suggest that the cold thermal sensations among students which was found to occur when setting classrooms' temperature at 20°C, was associated with a significant increase in the percentage of errors by ~10.5% for both, memory and vigilance tasks.
- Nevertheless, it was revealed from the results that setting classrooms' temperatures at temperatures 23°C can contribute to slightly cool thermal sensations for thee non-native students which was associated with significant lower percentage of errors by ~2% for memory and vigilance tasks, and can contribute to slightly warm thermal sensations for the Saudi students and/or the non-Saudis who spent 10 years or more in the country which was associated with significant lower percentage of errors by ~0.5% for memory but not vigilance tasks.
- On the other hand, the results suggest that investigated classrooms' temperatures of 25°C contributed to hot thermal sensations among the students was associated with a significant increase in the percentage of errors by ~22% for memory and learning tasks and ~16% for vigilance tasks.

- With regard to the CO_2 levels, the results of this study revealed that lowering CO_2 levels from 1800 ppm, which are suggested to be the range of prevalent CO_2 levels in educational buildings in Saudi Arabia based on the very limited published research up to date, was associated with a significant increase in the percentage of errors by ~24% for memory tasks, and ~12% for vigilance tasks.
- In relation to the ASHRAE standards adopted in Saudi Arabia for IAQ, it was found that decreasing the recommendation of CO_2 levels in classrooms from 1000 ppm, which is currently recommended by the ASHRAE standards, to become 600 ppm would lower percentage of errors significantly by ~13% for memory tasks, and ~6% for vigilance tasks.
- It is worth pointing out that since educational places are well-known for their high occupational capacity, which in turn causes the increase of classroom temperature above the recommended setting and also increases CO_2 levels, sensors in classrooms should be connected to the BMS in order to always maintain the recommended CO_2 levels of 600 ppm at constant levels during occupational periods, in buildings that employ central AC systems. For buildings which employ split AC systems, upgrading to a central AC system is highly recommended.
- Furthermore, the results of the study indicated that although both effects of temperature and CO_2 levels are of vital importance when considering the effects on learning, nevertheless; it was found that the effect on the accuracy of the cognitive tasks by CO_2 levels was larger compared to the effect of temperature, and particularly at CO_2 levels ~1800 ppm, but temperature effect had a greater influence on speed of response than CO_2 levels did.
- Furthermore, it was suggested from the results that acclimatisation to using home ACs termed "AC acclimatisation behaviour" can significantly influence students' cognitive performance for the tasks considered in this study, referring to the tasks conducive to learning. This factor was responsible for the preference of the Saudi participants to a somewhat lower temperature, relative to the non-Saudis, by an average of 2°C. Accordingly, it could be concluded that acclimatisation should be considered when developing IAQ

and thermal comfort standards in the mechanically ventilated buildings located in the hot climates relying on ACs for ventilation and cooling.

Accordingly, the findings of the study suggest that the recommended indoor temperatures and CO_2 levels for female university/college buildings in Jeddah, Saudi Arabia would be:

- The highest set classroom temperature, in the air-conditioned educational buildings located in the hot desert climates, would be 23°C and lowest would be 20°C for all learning spaces.
- For learning spaces where taught subjects require higher vigilance, the recommended set temperature would be 20°C. This could apply also to lecture halls where the greater attention of audiences is required.
- For learning spaces where taught subjects require more activated working memory and concentration (namely those dealing with numbers, such as maths, physics, mechanics, and learning new languages), the recommended set temperature would be in the range of temperature 20°C -23°C, but mostly closer to the 23°C, depending on the thermal comfort sensation of students. Most important, 23°C would be the higher limit. This also applies for timed task examination halls to avoid poor dexterity of hands.
- It is recommended to maintain the mean CO_2 levels within the ranges of 600 ppm for all educational spaces (equivalent to ventilation rate of 15 l/s per person).

8.2 Limitations of the Study

The main limitation of the study can be summarised as:

- First, it was not possible to conduct the experiment for more than eight participants at a time since a maximum of eight licenses of the BARS neurobehavioral battery with eight '9-Buttons' keyboards could have been obtained due to financial constraints.
- Also, it was not possible to disentangle the effects of pure CO_2 from ventilation rates. For instance, in the study by Satish et al. (2012), and the study by Allen et al. (2015), pure CO_2 was pumped to the rooms of investigation and was considered as a pollutant in itself, whereas in this study CO_2 was the bio-effluent from the participants in the investigated classrooms and was not considered to be a pollutant but an indicator for the efficiency of ventilation.
- Furthermore, it was not easy understand how battery tests relate to real learning and whether students may develop coping strategy in real environments. Therefore, it is less understood whether there are any compensation mechanisms which may affect performance in real life (e.g. the effect if the participants haven't foregone their morning coffee).

8.3 Future Work

1. Further investigation is required for the maximum level recommended for CO_2 levels in classrooms. Also, further investigation could be done adopting the same methodology to investigate the effect of temperature on memory and complex tasks in the very narrow range between 21°C - 23°C.
2. In addition, for practicality reasons and owing to segregation of females from males in the educational buildings in Saudi Arabia, this research was conducted only on female participants, and therefore it is worth applying the same methodology on males and investigate the effect of gender.
3. Furthermore, cost-benefit analysis could be performed to check the feasibility of applying the research findings. A meta-analysis could used to derive a model that integrates the economic outcomes of improved health

and performance into building cost-benefit calculations, together with energy and maintenance costs.

4. Also, acclimatisation could be studied as a main output of the study where multilevel models could be performed for thermal comfort separately to understand the factors associated with it and their effects.
5. In addition, integrating VOCs and indoor pollutants in a similar study adopting the same methodology would be recommended.
6. Moreover, the confounders of classroom size, university/college level, and the socio-economic variables to the multivariable multilevel model in addition to the student level variables needs to be investigated. In a similar notion, since cognitive performance is quite complex and nested, and could be interrelated with many confounders than those considered in the current study, adding these confounders to the multivariable multilevel model might have significant effects and is thus worth investigation.
7. Furthermore, further studies (including interventions) are needed in order to examine the causality of the observed relationships, the residual confounding, and whether the results can be generalised to other climates, building types, building envelopes, and ventilation modes.

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Appendix A: Sample of the questionnaires used to gather information on the base-line classrooms' temperature in educational buildings for adult students in Jeddah, Saudi Arabia

What is the mean set temperature in classrooms in your building?

ما هو متوسط درجة الحرارة المحددة في الفصول الدراسية في المبنى الخاص بك؟

Is this a constant temperature throughout the academic year, or varies according to the outdoor climate? Or varies for any other reason, please explain?

هل هذه درجة حرارة ثابتة طوال العام الدراسي، أم تختلف تبعا للمناخ الخارجي؟ أو يختلف لأي سبب آخر، يرجى توضيح؟

Appendix B: Sample of the questionnaire survey disseminated to the participants during the pilot study and intervention study

Participants' codes	D	A	H	S				R		
	University code			Participant number				Room number		

***Q1*. Today's Date تاريخ اليوم:** (*Day/Month/Year*) __/__/___

***Q2*. Time الوقت:** .... ***Q3*. Your Age عمرك:** ....

***Q4*. Your clothing level?** ماذا ترتدين؟

(choose from the following) اختاري من الآتي

- Bra+ Panties+ Light trousers+ short-sleeved dress + Sandals + Long sleeves silk long dress: "Abaya" = 0.8

الملابس الداخلية + سراويل خفيفة + فستان بأكمام قصيرة + الصنادل +عباية

-Bra+ Panties+ Light trousers + Long-sleeved dress + stockings + Shoes+ Abaya=0.9

الملابس الداخلية + سراويل خفيفة + فستان بأكمام طويلة + حذاء +عباية

-Bra+ Panties+ under wear T-shirt +Thick trousers + short-sleeved knit sport shirt+ stockings + Shoes+ Abaya=0.9

الملابس الداخلية + تي شيرت + سراويل سميكة + قميص الأكمام قصيرة+ جوارب+ حذاء +عباية

-Bra+ Panties+ under wear T-shirt + Light trousers + long-sleeved dress + Calf-length socks + Shoes+ Abaya=0.9

الملابس الداخلية + تي شيرت + قميص بأكمام طويلة + جوارب+ سراويل خفيفة+ حذاء+ عباية

-Bra+ Panties+ under wear T-shirt +Thick trousers+ Long-sleeve dress + Calf-length socks+ Shoes+ Abaya=1.0

الملابس الداخلية + سراويل سميكة + قميص بأكمام طويلة + جوارب + حذاء تي شيرت+ عباية

-Bra+ Panties+ under wear T-shirt + Thick trousers+ Long-sleeve flannel or sweatshirt shirt + Knee socks (thick)+ Slippers + Abaya=1.1

+ سراويل سميكة + قميص بأكمام طويلة + جوارب سميكة + حذاء+ تي شيرت+ عباية الملابس الداخلية

***Q5*. Did you drink Tea/Coffee/Coke/Cacao in the last 2 hours before participating?**

هل شربت شاي او قهوه او كوكا او كاكاو خلال الساعتين الماضيتين قبل المشاركه؟

☐ **Yes** نعم ☐ **No** لا

***Q6*. Were you exercising in the last 2 hours before participating?**

هل كنت تمارسين الرياضه خلال الساعتين الماضيتين قبل المشاركه؟

☐ **Yes** نعم ☐ **No** لا

***Q7*. Did you have your breakfast today?** .... هل تناولت الفطور اليوم؟

☐ **Yes** نعم ☐ **No** لا

***Q8*. Did you sleep less than 7 hours last night?** ....

هل نمت اقل من ٧ ساعات الليله الماضيه؟

☐ **Yes** نعم ☐ **No** لا

***Q.9*. Right now, how you feel about the current classroom temperature?**

Try to give an average rating.

حاليا، كيف تشعري بدرجة الحرارة في الفصل؟

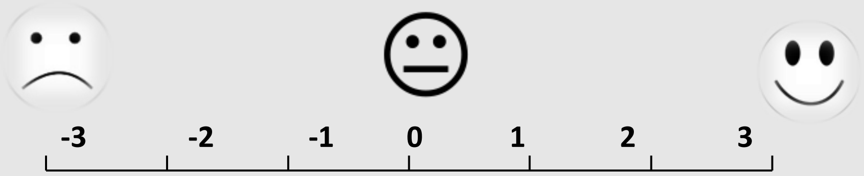
-3	-2	-1	0	1	2	3
Cold	slightly cold	cool	neutral	warm	slightly hot	Hot
بارد	**بارد قليلا**	**لطيف**	**معتدل**	**دافي ء**	**حار قليلا**	**حار**

***9.1* Would you like to change it?** هل تودي تغير ها ؟

☐ Yes نعم ☐ No لا

Q.10. How you feel about the level of difficulty of the cognitive tasks?

(If the difficulty level of the test is varying from task to another, try to give an average rating) ما درجة صعوبة الاختبار ؟



Extremely difficult صعب جدا

Extremely easy سهل جدا

Q.11. Do you think that your ability to answer the given tasks was affected due to any personal reasons?

هل تاثر اداءك باسباب شخصية؟

☐ No لا ☐ Yes نعم

Comments box, please write your comments here: اكتبي تعليقاتك هنا

....

....

....

....

....

....

....

END - THANK YOU FOR YOUR PARTICIPATION

THIS SECTION IS TO BE FILLED BY THE RESEARCEHR
Seasonal condition: ....
Classroom temperature: ....
Classroom relative humidity: ....
Air velocity from diffusers: ....
CO_2 concentration levels: ....
Ambient noise levels: ....

Appendix C: Descriptive Analysis

Figure C.1: A line graph showing the trend of change in the % of errors at the SRT test during the exposures of the different conditions

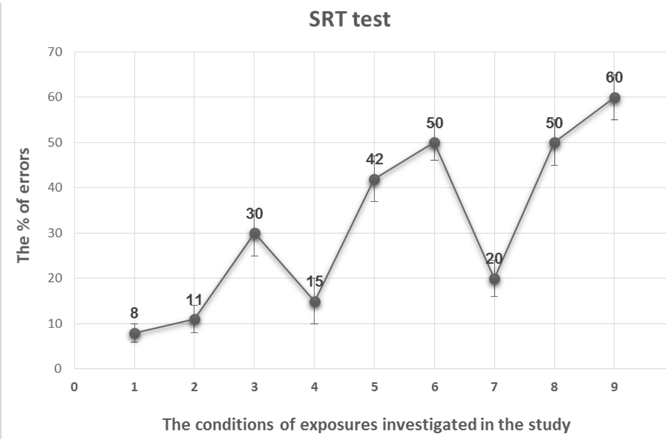


Figure C.2: A line graph showing the trend of change in the % of errors at the RL test during the exposures of the different conditions

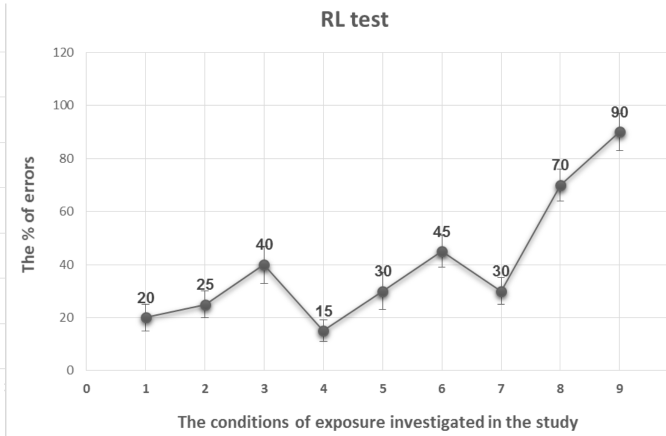


Figure C.3: A line graph showing the trend of change in the % of errors at the MTS test during the exposures of the different conditions

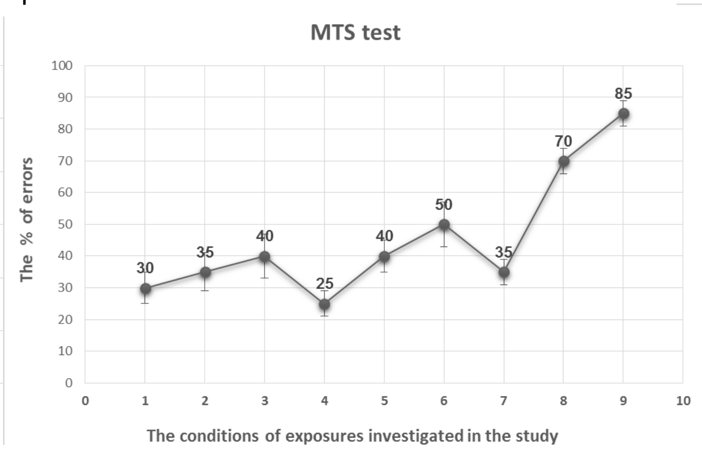


Figure C.4: A line graph showing the trend of change in the speed of response at the SRT test during the exposures of the different conditions

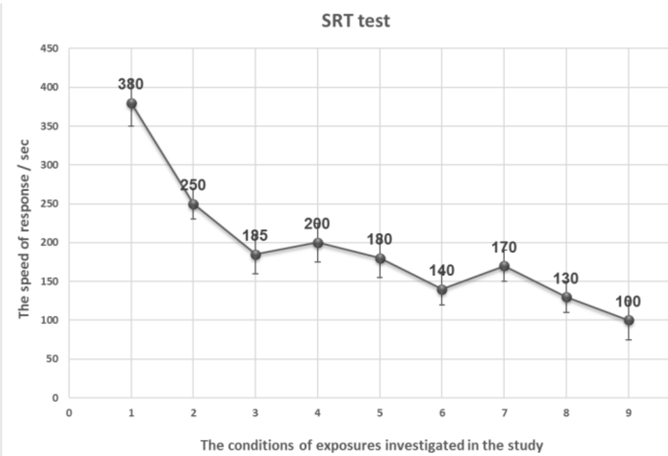


Figure C.5: A line graph showing the trend of change in the speed of response at the RL test during the exposures of the different conditions

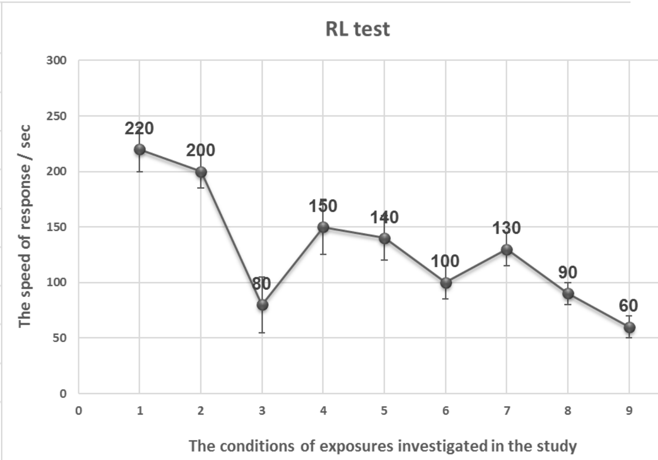
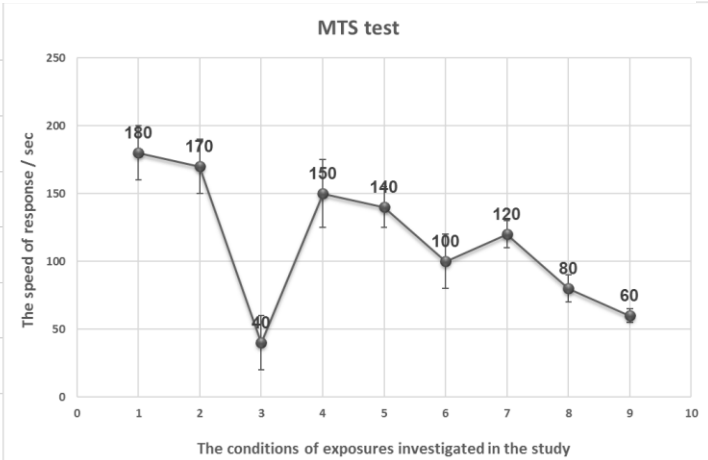


Figure C.6: A line graph showing the trend of change in the speed of response at the MTS test during the exposures of the different conditions



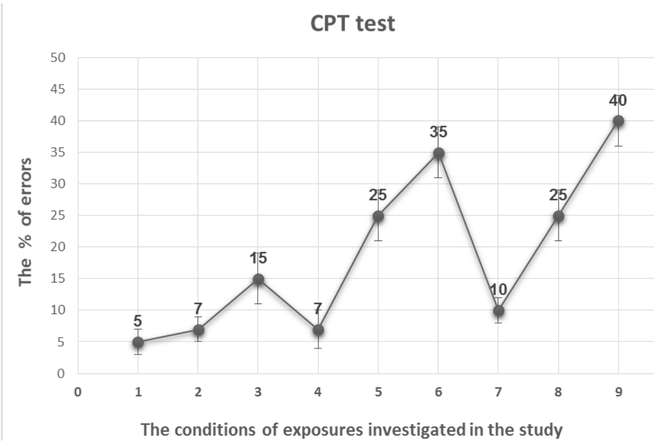


Figure C.7: A line graph showing the trend of change in the % of errors at the CPT test during the exposures of the different conditions

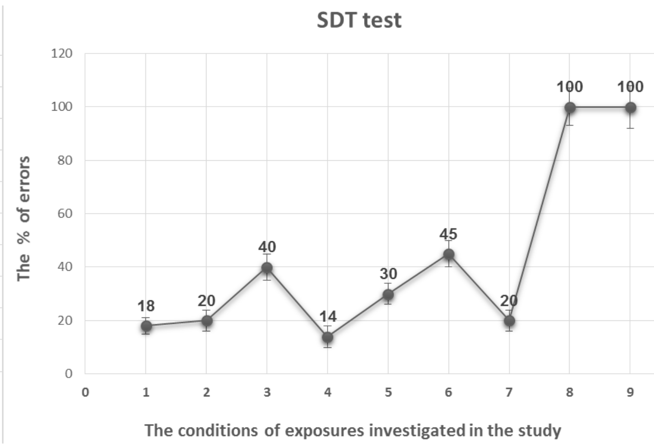


Figure C.8: A line graph showing the trend of change in the % of errors at the SDT test during the exposures of the different conditions

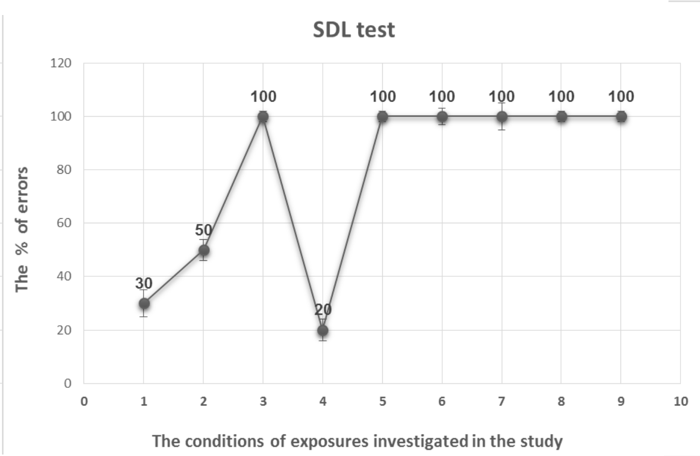


Figure C.9: A line graph showing the trend of change in the % of errors at the SDL test during the exposures of the different conditions

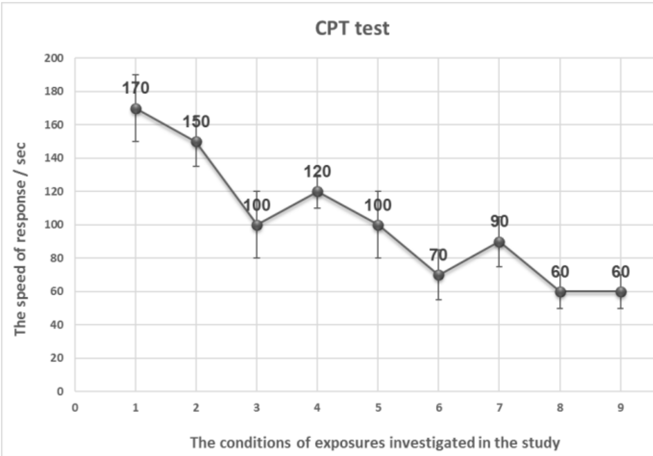


Figure C.10: A line graph showing the trend of change in the speed of response at the CPT test during the exposures of the different conditions

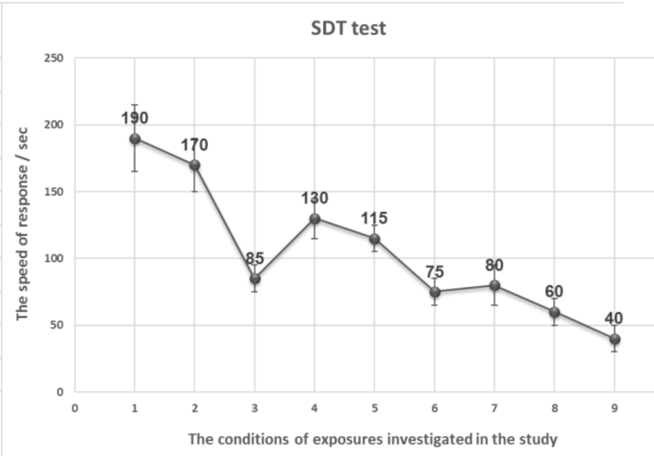


Figure C.11: A line graph showing the trend of change in the speed of response at the SDT test during the exposures of the different conditions

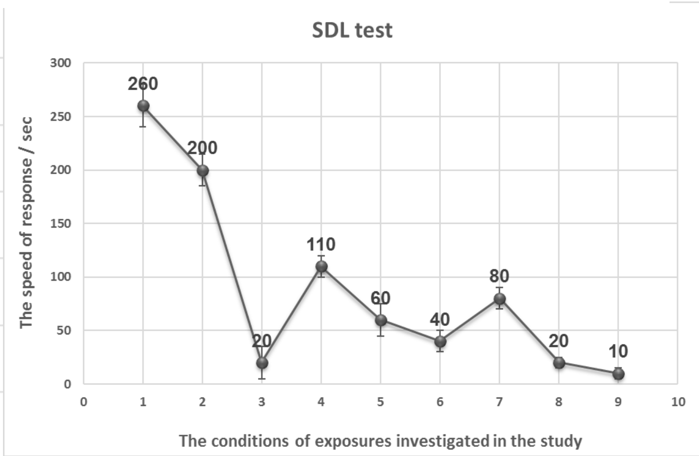
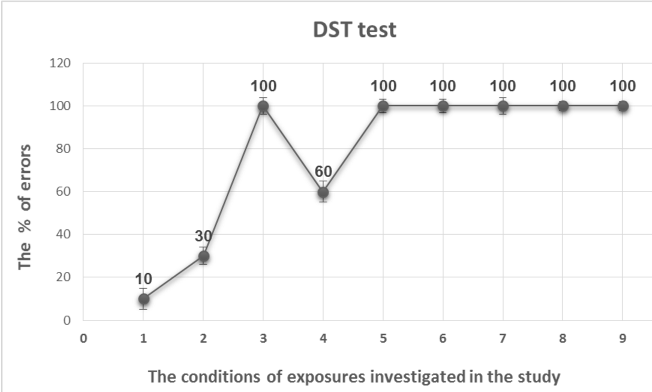


Figure C.12: A line graph showing the trend of change in the speed of response at the SDL test during the exposures of the different conditions

Figure C.13: A line graph showing the trend of change in the % of errors at the DST test during the exposures of the different conditions

Figure C.14: A line graph showing the trend of change in the % of errors at the Alternative Tapping test during the exposures of the different conditions



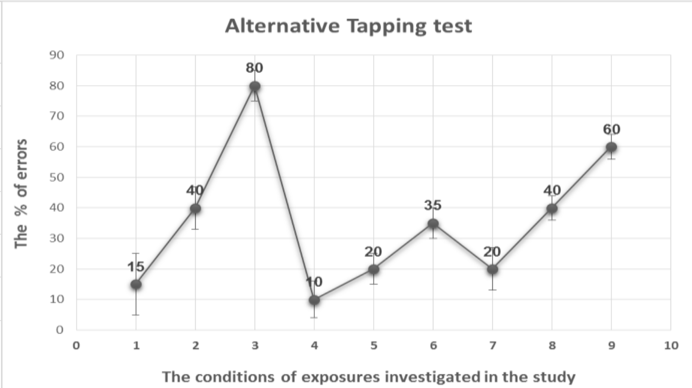
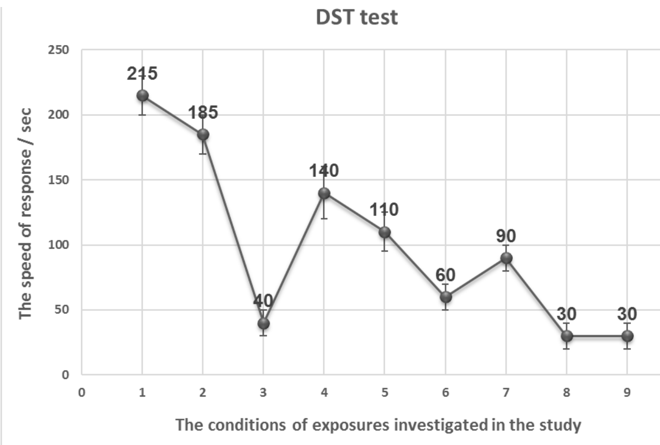
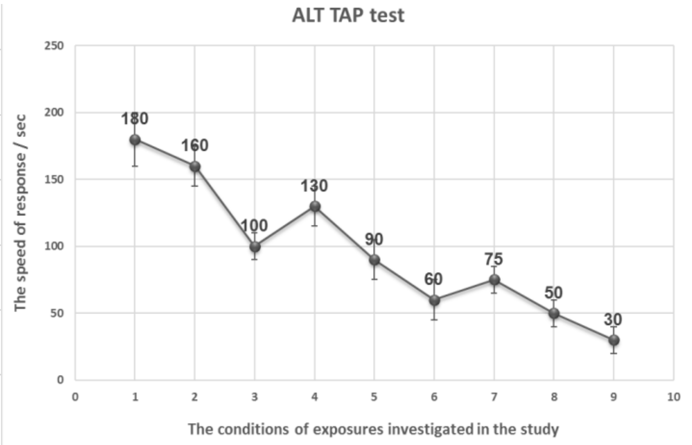


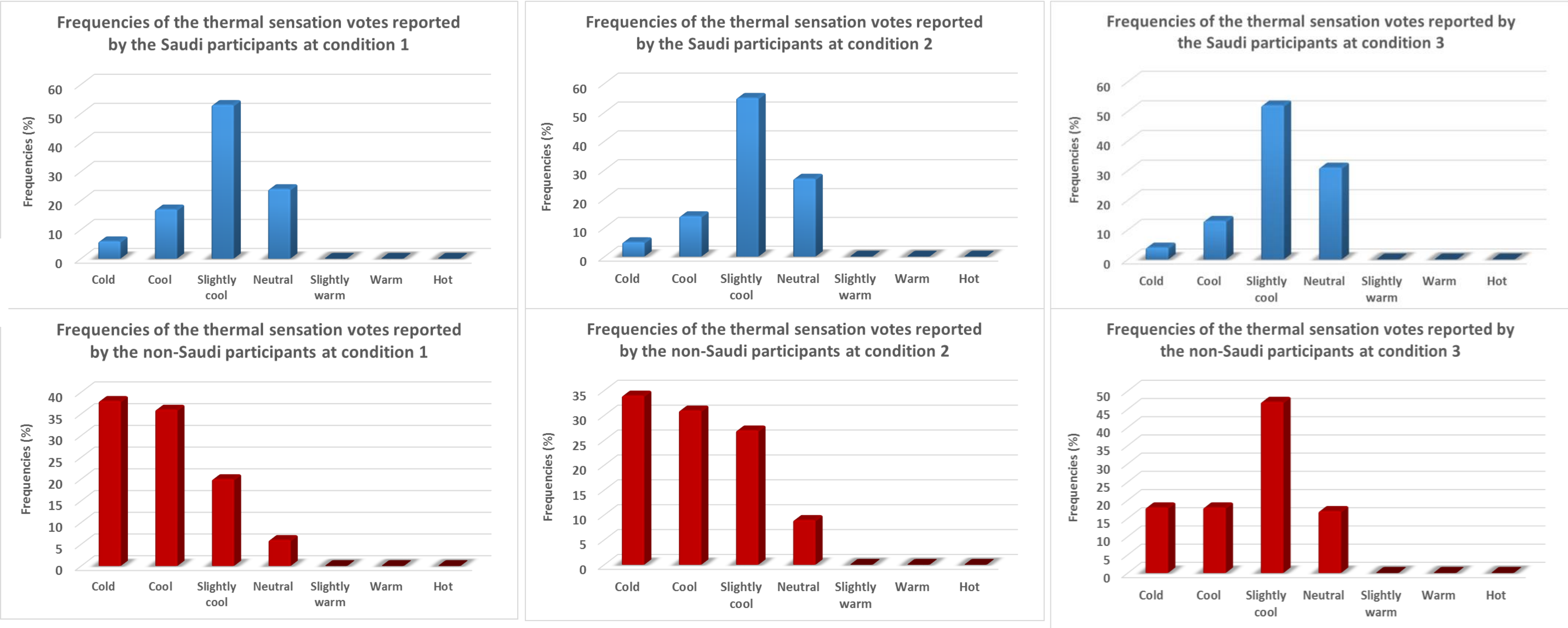
Figure C.16: A line graph showing the trend of change in the speed of response at the DST test during the exposures of the different conditions

Figure C.16: A line graph showing the trend of change in the speed of response at the Alternative Tapping test during the exposures of the different conditions

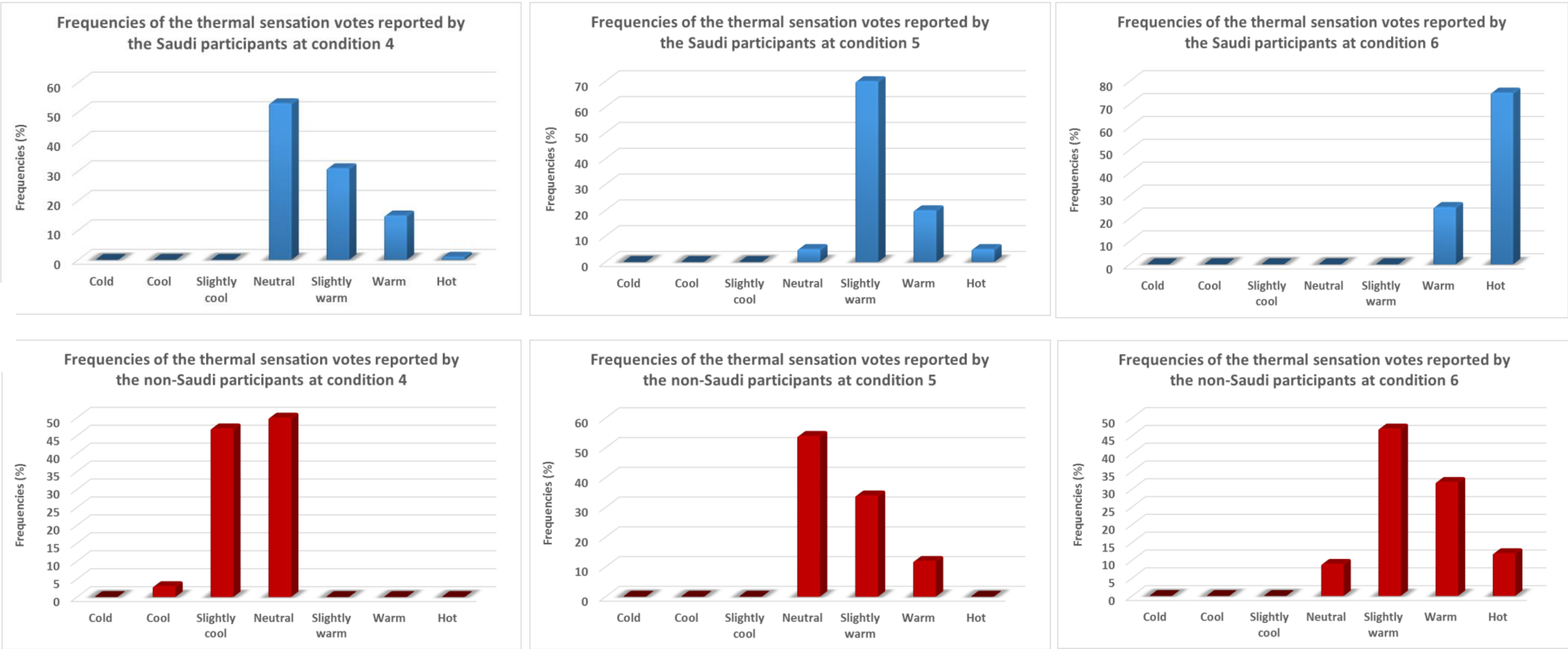




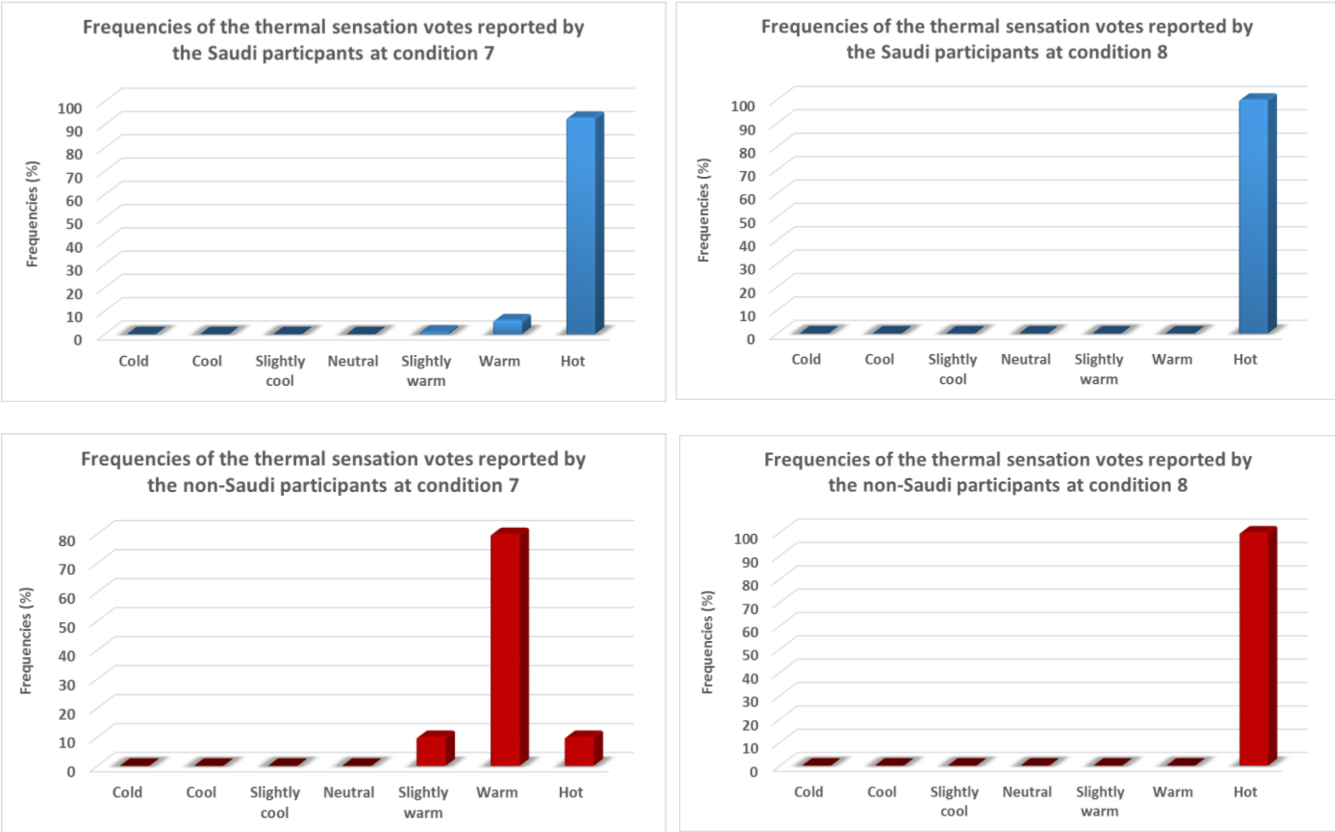
Bar charts showing the frequencies (%) of participants' thermal sensations voted during the exposure conditions, sorted by ethnicity (blue bars represent the votes from the Saudi participants and the red bars represent the votes from the non-Saudi participants).



Bar charts showing the frequencies (%) of participants' thermal sensations voted during the exposure conditions, sorted by ethnicity (blue bars represent the votes from the Saudi participants and the red bars represent the votes from the non-Saudi participants).



Bar charts showing the frequencies (%) of participants' thermal sensations voted during the exposure conditions, sorted by ethnicity (blue bars represent the votes from the Saudi participants and the red bars represent the votes from the non-Saudi participants).



Appendix D: Results of the uni-variable multi-level model analysis

Table D.1: Results of the effect of age on the accuracy (% of errors) obtained by the univariable multilevel analysis

Age	SRT error% estimate (95% CI)	p-value	RL error% estimate (95% CI)	p-value	MTS error% estimate (95% CI)	p-value	CPT error% estimate (95% CI)	p-value	SDT error% estimate (95% CI)	p-value	SDL error% estimate (95% CI)	p-value	DST error% estimate (95% CI)	p-value	ALTERNATIVE TAB error% estimate (95% CI)	p-value
16 vs. 15	-3.69 (-17.38, 9.99)	0.597	-5.26 (-21.13, 10.62)	0.516	-4.12 (-17.53, 9.30)	0.547	-1.60 (-9.04, 5.83)	0.672	-6.05 (-18.88, 6.78)	0.356	-9.51 (-28.97, 9.94)	0.338	-3.33 (-25.25, 18.58)	0.766	-6.54 (-23.58, 10.50)	0.452
17 vs. 15	-2.62 (-16.24, 11.00)	0.706	-2.84 (-18.64, 12.96)	0.724	-2.24 (-15.59, 11.11)	0.742	-2.04 (-9.43, 5.36)	0.590	-3.68 (-16.45, 9.09)	0.572	-5.75 (-25.11, 13.62)	0.561	-1.11 (-22.92, 20.70)	0.920	-3.26 (-20.22, 13.71)	0.707
18 vs. 15	-2.17 (-15.48, 11.13)	0.749	-3.24 (-18.68, 12.19)	0.681	-2.59 (-15.64, 10.45)	0.697	-1.04 (-8.27, 6.19)	0.777	-3.96 (-16.44, 8.52)	0.534	-6.61 (-25.53, 12.32)	0.494	-2.04 (-23.35, 19.27)	0.851	-3.42 (-20.00, 13.15)	0.686
19 vs. 15	-3.26 (-16.59, 10.07)	0.632	-4.31 (-19.78, 11.15)	0.584	-3.79 (-16.86, 9.28)	0.570	-1.14 (-8.38, 6.11)	0.758	-5.01 (-17.51, 7.50)	0.433	-8.20 (-27.16, 10.76)	0.397	-3.20 (-24.55, 18.15)	0.769	-3.80 (-20.41, 12.80)	0.654
20 vs. 15	-2.17 (-15.51, 11.16)	0.749	-3.88 (-19.35, 11.60)	0.623	-3.10 (-16.18, 9.98)	0.642	-1.73 (-8.98, 5.52)	0.640	-4.68 (-17.19, 7.82)	0.463	-7.19 (-26.16, 11.77)	0.457	-2.48 (-23.84, 18.88)	0.820	-3.75 (-20.36, 12.86)	0.658
21 vs. 15	-3.71 (-17.19, 9.78)	0.590	-4.71 (-20.36, 10.93)	0.555	-3.58 (-16.80, 9.65)	0.596	-0.77 (-8.09, 6.56)	0.837	-5.20 (-17.85, 7.45)	0.420	-9.56 (-28.74, 9.62)	0.329	-3.76 (-25.36, 17.84)	0.733	-4.57 (-21.37, 12.23)	0.594
22 vs. 15	-4.93 (-19.01, 9.15)	0.492	-5.86 (-22.19, 10.47)	0.482	-5.32 (-19.12, 8.49)	0.450	-2.03 (-9.68, 5.62)	0.603	-6.50 (-19.70, 6.70)	0.335	-11.00 (-31.02, 9.02)	0.282	-4.58 (-27.13, 17.97)	0.690	-5.11 (-22.65, 12.43)	0.568

Table D.2: Results of the effect of age on the speed of response obtained by the univariable multilevel analysis

Age	SRT speed/seconds estimate (95% CI)	p-value	RL speed/seconds estimate (95% CI)	p-value	MTS speed/seconds estimate (95% CI)	p-value	CPT speed/seconds estimate (95% CI)	p-value	SDT speed/seconds estimate (95% CI)	p-value	SDL speed/seconds estimate (95% CI)	p-value	DST speed/seconds estimate (95% CI)	p-value	ALTERNATIVE TAB speed/seconds estimate (95% CI)	p-value
16 vs. 15	12.85 (-29.05, 54.74)	0.548	2.47 (-29.28, 34.22)	0.879	1.81 (-23.45, 27.06)	0.889	18.83 (-10.19, 47.85)	0.203	-17.05 (55.41, 21.31)	0.384	77.81 (-30.56, 186.19)	0.159	11.52 (-30.65, 53.69)	0.592	6.26 (-26.48, 38.99)	0.708
17 vs. 15	6.24 (-35.46, 47.94)	0.769	-6.94 (-38.54, 24.67)	0.667	-8.56 (-33.70, 16.58)	0.504	13.63 (-15.25, 42.52)	0.355	-17.63 (-55.80, 20.55)	0.366	32.54 (-75.33, 140.42)	0.554	7.29 (-34.68, 49.27)	0.733	1.52 (-31.06, 34.10)	0.927
18 vs. 15	3.92 (-36.83, 44.66)	0.851	-5.09 (-35.96, 25.79)	0.747	-5.36 (-29.92, 19.21)	0.669	11.30 (-16.92, 39.53)	0.433	-15.75 (-53.06, 21.55)	0.408	43.08 (-62.32, 148.47)	0.423	8.80 (-32.21, 49.81)	0.674	3.07 (-28.77, 34.90)	0.850
19 vs. 15	7.59 (-33.23, 48.41)	0.715	-3.69 (-34.62, 27.24)	0.815	-3.38 (-27.99, 21.23)	0.788	12.42 (-15.86, 40.70)	0.389	-17.28 (-54.66, 20.09)	0.365	52.99 (-52.61, 158.58)	0.325	11.98 (-29.11, 53.07)	0.568	4.94 (-26.96, 36.84)	0.761
20 vs. 15	7.20 (-33.64, 48.04)	0.730	-0.38 (-31.33, 30.57)	0.981	-0.43 (-25.05, 24.19)	0.973	16.97 (-11.32, 45.25)	0.240	-15.20 (-52.58, 22.19)	0.426	45.01 (-60.63, 150.65)	0.404	10.31 (-30.80, 51.41)	0.623	5.10 (-26.81, 37.01)	0.754
21 vs. 15	12.97 (-28.32, 54.27)	0.538	-0.07 (-31.36, 31.23)	0.997	-0.18 (-24.72, 25.07)	0.989	13.67 (-14.94, 42.28)	0.349	-16.45 (-54.26, 21.36)	0.394	55.27 (-51.55, 162.09)	0.311	11.90 (-29.67, 53.46)	0.575	5.45 (-26.81, 37.72)	0.741
22 vs. 15	10.24 (-32.87, 53.35)	0.642	-5.61 (-38.28, 27.06)	0.736	-5.15 (-31.14, 20.84)	0.698	19.63 (-10.24, 49.49)	0.198	-23.21 (-62.68, 16.26)	0.249	51.99 (-59.53, 163.50)	0.361	10.57 (-32.82, 53.96)	0.633	3.26 (-30.42, 36.95)	0.849

Table D.3: Results of the effect of ethnicity on the accuracy (% of errors) obtained by the univariable multilevel analysis

Ethnicity	SRT error% estimate (95% CI)	p-value	RL error% estimate (95% CI)	p-value	MTS error% estimate (95% CI)	p-value	CPT error% estimate (95% CI)	p-value	SDT error% estimate (95% CI)	p-value	SDL error% estimate (95% CI)	p-value	DST error% estimate (95% CI)	p-value	ALTERNATIVE TAB error% estimate (95% CI)	p-value
non-Saudis vs.Saudis	-5.79 (-7.02, -4.56)	<0.001	-6.44 (-7.86, -5.01)	<0.001	-5.66 (-6.87, -4.46)	<0.001	0.39 (-0.28, 1.07)	0.253	-6.32 (-7.35, -5.29)	<0.001	-6.53 (-8.28, -4.77)	<0.001	-4.42 (-6.40, -2.44)	<0.001	-7.50 (-9.03, -5.97)	<0.001

Table D.4: Results of the effect of ethnicity on the speed of response obtained by the univariable multilevel analysis

Ethnicity	SRT speed/seconds estimate (95% CI)	p-value	RL speed/seconds estimate (95% CI)	p-value	MTS speed/seconds estimate (95% CI)	p-value	CPT speed/seconds estimate (95% CI)	p-value	SDT speed/seconds estimate (95% CI)	p-value	SDL speed/seconds estimate (95% CI)	p-value	DST speed/seconds estimate (95% CI)	p-value	ALTERNATIVE TAB speed/seconds estimate (95% CI)	p-value
non-Saudis vs.Saudis	18.57 (14.81, 22.33)	<0.001	3.11 (0.24, 5.99)	0.034	3.48 (1.19, 5.77)	0.003	0.62 (-2.05, 3.29)	0.650	-11.45 (-14.91, -7.99)	<0.001	25.49 (15.83, 35.16)	<0.001	5.84 (2.02, 9.65)	0.003	3.16 (0.19, 6.12)	0.037

Table D.5: Results of the effect of number of years spent in KSA by the non-Saudi participants on the accuracy (% of errors) obtained by the univariable multilevel analysis

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Numbr of years spent in KSA if not Saudi	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
2 vs. 1	-0.43 (-5.58, 4.72)	0.871	-1.08 (-15.85, 13.69)	0.886	-0.91 (-5.12, 3.30)	0.671	-0.01 (-1.72, 1.71)	0.994	-0.34 (-10.96, 10.28)	0.951	-0.31 (-5.99, 5.37)	0.914	-1.22 (-8.11, 5.67)	0.728	-0.54 (-6.60, 5.52)	0.861
3 vs. 1	-1.19 (-15.94, 13.56)	0.874	-1.54 (-6.69, 3.61)	0.559	-1.87 (-4.65, 0.90)	0.186	-0.03 (-2.75, 2.68)	0.981	-1.89 (-5.60, 1.81)	0.318	-1.65 (-6.13, 2.82)	0.469	-1.35 (-5.90, 3.19)	0.560	-1.63 (-5.63, 2.37)	0.425
4 vs. 1	-2.14 (-5.53, 1.26)	0.218	-2.36 (-17.13, 12.41)	0.754	-2.16 (-5.47, 1.16)	0.202	-0.13 (-4.53, 4.27)	0.955	-2.23 (-4.67, 0.22)	0.075	-1.81 (5.55, 1.94)	0.344	-2.11 (-9.00, 4.78)	0.548	-2.46 (-19.81, 14.89)	0.781
5 ≥ vs. 1	-2.48 (-6.54, 1.58)	0.001	-2.58 (-5.98, 0.83)	0.001	-2.22 (-14.27, 9.82)	0.001	-0.37 (-2.79, 2.05)	0.001	-2.69 (-5.62, 0.23)	0.001	-5.28 (-21.54, 10.98)	0.001	-2.68 (-8.11, 2.74)	0.001	-4.12 (-8.90, 0.65)	0.001

Table D.6: Results of the effect of number of years spent in KSA by the non-Saudi participants on the speed of response obtained by the univariable multilevel analysis

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Numbr of years spent in KSA if not Saudi	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
2 vs. 1	40.61 (-1.63, 82.85)	0.815	15.29 (-16.01, 46.60)	0.618	14.06 (-0.77, 28.88)	0.636	20.61 (4.43, 36.79)	0.330	42.73 (1.44, 84.01)	0.210	148.25 (102.07, 194.44)	0.793	33.17 (-5.40, 71.74)	0.724	17.89 (-12.84, 48.62)	0.760
3 vs. 1	37.05 (-5.19, 79.29)	0.847	13.41 (-0.13, 26.95)	0.338	12.17 (1.33, 23.07)	0.383	14.84 (-12.53, 42.21)	0.334	38.50 (2.78, 79.79)	0.626	135.31 (101.53, 169.08)	0.614	17.99 (-4.82, 40.79)	0.948	11.74 (-6.43, 29.91)	0.865
4 vs. 1	34.87 (16.60, 53.13)	0.231	9.15 (-22.15, 40.45)	0.567	11.17 (-13.90, 36.23)	0.458	13.61 (-13.76, 40.98)	0.288	34.35 (16.50, 52.21)	0.341	129.99 (51.88, 208.10)	0.596	16.47 (-6.33, 39.27)	0.686	9.20 (-4.09, 22.49)	0.576
5 ≥ vs. 1	34.68 (14.88, 54.47)	0.147	9.00 (-9.51, 27.51)	0.335	9.50 (-15.57, 34.57)	0.134	13.50 (13.87, 40.87)	0.031	33.21 (8.79, 57.62)	0.340	114.66 (36.55, 192.77)	0.428	15.06 (-1.62, 31.74)	0.988	8.78 (-21.96, 39.51)	0.771

Table D.7: Results of the effect of physical activity on the accuracy (% of errors) obtained by the univariable multilevel analysis

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of physical activity	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
physically active within the previous 2 hours vs. not	-13.95 (-30.21, 2.32)	0.093	-17.28 (-36.15, 1.59)	0.073	-13.85 (-29.81, 2.10)	0.089	-6.58 (-15.42, 2.26)	0.145	-6.64 (-18.92, 5.63)	0.289	-20.52 (-43.66, 2.62)	0.082	-22.48 (-48.53, 3.57)	0.091	-13.53 (-33.80, 6.73)	0.191

Table D.8: Results of the effect of physical activity on the speed of response obtained by the univariable multilevel analysis

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of physical activity	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
physically active within the previous 2 hours vs. not	50.69 (0.85, 100.53)	0.046	20.26 (-17.53, 58.05)	0.293	15.14 (-14.95, 45.24)	0.324	11.60 (-8.48, 31.68)	0.258	-2.44 (-48.06, 43.18)	0.917	44.51 (-38.41, 127.43)	0.293	25.90 (-24.25, 76.04)	0.311	18.86 (-20.07, 57.78)	0.342

Table D.9: Results of the effect of the number of sleeping hours during the nights before participation on the accuracy (% of errors) obtained by the uni-variable multilevel analysis

	SRT error%		RL error%		MTS error%		CPT error%		DST error%		SDL error%		SDT error%		ALTERNATIVE TAB error%	
Effect of sleeping hours	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
less than 7 hrs vs. more than 7 hours	4.14 (-1.76, 10.05)	0.169	0.51 (-6.34, 7.36)	0.884	0.97 (-4.82, 6.76)	0.742	0.95 (-2.26, 4.16)	0.561	1.12 (-3.54, 5.77)	0.637	7.88 (-0.52, 16.28)	0.066	10.04 (0.59, 19.49)	0.037	4.19 (-3.17, 11.54)	0.264

Table D.10: Results of the effect of the number of sleeping hours during the nights before participation on the speed of response obtained by the univariable multilevel analysis

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of sleeping hours	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
less than 7 hrs vs. more than 7 hours	-12.88 (-30.97, 5.21)	0.163	-7.66 (-21.37, 6.06)	0.274	-3.01 (-13.93, 7.91)	0.589	-2.44 (-10.38, 5.49)	0.546	2.61 (-13.95, 19.16)	0.758	-13.53 (-45.94, 18.89)	0.414	-12.38 (-30.58, 5.81)	0.182	-9.16 (-23.29, 4.96)	0.204

Table D.11: Results of the effect of caffeine on the accuracy (% of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of caffeine	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
caffeinated privileges on the same day of exposure/ participation	-6.43 (-13.85, 0.99)	0.089	-5.69 (-14.30, 2.92)	0.195	-3.00 (-10.27, 4.28)	0.420	-1.31 (-5.34, 2.72)	0.524	-3.01 (-8.61, 2.60)	0.293	2.17 (-8.39, 12.72)	0.688	2.91 (-8.97, 14.79)	0.631	2.06 (-7.19, 11.30)	0.663

Table D.12: Results of the effect of caffeine on the speed of response obtained by the univariable multilevel analysis

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of caffeine	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
caffeinated privileges on the same day of exposure/ participation	0.36 (-22.37, 23.10)	0.975	-0.05 (-17.28, 17.19)	0.996	1.66 (-12.07, 15.38)	0.813	1.70 (-7.47, 10.87)	0.716	-1.78 (-22.58, 19.03)	0.867	-13.30 (-51.16, 24.56)	0.491	1.73 (-21.14, 24.60)	0.882	0.69 (-17.06, 18.45)	0.939

Table D.13: Results of the effect of stress owing to personal reasons not related to the exposure conditions on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of stress owing to personal reasons not related to the exposure conditions	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
reported stress vs. not	2.32 (-4.98, 9.62)	0.534	2.93 (-5.54, 11.40)	0.498	2.08 (-5.08, 9.24)	0.569	-1.88 (-5.85, 2.08)	0.374	1.06 (-4.44, 6.56)	0.706	2.59 (-7.79, 12.98)	0.625	-1.13 (-12.82, 10.56)	0.850	7.64 (-1.45, 16.73)	0.100

Table D.14: Results of the effect of stress owing to personal reasons not related to the exposure conditions on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of stress owing to personal reasons not related to the exposure conditions	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
reported stress vs. not	-4.81 (-27.17, 17.56)	0.674	5.50 (-11.45, 22.46)	0.525	6.13 (-7.37, 19.63)	0.374	0.43 (-8.56, 9.42)	0.925	0.60 (-19.86, 21.06)	0.954	7.74 (-29.40, 44.87)	0.683	6.74 (-15.75, 29.23)	0.557	6.44 (-11.02, 23.90)	0.470

Table D.15: Results of the effect of ambient noise on the accuracy (% of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of noise	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
annoyed from noise vs. not	9.22 (0.71, 17.73)	0.034	3.49 (-6.39, 13.37)	0.489	1.93 (-6.42, 10.28)	0.650	-0.91(-5.54, 3.72)	0.700	1.05 (-5.37, 7.48)	0.748	-0.39 (-12.50, 11.73)	0.950	1.65 (-11.99, 15.28)	0.813	4.11 (-6.49, 14.72)	0.447

Table D.16: Results of the effect of ambient noise on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of noise	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
annoyed from noise vs. not	-17.25 (-43.33, 8.84)	0.195	1.09 (-18.69, 20.87)	0.914	6.44 (-9.31, 22.19)	0.423	-0.97 (-11.47, 9.53)	0.857	18.23 (-5.63, 42.10)	0.134	13.50 (-29.84, 56.85)	0.542	3.18 (-23.06, 29.43)	0.812	3.33 (-17.04, 23.70)	0.749

Table D.17: Results of the effect of the reported headache, dizziness and heaviness on head on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of detected and reported headeache/heaviness on head and dizziness	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
reported symptoms vs. not	18.76 (17.61, 19.91)	<0.001	23.54 (22.23, 24.84)	<0.001	15.51 (14.34, 16.67)	<0.001	12.48 (11.89, 13.07)	<0.001	19.74 (19.02, 20.46)	<0.001	27.90 (26.30, 29.51)	<0.001	28.34 (26.48, 30.20)	<0.001	29.61 (28.32, 30.91)	<0.001

Table D.18: Results of the effect of the reported headache, dizziness and heaviness on head on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of detected and reported headeache/heaviness on head and dizziness	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
reported symptoms vs. not	-63.90 (-67.29, -60.51)	<0.001	-26.77 (-29.62, -23.92)	<0.001	-19.58 (-21.86, -17.29)	<0.001	-23.38 (-24.72, -22.04)	<0.001	-38.87 (-42.25, -35.49)	<0.001	-67.08 (-73.04, -61.12)	<0.001	-46.09 (-49.78, -42.41)	<0.001	-38.75 (-41.57, -35.92)	<0.001

Table D.19: Results of the effect of the reported intolerable thermal discomfort on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of detected and reported untolerable thermal discomfort that impaires the ability to focus	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**
reported untolerable thermal discomfort vs. not	5.41 (4.23, 6.59)	<0.001	14.21 (12.89, 15.53)	<0.001	13.29 (12.18, 14.39)	<0.001	4.66 (4.02, 5.29)	<0.001	7.68 (6.81, 8.54)	<0.001	12.54 (10.88, 14.20)	<0.001	13.81 (11.94, 15.68)	<0.001	6.02 (4.54, 7.49)	<0.001

Table D.20: Results of the effect of the reported intolerable thermal discomfort on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of detected and reported untolerable thermal discomfort that impaires the ability to focus	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**
reported untolerable thermal discomfort vs. not	-11.57 (-15.21, -7.93)	<0.001	-21.50 (-24.20, -18.80)	<0.001	-18.79 (-20.93, -16.65)	<0.001	-8.87 (-10.31, 7.44)	<0.001	-21.49 (-24.77, -18.20)	<0.001	-62.47 (-68.22, -56.71)	<0.001	-36.44 (-39.96, 32.92)	<0.001	-25.94 (-28.69, -23.19)	<0.001

Table D.21: Results of the effect of the reported numbness in fingers on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Effect of numbness in fingers detected	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**
numbness in fingers detected vs. not	-29.49 (-30.38, -28.60)	<0.001	-19.14 (-20.50, -17.79)	<0.001	-20.25 (-21.33, -19.17)	<0.001	-13.74 (-14.30, -13.19)	<0.001	-8.42 (-9.32, -7.53)	<0.001	-26.46 (-28.07, -24.85)	<0.001	-47.92 (-49.38, -46.47)	<0.001	14.32 (12.82, 15.83)	<0.001

Table D.22: Results of the effect of the reported numbness in fingers on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of numbness in fingers detected	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**	**estimate (95% CI)**	**p-value**
numbness in fingers detected vs. not	61.82 (58.43, 65.20)	<0.001	81.55 (79.89, 83.22)	<0.001	45.50 (43.61, 47.40)	<0.001	32.61 (31.51, 33.71)	<0.001	19.40 (15.91, 22.89)	<0.001	124.32 (119.46, 129.18)	<0.001	89.36 (86.49, 92.24)	<0.001	73.51 (71.40, 75.63)	<0.001

Table D.23: Results of the effects of the clothing levels on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		DST error%		SDL error%		SDT error%		ALTERNATIVE TAB error%	
Effect of clothing level	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
0.9 vs. 0.8	-3.20 (-4.45, -1.95)	0.066	-2.24 (-3.69, -0.79)	0.130	-1.87 (3.09, -0.64)	0.129	-0.76 (-1.44, -0.08)	0.128	-1.69 (-2.83, -0.56)	0.135	-1.82 (-3.60, -0.04)	0.046	-4.91 (-6.91, -2.91)	0.156	-0.39 (-1.95, 1.17)	0.622
1.0 vs. 0.8	-5.92 (-11.89, 0.06)	0.053	-4.69 (-11.63, 2.25)	0.186	-4.21 (-10.07, 1.66)	0.161	-1.60 (-4.85, 1.65)	0.336	-4.43 (-10.11, 1.25)	0.127	-3.43 (-11.94, 5.09)	0.431	-2.79 (-12.35, 6.78)	0.568	-5.44 (-12.90, 2.02)	0.153
1.1 vs. 0.8	0.08 (-5.89, 6.06)	0.978	1.06 (-5.88, 8.00)	0.764	0.68 (-5.18, 6.55)	0.819	0.43 (-2.83, 3.68)	0.798	2.41 (-3.26, 8.09)	0.405	0.53 (-7.99, 9.04)	0.903	-2.12 (-11.68, 7.45)	0.664	0.89 (-6.57, 8.35)	0.815

Table D.24: Results of the effects of the clothing levels on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of clothing level	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
0.9 vs. 0.8	2.63 (-1.20, 6.46)	0.179	7.41 (4.52, 10.31)	0.012	3.96 (1.65, 6.27)	0.100	6.22 (3.85, 8.59)	<0.001	3.30 (-0.21, 6.81)	0.065	22.60 (13.48, 31.71)	0.150	7.24 (3.39, 11.10)	0.250	6.40 (3.41, 9.39)	0.365
1.0 vs. 0.8	13.97 (-4.37, 32.31)	0.136	6.06 (-7.81, 19.93)	0.392	4.46 (-6.60, 15.52)	0.429	0.92 (-12.29, 14.13)	0.892	-3.53 (-20.30, 13.25)	0.681	14.70 (-34.11, 63.51)	0.555	0.60 (-17.83, 19.02)	0.949	2.05 (-12.25, 16.35)	0.779
1.1 vs. 0.8	-1.37 (-19.71, 16.97)	0.884	3.26 (-10.61, 17.13)	0.645	2.44 (-8.62, 13.50)	0.665	1.61 (-11.60, 14.82)	0.812	9.10 (-7.68, 25.87)	0.289	2.14 (-46.67, 50.96)	0.931	7.80 (-10.63, 26.22)	0.407	4.63 (-9.67, 18.93)	0.526

Table D.25: Results of the effects of the AC set temperature at home on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Average AC temperature setting at home	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
18°C vs. 20°C	-0.93 (-1.90, 0.96)	0.008	-1.81 (-2.25, 0.64)	0.009	-0.30 (-1.21, 0.39)	0.002	-0.05 (-1.60, 0.70)	0.005	-0.96 (-1.17, 0.76)	0.009	-0.83 (-2.06, 0.60)	0.002	-0.29 (-1.12, 0.54)	0.001	-0.47 (-1.17, 0.23)	0.005
19°C vs. 20°C	-1.39 (-2.69, -0.91)	0.008	-1.88 (-2.71, -0.95)	0.009	-1.19 (-2.43, -0.04)	0.002	-0.27 (-1.56, -0.10)	0.005	-1.51 (-2.96, -0.05)	0.009	-1.48 (-2.18, 0.22)	0.002	-1.55 (-2.92, 0.82)	0.001	-0.94 (-1.05, 0.17)	0.005
21°C vs. 20°C	-2.06 (-3.71, -1.40)	0.008	-2.36 (-3.44, -1.28)	0.009	-1.41 (-3.01, -0.81)	0.003	-0.45 (-2.02, -0.92)	0.005	-1.55 (-3.52, -0.57)	0.009	-2.39 (-3.17, -1.61)	0.002	-2.12 (-3.44, -1.80)	0.001	-1.39 (-2.69, -0.09)	0.004
22°C vs. 20°C	-2.37 (-4.66, -1.09)	0.008	-2.95 (-3.60, -1.30)	0.009	-1.50 (-3.73, -0.86)	0.003	-1.09 (-2.17, -0.96)	0.004	-2.22 (-3.86, -1.47)	0.009	-2.87 (-4.13, -1.62)	0.002	-3.00 (-4.72, -2.29)	0.001	-2.16 (-3.00, -1.32)	0.004
23°C vs. 20°C	-3.54 (-4.84, -2.92)	0.006	-2.97 (-4.05, -1.48)	0.008	-2.03 (-3.31, -1.36)	0.003	-1.38 (-2.94, -0.70)	0.004	-2.43 (-4.34, -0.20)	0.008	-3.19 (-4.59, -2.20)	<0.001	-3.90 (-4.77, -2.98)	<0.001	-2.51 (-3.45, -1.48)	0.004
24°C vs. 20°C	-4.29 (-5.76, -3.81)	0.006	-3.78 (-4.85, -2.71)	0.007	-2.17 (-3.70, -1.65)	0.003	-2.35 (-3.75, -1.06)	0.004	-2.50 (-4.62, -0.38)	0.007	-3.89 (-4.29, -2.49)	<0.001	-3.94 (-4.17, -2.05)	<0.001	-3.18 (-4.04, -2.32)	0.003

Table D.26: Results of the effects of the AC set temperature at home on the speed of response obtained by the univariable multilevel analysis

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Average AC temperature setting at home	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
18°C vs. 20°C	-11.11 (-20.01, -2.21)	0.003	-10.32 (-18.36, -5.72)	0.007	-10.86 (-16.47, -4.74)	0.006	-10.38 (-18.88, -4.12)	0.006	-10.71 (-18.08, -2.66)	0.005	-10.01 (-16.01, -3.02)	0.005	-9.33 (-18.99, -5.65)	0.005	-10.68 (-14.56, -6.93)	0.005
19°C vs. 20°C	-12.38 (-17.81, -3.04)	0.003	-11.07 (-18.75, -9.90)	0.006	-11.14 (-17.08, -7.37)	0.006	-10.52 (-18.75, -2.70)	0.006	-10.95 (-19.25, -2.34)	0.005	-11.02 (-17.69, -4.36)	0.005	-10.18 (-20.17, -6.53)	0.005	-11.34 (-18.71, -5.39)	0.005
21°C vs. 20°C	-12.54 (-20.41, -4.67)	0.003	-12.64 (-20.65, -6.92)	0.005	-11.37 (-18.63, -8.38)	0.005	-10.84 (-19.65, -3.97)	0.005	-11.24 (-19.72, -3.77)	0.004	-11.43 (-19.67, -5.20)	0.004	-10.25 (-20.83, -8.47)	0.005	-11.79 (-20.68, -5.26)	0.005
22°C vs. 20°C	-12.81 (-20.55, -5.07)	0.003	-13.02 (-21.43, -7.40)	0.005	-12.06 (-20.37, -4.25)	0.005	-11.69 (-19.70, -4.31)	0.004	-11.83 (-20.26, -5.40)	0.004	-11.59 (-20.44, -5.74)	0.004	-11.68 (-22.52, -8.85)	0.001	-12.09 (-22.48, -6.66)	0.004
23°C vs. 20°C	-15.83 (-24.83, -5.83)	0.001	-13.59 (-21.24, -8.06)	0.005	-12.33 (-20.82, -3.17)	0.005	-12.80 (-20.02, -2.42)	0.004	-12.16 (-20.55, -5.87)	0.004	-12.15 (-21.70, -6.00)	0.001	-12.06 (-24.42, -8.53)	0.001	-12.14 (-24.68, -6.95)	0.004
24°C vs. 20°C	-17.67 (-30.97, -3.63)	<0.001	-13.87 (-21.86, 9.12)	0.002	-13.84 (-20.60, -4.93)	0.005	-12.86 (-20.39, -2.67)	0.004	-12.99 (-20.87, -6.10)	0.003	-13.01 (-22.87, -6.85)	0.001	-13.79 (-25.71, -9.14)	0.001	-13.14 (-25.30, -7.03	0.004

Table D.27: Results of the effects of the order of exposures on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

	SRT error%		RL error%		MTS error%		CPT error%		SDT error%		SDL error%		DST error%		ALTERNATIVE TAB error%	
Order of exposure	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
2 vs. 1*	0.53 (0.36, 0.76)	0.521	0.50 (0.25, 0.75)	0.670	0.70 (0.35, 1.15)	0.532	0.25 (0.15, 0.40)	0.662	1.05 (0.55, 1.50)	0.415	1.66 (1.15, 2.16)	0.335	1.33 (0.75, 0.58)	0.567	0.76 (0.25, 1.27)	0.663
3 vs. 1	1.14 (0.87, 3.07)	0.437	1.60 (0.80, 2.20)	0.450	2.08 (1.16, 3.16)	0.326	1.20 (0.90, 0.50)	0.428	1.36 (0.82, 1.54)	0.405	2.47 (1.64, 3.30)	0.295	1.87 (1.12, 2.62)	0.459	-2.95 (-3.56, -2.34)	0.625
4 vs. 1	0.22 (0.11, 0.31)	0.991	0.82 (0.44, 1.24)	0.874	1.16 (0.08, 2.08)	0.315	0.93 (0.56, 1.36)	0.555	0.80 (0.40, 1.20)	0.448	1.23 (0.90, 1.56)	0.225	0.95 (0.40, 1.35)	0.525	-6.56 (-7.64, -5.48)	0.575
5 vs. 1	0.30 (0.15, 0.45)	0.985	0.62 (0.34, 0.94)	0.900	1.12 (0.60, 1.64)	0.580	1.50 (0.70, 2.30)	0.523	2.10 (1.70, 3.50)	0.379	2.38 (1.80, 2.96)	0.310	1.87 (1.05, 2.69)	0.480	1.34 (1.15, 1.53)	0.521
6 vs. 1	1.20 (0.60, 1.80)	0.442	2.10 (1.20, 3.20)	0.396	1.18 (1.09, 1.27)	0.725	1.65 (1.10, 2.15)	0.446	2.75 (2.00, 3.50)	0.376	-0.10 (-0.82, 0.63)	0.256	2.75 (2.14, 3.36)	0.416	0.63 (0.22, 1.04)	0.567
7 vs. 1	0.84 (0.42, 1.22)	0.510	0.70 (0.35, 1.15)	0.556	0.56 (0.20, 0.82)	0.550	1.04 (0.88, 1.28)	0.419	1.10 (0.70, 1.50)	0.312	-0.25 (-0.94, 0.45)	0.264	1.85 (1.17, 2.53)	0.511	1.14 (0.75, 1.53)	0.517
8 vs.1	1.60 (0.80, 2.20)	0.405	1.94 (0.97, 2.71)	0.335	2.40 (1.20, 3.60)	0.314	1.80 (1.20, 2.40)	0.395	2.30 (1.80, 2.70)	0.298	3.16 (2.06, 4.26)	0.210	-2.41 (-4.68, -0.14)	0.465	1.78 (1.10, 2.46)	0.520
9 vs.1	2.42 (1.21, 3.21)	0.377	2.50 (1.25, 3.25)	0.226	2.80 (1.40, 4.20)	0.415	2.20 (1.20, 3.20)	0.355	-0.61 (-2.24, 1.02)	0.285	2.25 (1.75, 2.75)	0.210	2.16 (1.60, 2.72)	0.575	0.62 (0.30, 0.92)	0.590
10 vs.1	2.41 (2.04, 2.78)	0.730	0.27 (-0.74, 1.29)	0.450	-2.14 (-3.50, -0.78)	0.548	-1.84 (-6.93, 3.24)	0.384	3.10 (2.20, 4.00)	0.747	2.90 (1.90, 3.90)	0.570	-3.87 (-4.99, -2.76)	0.355	1.20 (0.90, 1.50)	0.715
11 vs.1	-4.30 (-5.67, -2.93)	0.981	4.09 (1.99, 6.18)	0.492	3.30 1.49, 5.12)	0.282	1.13 (-2.63, 4.90)	0.366	2.42 (1.23, 6.39)	0.989	3.50 (2.80, 4.20)	0.642	2.70 (2.40, 3.00)	0.889	1.87 (1.40, 2.34)	0.769
12 vs.1	3.48 (1.19, 5.77)	0.989	3.25 (1.66, 4.85)	0.335	-0.61 (-2.24, 1.02)	0.494	-0.74 (-4.07, 2.60)	0.408	1.87 (0.10, 4.27)	0.724	5.51 (3.43, 7.59)	0.596	0.03 (-2.70, 2.76)	0.389	0.72 (0.13, 1.30)	0.820
13 vs.1	4.38 (3.59, 5.17)	0.504	0.89 (0.21, 1.58)	0.420	3.33 (1.53, 5.12)	0.697	-1.19 (-4.81, 2.44)	0.365	5.95 (2.10, 12.01)	0.642	2.11 (0.82, 3.40)	0.989	-2.31 (-3.26, -1.35)	0.198	-1.54 (-5.71, 2.62)	0.733
14 vs.1	2.12 (0.47, 3.77)	0.879	-1.91 (-3.11, -0.71)	0.463	2.50 (1.06, 3.95)	0.632	0.58 (-1.08, 2.25)	0.325	-4.12 (-6.70, -1.54)	0.736	-8.29 (-9.62, -6.95)	0.973	-2.00 (-3.18, 0.83)	0.361	8.05 (2.48, 13.61)	0.690
15 vs.1	5.56 (3.49, 7.64)	0.769	0.16 (-2.02, 2.35)	0.433	4.09 (2.12, 6.07)	0.597	-1.37 (-4.27, 1.53)	0.404	-0.74 (-2.08, 0.60)	0.997	5.22 (4.35, 6.01)	0.698	3.52 (0.84, 7.88)	0.761	1.42 (-5.51, 8.34)	0.770
16 vs.1	5.51 (3.43, 7.59)	0.736	0.97 (-0.05, 1.94)	0.457	2.15 (0.85, 3.44)	0.706	3.30 (1.41, 5.20)	0.311	0.08 (-1.74, 1.89)	0.769	-3.13 (-4.40, -1.85)	0.788	1.30 (3.24, 5.83)	0.594	-2.10 (-8.40, 4.19)	0.570
17 vs.1	-2.59 (-4.13, -1.05)	0.642	0.40 (-1.49, 2.30)	0.355	0.27 (-1.20, 1.75)	0.596	2.20 (1.21, 3.20)	0.361	-1.23 (-2.43, -0.02)	0.879	-0.25 (-0.94, 0.45)	0.889	1.57 (-3.20, 6.33)	0.568	-4.50 (-10.61, 9.60)	0.570
18 vs.1	2.68 (1.33, 4.02)	0.730	7.87 (5.09, 10.65)	0.249	0.40 (-1.49, 2.30)	0.450	1.23 (-13.21, 15.67)	0.554	5.64 (4.60, 6.69)	0.980	3.49 (1.03, 5.94)	0.547	1.83 (-3.71, 7.38)	0.249	0.27 (-0.74, 1.29)	0.840
19 vs.1	1.19 (-0.55, 2.93)	0.815	7.14 (5.08, 9.19)	0.384	-1.19 (-2.85, 0.48)	0.426	4.72 (2.55, 6.90)	0.423	-0.36 (-2.30, 1.57)	0.749	-1.92 (-5.57, -1.72)	0.603	1.89 (-1.82, 5.60)	0.592	2.49 (-10.18, 15.16)	0.700
20 vs.1	4.72 (2.55, 6.90)	0.667	10.30 (2.47, 18.12)	0.389	5.60 (3.06, 8.15)	0.394	-1.67 (-3.96, 0.62)	0.769	1.22 (0.84, 3.41)	0.632	1.86 (0.33, 3.40)	0.777	-1.42 (-8.07, 5.24)	0.733	2.08 (-8.24, 12.40)	0.741
21 vs.1	3.31 (1.41, 5.20)	0.548	2.02 (-0.62, 4.67)	0.450	-0.11 (-1.67, 1.44)	0.249	-3.02 (-5.01, -1.02)	0.851	0.87 (0.31, 2.74)	0.749	-0.70 (-1.33, 0.06)	0.837	-2.66 (-12.02, 6.71)	0.366	1.38 (-2.12, 4.88)	0.754
22 vs.1	3.79 (1.80, 5.78)	0.749	-3.24 (-4.33, -2.15)	0.492	1.02 (-0.43, 2.47)	0.404	0.53 (-0.46, 1.51)	0.715	0.60 (0.12, 2.31)	0.889	2.22 (-1.40, 5.85)	0.603	5.84 (2.02, 9.65)	0.408	-3.68 (-4.75, -2.62)	0.568
23 vs.1	1.60 (-0.99, 4.19)	0.724	5.37 (4.46, 6.30)	0.349	0.89 (0.21, 1.58)	0.311	4.05 (2.12, 6.07)	0.698	-0.55 (-1.14, -0.25)	0.555	3.96 (1.44, 6.48)	0.590	3.16 (0.19, 6.12)	0.365	2.71 (1.30, 4.13)	0.365
24 vs.1	2.20 (1.21, 3.20)	0.742	0.70 (-1.93, 3.32)	0.389	0.16 (-2.02, 2.35)	0.361	3.24 (-2.90, 9.37)	0.879	-0.27 (-1.37, 0.83)	0.482	-1.92 (-5.57, -1.72)	0.997	-0.07 (-1.91, 1.78)	0.433	0.57 (-0.33, 1.46)	0.623
25 vs.1	0.04 (0.78, 0.85)	0.516	-4.47 (-6.19, -2.75)	0.642	1.24 (-0.81, 3.28)	0.355	1.65 (-4.08, 7.39)	0.667	-0.13 (-0.98, 0.73)	0.697	1.89 (-1.82, 5.60)	0.538	-3.15 (-10.13, 7.43)	0.463	0.25 (-0.58, 1.07)	0.240

1*: the order which was used in the intervention: 1,5,3,2,9,6,4,8,7
2:1,2,3,4,5,6,7,8,9
3:1,3,2,4,5,6,7,8,9
4:1,4,2,3,5,6,7,8,9
5:1,5,2,3,4,6,7,8,9
6:1,6,2,3,4,5,7,8,9
7:1,7,2,3,4,5,6,8,9
8:1,8,2,3,4,5,6,7,9
9:1,9,2,3,4,5,6,7,8
10:1,2,4,3,5,6,7,8,9
11:1,2,5,3,4,6,7,8,9
12:1,2,6,3,4,5,7,8,9
13:1,2,7,3,4,5,6,8,9
14:1,2,8,3,4,5,6,7,9
15:1,2,9,3,4,5,6,7,8
16:1,2,3,5,4,6,7,8,9
17:1,2,3,6,4,5,7,8,9
18:1,2,3,7,4,5,6,8,9
19:1,2,3,8,4,5,6,7,9
20:1,2,3,9,4,5,6,7,8
21:1,2,3,4,6,5,7,8,9
22:1,2,3,4,7,5,6,8,9
23:1,2,3,4,8,5,6,7,9
24:1,2,3,4,9,5,6,7,8
25:1,2,3,4,5,7,6,8,9

Table D.28: Results of the effects of the order of tests on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/sec		RL speed/sec		MTS speed/sec		CPT speed/sec		SDT speed/sec		SDL speed/sec		DST speed/sec		ALTERNATIVE TAB speed/sec	
Order of exposure	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
2 vs. 1	-15.50 (-18.50, -12.00)	0.500	-13.50 (-16.65, -0.35)	0.320	-8.75 (-10.50, -6.25)	0.360	-12.35 (-14.70, -10.00)	0.405	12.66 (9.06, 16.26)	0.555	-13.05 (-15.10, -11.00)	0.485	13.82 (5.93, 21.72)	0.535	16.04 (10.04, 22.03)	0.417
3 vs. 1	-16.73 (-19.98, -13.47)	0.450	-22.89 (-28.62, -17.17)	0.420	-9.40 (-12.80, -6.00)	0.300	-11.50 (-13.50, -9.00)	0.410	-9.40 (-11.80, -7.00)	0.525	12.04 (-8.34, 15.74)	0.497	-15.70 (-17.00, -13.70)	0.510	15.68 (10.62, 20.73)	0.476
4 vs. 1	-12.40 (-14.80, -10.40)	0.590	-11.17 (-17.63, -4.70)	0.410	-20.08 (-43.47, 3.30)	0.410	17.01 (6.81, 27.22)	0.520	11.90 (5.26, 13.55)	0.536	11.20 (9.89, 12.50)	0.512	9.33 (6.89, 11.77)	0.490	8.71 (6.53, 10.88)	0.410
5 vs. 1	-10.25 (-15.50, -5.00)	0.610	4.82 (2.47, 7.18)	0.500	-8.85 (-16.18, -1.51)	0.400	6.67 (-11.07, 24.41)	0.300	12.27 (8.81, 15.74)	0.514	13.82 (10.11, 17.52)	0.541	12.78 (7.45, 18.11)	0.487	-11.50 (-13.40, -9.90)	0.505
6 vs. 1	-16.00 (-18.50, -14.50)	0.440	8.57 (5.95, 11.19)	0.480	-11.81 (-18.24, -5.37)	0.350	-8.90 (-29.76, 11.96)	0.450	-13.30 (-15.60, -11.60)	0.572	6.40 (0.65, 12.14)	0.423	-19.50 (-21.50, -17.00)	0.529	25.22 (23.61, 28.84)	0.394
7 vs. 1	-11.15 (-13.05, -9.26)	0.550	14.79 (12.16, 17.42)	0.500	8.95 (-2.66, 20.57)	0.366	-15.60 (-17.60, -13.00)	0.450	-14.00 (-15.50, -12.50)	0.500	-12.20 (-14.40, -10.00)	0.490	15.70 (9.55, 21.86)	0.500	6.01 (2.92, 9.11)	0.249
8 vs.1	10.34 (-3.00, 13.68)	0.400	-14.50 (-16.50, -12.00)	0.500	-16.12 (-21.13, -11.10)	0.408	-11.06 (-35.46, 13.34)	0.400	6.57 (0.93, 14.07)	0.520	-12.50 (-13.00, -12.00)	0.570	9.00 (6.74, 11.25)	0.482	8.71 (6.53, 10.88)	0.404
9 vs.1	10.30 (2.47, 18.12)	0.570	-12.15 (-14.30, -10.00)	0.550	-13.40 (-15.80, -11.00)	0.400	-27.42 (-48.82, 6.01)	0.370	12.27 (8.81, 15.74)	0.570	-13.30 (-15.50, -11.80)	0.480	-14.60 (-16.60, -12.00)	0.450	10.02 (8.17, 11.87)	0.311
10 vs.1	-15.50 (-18.00, -12.50)	0.389	-16.00 (-19.00, -13.00)	0.555	-14.00 (-16.00, -12.00)	0.555	6.02 (-13.87, 25.91)	0.572	-14.67 (-22.56, -6.77)	0.561	19.19 (13.36, 25.01)	0.285	12.65 (-8.47, 16.83)	0.927	-13.70 (-15.70, -11.00)	0.361
11 vs.1	-16.30 (-19.00, -13.60)	0.667	7.06 (4.24, 9.88)	0.749	-14.60 (-15.60, -13.00)	0.523	-16.10 (-18.00, -14.10)	0.534	14.67 (6.77, 22.56)	0.494	20.87 (16.40, 25.33)	0.338	11.00 (3.97, 18.04)	0.355	11.83 (10.06, 13.61)	0.355
12 vs.1	-15.49 (-18.51, -12.47)	0.355	13.78 (10.95, 16.61)	0.632	11.93 (1.74, 22.12)	0.446	-17.20 (-19.40, -15.80)	0.433	-8.10 (-10.10, -6.00)	0.397	-15.20 (-17.00, -13.20)	0.561	16.54 (11.74, 21.34)	0.520	19.89 (16.60, 23.19)	0.590
13 vs.1	8.70 (6.34, 11.07)	0.450	-16.08 (-19.09, -13.08)	0.408	-12.59 (-16.00, 0.81)	0.300	5.32 (-8.50, 19.19)	0.640	-15.15 (-30.88, 0.59)	0.457	-16.10 (-17.10, -15.00)	0.256	12.65 (-8.47, 16.83)	0.850	-15.60 (-17.20, -13.80)	0.592
14 vs.1	14.84 (12.46, 17.21)	0.724	-15.30 (-18.10, -12.20)	0.365	28.27 (7.67, 48.87)	0.788	15.76 (3.48, 28.03)	0.837	-16.28 (-20.36, -12.20)	0.329	13.82 (10.11, 17.52)	0.264	-6.69 (-14.11, 0.72)	0.623	11.58 (9.94, 13.22)	0.492
15 vs.1	-15.00 (-17.50, -12.50)	0.389	-14.00 (-16.00, -12.00)	0.989	10.38 (-12.85, 33.60)	0.314	-8.36 (-24.64, 7.91)	0.603	15.37 (11.61, 19.13)	0.384	-7.57 (-15.94, 0.80)	0.210	12.31 (10.25, 14.38)	0.567	-14.20 (-16.80, -12.60)	0.575
16 vs.1	-16.73 (-19.98, -13.47)	0.837	7.64 (4.86, 10.41)	0.504	11.93 (1.74, 22.12)	0.335	-12.40 (-14.80, -10.00)	0.669	-10.50 (-13.00, -7.00)	0.366	17.07 (10.38, 23.76)	0.326	-11.89 (-20.43, -3.34)	0.761	13.37 (10.30, 16.44)	0.500
17 vs.1	-15.70 (-18.70, -12.00)	0.596	9.93 (6.70, 13.15)	0.603	-10.00 (-12.00, -8.00)	0.596	-13.50 (-14.50, -11.00)	0.788	-12.00 (-14.50, -10.50)	0.408	15.94 (9.49, 22.39)	0.315	9.37 (-3.69, 15.04)	0.463	-9.20 (-12.00, -7.20)	0.777
18 vs.1	-11.06 (-17.44, -4.69)	0.450	17.14 (13.90, 20.38)	0.325	-11.20 (-14.40, -8.00)	0.595	-13.10 (-19.85, -6.36)	0.584	10.89 (8.27, 13.51)	0.365	-5.90 (-13.35, 1.55)	0.494	-16.00 (-18.00, -14.00)	0.747	11.60 (9.19, 14.02)	0.758
19 vs.1	8.50 (5.75, 11.25)	0.311	12.62 (9.84, 15.41)	0.249	-12.10 (-14.20, -10.20)	0.510	-27.87 (-34.65, -21.09)	0.623	-22.13 (-28.43, -15.83)	0.311	-20.50 (-22.50, -18.00)	0.482	-10.23 (-16.94, -3.52)	0.741	14.67 (6.77, 22.56)	0.632
20 vs.1	-16.40 (-19.00, -13.80)	0.361	8.49 (5.41, 11.57)	0.404	28.27 (7.67, 48.87)	0.405	-14.31 (-25.35, -3.26)	0.555	13.64 (10.48, 16.79)	0.361	7.97 (5.28, 10.66)	0.329	18.05 (11.93, 24.18)	0.849	15.37 (11.61, 19.13)	0.597
21 vs.1	14.51 (11.74, 17.27)	0.554	14.88 (11.79, 17.98)	0.879	-21.80 (-49.11, 5.52)	0.662	-15.98 (-23.43, -8.52)	0.749	-14.80 (-16.00, -12.80)	0.355	10.98 (9.53, 12.42)	0.448	-17.08 (-24.178, -9.98)	0.521	-13.00 (-15.50, -11.50)	0.640
22 vs.1	-13.15 (-20.27, -6.03)	0.730	11.37 (7.21, 15.53)	0.997	-15.50 (-22.37, -8.62)	0.420	-11.07 (-17.49, -4.65)	0.590	-15.20 (-17.40, -13.40)	0.736	-13.50 (-15.50, -11.00)	0.397	8.68 (7.31, 10.04)	0.404	12.04 (9.11, 14.97)	0.837
23 vs.1	-15.45 (-19.00, -11.90)	0.516	19.97 (15.79, 24.15)	0.448	-8.65 (-15.82, -1.47)	0.463	-11.89 (-18.91, -4.87)	0.492	15.94 (9.49, 22.39)	0.642	-14.50 (-17.00, -12.00)	0.457	-17.20 (-19.40, -15.60)	0.517	-8.40 (-10.80, -6.00)	0.459
24 vs.1	-11.64 (-26.39, 3.11)	0.408	-31.72 (-45.75, -17.70)	0.379	-11.59 (-17.88, -5.29)	0.538	8.55 (3.16, 13.95)	0.482	6.95 (5.76, 8.14)	0.730	18.05 (11.93, 24.18)	0.405	17.55 (6.98, 28.13)	0.570	-11.25 (-21.85, -0.65)	0.525
25 vs.1	-16.20 (-19.10, -13.10)	0.377	-15.30 (-25.18, -5.42)	0.724	-8.90 (-29.76, 11.96)	0.500	-14.70 (-16.20, -12.50)	0.570	-14.67 (-22.56, -6.77)	0.815	-23.59 (-34.45, -12.73)	0.282	-19.90 (-22.10, -17.00)	0.590	-10.00 (-12.00, -8.00)	0.480

1*: the order which was used in the intervention: 1,5,3,2,9,6,4,8,7
2:1,2,3,4,5,6,7,8,9
3:1,3,2,4,5,6,7,8,9
4:1,4,2,3,5,6,7,8,9
5:1,5,2,3,4,6,7,8,9
6:1,6,2,3,4,5,7,8,9
7:1,7,2,3,4,5,6,8,9
8:1,8,2,3,4,5,6,7,9
9:1,9,2,3,4,5,6,7,8
10:1,2,4,3,5,6,7,8,9
11:1,2,5,3,4,6,7,8,9
12:1,2,6,3,4,5,7,8,9
13:1,2,7,3,4,5,6,8,9
14:1,2,8,3,4,5,6,7,9
15:1,2,9,3,4,5,6,7,8
16:1,2,3,5,4,6,7,8,9
17:1,2,3,6,4,5,7,8,9
18:1,2,3,7,4,5,6,8,9
19:1,2,3,8,4,5,6,7,9
20:1,2,3,9,4,5,6,7,8
21:1,2,3,4,6,5,7,8,9
22:1,2,3,4,7,5,6,8,9
23:1,2,3,4,8,5,6,7,9
24:1,2,3,4,9,5,6,7,8
25:1,2,3,4,5,7,6,8,9

Table D.29: Results of the effects of thermal sensations on the accuracy (percentages of errors) obtained by the univariable multilevel analysis.

Effect of thermal comfort	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
cold vs. neutral	0.52 (0.08, 1.26)	0.005	0.18 (0.04, 0.43)	0.005	0.78 (0.11, 1.96)	0.005	0.10 (0.08, 0.30)	0.005	0.15 (0.40, 0.69)	0.005	0.91 (0.40, 1.41)	0.005	0.93 (0.51, 1.33)	0.005	0.87 (0.17, 0.91)	0.005
cool vs. neutral	-2.02 (-3.09, -1.95)	<0.001	-2.09 (-3.65, -1.16)	<0.001	-2.21 (-3.95, -1.47)	<0.001	-2.77 (-3.69, -1.84)	<0.001	-1.64 (-2.40, -0.87)	<0.001	-2.32 (-3.31, -1.33)	<0.001	-2.87 (-3.79, -1.95)	<0.001	-1.11 (-2.95, -0.27)	<0.001
slightly cool vs. neutral	-3.60 (-4.68, -2.52)	<0.001	-3.58 (-4.14, -2.02)	<0.001	-3.79 (-4.65, -2.93)	<0.001	-3.77 (-4.09, -2.46)	<0.001	-2.39 (-3.69, -1.09)	<0.001	-3.35 (-4.79, -2.91)	<0.001	-3.61 (-4.36, -2.87)	<0.001	-2.58 (-3.40, -1.75)	<0.001
slightly warm vs. neutral	1.44 (0.55, 2.33)	<0.001	-1.47 (-2.28, -0.66)	0.014	-1.95 (-2.74, -0.16)	0.004	1.84 (0.68, 3.00)	<0.001	-1.16 (-3.79, -0.53)	0.020	-1.54 (-2.34, -0.74)	<0.001	-1.73 (-2.44, -3.02)	<0.001	-3.47 (-4.05, -2.90)	<0.001
warm vs. neutral	2.41 (1.58, 3.25)	<0.001	2.54 (1.51, 3.58)	<0.001	2.56 (1.78, 3.35)	<0.001	2.53 (1.32, 3.72)	<0.001	2.48 (1.60, 3.35)	<0.001	4.03 (3.75, 5.31)	<0.001	4.10 (3.15, 5.04)	<0.001	2.46 (1.11, 3.81)	<0.001
hot vs. neutral	4.42 (3.66, 5.18)	<0.001	4.70 (3.22, 5.18)	<0.001	5.25 (4.18, 6.33)	<0.001	4.85 (3.53, 5.18)	<0.001	5.09 (4.01, 6.18)	<0.001	5.46 (4.46, 6.46)	<0.001	5.52 (4.83, 6.22)	<0.001	4.22 (3.94, 5.51)	<0.001

Table D.30: Results of the effects of thermal sensations on the speed of response obtained by the univariable multilevel analysis.

	SRT speed/seconds		RL speed/seconds		MTS speed/seconds		CPT speed/seconds		SDT speed/seconds		SDL speed/seconds		DST speed/seconds		ALTERNATIVE TAB speed/seconds	
Effect of thermal comfort	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value	estimate (95% CI)	p-value
cold vs. neutral	90.14 (78.40, 101.87)	<0.001	51.22 (47.06, 55.37)	<0.001	20.47 (14.73, 26.22)	<0.001	34.85 (31.25, 38.45)	<0.001	15.35 (6.03, 24.67)	0.001	-0.89 (-17.33, 15.56)	0.916	12.23 (4.56, 19.90)	0.002	25.35 (19.99, 30.71)	<0.001
cool vs. neutral	54.57 (47.38, 61.76)	<0.001	40.41 (37.88, 42.93)	<0.001	16.27 (12.76, 19.79)	<0.001	22.91 (20.72, 25.09)	<0.001	1.20 (-4.60, 6.99)	0.685	15.73 (5.72, 25.74)	0.002	6.25 (1.56, 10.94)	0.009	17.27 (14.00, 20.54)	<0.001
slightly cool vs. neutral	67.48 (61.67, 73.28)	<0.001	28.03 (26.02, 30.05)	<0.001	10.92 (8.09,13.75)	<0.001	20.07 (18.32, 21.81)	<0.001	-22.10 (-26.87, -17.32)	<0.001	82.49 (74.48, 90.50)	<0.001	16.59 (12.82, 20.36)	<0.001	18.53 (15.90, 21.16)	<0.001
slightly warm vs. neutral	-31.35 (-36.84, -25.86)	<0.001	-29.27 (-31.17, -27.37)	<0.001	-10.77 (-13.45, -8.10)	<0.001	-12.60 (-14.24, -10.95)	<0.001	5.81 (1.25, 10.37)	0.013	-45.05 (-52.59, -37.51)	<0.001	-34.30 (-37.86, -30.74)	<0.001	-26.84 (-29.32, -24.36)	<0.001
warm vs. neutral	-22.92 (-27.58, -18.25)	<0.001	-53.05 (-54.66, -51.44)	<0.001	-29.37 (-31.64, -27.10)	<0.001	-17.40 (-18.79, -16.00)	<0.001	-27.10 (-30.99, -23.21)	<0.001	-69.35 (-75.75, -62.95)	<0.001	-83.83 (-86.86, -80.81)	<0.001	-63.10 (-65.21, -70.00)	<0.001
hot vs. neutral	-32.28 (-36.37, -28.18)	<0.001	-85.73 (-87.14, 84.32)	<0.001	-58.70 (-60.70, -56.71)	<0.001	-30.37 (-31.59, -29.15)	<0.001	-87.76 (-91.17, -84.35)	<0.001	-136.22 (-141.84, -130.60)	<0.001	-117.41 (-120.07, -114.76)	<0.001	-91.81 (-93.66, -89.97)	<0.001

Appendix E: Effect Sizes of Thermal Comfort Sensations stratified by ethnicity

Effect of thermal comfort perception	SRT accuracy (error%) estimate (95% CI)	p-value	RL accuracy (error%) estimate (95% CI)	p-value	MTS accuracy (error%) estimate (95% CI)	p-value	CPT accuracy (error%) estimate (95% CI)	p-value	SDT accuracy (error%) estimate (95% CI)	p-value	SDL accuracy (error%) estimate (95% CI)	p-value	DST accuracy (error%) estimate (95% CI)	p-value	ALTERNATIVE TAB accuracy (error% estimate (95% CI)	p-value
Saudis																
Condition 1 (20°C, CO2=600 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	-1.72 (-3.43, 0.99)	<0.001	-5.34 (-6.37, -4.31)	<0.001	-5.37 (-7.43, -3.31)	<0.001	-1.70 (-4.12, -0.73)	<0.001	-4.93 (-6.92, -1.07)	<0.001	-5.61 (-7.54, -2.32)	<0.001	-5.91 (-7.56, -2.25)	<0.001	-2.79 (-3.72, -1.86)	<0.001
slightly cool vs. neutral	-0.97 (-1.92, -0.62)	<0.001	-3.58 (-5.12, -2.05)	<0.001	-3.94 (-4.64, -3.24)	<0.001	-0.76 (-1.44, -0.09)	<0.001	-3.21 (-10.35, 3.92)	<0.001	-3.57 (-4.97, -2.16)	<0.001	-3.78 (-4.76, -2.20)	<0.001	-1.79 (-3.66, -0.08)	<0.001
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	---		---		---		---		---		---		---		---	
non- Saudis																
Condition 1 (20°C, CO2=600 ppm)																
cold vs. neutral	1.69 (0.91, 3.28)	0.008	1.32 (0.08, 2.45)	0.010	1.83 (0.31, 3.66)	0.010	1.82 (0.91, 2.65)	0.007	1.36 (0.91, 2.62)	0.010	1.33 (0.15, 2.81)	0.010	1.24 (0.24, 2.24)	0.010	1.55 (0.72, 3.82)	0.010
cool vs. neutral	-1.10 (-3.31, -0.12)	0.006	-2.11 (-4.71, -0.48)	0.007	-2.48 (-4.18, -0.22)	0.008	-1.21 (-3.15, -0.73)	0.007	-2.07 (-4.69, -0.55)	0.008	-2.90 (-5.23, -0.03)	0.007	-2.21 (-4.55, -0.12)	0.010	-1.37 (-3.81, -0.07)	0.010
slightly cool vs. neutral	-0.27 (-1.27, -0.73)	0.005	-1.40 (-2.81, -0.01)	0.005	-1.87 (-2.97, -0.22)	0.005	-0.96 (-1.98, -0.06)	0.005	-1.10 (-3.31, -0.12)	0.005	-1.47 (-3.09, -0.15)	0.006	-1.71 (-3.12, -0.71)	0.006	-0.80 (-1.71, -0.11)	0.008
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	---		---		---		---		---		---		---		---	
Saudis																
Condition 2 (20°C, CO2=1000 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	-1.63 (-3.90, -0.44)	<0.001	-4.21 (-5.22, -2.21)	<0.001	-4.14 (-5.98, -3.29)	<0.001	-0.49 (-1.08, 0.10)	<0.001	-3.18 (-4.33, -2.03)	<0.001	-4.33 (-5.55, -3.88)	<0.001	-4.93 (-5.09, -3.24)	<0.001	-1.59 (-2.09, -0.91)	<0.001
slightly cool vs. neutral	-0.13 (-0.84, -0.58)	<0.001	-2.40 (-3.71, -1.10)	<0.001	-2.69 (-3.27, -1.11)	<0.001	-0.38 (-2.19, 1.43)	<0.001	-1.35 (-2.38, -0.32)	<0.001	-2.22 (-3.42, -1.01)	<0.001	-2.93 (-3.53, -1.32)	<0.001	-1.08 (-2.53, -0.37)	<0.001
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	---		---		---		---		---		---		---		---	
non- Saudis																
Condition 2 (20°C, CO2=1000 ppm)																
cold vs. neutral	0.83 (0.61, 1.27)	0.010	1.02 (0.97, 2.67)	0.010	1.74 (0.64, 2.84)	0.010	1.32 (0.32, 2.96)	0.010	1.04 (0.61, 2.48)	0.010	1.71 (0.94, 2.49)	0.008	1.19 (0.74, 2.11)	0.008	1.48 (0.89, 2.07)	0.008
cool vs. neutral	-0.64 (-1.20, -0.47)	0.010	-1.50 (-2.81, -0.18)	0.008	-1.11 (-2.32, -0.11)	0.008	-1.40 (-2.44, -0.64)	0.010	-1.58 (-2.93, -0.23)	0.008	-1.16 (-2.98, -0.33)	0.008	-1.02 (-2.53, -0.51)	0.008	-1.16 (-2.27, -0.46)	0.008
slightly cool vs. neutral	-0.18 (-0.66, -0.29)	0.010	-0.43 (-1.46, -0.39)	0.010	-1.30 (-2.05, -0.06)	0.010	-0.21 (-0.97, -0.07)	0.010	-1.08 (-2.40, -0.75)	0.010	-0.83 (-1.97, -0.09)	0.010	-0.55 (-0.96, -0.14)	0.010	-0.28 (-0.57, -0.09)	0.010
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	---		---		---		---		---		---		---		---	
Saudis																
Condition 3 (20°C, CO2=1800 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	3.27 (2.23, 4.31)	<0.001	4.57 (3.22, 5.92)	<0.001	4.56 (3.22, 5.91)	<0.001	2.46 (1.32, 3.23)	<0.001	3.92 (2.30, 5.14)	<0.001	5.40 (4.04, 6.75)	<0.001	5.25 (4.93, 6.57)	<0.001	4.86 (-0.57, 10.29)	<0.001
warm vs. neutral	5.79 (3.95, 7.63)	<0.001	7.85 (5.46, 10.24)	<0.001	7.82 (5.44, 10.21)	<0.001	4.58 (3.80, 5.95)	<0.001	5.65 (4.33, 6.97)	<0.001	8.99 (6.58, 11.39)	<0.001	8.72 (7.05, 9.39)	<0.001	5.60 (2.54, 8.67)	<0.001
hot vs. neutral	---		---		---		---		---		---		---		---	
non- Saudis																
Condition 3 (20°C, CO2=1800 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	-0.75 (-0.96, -0.53)	0.030	-0.70 (-0.84, -0.57)	0.030	-0.65 (-0.86, -0.57)	0.030	-0.18 (-1.39, 1.03)	0.030	-0.29 (-1.46, 0.88)	0.030	-0.40 (-0.73, 0.72)	0.030	-0.39 (-0.70, 0.08)	0.030	-0.71 (-0.96, 0.37)	0.030
slightly warm vs. neutral	0.54 (0.19, 1.27)	0.030	0.71 (0.02, 1.44)	0.030	0.67 (0.11, 1.15)	0.030	0.86 (0.33, 0.91)	0.030	0.55 (0.11, 1.21)	0.030	0.16 (0.01, 0.32)	0.030	0.63 (0.23, 1.09)	0.030	0.81 (0.33, 1.19)	0.030
warm vs. neutral	2.14 (1.50, 3.77)	0.030	2.68 (0.32, 3.68)	0.030	2.81 (1.52, 4.10)	0.030	2.33 (1.88, 3.54)	0.030	2.27 (1.36, 3.81)	0.030	2.49 (1.81, 3.79)	0.030	2.74 (1.29, 3.76)	0.030	1.92 (0.33, 2.51)	0.030
hot vs. neutral	---		---		---		---		---		---		---		---	
Saudis																
Condition 4 (23°C, CO2=600 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	-1.83 (-2.65, -1.00)	<0.001	-1.38 (-2.99, -0.76)	<0.001	-1.37 (-2.55, -0.19)	<0.001	-1.94 (-2.04, -0.15)	<0.001	-1.98 (-2.98, -0.03)	<0.001	-1.46 (-2.84, -0.92)	<0.001	-1.57 (-2.20, -0.95)	<0.001	-0.94 (-1.00, -0.12)	<0.001
slightly warm vs. neutral	0.54 (0.04, 1.55)	<0.001	1.15 (0.70, 2.61)	<0.001	1.01 (0.46, 2.04)	<0.001	0.90 (0.22, 1.52)	<0.001	1.72 (0.54, 2.89)	<0.001	1.40 (0.13, 2.32)	<0.001	1.42 (0.96, 2.13)	<0.001	0.81 (0.30, 1.17)	<0.001
warm vs. neutral	3.25 (2.63, 4.13)	<0.001	2.57 (1.09, 3.22)	<0.001	2.75 (1.08, 3.58)	<0.001	1.17 (0.55, 2.89)	<0.001	2.63 (1.25, 3.52)	<0.001	3.22 (2.20, 4.64)	<0.001	2.96 (1.15, 4.77)	<0.001	2.09 (1.18, 3.29)	<0.001
hot vs. neutral	---		---		---		---		---		---		---		---	
non- Saudis																
Condition 4 (23°C, CO2=600 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	-0.43 (-0.75, -0.10)	0.040	-0.74 (-1.14, -0.46)	0.040	-0.93 (-1.05, -0.19)	0.040	-0.34 (-1.84, 0.16)	0.040	-0.57 (-0.96, -0.08)	0.040	-0.60 (-1.19, -0.19)	0.040	-0.68 (-1.51, -0.15)	0.040	-0.58 (-1.30, -0.15)	0.040
slightly cool vs. neutral	-1.46 (-2.06, -0.25)	0.040	-1.80 (-2.07, -0.53)	0.040	-1.85 (-2.86, -0.84)	0.040	-1.26 (-2.63, -0.11)	0.040	-1.61 (-2.30, -0.92)	0.040	-1.33 (-2.03, -0.62)	0.040	-1.74 (-2.73, -0.24)	0.040	-1.90 (-2.45, -0.66)	0.040
slightly warm vs. neutral	-0.40 (-1.61, 0.45)	0.040	-0.50 (-1.20, 0.01)	0.040	-0.80 (-1.62, 0.54)	0.040	-0.19 (-0.48, -0.09)	0.040	-0.16 (-0.83, 0.50)	0.040	-0.20 (-0.51, 0.11)	0.040	-0.26 (-0.86, 0.14)	0.040	-0.22 (-0.82, 0.62)	0.040
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	---		---		---		---		---		---		---		---	
Saudis																
Condition 5 (23°C, CO2=1000 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	1.10 (0.35, 2.14)	<0.001	1.14 (0.55, 2.48)	<0.001	1.25 (0.58, 2.08)	<0.001	1.32 (0.64, 2.27)	<0.001	1.29 (0.14, 2.71)	<0.001	1.23 (0.53, 2.40)	<0.001	1.25 (0.45, 2.45)	<0.001	0.82 (0.12, 1.76)	<0.001
warm vs. neutral	2.08 (1.76, 3.92)	<0.001	2.33 (1.65, 3.01)	<0.001	2.81 (1.10, 3.52)	<0.001	2.39 (1.42, 3.21)	<0.001	2.61 (1.98, 3.23)	<0.001	2.83 (1.01, 3.66)	<0.001	2.75 (1.22, 3.73)	<0.001	2.21 (1.42, 3.85)	<0.001
hot vs. neutral	3.25 (2.54, 4.97)	<0.001	3.35 (2.84, 4.46)	<0.001	3.65 (2.57, 4.86)	<0.001	3.26 (2.28, 4.21)	<0.001	3.24 (2.49, 4.99)	<0.001	3.59 (2.81, 4.79)	<0.001	3.33 (1.98, 4.63)	<0.001	2.94 (1.18, 3.70)	<0.001
non- Saudis																
Condition 5 (23°C, CO2=1000 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	0.40 (0.12, 0.79)	0.005	0.54 (0.14, 1.14)	0.005	0.85 (0.16, 1.54)	0.005	0.29 (0.15, 0.97)	0.005	0.24 (0.07, 1.40)	0.005	0.42 (0.07, 1.44)	0.005	0.44 (0.11, 1.44)	0.005	0.52 (0.35, 0.70)	0.005
warm vs. neutral	0.77 (0.46, 0.91)	0.005	0.81 (0.19, 1.53)	0.005	0.95 (0.50, 1.81)	0.005	0.74 (0.31, 0.82)	0.005	0.62 (0.18, 1.65)	0.005	0.76 (0.15, 1.53)	0.005	0.87 (0.14, 1.59)	0.005	0.92 (0.56, 1.28)	0.005
hot vs. neutral	---		---		---		---		---		---		---		---	
Saudis																
Condition 6 (23°C, CO2=1800 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	5.76 (4.47, 7.04)	<0.001	6.35 (5.72, 7.97)	<0.001	6.54 (5.88, 7.19)	<0.001	5.78 (4.25, 6.80)	<0.001	5.83 (4.38, 6.29)	<0.001	6.12 (5.67, 7.44)	<0.001	6.78 (5.27, 8.29)	<0.001	6.26 (5.07, 7.46)	<0.001
hot vs. neutral	8.09 (6.92, 9.25)	<0.001	8.05 (7.53, 9.57)	<0.001	8.05 (7.51, 9.60)	<0.001	7.83 (6.10, 8.76)	<0.001	8.43 (7.08, 9.79)	<0.001	7.84 (6.01, 8.69)	<0.001	8.64 (7.38, 9.65)	<0.001	7.05 (6.75, 8.34)	<0.001
non- Saudis																
Condition 6 (23°C, CO2=1800 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	1.11 (0.16, 2.28)	0.010	1.46 (0.25, 2.98)	0.010	2.05 (1.77, 3.67)	0.010	1.53 (0.17, 2.23)	0.010	1.84 (0.53, 3.22)	0.010	1.20 (0.10, 2.40)	0.010	1.45 (0.72, 2.63)	0.010	1.15 (0.30, 2.32)	0.010
warm vs. neutral	4.18 (3.17, 5.20)	0.040	4.24 (3.69, 5.38)	0.040	4.79 (3.21, 5.37)	0.040	4.41 (3.39, 5.21)	0.040	4.41 (3.20, 5.62)	0.040	4.36 (3.91, 5.62)	0.040	4.31 (3.15, 5.77)	0.040	3.92 (2.90, 4.94)	0.040
hot vs. neutral	7.73 (6.81, 8.66)	0.040	7.99 (6.66, 8.32)	0.040	7.90 (6.51, 8.29)	0.040	7.49 (6.81, 8.80)	0.040	7.98 (6.82, 9.14)	0.040	7.76 (6.05, 8.53)	0.040	7.91 (6.55, 8.37)	0.040	6.74 (5.81, 7.67)	0.040
Saudis																
Condition 7 (25°C, CO2=600 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	2.77 (1.21, 3.76)	<0.001	2.62 (1.95, 3.19)	<0.001	2.68 (1.22, 3.58)	<0.001	2.46 (1.38, 3.30)	<0.001	2.15 (1.27, 3.57)	<0.001	2.10 (1.35, 3.55)	<0.001	2.15 (1.66, 3.45)	<0.001	1.70 (0.51, 2.42)	<0.001
hot vs. neutral	3.66 (2.32, 4.63)	<0.001	3.78 (2.77, 4.33)	<0.001	4.00 (2.89, 5.88)	<0.001	3.14 (2.72, 4.99)	<0.001	3.17 (1.24, 4.57)	<0.001	3.52 (2.61, 4.66)	<0.001	3.09 (2.00, 4.82)	<0.001	2.68 (0.99, 3.38)	<0.001
non- Saudis																
Condition 7 (25°C, CO2=600 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	1.89 (0.55, 2.27)	0.030	1.10 (0.39, 2.20)	0.030	1.44 (0.05, 2.16)	0.030	1.67 (0.37, 2.04)	0.030	1.19 (0.75, 2.97)	0.030	1.22 (0.82, 2.62)	0.030	1.53 (0.69, 2.76)	0.030	1.23 (0.34, 2.89)	0.030
hot vs. neutral	2.50 (1.91, 3.91)	0.040	2.11 (0.75, 2.53)	0.040	2.66 (1.05, 3.73)	0.040	2.75 (1.86, 2.36)	0.040	2.88 (1.13, 3.36)	0.040	2.37 (1.58, 3.15)	0.040	2.71 (1.02, 2.44)	0.040	2.00 (1.72, 3.72)	0.040
Saudis																
Condition 8 (25°C, CO2=600 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	10.70 (9.78, 11.39)	<0.001	11.18 (10.64, 12.74)	<0.001	11.79 (10.73, 12.15)	<0.001	10.24 (9.61, 11.12)	<0.001	10.35 (9.37, 11.68)	<0.001	12.68 (11.77, 13.13)	<0.001	12.55 (11.04, 13.14)	<0.001	9.21 (8.58, 10.00)	<0.001
non- Saudis																
Condition 8 (25°C, CO2=1000 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	8.68 (7.32, 9.68)	0.020	9.69 (8.91, 10.28)	0.020	9.32 (8.08, 10.45)	0.020	9.16 (8.01, 10.32)	0.020	8.93 (8.23, 10.09)	0.020	10.56 (9.19, 11.08)	0.020	10.00 (9.00, 11.00)	0.020	7.23 (6.06, 8.59)	0.020
Saudis																
Condition 9 (25°C, CO2=1800 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	12.13 (11.09, 13.36)	<0.001	14.52 (13.87, 15.91)	<0.001	15.42 (14.23, 16.40)	<0.001	12.13 (11.12, 13.86)	<0.001	13.17 (12.49, 14.82)	<0.001	15.18 (14.44, 16.80)	<0.001	15.74 (14.41, 16.89)	<0.001	12.43 (11.37, 13.23)	<0.001
non- Saudis																
Condition 9 (25°C, CO2=1800 ppm)																
cold vs. neutral	---		---		---		---		---		---		---		---	
cool vs. neutral	---		---		---		---		---		---		---		---	
slightly cool vs. neutral	---		---		---		---		---		---		---		---	
slightly warm vs. neutral	---		---		---		---		---		---		---		---	
warm vs. neutral	---		---		---		---		---		---		---		---	
hot vs. neutral	10.11 (9.61, 11.61)	0.002	12.20 (11.51, 13.11)	0.002	13.48 (12.70, 14.74)	0.002	10.70 (8.69, 11.29)	0.002	11.03 (10.35, 12.29)	0.002	13.57 (12.01, 14.12)	0.002	14.92 (13.11, 15.27)	0.002	10.63 (9.80, 11.53)	0.002

Appendix F: Consent Form and Information Sheet

Informed Consent Form for participating in the Research Study

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Project: **Colleges indoor thermal environment and students' cognitive performances in desert climates**

This study has been approved by the UCL Research Ethics Committee (Project ID Number): 4158/002

If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

CONSENT FORM: Statement of Research Purposes

We would like to invite you to participate in this research project exploring how classroom temperature and CO_2 levels impair students' cognitive performance in university/college buildings in harsh desert climates. Cognitive refers to processes such as memory, attention, perception, action, problem solving and mental imagery capacity. Your participation is voluntary and whether you decide to take part is completely up to you. If you do choose to participate you may later withdraw at any time without giving a reason.

Explanation of Research Project:

The name of research project is "The Effects of Temperature and CO2 Levels on Cognitive Performance of Female Students in Saudi Arabia". The purpose of my study is to find out how classrooms' temperature and CO_2 levels affect students' cognitive performance. During my research, I will be giving you questionnaire forms asking about your classroom thermal perception, indoor air temperature satisfaction and dissatisfaction. Also, I will ask you to sit for around 40 minutes. Cognitive performance test, which employs a set of neurobehavioral simple tests. These questions shall not be stressful for you.

We have chosen to talk to you, since you are a student at this college.

You will receive no personal benefit from being part of the study, however, your participation will help us understand your thermal environment perception. This requires about 20 minutes of your time.

As for the cognitive performance study, you will receive remarks and suggestions for improvement after assessing your cognitive skills as a mean by which you shall benefit from this study. This requires about 30 minutes of your time.

In addition, the questionnaire forms that will be distributed to you contains a set of questions that we would like to ask you, none of these questions we are asking you are related to personal issues and non of these questions shall be upsetting to you. Please find the e-mail contact of the examiner at the end of this form in case you need to report your concerns and problems caused by the participation in this research project.

Your answers to our questionnaire forms will be filled on the same provide paper, while we will save your answers of the cognitive test on Microsoft Excel sheets. Any information you may provide will be confidential. This means that while we may publish and share the information you provide for research purposes, your name and identity will be not be provided. You can stop being a part of the study at any time. Your participation in this study is voluntary. There is no compensation made for your participation in the study. If you wish not to be a part of this study, please don't hesitate to inform us.

Do you have any questions about the project?

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It is also important to be informed that:

i. All information will be anonymized.
ii. Transfer procedures comply with all the principles of the UK Data Protection Act 1998.
iii. Your personal data shall be processed fairly and lawfully, where the data obtained:
   - Will be kept only for the purpose stated,
   - Are adequate, relevant and not excessive,
   - Will not be kept for longer than is necessary for that purpose,
   - Processed in accordance with the rights of data subjects under the UK Data Protection Act, and;
   -Appropriate technical and organisational measures shall be taken against unauthorised or unlawful processing

Also, you need to know that if you to withdraw at any time, or decision not to take part, will not affect the standard of care/education you receive.

If you agree to be in this study, please let us know by saying YES.

Please circle: YES or NO

[If YES] Thank you for your agreement in participating in this study. Next, you will be asked to sign a consent form as an agreement to save your cognitive test answers.

If you agree to do so, please let us know by saying YES.

Please circle: YES or NO

Signature of Researcher

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Participant's Statement

I ,

- have read the notes written above and the Information Sheet, and understand what the study involves.
- understand that if I decide at any time that I no longer wish to take part in this project, I can notify the researchers involved and withdraw immediately.
- consent to the processing of my personal information for the purposes of this research study.
- understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.
- agree that the research project named above has been explained to me to my satisfaction and I agree to take part in this study.

Information Sheet for participating in the Research Study

You will be given a copy of this information sheet.

Title of Project: **Colleges indoor thermal environment and students' cognitive performances in desert climates**
This study has been approved by the UCL Research Ethics Committee (Project ID Number): **4158/002**

Researchers Supervised by: Dr Dejan Mumovic (Principal Investigator)
Riham Ahmed, research applicant

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We would like to invite you to participate in this research project exploring how classroom temperatures and CO_2 levels impair students' cognitive performance in university/college buildings in harsh desert climates. Cognitive refers to processes such as memory, attention, perception, action, problem solving and mental imagery capacity. Your participation is voluntary and whether you decide to take part is completely up to you. If you do choose to participate you may later withdraw at any time without giving a reason.

What is the research project about?

The purpose of the study is to determine how classrooms thermal environments are associated with students' cognitive performance. Suggestive evidence in published literature links impaired human cognitive performance with indoor elevated temperatures. However, confounding findings links higher body temperatures with better performance and alertness, with reference to improved working memory, reaction time and visual attention. Yet, a gap of knowledge has been encountered relating indoor thermal environments with human intellects and particularly adult students' cognitive performance since all available data are obtained either from schools or from office buildings' studies. This is in addition to the limited empirical evidence obtained from harsh climate regions where it is evident that occupants' thermal comfort and neutral temperature sensations have a positive linear relationship with the temperatures prevailing outdoors and that the surrounding context affect occupants' psychological adaptation which in return influences their habituation and expectation and thus alters their thermal perception which is claimed to be influencing humans' cognitive performance. Hence, the specific aim of this study is to collect empirical evidence on the implications of indoor classrooms' temperatures and ventilations (CO_2 levels) in hot desert climates for students' Cognitive performance.

What is required of me?
The study involves two parts. Firstly, You will be asked to sit for a cognitive test. This task involves you answer a set of cognitive assessment questions including: attention, complex function, response speed, learning, motivation, memory, visual memory + delay, response speed and coordination tasks. This task will take around 30 minutes to complete in total. You will be asked to complete this task in one sitting.
Afterwards, you will be invited to complete a series of questionnaires. These questionnaires are intended to give information about your thermal satisfaction in your university classrooms. They will include only one question about your past experiences. The questions also require some information related to the cognitive test. This include information about the level of difficulty of the given test and if your performance has been affected due to the classroom thermal environment or any other factor, which will determine asking few questions about the food you have eaten on the day of the test and the amount of sleep you had the night before you sit for the test as well as your general physical exercise trend since it has been revealed that food, sleep and exercise are influencing humans' cognitive performance. This is to be done directly after you finish answering the cognitive performance test.

You can expect that the questionnaires will take you about 15 minutes to complete.
If you decide to stop, the questions you have already completed can still be submitted, or you can choose not to submit any questionnaires. Submission of completed questionnaires will be taken as consent to participate. Further directions will be provided as you complete the questionnaires. We will provide you with further instructions about the experimental task as you proceed. You will have the option at the end of the task to choose to submit your data, which will be taken as you are giving consent to participate.

Acknowledgement of your time: Community service hours
As an acknowledgement of your time, we will offer all participants the chance to earn community service hrs.

Why should I take part?
If you chose to take part you will be contributing to a study that will further our understanding of humans' cognitive performance impairment due to indoor thermal environmental conditions in desert climates and hence benefit your community. This will hopefully help us understand more about classrooms' thermal environment impact over students' intellects; which will be reflected by nature on your learning outcomes.

The researcher takes your well-being seriously and if any of the content of the questionnaires causes you distress you should contact the researcher who can offer you further support and information if necessary.

What will happen to the information I provide?
We will keep the answers that you will provide to the questionnaires along with the cognitive test answers confidential. We will only take your email address if you wish to earn the community service hours. Only the researcher, Riham Ahmed, will have access to this information and it will be kept securely. In the final report all data will be completely anonymous and summarised. We will submit this research to UCL as part of the requirements for the researcher's doctorate in Built Environmental studies and may also be published in an academic journal. All participants will be able to request a copy of the research findings by contacting the researcher.

Who can I contact if I have questions about this study?
Please read carefully the information above. You may ask the researcher if there is anything that is not clear or if you would like to inquire about more information. You can contact Riham Ahmed, the researcher, or Dr.Dejan Mumovic, the project supervisor, using the contact details below.

Thank you for taking the time to read this information sheet.

All data will be collected and stored in accordance with the Data Protection Act 1998.