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A longitudinal investigation of work environment stressors on the performance and wellbeing of office workers

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ABSTRACT

This study uses a longitudinal within-subjects design to investigate the effects of inadequate Indoor Environmental Quality (IEQ) on work performance and wellbeing in a sample of 114 office workers over a period of 8 months. Participants completed a total of 2261 online surveys measuring perceived thermal comfort, lighting comfort and noise annoyance, measures of work performance, and individual state factors underlying performance and wellbeing. Characterising inadequate aspects of IEQ as environmental stressors, these stress factors can significantly reduce self-reported work performance and objectively measured cognitive performance by between 2.4% and 5.8% in most situations, and by up to 14.8% in rare cases. Environmental stressors act indirectly on work performance by reducing state variables, motivation, tiredness, and distractibility, which support high-functioning work performance. Exposure to environmental stress appears to erode individuals' resilience, or ability to cope with additional task demands. These results indicate that environmental stress reduces not only the cognitive capacity for work, but the rate of work (i.e. by reducing motivation). Increasing the number of individual stress factors is associated with a near linear reduction in work performance indicating that environmental stress factors are additive, not multiplicative. Environmental stressors reduce occupant wellbeing (mood, headaches, and feeling 'off') causing indirect reductions in work performance. Improving IEQ will likely produce small but pervasive increases in productivity.

1. Introduction

A growing body of evidence shows that inadequate Indoor Environmental Quality (IEQ) can cause illness, adversely affect wellbeing and reduce worker productivity (Broadbent, 1971; Clausen and Wyon, 2008; Cui et al., 2013; Hygge and Knez, 2001; Lan et al., 2010; Witterseh et al., 2004). Fisk and Rosenfeld (1997) estimate that improving IEQ may improve productivity by between .5% and 5%. While the costs of regulating IEQ are significant (Kwon et al., 2011), the annual cost of employee salaries are approximately 100 times that of annual building costs (rent and maintenance) (Fisk and Rosenfeld, 1997). Fisk (2000) estimates that in the United States, the direct annual cost of inadequate IEQ on lost productivity, excluding illness, is between $20 and $160 billion dollars. According to Lan et al. (2014), the effect of IEQ on productivity is not considered in building design. To improve building design, building scientists require a sophisticated understanding of building occupant/building environment interaction in order to accurately predict how changes in building design and IEQ regulation are likely to affect occupants. Specifically, we do not understand how inadequate IEQ affects work performance and how individuals adapt and compensate for discomfort and stress. Recent studies have shown the benefit of improved IEQ on worker performance in actual offices (Agha-Hossein et al., 2013; Budaiwi, 2007). Small productivity gains are likely to be profitable for most organisations and provide better quality of life for building occupants (Dai et al., 2014; Fisk, 2000; Lan et al., 2011).

Ergonomists have long considered factors including, temperature, noise and lighting, to be environmental stressors (Broadbent, 1971). Uncomfortable or inadequate workspaces appear to redirect an individual's resources away from work performance, placing additional stresses on cognitive reserves, attention, and/or concentration. For example, early research showed that increasing the temperature (from 22.8 to 30.6 °C) caused thermal stress that reduced performance by 5% (Viteles and Smith, 1946). Later studies

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show that thermal stress increases task demands and places an additional load on cognitive reserves; performance degrades when the load exceeds the reserve (Hocking et al., 2001). Similarly, Matsangas et al. (2014) exposed individuals to low-frequency motion, causing mild motion sickness, another form of stress. While individuals initially report mild motion sickness, performance was unaffected. After further exposure, the ability to compensate for the additional stress decreased, consequently causing a reduction in performance. Mild motion sickness can also occur in office environments located in tall buildings, caused by wind-induced building motion (Lamb et al., 2014). Other studies have shown that increasing effort to counter thermal discomfort and maintain performance can cause a reduction in motivation and also cause low mood (Lan et al., 2010). Similarly, increases in humidity can adversely affect performance (Shi et al., 2013; Tsutsumi et al., 2007). Changing light levels can also adversely affect eye fatigue, distraction, and causing difficulty perceiving letters and annoyance (Kim and Kim, 2007).

While the effect of individual stressors have been studied, few studies have investigated the combined effects of multiple stressors (Clausen and Wyon, 2008; Dai et al., 2014), particularly the combined influence of thermal comfort, noise annoyance, and lighting comfort. Where they have been studied (Clausen and Wyon, 2008; Hygge and Knez, 2001; Witterseh et al., 2004), the results are inconclusive and are contradictory (Liebl et al., 2012). The range of methods used and individual study constraints complicate the interpretation of these studies. The current research investigates how environmental stress factors interact, and their effect on work performance in a real office environment.

Fisk (2000) notes three main limitations of experimental studies that attempt to address real-world work performance. One, experimental studies likely overestimate work performance reductions, using the example that a 50% in test accuracy is unlikely to cause a 50% reduction in worker performance. Two, typically measured cognitive tasks (e.g. reaction time), do not accurately reflect the types of work carried out in offices. Three, experimental studies manipulate stress factors over an unrealistically large range than found in most actual buildings. In addition to these limitations, experimental studies typically recruit younger participants (often university volunteers) who may not be representative of office workers, likely to be older and more experienced than the average university student. A number of factors concomitant with age, such as attitudes, tolerance and expectations, may affect the response to environmental stress factors. Experimental studies almost always employ cognitive tests and standard performance measures that participants have no inherent investment in, in contrast to the workplace where individuals are likely to be intrinsically or extrinsically motivated to maintain a high level of performance. Therefore actual office workers may be more resilient to moderate challenges of environmental stress. Further, stress factors in an experimental environment may have a differential effect on performance. A novel "stress" such as an arbitrary noise may be a mild inconvenience in an experiment, but an irregular but frequently experienced noise at work (e.g. loud air conditioning) may have a large impact on work performance. Finally, experimental studies typically expose participants to short durations of stress, often around 2 h or less, significantly less than office workers who may experience up to 8 h of environmental stress during an average work day. Stress of a low intensity for a long duration may have equal or greater impact than a high intensity stress for a short period. The obvious method to overcome these limitations is to examine the effect of a realistic set of environmental stressors that occur in real office buildings.

The interaction between an individual and their environment is complex. Humans are not passive systems where a change in the physical environment produces a response of a given magnitude. Instead, humans respond physiologically (e.g. release sweat to decrease temperature) and psychologically (e.g. increase effort in response to a challenge) to changes in the environment (Parsons, 2000). Psychologists categorise individual characteristics into two components. Stable characteristics are called "traits" (e.g. introversion/extroversion), and dynamic characteristics, are called "states" (e.g. motivation, mood) (Chaplin et al., 1988). States may be a form of resilience; a capacity to achieve a positive outcome despite challenges (Luthar and Cicchetti, 2000). Individual states may explain the response to environments stresses. Cui et al. (2013) show that motivation decreases during thermal stress, and that reductions in motivation provide a better explanation for reductions in performance than direct effects of thermal stress. Understanding the role of individual states in the relationship between environmental stressors and the adverse effects on well-being and work performance may facilitate the development of a more sophisticated understanding of the individual/environment interaction. Individual differences in the sensitivity to changes in environmental stressors complicates the person/environment interaction; individuals differ, for example, in their sensitivity to sound and temperature (Clausen and Wyon, 2008; Parsons, 2000). Further, females tend to show greater dissatisfaction with IEQ than males (Kim et al., 2013). The literature on individual adaptation to environmental stressors, and the effect those adaptations on productivity is limited.

The current study addresses the limitations of previous experimental studies and examines the effect of environmental stress factors on real office workers in their actual office environment. We focus on the effects of reported stress-induced discomfort on work performance and well-being in a large sample across a wide variety of office settings and environmental conditions, rather than address the objectively measured conditions that cause discomfort. Participants completed online surveys measuring work performance, well-being, and environmental stress factors including, perceived thermal comfort, lighting comfort and noise annoyance, over a period of 8 months. The study addresses four main aims: one, qualify the effects of environmental stress factors on work performance and wellbeing; two, assess the cumulative effects of environmental stress factors; three, investigate the role of 'state' variables as potential mediators between environmental stressors and work performance; and, four, investigate how individuals might compensate for environmental stressors.

2. Method

2.1. Participants

The current study recruited participants from a large-scale ground level survey examining the occupant response to wind-induced building motion (Lamb et al., 2013). The study recruited additional participants from the work colleagues of the initial participants. Participants gave their informed consent and received an incentive of $200 (NZD). 114 participants completed a total of 2261 surveys across a period of 231 study days (8 months) in Wellington, New Zealand. On average, each participant completed 19.8 surveys (min = 7; max = 27). The sample overrepresented female participants (71.9%, $N = 82$). Participants reported a mean age of 39.5 years ($SD = 10.9$) and were of primarily a "professional" occupation (69.5%, $N = 73$), followed by "administration" (24.8%, $N = 26$). Participants reported that they worked in one of 66 different buildings in Wellington. Sample sizes varied with a median of 2 participants per building (min = 1; max = 15). Participants worked on a median of the 8th floor (min = 0 (ground floor); max = 28) in buildings with a median height of 12 floors (min = 2;