Real-world analysis of motion sickness sensitivity questionnaires for cases of tall building movement

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ABSTRACT: Within the research field of wind-induced tall building movement and occupant comfort there is a lack of naturalistic based study on the significant and potentially negative impact of motion sickness on occupants of wind-moved buildings. Recently a wealth of data has become available through a PHD students work of over 250 surveys that asked a ‘random’ selection of people in Hong Kong about their experience of wind-induced tall building movement.

This study will statistically analyse the resultant full-scale wind-induced tall building movement database (Hong Kong database) to investigate 1) what can be seen to affect the motion sickness cases reported by respondents within the data from the Hong Kong Database? And 2) what is the severity is of the motion sickness cases reported in the full-scale database?

This study has found that the reported cases of motion sickness within the population of the Hong Kong database range in severity depending on motion sickness sensitivity; number of symptoms suffered and the nausea rank of these symptoms. Additionally the study found that despite 13 different independent variables being tested, only 3 factors had a statistical association to the 3 motion sickness indicators; Gender, How often people complained and Acceptability.

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INTRODUCTION

Within the research field of wind-induced tall building movement and occupant comfort there is a lack of naturalistic based study on the potential impacts of motion sickness on occupants. Recently a database of over 266 surveys has become available through a PHD students work that has asked a ‘random’ selection of people in Hong Kong about their experience of wind-induced tall building movement.

This study will use this unique opportunity to investigate what can be seen to affect the motion sickness cases experienced by occupants and in a secondary aim, will address what the severity is of the motion sickness cases are as demonstrated by the full-scale database.

1. Motion Sickness and Tall buildings: Background Information

1.1. Motion Sickness

The problem of motion sickness is as old as transport itself. In fact most people suffer motion sickness at some stage in their lifetime, most as a child, and for some it is a lifelong affliction (Reason and Brand, 12). The problem with the diagnoses of motion sickness though is that there are many different circumstances in which it can occur depending on the person; “the theories concerning its aetiology are abound” (Reason and Brand, 217).

In 1975 Reason and Brand published a summary collection of the knowledge on motion sickness at the time. In the conclusive sections of the book the authors were able to come up with just one singular conclusion. Motion sickness as described by the literacy and philosophy covered in the book characterised motion sickness by its symptoms; “cold sweating, nausea, vomiting, distraction and lack of concentration and/a loss of balance” (Reason and Brand, 275). Years later this was echoed by a study by Yamada and Goto in 1972 who determined that individuals experiencing motion sickness may experience a wide range of symptoms including headaches, nausea, fatigue and disorientation (Yamada and Goto).

The cause, said Reason and Brand; “the sensory rearrangement when the pattern of inputs from the vestibular system, other proprioceptors and vision is at variance with the stored patterns derived from recent transactions with the spatial environment” (Reason and Brand, 275).
The effect of motion sickness on performance can be profound. While in some cases vibration has been shown to increase some activities of the brain above the performance levels of stationary environments (Shawood and Griffiths, 1983) the general effects of motion on performance occur when the motion reduces motivation, due to motion sickness, or increases fatigue, due to increased energy use (Burton, 2002). This is supported by the 1997 study by Griffin that describes how whole body vibration or extended periods of movement could affect the complex and specific mental processes, impeding performance.

Indeed the motion doesn’t need to be at a perceptible level to have an effect. Hansen et al’s 1973 study and Goto’s 1983 study shows effects on subject performance seen at imperceptible levels when experienced over long periods of time; the condition of motion sickness and its scale increasing over the duration of the movement.

1.2. Studies in wind-induced tall building movement and motion sickness

Instigated by Hansen et al’s studies (1973) there has been some extensive work and research done into how occupants perceive and are ‘disturbed’ (Hansen et al) by wind-moved buildings, the resultant of which is in an excellent breadth of knowledge that can be used to inform the reasons behind this study and its methodology.

Kenny C.S Kwok and Burton (2009) gives a succinct summary of these historical studies around wind-excited tall buildings and occupant’s perception of movement and vibration. The paper, titled ‘Perception of vibration and occupant comfort in wind-excited tall buildings’, breaks down historical studies done into 2 groups; Field experiments and/ surveys of building occupants and Motion simulator and shake table experiments.

Hansen et al’s study fits into the group of Field experiments and surveys and was the first to correlate occupant discomfort with the wind-induced vibrations and movement of 2 170m tall buildings. The research, described as a ‘Landmark study’ by Kwok et al, was able to identify, through occupant surveys of the two buildings after 2 major storms, that a significant proportion of the occupants were ‘disturbed’ by building vibrations (Kwok et al, 369). Its concluded that in recognising that people react to individual storms as single events and that it was appropriate to develop a -what Kwok et al refers to as ‘tentative’, building vibration criteria imposing a limit of 5mg rms building acceleration limit for occupant comfort (Kwok et al, 369).

Kwok et al’s historical review presents a number of studies that follow this line of thought and further investigate the issue of how occupants perceive and can be affected by wind-induced tall building movement. Goto’s 1983 study is one such example. It identified that in 5 tall buildings in Japan, after a typhoon, over 90% of occupants on floor 13 and above perceived building vibration and stated “they would never tolerate a similar level of vibration in the future or once in 10 years” (Kwok et al, 369). Lee’s 1983 study also demonstrated that people can perceive building vibration and movement with his case study of a lecture theatre in a ‘severe storm’ and that the movement perceived depended on position and location on the floor plate. This study of movement and how it is perceived has also been explored in Isyumov et al (1999, 2000a) and by Denoon (1991) and in the simulation tests by Khan and Parmelee (1971), Chen and Robertson (1972), Goto (1975), Irwin (1981), Irwin and Goto (1984) and Denoon (2001) with continued work to determine thresholds controlling how much motion is perceived.

Out of the 27 studies covered in Kwok et al’s historical review only Goto’s work, and Goto’s work with Irwin actually identifies motion sickness and nausea as an element linked to wind-induced tall building movement. Lees 1983 study even notes a case against motion sickness- as he makes particular note that “no cases of nausea or motion sickness were reported by any of those in the lecture theatre room where the case study was run” (Lee and Meijer, 31); although, it’s important to note the sample size of the population used is unclear in Lee’s report. Goto’s motion sickness supporting 1975 study was a series of simulator experiments on human test subjects specifically looking at the human response to wind-induced building movement environments. In simulating low frequency building vibration using frequencies 0.1 to 1 Hz and test amplitudes from 10-500mm as displacements Goto observed “varying degrees of exhibiting symptoms of motion sickness, difficulty walking a straight line and up and down stairs, and difficulties in performing manual tasks: tracing straight and square shapes, under simulated building vibration”. This is of considerable difference to Lee’s observations of no motion sickness symptoms at all.

However overall there is a lack of research that progresses onwards from how much people perceive building movement that has moved onto investigate of the issue of how it is affecting occupants’ wellbeing, especially in the field of naturalistic studies and full scale studies.

2. Introduction to Hong Kong survey database

The data collected from the Hong Kong Database was entered into a Microsoft Excel spread sheet to form the Hong Kong survey data base unfortunately when data from the surveys were being entered into this database; the data for
respondents who did not experience wind-induced building motion was not recorded beyond age, gender and motion sickness sensitivity. This is a significant loss of potential analytical data and means analysis of the dataset is restricted to using the data of the specific sample size left that experienced the wind-induced tall building movement. This restricts the investigation of this research, limiting it to draw conclusions that only compares motion sickness between different variables for those who had perceived wind-induced motion sickness, lessening the sample size from a potential 4218 to 266 (90%).

Summary analysis was conducted to assess the data available within this smaller (but still significant) sample size.

It was found that of the 266 people who perceived wind-induced tall building motion there was a slightly larger population of males than females (148:118 respectively) with a sample population age range of 16-74.

An analysis of the ‘Places’ where people had perceived the motion showed that predominately respondents were at Home when they felt the movement (69%) (See fig 2.1). The remaining portions were divided up between those who were at a Tourist Location (17%) (Tourist Location was unspecified), Office (14%) or at a Hotel (2%).

Note: Data for different ‘Place’ types was analysed together as a whole and then separately for both the main research questions to ensure trends and associations found did not differ according to Place.

Though the surveys were completed by people in Hong Kong’s Central Business District (CBD) not all people experienced the wind-induced tall building motion in Hong Kong’s CBD, indeed not all even experienced the motion in Hong Kong. 3 cases of wind-induced tall building movement were actually reported in building in Japan, Tokyo, 2 in Malaysia, and 1 case was reported in the USA, New York, Taiwan, New Zealand and Australia. In total 191 buildings were reported as buildings where wind-induced tall building motion had been perceived with 75 people not reporting which building they had been in.

The Hong Kong Survey asked the people who had perceived wind-induced tall building movement what the total number of storeys was of the building they had been in and what floor they were on at the time that they perceived the building’s movement. The distribution of these 2 variables can be seen in fig 2.2. 84% of buildings reported had a floor height between 16-40 stories and this majority is then reflected in the distribution of values given for floor where movement was felt with 86% of cases being reported in the same range.

From the ‘total number of stories of the building’ and the ‘floor where movement was felt’ data a position was calculated that gave each reported case’s proximity to the top floor. The proximity distribution (see fig below 2.3.) shows a trend whereby more respondents’ perceived wind-induced building motion as their proximity to the top of the building increases.
Respondents were also asked what physical position they were in; sitting, standing or lying down and what it was that alerted them to that movement. Of the responses 47% of people reported that they were Sitting when they perceived the movement, while 44% were Standing and 9% were Lying Down. The largest indicator of building movement was found to be feeling the movement through a ‘feeling’ in a Body Part. (See fig below 2.4.)

The duration of the ‘Events’ experienced was described by 4 response options: Less than a minute, 1-10 minutes, 10-30 minutes and lastly Longer than 30 minutes. 73% of respondents identified that the motion they had perceived lasted
for less than a minute while 16% identified events 1-10 minutes long, 5% perceived motion for 10-30 minutes and 6% said the event had lasted longer than 30 minutes.

Statistics for frequency of event(s) were hard to determine. Respondents were asked; ‘how often did you experience building motion caused by the wind?’ with possible responses limited to: everyday, once a week, once a month, once a year and during a typhoon. The total number of answers (598) indicates that respondents choose more than one answer for this question, and analysis showed that over half of respondents selected an answer that fit under another answer i.e. once a week and once a month. As a consequence there were a large number of invalid answers and so frequency of event(s) as a variable was disregarded for this study.

Of the 266 people that perceived wind-induced building motion 87 suffered from motion sickness symptoms (32.7%). Symptoms experienced ranged from nausea (unwell) to headaches, dizziness, difficulty concentrating, difficulty maintaining balance, being annoyed by the movement and symptoms of fear.

The most frequently reported symptom was fear (39%) (see fig 2.5); this is consistent with Mellissa Burton and Denoon’s findings that fear is a major factor in symptom of wind-induced tall building movement when perceived in full-scale studies (Mellissa Burton, 221 and Denoon 2000a, 30). The 2\textsuperscript{nd} most evident symptom is nausea (feeling unwell) followed by dizziness (see fig 2.5).

Almost all respondents gave a self-determined motion sickness sensitivity (2 who gave no answer to this question) ranked from ‘not at all’ to ‘very much so’. The distribution of the 266 sample size, see above, (fig 2.6), shows that ¾ of respondents said they weren’t susceptible to motion sickness at all, and indeed none of those who reported ‘not at all’ reported any motion sickness symptoms. 48 people (18%) then reported they were ‘moderately’ sensitive to motion sickness and 3% and 4% said they were ‘slightly’ and ‘very much’ sensitive respectively.

3. RESEARCH QUESTIONS

3.1 Research Question 1: What can be seen to affect the motion sickness cases experienced by occupants in wind-moved tall buildings?

Research question 1 statistically analyses what can be seen to affect the motion sickness cases experienced by occupants in wind-moved tall buildings using chi square to test for statistically significant relationships between the key motion sickness variables; 1) the number of motion sickness symptoms respondents reported to have suffered from, 2) the self-reported motion sickness sensitivity scores reported by respondents and 3) the severity of nausea (higher ranked symptoms) experienced by respondents and the key independent variables (or responses) in the survey:

1. Age
2. Gender
3. Whether the occupant had heard of wind-induced tall building movement and so was pre-conditioned
4. Height of floor where wind-induced tall building motion was felt
5. Total floor height of building where wind-induced tall building motion was felt
6. Proximity to the top floor of the building when movement was felt
7. Stimulus/ Duration of event
8. Physical position
Associations were initially calculated across the whole data set available for each variable that was to be tested; not split up according to „Place”. After this the same association tests were then run for each „Place” type to test if the statistical associations found differed from the results for the „whole data set” however „Hotel”, „Office” and „Tourist location” sample size was so small, with too many blank cells and gaps in data, that chi square results were unreliable (cell count less than 5 for greater than 50% of data, SPSS). „Home” data however had a substantial enough sample size to be individually tested -69% of total respondents’ perceived wind-induced building motion in their „Home”. This meant that association trends of the „whole data set” could only be checked against the „Home” filtered data; more data collection would needed to include „Office”, „Hotel” and „Tourist Location” Place types for this study.

Results of these chi square tests showed that only gender, how often people complained and acceptability variables had a statistically significant relationship to the number of respondents that reported the identified motion sickness factors.

In the chi square test of motion sickness sensitivity and gender produced a resultant chi square value of $x^2=0.02=<0.05$ indicating there was a statistically significant association between the two variables. Pearson’s R and Spearman’s correlation couldn’t be calculated as neither set of data for the variables was numeric. The standardised adjusted residuals however show that females were more likely to have higher motion sickness sensitivities than males with reported motion sickness sensitivities for females being consistently higher than expected as opposed to the expected values for males. Female sensitivity to motion sickness also increases as motion sickness sensitivity increases; shown in adjusted standardised residual trends.

According to Jokerst this female attributed greater sensitivity to motion sickness is to be expected. Jokerst tested the reliability of reports that females were more susceptible to motion sickness than males in 1999 and found that female subjects showed higher symptoms scores than males with „significant statistical differences between the genders” (Jokerst, 965). This same result is confirmed in studies by Park and Senqi and by Klosterhaffen et al.

When number of symptoms suffered was tested for statistical association to the variables it showed the same statistically significant relationship as motion sickness sensitivity to gender but with a chi square value of $x^2=0.043=<0.05$.

Chi square tests for the number of symptoms suffered and how often people complained showed a statistical association with a chi square value of $x^2=0.00=<0.05$. Pearson’s R and Spearman’s correlation confirmed this relationship with sig (2-tailed) values of 0.000 and 0.002 respectively. The strength of this statistical relationship however was weak with a Pearson's R of 0.276 and Spearman’s correlation of 0.190. This means that although there is a relationship between the variables it is not likely to be statistically significant as the variables are not strongly correlated.

The number of high ranked nausea symptoms factor for motion sickness only correlated to acceptability $x^2=0.038=<0.05$. The Pearson's R and spearman's correlation for the same variables showed negative values (Pearson’s R=-0.140 and Spearman’s correlation=-0.125) meaning that as the severity of the nausea increases (more high ranked nausea symptoms) the acceptability of the wind-induced tall building movement decreases. The correlation between the variables is again weak so doesn’t show any great statistically significant relationship between variables.

Wind-induced tall building movement studies suggest that cues should have an impact on motion sickness; so too should body positions, duration of event and frequency of event (this can’t be tested with the data in this study, see Section 2) (Studies: Bashor,R et al and Kwok et al) so to test results main variables were tested again; this time adjusted standardised residuals were used for every equation to see if there were any trends that the relationship and correlation tests had not shown.

As Broffit and Cortina suggest in their paper, chi square’s calculation ‘if crude’ (Broffit, 30) held true and no other associations between variables were found despite the additional statistical test; even when the data was filtered into just „Home” data the trends identified of gender, how often people complained and acceptability remained.

Chi square calculations were used to test the association between motion sickness sensitivity, number of symptoms suffered and rank of symptoms suffered; the 3 motions sickness factors.

All chi square tests done for this research question gave a chi square value less than $x^2=<0.05$ meaning that there was a statistical relationship between variables that was more than chance. Pearson’s R and Spearman’s Correlation were then used to assess the strength of the relationship and check the critical value of the chi square given (note: none of the variables for this research question needed to be grouped).
For the chi square of association between motion sickness sensitivity and number of symptoms the null hypothesis was tested that there was no significant difference between the category of motion sickness sensitivity and the frequency of symptoms. The resultant chi square value through SPSS was $X^2=0.00$ which was reflected in Pearson’s R and Spearman’s Correlation with sig (2-tailed) values of 0.00; a near perfect proof of association. Pearson’s R and Spearman’s correlation was 0.429 and 0.449 respectively, meaning that there is a relationship, but because the results are neither close to 0.00 nor to 1.00 the variable’s relationship is neither weak nor strong. The positive resultants though mean that as motion sickness sensitivity increase so too does the number of symptoms a person will experience. So a person with higher motion sickness sensitivity is more likely to suffer a greater amount of motion symptoms.

People with higher motion sickness sensitivities are also more likely to suffer more high ranked nausea symptoms; $X^2=0.00$ and Pearson’s R=0.5533 with a sig (2-tailed) of 0.00. Spearman’s correlation could not be calculated as both sets of data for the variables are ordinal.

Chi Square tests on people with high ranked nausea symptoms and number of symptoms showed a strong positive relationship between the variables. Chi square showed an association of $0.00=x^2$ while Pearson’s R=0.838 sig (2-tailed) of 0.00 and Spearman’s correlation calculated a slightly weaker (but still strong) relationship of 0.799 sig (2-tailed) of 0.00.

3.2 Research Question 2: What is the Severity of motion sickness that is experienced by person(s) as reported in the database?

Research question 2 looks at the motion sickness cases reported by those who experienced wind-induced tall building movement and analyses the magnitude of motion sickness cases in terms of 3 key factors: 1) the number of motion sickness symptoms respondents reported to have suffered from, 2) the range of self-reported motion sickness symptoms reported by respondents and 3) the severity of nausea (higher ranked symptoms) experienced by respondents.

As discussed in summary statistics 32.7% of those who perceived wind-induced tall building movement experienced motion sickness symptoms; of those 23% experienced high ranked nausea symptoms. High ranked nausea symptoms as defined by Reason and Brand identify vomiting at the worse extreme of the scale, with nausea (sore abdominal areas), headaches, cold sweating and dizziness while at the other end of the scale are symptoms like dry mouth, breaks in concentration, social withdrawal and drowsiness (Reason and Brand, 1975) offer less interruption in task performance and normal behaviour (Golding, 515). High ranked symptoms in the Hong Kong database are headaches, nausea (unwell, vomiting), dizziness and disturbance in balance. Of the 32.7% (87 people) that experienced symptoms 70% experienced the higher ranked symptoms (61 people) meaning that 3 out of 4 of people who experienced motion sickness symptoms experienced high ranked forms of nausea. Additionally 1 out of 4 people who experienced motion within this database felt high ranked nausea symptoms. This indicates a statistically significant portion of the population of this study would have had their normal activities disturbed by motion sickness attributed to wind-induced tall building movement.

CONCLUSIONS

The Hong Kong survey database covers a wide scope of information on people’s experience of wind-induced tall building movement.

This study has found that the reported cases of motion sickness within the population of the Hong Kong database range in severity depending on motion sickness sensitivity; number of symptoms suffered and the nausea rank of these symptoms.

87 people in the Hong Kong database experienced motion sickness symptoms; that’s 1 in 4 people of those who perceived the wind-induced tall building movement. The people experienced symptoms ranging from fear, annoyance and difficulty concentrating right through to symptoms of drowsiness, difficulty maintaining balance, dizziness, headaches and, at the most severe end of the scale, nausea of abdominal discomfort and vomiting. It was found through data analysis that 75% of the people who suffered motion sickness symptoms experienced the high nausea symptoms of dizziness, headaches and nausea-sore abdominal areas. This means that 24% (65 persons) of the people who perceived wind-induced tall building movement (266 people) would have likely been disturbed from normal task performance and behaviour (Golding, 2006).

In the data analysis of the 1st research question, despite a large number of variables being tested, only 3 factors were identified as associating to the 3 motion sickness indicators (only 1 of these factors associated was one of factors suggested by the background study). Gender was found to be associated with motion sickness sensitivity, this was the same relationship as suggested by the studies of Jokerst and Park and Senqi. Gender and How often people complained was found to be associated to the number of symptoms people suffered; though the relationship between number of symptoms and complaints was found to be statistically weak (Pearson’s R=0.279) adjusted standardised residuals...
revealed a trend whereby as the **number of symptoms** increased so too did the frequency of complaints. Finally, **Acceptability** was found to have an association with the severity of nausea experienced by people in the database (high ranked of nausea symptoms). The relationship was not statistically strong but identified a trend that when severity of nausea increase acceptability of the wind-induced tall building motion decreased.

The results of this paper show that motion sickness cases in wind-induced tall building movement are evident in a significant portion of the Hong Kong survey database responses. The severity of the motion sickness of a person was found to be related to a person's **motion sickness sensitivity** as, with increased sensitivity, a person is more likely to suffer from an increased **number of symptoms** and an increased number of **high ranked nausea symptoms**.

**REFERENCES**


