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Experience with Wind-Induced Building Motion in Wellington, New Zealand: Motion Sickness, Compensatory Behaviours and Work Location Preferences

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Introduction

New high strength materials, new techniques of construction and sophisticated computer modelling techniques have introduced a new generation of tall buildings that are inherently light weight, slender, have low damping, and are significantly more wind sensitive than older buildings (e.g. Burton et al., 2006; Kwok et al., 2009). Wind excitation induces low-frequency, low acceleration, building vibration, mostly between 0.08 and 1 Hz. Building motion has been shown to be perceptible by building occupants (e.g. Hansen et al., 1973; Goto, 1983), can cause fear and alarm (e.g. Hansen et al., 1973; Burton, 2006) and can induce symptoms of motion sickness in some occupants (e.g. Goto, 1983). The effect of building motion on building occupant work performance is not well understood. There are no internationally accepted guidelines or regulations that constitute an 'acceptable' level of building motion (Kwok et al., 2009) or an agreed upon set of criteria for which any guidelines should be based.

Previous survey research

Relatively few studies have examined the actual occupant response to building motion in real-world environments. Hansen et al. (1973) conducted the first study finding that between 36% and 47% of occupants experienced motion sickness in two buildings following wind storms. Goto (1983) found that following a typhoon (with a peak acceleration of approximately 14 mG) over 95% of occupants above the 13th floor in each building reported the perception of building motion. Seventy-two percent of occupants reported experiencing physiological or psychological symptoms, including motion sickness, headaches and "uneasiness and strain", the likelihood of which increased with height. Denoon et al. (2000) examined perception thresholds of occupants in two airport control towers and a port communications centre. Denoon et al. (2000) observed no correlation between those who reported building motion was unacceptable, and those who issued an official complaint to their employer. Control tower workers reported building motion became more acceptable over time, suggesting some degree of habituation. No systematic relationship between building motion and cognitive performance could be established. Burton (2006) collected information about experience with building motion from 5000 Hong Kong residents. Only 5.8% of the sample reported experience with building motion. Of that small percentage, only 2.3% issued a formal complaint to their employer or the building owner. While the perception of motion is a key factor, Kwok et al. (2009) states the focus of research should move towards understanding the effects of motion on building occupants, particularly the comfort of occupants and their general wellbeing.

Motion sickness and Low-Dose Motion Sickness

The most reliably produced symptoms of motion sickness are nausea, vomiting, cold-sweating and pallor (Reason & Brand, 1975). These are preceded by early onset or prodromal symptoms of motion sickness such as tiredness, headaches and other "head" symptoms. Walton et al., (2011) argue that a dose-response model should be adopted. Tall buildings are 'low-dose' environments with relatively low accelerations exerted on occupants compared with highly nauseating motion such as ships or roller coasters which induce high level symptoms such as vomiting. Therefore, in low-dose environments, early onset symptoms that precede frank motion sickness should be measured, namely drowsiness, difficulty concentrating and mood. These early onset symptoms are usually referred to as Sopite Syndrome (Graybiel & Knepton, 1976).

A debate exists over the mechanism that produces motion sickness. Sensory Conflict Theory (Reason & Brand, 1975) posits that motion sickness is the result of 'conflicting' perceptions of the environment, typically visual and vestibular, where motion is felt and not seen or vice versa. Stoffregen and Riccio (1991) reject the fundamental notion of 'sensory conflict' and counter with Postural Instability Theory (Riccio & Stoffregen, 1991) which contends that motion sickness is the result of the inability to maintain stability (or control) in a motion environment. Each theory generates different hypotheses as to how symptoms of motion sickness might occur and be mitigated. Therefore, any study of the effects of motion sickness should at least consider the implications of each theory. Walton et al. (2011) argue that prodromal symptoms of motion sickness will be subtle and potentially masked to occupants by work stress or health issues, and possibly misattributed to other factors. With respect to Postural Instability Theory, designing for anything other than an actual reduction of building acceleration may be ineffective in reducing prodromal symptoms of motion sickness. Most importantly, Postural Instability Theory characterises individuals as active managers of their environment, not passive recipients of sensory information. Therefore, motion environments should induce observable changes in an individuals' behaviour that can be measured.

A Survey of Wellington Tall-Building Occupants

This study takes an ecological approach to the examination of the effects of tall building motion of building occupants. Such an approach characterises building occupants as active in their environment, examining occupant responses to building motion, with regard to how individuals manage and adapt to their physical environment. Such an approach requires an understanding of the characteristics of people working across all levels of tall buildings, not just those on the floors most affected by building motion. Few studies have collected comprehensive real-world data across a wide range of buildings collecting detailed information about individuals' work environments, including psychological variables, most importantly susceptibility to motion sickness. This study collects data from a random sample of central city workers, in Wellington, New

Zealand. Wellington was chosen due to its consistently high wind conditions. The following hypotheses were examined:

(1) Motion sickness susceptible individuals will prefer lower floors and will be more likely to work on lower floors, (2) Building motion will be judged to be unpleasant and highly susceptible individuals will judge the motion to be more unpleasant, (3) Building occupants will report symptoms of low-dose motion sickness, (4) Individuals who are affected by building motion will display compensatory behaviours to manage their environment, (5) Non-susceptible individuals will report higher levels of habituation to motion than susceptible individuals, (6) Few if any instances of formal complaints about building motion will be reported,

Method

Four thousand surveys were distributed in Wellington, New Zealand during late August 2011. 1014 completed surveys were returned (25.4%). Respondents were fairly evenly represented across gender (males=45.1%, females=54.6%) and reported a mean age of 40.3 years (SD=13.04). The majority of respondents were in full-time employment (84.4%). Occupation categories included 'professional' (59%), 'manager' (10.7%) and 'clerical / administration (14.6%). Respondents were spread across 201 different buildings / addresses (sample sizes ranged from 1 to 63). Respondents' current work floors ranged from the ground floor to 29th floor (the tallest building in Wellington) with a mean floor of 7.6 (SD=6.2). The survey requested information about individuals experience with building motion, motion sickness and general measures of satisfaction with their current work environment. An 8 page survey contained 95 items and was divided into 3 main sections. Section A included items about the respondents current work environment. Section B requested information about experience with building motion. Section C measured susceptibility to motion sickness and included demographic items. Survey packs were distributed on the streets of the Wellington Central Business District (CBD). Respondents who took survey packs were able to complete them at their leisure and return it in the freepost return envelope.

Results

Experience with Building Motion

The majority of the sample (86.1%, N=851) reported experience with building motion. Almost half of respondents 47.9% (N=428) reported experience with wind-induced building motion. Most of the remainder of building motion experience was due to earthquakes. Nearly two-thirds (62.8%, N=260) of respondents who experienced wind induced building motion, experienced motion in their current workplace, and 54.9% (N=224) indicated they had experienced building motion in a previous work place. Respondents were asked how often they experienced perceptible building motion. Marginally under a fifth (19.5%) of full time workers reported perceptible motion occurring at least once a week. Just under half of respondents experienced building motion once every 1 to 3 months. The remainder reported less frequently occurring motion.

Susceptibility to Motion Sickness

Just under a third of all full time workers indicated they were 'Not at all' susceptible to motion sickness (29.4%, N=247), 44.0% (N=370) indicated they were 'Slightly' susceptible, 16.1% (N=135) 'Moderately' susceptible and 10.6% (N=89) 'Very much so'. A Chi-square test showed that susceptibility to motion sickness was independent of the type of motion felt, $X^2(12, N=750) = 16.01$, *n.s.* Individual susceptibility to motion sickness had no significant effect on the likelihood of perceiving wind-induced building motion.

Current Work Floor: Preference vs. Actual

A significant linear trend was found where respondents preference to work on lower floors increased as susceptibility to motion sickness increased, F (3, 683) = 10.7, $p < .01$. Preference for working on higher or lower floors had no significant relationship with the actual floor respondents worked on. Susceptibility to motion sickness also had no significant relationship with current work floor, F (3, 838) = 1.4, *n.s.* A significant linear relationship was found where higher levels of susceptibility to motion sickness were associated with stronger preferences for individuals' organisation to move to a different building, F (1, 244) = 8.8, $p < .01$. These results show that respondents who are susceptible to motion sickness prefer to work on lower floors, but current work floors show no relationship to those preferences. Further analysis was conducted to examine the extent to which respondents seek or avoid other types of motion environments that they might have relatively more control over than their place of work, e.g. cars, buses, ships, roller coasters etc. Overall, significant differences were observed for 7 of the 11 motion environments, including ships, roller coasters video games and the back seat of cars. In all cases, except one, means were significantly lower for respondents who indicated they were highly susceptible to motion sickness or preferred to work in the lower third of a tall building. These differences indicate that motion sick prone individuals avoid certain types of motion environments that can often induce motion sickness.

Judgements of the Unpleasantness of Motion

All analyses from this section on, unless otherwise stated, are restricted to full time workers who indicated experience with wind-induced building motion only. Respondents judged the unpleasantness of building motion on a 10-point scale with a mean of 6.1 (SD=1.8) with a negatively skewed distribution. A response of the mid-point (5) represented 'not sure / neutral' and higher values indicated higher ratings of unpleasantness. Judgements of unpleasantness showed a significant linear increases with increases in susceptibility to motion sickness, F (3, 284) = 15.63, $p < .001$. There was no significant correlation between judgements of unpleasantness and current work floor, r (286) = .08, *n.s.* Unpleasantness did however correlate significantly with the number of symptoms of motion sickness reported, r (286) = .55, $p < .001$, where higher judgements of unpleasantness were associated with higher numbers of reported symptoms.

Symptoms of Motion Sickness

Twenty-nine respondents reported experiencing no symptoms due to wind induced building motion. Difficulty concentrating was the most frequently reported symptom (37.9%), followed by feeling 'weird' (29.3%), dizziness (22.4%) and nausea (20.3%). Three participants (1%) indicated that building motion caused vomiting. The effects of motion were compared across wind-induced motion and earthquake induced motion. Reports of dizziness, nausea, feeling 'weird' and difficulty concentrating were less frequent in earthquakes than wind-induced motion caused by wind, though symptoms were still reported by a small proportion of people. Reports of fear were almost 3 times higher in earthquakes compared with wind-induced motion. This is expected, even in Wellington, where earthquakes and tremors are regular occurrences, given that earthquakes have historically caused far more deaths and injuries than even extreme wind events such as cyclones and tornados. The number of symptoms of motion reported increased significantly, and linearly, with increases in susceptibility to motion sickness, F (1, 286) = 35.05, p < .001. Despite some respondents reporting they are 'not at all' susceptible to motion sickness, some still report symptoms associated with building motion.

Low-Dose Motion Sickness

A significant main effect of frequency of occurrence was found, F (2, 109) = 8.1, $p < .05$, where respondents who experienced motion once a week or more, reported higher levels of tiredness than the group who experienced building motion less frequently than once a week. There was no main effect of susceptibility to motion sickness, F (3, 109) = .91, *n.s.*

Productivity and Compensatory Behaviours

Over half of respondents indicated that they do not experience any symptoms therefore required no strategies to alleviate any negative effects of building motion. The most frequent strategy employed is standing up and walking around the office (24.1%) and take a break outside the building (20.3%). Individuals who indicated at least some susceptibility to motion sickness were significantly more likely to stand up and walk around (27.4%) than those who reported no susceptibility to motion sickness (14.7%), $X^2(1, N = 290) = 4.96, p > .05$. The same trend was observed for taking a break outside the building; individuals with some susceptibility were significantly more likely to leave the building (24.2%) than non-susceptible individuals (9.3%), $X^2(1, N = 290) = 7.57, p > .01$.

Habituation

Respondents judged the degree to which building motion affected them over time on a scale anchored at: 1 = "motion became much worse over time", 3 = "no change" and 5 "motion became much better over time". Respondents reported a mean of 3.37 (SD = .83), and which was negatively skewed, showing a tendency towards habituation over time. Respondents who indicated that motion never affected them were filtered out (17.4%, N = 50). Habituation was independent of susceptibility to motion sickness, Kruskal-Wallis (3, N = 237) = 6.7, *n.s*. Males were significantly more likely to report habituation, U (N = 287) = 7974, $p < .01$. No significant age differences were observed, Kruskal-Wallis (8, N = 290) = 14.2, n.s.

Complaint Behaviour

Over half (57.6%) of respondents indicated they had never complained to another individual about building motion. When complaints were made regarding wind induced building motion, they were most frequently made to co-workers, accounting for a quarter of complaints (24.8%), followed by complaints to family (13.4%). The frequency of complaints decreased as the level of authority increased. Only 3.8% of complaints were as high as to a team leader. Significantly, no complaints were made to building owners. As a point of comparison, people are less likely to complain about earthquake-induced motion, at all levels. The main reason for not complaining was that "building motion cannot be fixed", indicated by 38.6% of respondents. About a third of respondents indicated that "complaining would make no difference" (31.7%). The least reported reason, though still a reasonable proportion, was "building motion doesn't seem to bother other people" (15.2%).

Discussion

Preference for Work Environment

In relatively unconstrained situations, motion sickness susceptible individuals were found to avoid nauseogenic environments (e.g. ships, roller coasters, travel in the back seat of cars) compared with non-susceptible individuals. Despite clear preferences for working on lower floors, these highly susceptible individuals are equally likely to work on the highest floors as non-susceptible individuals. This suggests that individuals are constrained in their ability to choose their preferred work environment. It is likely that the physical work environment is a secondary consideration to other factors such as remuneration and job satisfaction, given that higher-level and hence higher-paid jobs are typically performed on the more 'prestigious' higher floors. Further, susceptible individuals working on high floors indicated a relatively higher preference to move their work location. Preference to move work location and lease durations may be a better metrics for building performance than predicted tolerance for building motion over a given return period (Hansen et al., 1973) or the perception of motion.

Motion is Unpleasant and Related to Susceptibility

On average, when motion was judged to be mildly unpleasant, judgements of unpleasantness were found to be linearly related to susceptibility to motion sickness. Therefore the worst affected individuals will be found in the upper levels of buildings that are subject to the highest accelerations. At least one symptom of motion sickness was reported by 30% of respondents. Three participants reported vomiting, which is reported very infrequently if ever in the literature, and is normally a response reserved for more severe motion environments. That vomiting is reported even in non-extreme wind events indicates that the occupant response in real-world environments is not sufficiently understood, mainly attributable to the low number of such studies and due to the short durations of exposure to motion in simulator studies (typically less than one hour). Susceptibility to motion sickness is central to understanding the occupant response to building motion, but individual variables such job satisfaction, remuneration, relative employment opportunities might provide additional insight into why individuals tolerate unpleasant environmental conditions, especially if work performance is degraded.

Work Performance and Compensatory Behaviours

While it was not possible to measure variation in work performance using a one-sample survey methodology, it was possible to identify motion-induced behaviours that are detrimental to productivity. Building motion was reported to affect over a third of occupants' ability to concentrate. The relationship between impaired concentration and work performance needs to be quantified and it could have significant implications, particularly for professional occupations. Difficulty concentrating has also been noted by Goto (1983) and Burton (2006). Half of respondents indicated that they do not experience any symptoms of motion and therefore reported no need to adopt any strategies manage their environment. The remaining half of affected respondents do however engage in compensatory behaviours to attempt to alleviate their symptoms, primarily by reducing their exposure to motion through taking breaks outside their building and standing up and walking around. The physiological mechanisms by which walking around reduces symptoms of motion sickness is not clear.

While susceptible individuals were more likely to engage in compensatory behaviours, 15% of non-susceptible individuals also engaged in these behaviours suggesting that an annoyance factor might be present at lower levels of susceptibility. Assuming that these individuals did not work longer hours to offset this lost time, these behaviours reduce productive time. However, the quantity of lost time is not known. Other compensatory behaviours such as time spent engaging in non-work activities at respondents' desks were not measured. It is unlikely that individuals could retrospectively estimate how much time was spent on these strategies with any level of accuracy. Moreover, it would be almost impossible to estimate losses due to more subtle behaviours associated with low-dose motion sickness such as daydreaming. Only a longitudinal methodology would be able to measure any real differences across time and actual accelerations. These findings support Walton et al.'s (2011) prediction that individuals will attempt to actively manage their environment in an attempt to improve their comfort.

Symptoms of Low-dose of Motion Sickness

When asked to rate how tired occupants typically were after work (not in the context of building motion), individuals were significantly more likely to report higher levels of after work tiredness when they reported exposure to wind-induced building motion at least once a week. This effect was independent of susceptibility to motion sickness; therefore even non-susceptible individuals were more likely to report increased tiredness. This suggests that while the approximately half of respondents who reported no compensatory strategies to cope with building motion, they may be affected more subtlety by low-dose symptoms. This is supported by Graybiel and Knepton (1976) where all subjects were affected by Sopite Syndrome regardless of susceptibility to motion sickness. Difficulty concentrating, the most reported symptom of exposure to motion in this study, is a primary symptom of Sopite Syndrome. Again, a longitudinal method is required to provide further evidence.

People Habituate to Some Extent

Overall, respondents indicated a trend towards habituation to building motion over time. Habituation was independent of susceptibility to motion sickness and age, but males were more likely to habituate than females. Denoon et al. (2000) also found evidence of habituation from airport control tower workers who reported building motion became more acceptable over time. Despite an overall trend toward decreased effects of motion over time, a significant proportion of individuals indicated that the effects motion became worse over time, suggesting that habitation might not merely be the product of repeated exposure to motion.

Complaints are Rare

Complaints about wind-induced building motion were most frequently made to co-workers and family, by about a quarter of respondents. Only 3.8% of complaints reached the respondents' team leader, and fewer reached the organisation's CEO. No formal complaints were issued to a higher authority. This percentage is comparable to Burton (2006) who found that only 2.3% of respondents who had previously experienced wind-induced building motion made a formal complaint to their employer or the building owner. The results indicate that there is a general perception that little can be done to improve building motion. Throughout the engineering literature on building motion, there is a belief that complaint is a suitable metric for measuring building performance, for example, Isyumov and Kilpatrick (1996). At least in office buildings, it is clear that people almost never formally complain about building motion. Formal complaint should not be used as the primary metric to inform building performance.

Limitations

The main limitation of this study is that that the building accelerations and frequencies experienced by respondents are unknown. Wellington has relatively few tall buildings compared with larger cities and has a fairly unique wind climate, therefore the extent to which these findings generalise to other cities with different wind climates is not known.

Conclusions

Individuals are unable to avoid working in tall building, even if they are affected by motion sickness. Building motion is frequently perceptible by its occupants and induces motion related responses, and individuals actively manage this environment by engaging in compensatory behaviours to mitigate symptoms of motion sickness. Individual factors, particularly susceptibility to motion sickness, are important to measure when evaluating the occupant response to building motion. The effect of changes in building acceleration and exposure to motion need to be quantified systematically in a sample of real-world building occupants.

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