17th Australasian Wind Engineering Society Workshop
Wellington, New Zealand
12-13 February 2015

The effect of wind-induced building motion in a longitudinal sample of office workers in Wellington, New Zealand

S. Lamb[1], K.C.S. Kwok[1] and D. Walton[2]

[1]Institute for Infrastructure Engineering,
University of Western Sydney, Penrith, Australia

[2]Research and Evaluation,
Health Promotion Agency, Wellington, New Zealand

Abstract

47 office workers located on high floors and 53 office workers on or near the ground floor in Wellington, New Zealand, completed 1,909 short online surveys across a period of 8 months. Participants completed these surveys during a range of wind conditions from calm to near-gale. The results show that sopite syndrome (mild motion sickness) is the main consequence of exposure to wind-induced building motion, which causes a large reduction in work performance. Thresholds of motion perception are the basis for current serviceability criteria. We argue that the next generation of serviceability criteria should aim to reduce the incidence of sopite syndrome, thereby maintaining work performance and occupant wellbeing.

Introduction

Wind-induced building motion poses a design challenge for structural engineers who must balance building costs against performance. Allowing higher building accelerations reduces building costs but may cause motion sickness, occupant discomfort and reduced work performance. Previous research attempting to understand the occupant response to motion (Burton, Kwok, and Hitchcock, 2011; Chen and Robertson, 1972; Tamura, Kawana, Nakamura, Kanda, and Nakata, 2006) favoured motion simulators because of their convenience, controllability and simplicity compared with the complexity of studying occupants in real buildings and the difficulty of accessing office buildings. In addition to the inability to mimic real-life work environments, simulator studies have significant limitations. They use task performance measures that may be too simple to detect true performance differences, expose participants to unrealistic short durations of motion, and do not allow participants to display adaptive behaviours (e.g. taking breaks, using medication). Consequently, past and present building design criteria may be inadequate to ensure a healthy and productive work environment, as they are based on an incomplete understanding of the human response to building motion and focus primarily on motion perception thresholds and occupant complaint (Architectural Institute of Japan, 2004; ISO 10137, 2007).

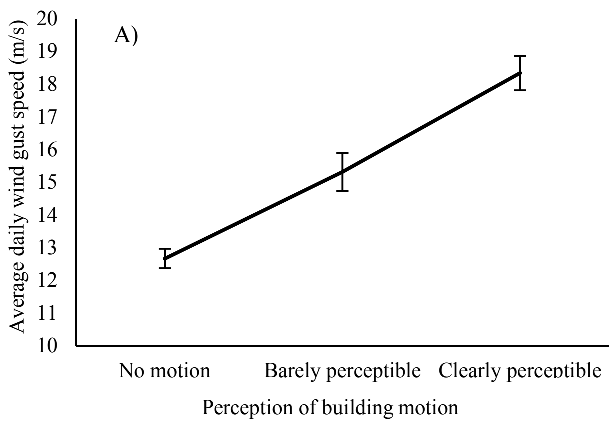
Motion sickness can occur in response to tall building motion and is characterised by nausea, and sometimes vomiting. Sopite syndrome, a form of mild motion sickness, is a less known consequence of long duration exposure to low-acceleration, low-frequency motion, similar to that of building motion. Sopite syndrome has a sedative effect on individuals, causing symptoms of sleepiness, difficulty concentrating, low mood, and decreased motivation, which may never develop into nausea (Graybiel and Knepton, 1976). These symptoms may be subtle, and individuals are unlikely to be aware that they are affected.

The occupant response to motion is complex, governed by human physiology, and moderated the psychological response to motion and discomfort, all occurring within a sophisticated engineered environment. Few studies attempt to measure the occupant response to motion in real tall buildings, mainly because of the cost, time and inconvenience compared to motion simulators. We use a longitudinal study design to investigate the effects of building motion on work performance (Lamb, Kwok, and Walton, 2014).

Method

In Wellington, New Zealand, we recruited 47 office workers located on high floors, spread across 22 wind-sensitive buildings, and 53 office workers on or near the ground floor (a control or comparison condition). Participants completed a total of 1909 short online surveys across a period of 8 months, during conditions ranging from calm (1.2 m/s) to near gale (29.0 m/s). The survey measured: (1) reported perception of motion, (2) symptoms of sopite syndrome and motion sickness, (3) work performance, and (4) compensatory/adaptive behaviours. The "Work Environment Survey" also measured a variety of other general measures about the work environment to mask the actual purpose of the survey. The analysis used objectively measured wind speeds and predicted accelerations to support participant reports of building motion. The large number of study buildings and building owner permissions limited us from measuring accelerations in all buildings.

On allocated survey days, participants indicated if they could 'possibly' feel building motion (barely perceptible), 'definitely' feel motion (clearly perceptible), or reported no instances of motion. Shown in Figure 1, the lowest wind speeds corresponded to no reported motion perception. Wind speeds and predicted building accelerations were significantly higher during 'possible' motion and significantly higher again during 'definite' motion.



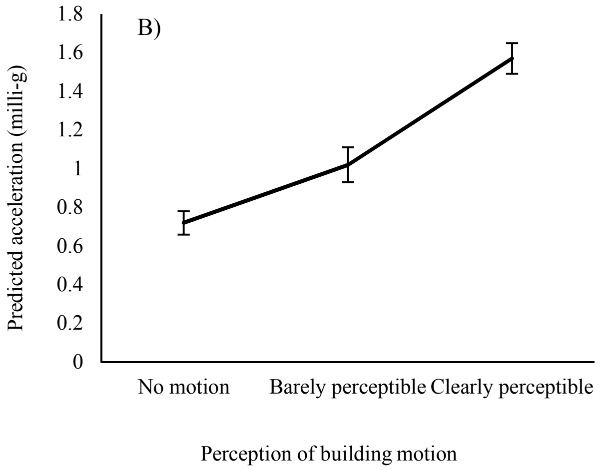


Figure 1. (A) Average daily gust speeds by reported building motion, and (B) Predicted peak building accelerations by perception of motion.

Participants were significantly more likely to report nausea, dizziness and feeling 'off' (slightly unwell), distraction and sleepiness during perceptible building motion. Aggregating these symptoms to include both classic symptoms of motion sickness and sopite syndrome, we found that moderate symptoms are 2-3 times more likely to occur during building motion than during baseline (no-motion). Sopite syndrome accounts for 80% of the reported symptoms. Sopite syndrome-like symptoms occur with a baseline incidence of about 12%, because similar symptoms can occur during static conditions, for example, people can report tiredness for a variety of reasons such as work stress, or feel distracted because of personal/family stress.

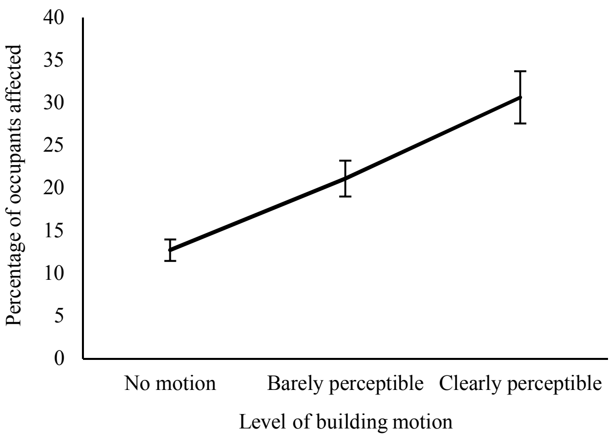


Figure 2. The proportion of participants reporting moderate to high severity sopite syndrome/motion sickness symptoms across motion perception.

Self-reported work performance significantly decreases as participants report higher levels of sopite syndrome/motion sickness. Performance is above average at baseline and drops below average with moderate to high level sopite syndrome/motion sickness, a large decrease equivalent to nearly 1 standard deviation (effect size 0.91). However, performance does not decrease solely due to reported building motion, only when participants report sopite syndrome/motion sickness. Performance on the Stroop Test, a word/colour matching task shows the same decreasing trend, see Figure 3. Because performance reductions only occur during motion sickness, the cause of the performance reduction is unlikely to be the result of building vibration directly interfering with performance. More likely, sopite syndrome/motion sickness causes stress, decreasing mental resources available for work performance.

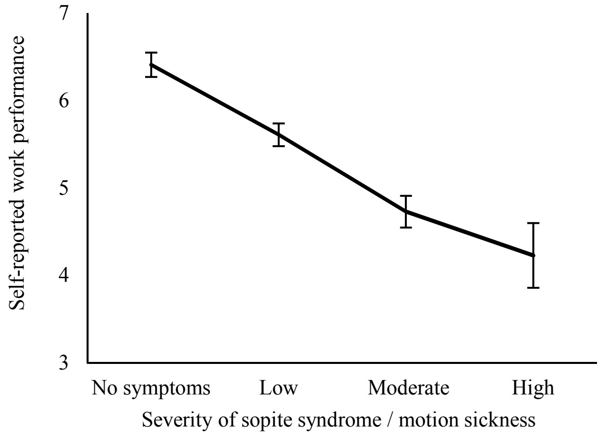


Figure 3. Self-reported work performance by symptoms of sopite syndrome/motion sickness. The scale mid-point of 5 reflects 'average' work performance, with higher scores indicating above average performance.

In an effort to improve their comfort, participants reporting sopite syndrome/motion sickness spent 46% longer (21 mins.) outside their building during the work day than those suffering no ill effects. Further, participants reported a 28% increase in the use of analgesic medication (painkillers) when experiencing sopite syndrome/motion sickness.

We estimate that 5.4% of office workers in the top third of wind-sensitive buildings in Wellington, experience moderate to high symptoms of sopite syndrome/motion sickness that cause a large impact of work performance, approximately 53 work days a year. During the study, wind speeds only reached 75% of the one-year return period, so the observed effects and proportion of affected occupants is likely to be conservative.

Discussion

This research shows that wind-induced building motion can significantly reduce the work performance of occupants. At least in the range of observed accelerations, building motion does not appear to directly interfere with the physical activity of work, rather low-frequency motion causes sopite syndrome, and these symptoms of sleepiness and reduced motivation appear to cause the reduced work performance. Further, the reported discomfort is sufficient to cause occupants to take medication to improve their comfort, though analgesic medication is unlikely to reduce symptoms associated with motion sickness. Motion sickness tablets may be effective at treating nausea, but these are likely to exacerbate sleepiness.

Despite the significant implications for real-world work environments, few studies have sought to develop a fundamental understanding of sopite syndrome. While we know the condition has real and significant adverse effects on those exposed to low-frequency motion, we do not understand: (1) the development of symptoms with exposure to motion, (2) the motion dose required to produce these symptoms (the frequency, acceleration, motion type, individual susceptibility), (3) how and why sopite syndrome affects performance, and (4) whether sopite syndrome is low-severity motion sickness or an independent condition caused by similar environmental conditions. Our limited understanding of why sopite syndrome and motion sickness occur complicates the task of creating building standards designed to reduce or prevent these conditions. Developing a comprehensive understanding of sopite syndrome will facilitate the creation of a new generation of serviceability criteria, requiring contributions from psychologists, physiologists and engineers.

Understanding the cause and development of sopite syndrome requires input from a broad range of scientific disciplines. Sleep researchers have recently reinforced that low-frequency motion causes sleep, more importantly, that rocking produces a deeper sleep than during normal sleep in a static environment (Bayer et al, 2011). Sopite syndrome may not simply initiate sleepiness, but may continuously suppress physiological and psychological arousal. The vestibular system is central to motion sickness, located in the inner ear and is responsible for balance and the perception of motion. Recent research has shown that the vestibular system fires in response to motion that is imperceptible to an individual, and that individuals who report motion sickness, show a greater coupling of parasymapthic nerve activity and physiological responses, e.g. blood pressure (Hammam, Dawood, and Macefield, 2012). This research indicates that building motion well below the threshold of motion perception may affect occupants, as barely perceptible motion caused significantly higher levels of sopite syndrome/motion sickness.

We recommend that future serviceability criteria abandon the concept of motion tolerance, as evidently occupants will tolerate high levels of building motion, but with large adverse effects for them and their organisations. Future criteria should instead try to establish the maximum allowable accelerations that have a minimal disruption to building occupants. Sopite syndrome is the main cause of work performance reductions and occupant discomfort. Rather than address perception thresholds, future serviceability should determine the minimum 'dose' of motion that causes motion sickness and associated adverse effects. Motion dose is likely a complex combination of acceleration, frequency, motion type, and duration of exposure to motion, also affected by individual susceptibility to motion sickness. Future studies could perform a cost-benefit analysis to determine the optimal investment into the reduction of building accelerations taking into account the costs of lost productivity, turnover and risk of adverse building reputation, comparable to that undertaken in regard to thermal comfort (Dai, Lan, and Lian, 2014).

Conclusions

Sopite syndrome is the main consequence of exposure to wind-induced building motion, and is the primary cause of reductions in work performance. These effects occur at lower accelerations than previously thought. Highly susceptible individuals appear unable to avoid working in high-rise environments, therefore design criteria must address the wellbeing of the most sensitive individuals. Building motion appears to have a minimal disruptive effect on work performance directly, instead building motion induces motion sickness which causes work performance reductions. A new generation of serviceability designed to minimize motion sickness, rather than address perception thresholds, will allow engineers and designs to create a new generation of buildings that will ensure an improved level of comfort and performance for building occupants.

References

Architectural Institute of Japan (2004) Guidelines for the evaluation of habitability to building vibration. Tokyo, Japan: Architectural Institute of Japan.

Bayer L, Constantinescu I, Perrig S, Vienne J, Vidal P, Mühlethaler M, and Schwartz S (2011) Rocking synchronizes brain waves during a short nap, Current Biology 21:461–462.

Burton M D, Kwok K C S, and Hitchcock P A (2011) Effect of low frequency motion on the performance of a dynamic manual tracking task, Wind and Structures 14: 517–536.

Chen P W, and Robertson L E (1972) Human Perception Thresholds of Horizontal Motion, Journal of the Structural Division 92:1681–1695.

Dai C, Lan L, and Lian Z (2014) Method for the determination of optimal work environment in office buildings considering energy consumption and human performance, Energy and Buildings 76:278–283.

Denoon R O, and Kwok K C S (2011) Implications of full-scale building motion experience for serviceability design, Wind and Structures 14:537–557.

Graybiel A, and Knepton J (1976) Sopite syndrome: a sometimes sole manifestation of motion sickness, Aviation, Space, and Environmental Medicine 47:873–882.

Hammam E, Dawood T, and Macefield V G (2012) Low-frequency galvanic vestibular stimulation evokes two peaks of modulation in skin sympathetic nerve activity, Experimental Brain Research 219:441–446.

ISO 10137 (2007) Bases for design of structures - serviceability of buildings and walkways against vibration, Geneva, Switzerland: International Organization for Standardization.

Lamb S, Kwok K C S, and Walton D (2014) A longitudinal field study of the effects of wind-induced building motion on occupant wellbeing and work performance, Journal of Wind Engineering and Industrial Aerodynamics 133:39–51.

Tamura Y, Kawana S, Nakamura O, Kanda J, and Nakata S (2006) Evaluation perception of wind-induced vibration in buildings, Proceedings of the ICE - Structures and Buildings 159:283–293.