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Psycho-biological factors associated with underground spaces: What can the new era of cognitive neuroscience offer to their study?

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A R T I C L E I N F O

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A B S T R A C T

Working in underground spaces appears to be a possible solution for urban areas with lack of space or areas characterised by extremes of temperature. Besides pure engineering questions, it is also critical to understand the relationship between the architectural specificities of underground spaces and human behaviour and performance. Research to date has provided preliminary evidence on this question. Yet, during the last decade, contemporary cognitive neuroscience, experimental psychology and behavioural science have made impressive progress in the measurement, monitoring and understanding of human cognition and behaviour. These novel approaches offer advanced tools to study the human brain, body and mind; other disciplines (economics, political science, ergonomics and, recently, architecture) have successfully adopted these methods. The aim of the present paper is to introduce these concepts to the research community who studies the effects of underground work and offer practical examples of how these methods can be employed to understand crucial problems related to "underground psychology". These new conceptual tools enable reliable isolation of various cognitive functions in a quantifiable way; identification of individual differences in responses to the environment; uncovering of underlying motivational factors; and establishment of a more mechanistic explanation of human behaviour. Cognitive neuroscience inspired methods offer a new exciting, comprehensive, more objective, and systematic examination of human behaviour in underground spaces and open new possibilities for identification of effective interventional strategies to improve the design of modern underground environments.

1. Introduction

As urban areas become ever more crowded, planners and designers of urban spaces seek ever new solutions to this challenge. One of the existing solutions that is receiving new attention is underground space use. Theoretically, many above ground activities could also be conducted underground. A second driver for consideration of underground spaces is extreme environmental temperatures as experienced for example in Canada or Finland during winter or high temperatures during summer in Australia where underground space can provide a much more easily controllable temperate environment. There are many potential traditionally above-ground activities that do not require natural daylight, such as office and retail work. One of the key considerations in the adoption and acceptance of these new workspaces is to ensure that underground working does not negatively affect human psychology and performance.

Much of the research evidence into effects of underground spaces on work is more than three decades old and merits careful consideration in light of modern scientific advances. Past investigations into the psychological effects of working underground have mainly focused on subjective reports, such as attitudes to working spaces and perceived, self-assessed changes in mood (e.g. Carmody and Sterling, 1987, 1993; Nagy et al., 1995). Studies of the effects of underground spaces on workload suggested that if environmental factors were controlled (e.g. light level, temperature, humidity), then work performance was largely unaffected (Collins, 1975). For instance, Lutz (1976) studied pupils' responses who attended an underground school, and found no differences with respect to anxiety, behavioural problems or academic work problems. In fact, this report suggested medical benefits from being in the underground school, as it featured a filtered ventilation system.

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While work performance seemed not to suffer, subjective reports have indicated that underground workers were less satisfied with their surroundings, considered that their environment hindered their work, and were more anxious, depressed and hostile (Hollon et al., 1980). This was true even in comparison to workers in windowless rooms located above ground, indicating that it was not just the lack of natural light that reduced the perceived comfort. Reports from underground workers tended to focus on perceived impacts on health (Wada and Sakugawa, 1990), problems with the environment (Küller and Wetterberg, 1996), lack of view (Carmody and Sterling, 1987) and fear of entrapment (Carmody, 1997). These studies varied significantly in their research designs, contexts, subjects studied, duration, etc. and were dependent on engineering solutions of their present day. When assessed by today's scientific standards they have considerable methodological weakness and risks of bias which were not accounted for in interpretation of findings. We should thus interpret their conclusions and findings with caution when planning modern underground working environments. They provide insufficiently conclusive answers to plan next steps on them either in implementation of underground spaces or research on the topic.

Whereas past research offered important insights in the potential effects of and associations with working in underground spaces, they (mostly because of the absence of appropriate methods and techniques) lacked a deeper examination of the mechanisms involved. Modern technological, methodological and theoretical developments in the fields of cognitive neuroscience and experimental psychology offer an array of new powerful tools and techniques to better understand the human brain. We present examples of possible novel approaches that can be deployed to study psychology of underground work with a view of advancing the state of the art in designing underground spaces. This paper is constructed as follows: first we put the psychological effects of underground spaces into the context of an effortful response to stressors that either overload or underload an individual; then we introduce the methods that can investigate environmental effects; and finally we examine the possibility of applying interventions to improve underground spaces for work.

2. Environmental stressors

Stressors related to underground work, such as poor lighting, temperature and humidity levels can now be controlled to a level which is almost identical to any other office environment. However in real-world situations, designs often have to take a balance between effectiveness and efficiency – while it is possible to achieve the same levels of environmental factors as an above ground workplace, the operating cost may be unacceptable, such as in factories (Wijewardane and Jayasinghe, 2008) where minimising environmental maintenance costs is necessary to stay competitive in the market. In underground environments that are not strictly controlled for environmental factors, the most salient factors are thermal comfort, noise and lighting. When environmental factors like these are tightly controlled to match aboveground environments, the environment can still be a cause of stress, with a necessary lack of windows, and poor design choices leading to a lack of visual interest. Below we present an overview of each of these major environmental stressors.

2.1. Thermal comfort

Building underground can provide isolation from many climates. The large thermal mass of surrounding rock or soil allows for a uniform thermal environment compared to aboveground (Godard, 2004). However, heat generated underground can be difficult to dissipate. For example, underground railway systems require specialised cooling and air conditioning solutions, and Ampofo et al. (2004) suggest that thermal comfort criteria of underground railways should be more lax than for office environments. Thermal comfort has a complex effect on performance; while decrements in task performance can occur with heat stress, this is only reflected in certain laboratory tasks (Maula et al., 2015). V. Miller et al. (2011) found that neither core body temperature, nor cardiovascular measures were affected by heat stress since workers adjusted work rates (self-pacing) as a protective response. However, deterioration of task performance and mood, and elevation of stress hormones can be seen when workers are unable to control their rate of work (McMorris et al., 2006). This can lead to corner-cutting, and unsafe work behaviour increases significantly at higher temperatures (Ramsey et al., 1983). Heat stress also reduces serum vitamin C levels, and underground mineworkers in hot environments were once recommended to take vitamin C supplements (Strydom et al., 1977), although these may not necessarily be required as long as workers are well acclimatised and have a balanced diet in proportion to their energy expenditure (Askew, 1995). When measuring the effects of heat stress, the standard temperature scale used is the wet bulb globe temperature. However, this assumes a linear interaction of heat with the effects of humidity, which reduces heat loss through sweating. Vasmatzidis et al. (2002) found a much more detrimental effect of heat on cognitive performance and memory when relative humidity was at 70% than at 30%; in normal atmospheric conditions increased humidity is associated with greater subjective sleepiness and fatigue (Howarth and Hoffman, 1984; Sanders and Brizzolara, 1982).

2.2. Noise

While underground environments are inherently quiet places, suboptimal engineering and design decisions relating to the structure and shape of underground tunnels and rooms can lead to acoustic problems (Kang, 1997). Such problems, both above and below ground can be mitigated by appropriate design solutions. Here we consider the effects of noise to emphasise the importance of designing underground spaces to take account of this factor. Effects of noise have been extensively studied in the literature, with mixed results depending on the type of task performed. Levels of noise have been shown to increase task performance (Cohen et al., 1980; Hockey, 1970; Wilding and Mohindra, 1980), decrease task performance (Hancock, 1984; Hartley, 1981; Smith, 1991), or have no effect (Sundstrom et al., 1994), depending on the task studied. However, where task performance decrements have not been found, it is likely that there are physiological 'costs' such as changes in catecholamine and cortisol excretion (Lundberg and Frankenhaeuser, 1978), increased cardiovascular responses, and muscular tension (Hanson et al., 1993). Where decrements are found in either primary task performance, or more secondary measures, results consistently point to random variations in the quality of the noise causing more problems than steady unchanging noises (Banbury et al., 2001; Dornic and Laaksonen, 1989; Driskell et al., 1992; Percival and Loeb, 1980).

2.3. Lighting

In underground spaces, workers have consistently rated lighting conditions as less favourable than above ground workers, even if their lighting was objectively comparable (Nagy et al., 1995; Hollon et al., 1980). Lighting of underground spaces has the potential to be preferable to windowed spaces, as lighting can be brighter and more uniform with less glare. The luminance level and quality of light have been shown to affect cognitive