FULL-SCALE AND LABORATORY EXPERIMENTS TO DETERMINE THE EFFECTS OF WIND-INDUCED BUILDING MOTION ON COGNITIVE EFFICIENCY

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Abstract

A series of full-scale experiments was carried out to determine the effects, if any, of wind-induced building motion on cognitive efficiency. The experiments were firstly tried in Airport Control Towers using Air Traffic Controllers as the subjects. The cognitive tests were then used with volunteers in another flexible control tower. The results of these tests were inconclusive. A laboratory experiment has been designed to carry out the cognitive tests at higher amplitudes and under more controlled conditions.

Introduction

Current serviceability acceleration criteria[1] for wind-induced tall building motion are based solely on occupant comfort considerations. Should there be a measurable decrease in cognitive efficiency below serviceability acceleration levels in tall buildings, this has the potential to be a significant cost burden to commercial occupants of such buildings. This investigation is part of a larger project to develop new methods for the design of wind-sensitive buildings and to redefine serviceability accelerations.

The effects of building motion on cognitive performance have not been widely considered. Building Research Establishment in collaboration with psychologists from Plymouth Polytechnic attempted a basic study in the 1970s but this is the only readily accessible research in the field[2]. That study was limited by a lack of control of the subjects, sinusoidal motion only being applied to the test building by exciters, and the use of very basic psychological test techniques.

The investigation presented here utilises a computer based series of psychological tasks which subjects complete on multiple occasions under varying motion conditions. The tasks test levels of performance for a range of cognitive functions.

The Cognitive Tests

The cognitive tests utilised in this study were used with a computer based system developed by Cognitive Drug Research Ltd. (CDR). As suggested by the company name, the CDR system is most commonly used in the investigation of the effects of prescription drugs on cognitive performance. Each battery of tests took about 15 minutes to perform and involved a subject sitting in from of a computer terminal and responding as instructed by the program using 'yes' and 'no' buttons on the desk in front of them. Four training sessions were required to accustom the subjects to the tasks. The test sessions were then performed twelve times under various motion conditions.

The tasks performed were:

1. Simple Reaction Time - measures pure reaction time which is a measure of the subject's alertness, ability to concentrate and speed of reaction to an unexpected event.
2. Choice Reaction Time - measures the subject's reaction time together with the processing time required to identify a stimulus and select an appropriate response.
3. Word Recognition – measures the ability to store and retrieve verbal information, this being a measure of cued secondary memory retrieval.

4. Spatial Memory – measures the ability to keep spatial information in working memory, and can be used to obtain a powerful indicator of recognition.
5. Logical Reasoning – measures complex semantic processing.
6. Memory Scanning – measures the ability to hold information in short term memory and then retrieve it.
7. Number Vigilance – measures sustained vigilance.

The Airport Tower Experiments

The first location at which the CDR system was used was the Brisbane Airport Control Tower. A laptop computer installed with the CDR software was installed in the tower cab. Each of the thirty Air Traffic Controllers (ATCs) was given a pair of disks to use for recording test results. These disks were stored adjacent to the laptop computer. The intention was that the ATCs would complete the tasks in their own time over a period of a few months following installation of the computer. Eighteen months after installation, the computer and disks were removed from the tower for analysis. At this time, there were fifteen subjects' disks remaining. Of these fifteen subjects, only one had completed more than the four training sessions.

There are a number of lessons worth drawing from the approach used at Brisbane Airport Control Tower with regards to experimental design. Firstly, for this type of work to be successful, a regular on-site presence by the investigator is required to ensure that the subjects are aware of progress in the project. This presence is also used to hurry the rate of test completion along by applying friendly encouragement to the subjects. Secondly, a definite time-scale for completion of the tests must be given to the subjects with some incentive for them to participate and complete the testing. Thirdly, an appropriate time during the day should be identified for participation in the tests. The best time for this is probably during meal breaks as it is less likely that subjects would wish to arrive early at work or leave work late in order to participate.

The Brisbane Airport Control Tower project also suffered from other flaws. The fact that the subjects were unsupervised while conducting tasks meant that there was no possibility of identifying external factors which may have affected their performance in the tests, such as fatigue level or external distractions. As the computer was located in the tower cab, there would have been plenty of activity and potential distractions occurring around the subject being tested. As the tasks are largely based on response times, any such distractions are unacceptable. Furthermore, there was no control over the motion conditions during which the tests were performed. Due to the wind-induced response properties of the tower[3], it is unlikely that, having tests performed at random times, a significant percentage of the tests would have been performed during periods of perceptible motion. Combined with the fact that it is likely that any effect of motion on cognitive performance is a fairly small one, it is unlikely that the experimental approach adopted at Brisbane could have yielded reliable data.

Sydney Airport Control Tower is more wind sensitive than Brisbane Airport Control Tower[3], with perceptible motions during most fresh to strong winds. A different approach was adopted to CDR testing at Sydney. At Sydney Airport Control Tower, the testing was conducted during meal breaks in a room below the tower cab, where disturbances could be minimised. The testing was also conducted under the supervision of the investigator who recorded the date, time, time at work of the subject, the subject's perception of temperature and perception of any motion experienced during the testing. By this method, the investigator also had some degree of control over the range of motion conditions during which the tests were administered.

The main problem with completing the tests at Sydney Airport Control Tower was the difficulty of persuading the ATCs to perform the tests during the times the investigator was present. There were two reasons for this; firstly the stress of the job and secondly the extra training being undertaken by the ATCs at the time. Sydney Airport is Australia's busiest airport with flight paths often determined by noise, rather than operational, requirements. As a result, ATCs are often fairly tired and in need of a rest during meal breaks. They often did not wish to engage in computer based psychological testing during these periods, especially as these were often during windy periods when air traffic control can be even more stressful than the norm. Additionally, at the time of the tests, extensive computer based training was being undertaken in preparation for a new air traffic control system. This contributed to the lack of willingness to engage in the psychological testing on a regular basis. After the first four months of the CDR testing at Sydney Airport Control Tower, it was clear that, continuing the tests at the same rate, four to five years would be required to complete testing of twenty subjects. This part of the project was thus discontinued.

The POCC Experiment

The final full-scale experiments utilising the CDR system were conducted at the Port Operations and Communications Centre (POCC) in Sydney. This is a very well known wind-sensitive structure[4] with a first mode natural frequency of 0.39 Hz, located only 15 minutes from The University of Sydney. The POCC was instrumented with accelerometers and three computers installed with the CDR system were installed in the lift lobby of the tower. The computers were adjacent to each other and small stools were provided to seat the subjects. The use of stools was deliberate to encourage an alert posture during the testing.

Eight subjects from the Department of Civil Engineering, The University of Sydney completed a full set of sixteen test sessions in under three months. The volunteer subjects undertook the four training sessions at the University of Sydney, before participating in twelve test sessions at the POCC. The standard form of the tests at the POCC was to take three of the subjects from the University to the POCC during appropriate climatic conditions. While at the POCC, the subjects undertook three series of the tests with a fifteen minute break between each. Immediately following each series of tests, the subjects were taken individually into an adjoining room and asked for their perceptions of tower motion during the time the tests were being undertaken. The tests were undertaken during a range of motion conditions with combined r.m.s. accelerations from close to zero up to 2.2 milli-g (see Figure 1).

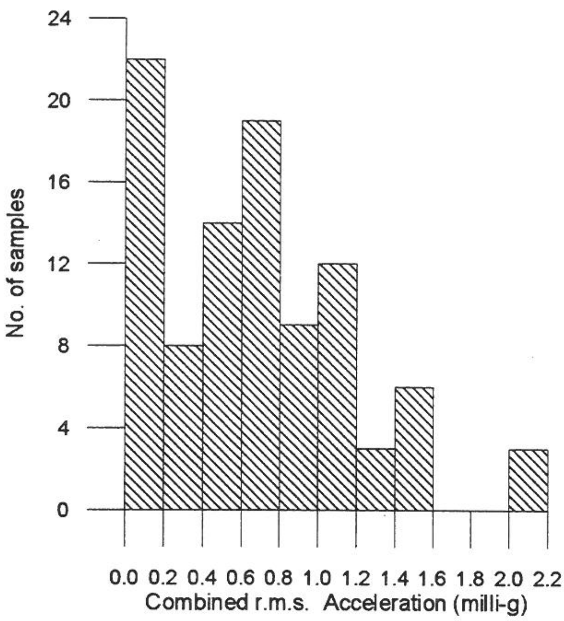

Figure 1 Acceleration Distribution at POCC During CDR Testing

The computers were installed in front of a small window to give an external visual reference but there were no other visual cues to motion. The only auditory cue to motion was wind noise. The primary cues to motion were, therefore, kinaesthetic.

Initial analysis of the test results have shown that the effects of motion on cognitive performance are small and outweighed by the effects of subject fatigue; subject fatigue, in this case, being measured by the number of hours worked by the subjects prior to commencing each test session. Further analysis is to take place shortly to remove the fatigue effects from the initial analysis. However, due to the small sample size, it may still not prove possible to definitively quantify the effects of building motion on various cognitive processes.

A Laboratory Motion Simulator

As can be seen, obtaining full-scale data on the effects of building motion on cognitive function is not practical on a moderate to large scale. The alternative is to carry out laboratory experiments using a motion simulator to simulate wind-induced building motion. To this end, a building motion test room has been equipped for use on the shake table at the National Facility for Dynamic Testing and Research.

The room is 3m by 3m and based on a normal site hut. The interior is equipped with six personal computers installed with the CDR software. Seating arrangements are similar to the POCC experiment with two lines of three subjects, seated back to back, on small stools. Air conditioning has been fitted to both provide a comfortable working temperature, and as a white noise generator, to mask the noise of the shake table hydraulics.

Initial tests will be conducted using an acceleration record from the POCC. This record will be scaled to the required r.m.s. acceleration. In later experiments, the same record may be used but also scaled in the time domain. The room will, however, still be instrumented with accelerometers to ensure the validity of the input data. The initial tests will investigate the effects of amplitude and subject orientation relative to the motion. Later tests will investigate frequency effects. Following each test, subjects will be removed from the simulator individually and surveyed on their perception of motion during the testing. It is intended to use subjects drawn largely from the structural engineering community. This will have the advantage for the volunteers that they will be able to experience the serviceability accelerations for which they are designing.

Conclusions

Full-scale experiments were carried out in three wind-sensitive control towers to determine the effects of building motion on cognitive efficiency. It was only possible to obtain reasonably reliable and extensive data at one of the locations. Results were obtained at this location only by taking volunteers to the site during appropriate wind conditions. Any effects of the motion on cognitive performance were masked by the larger fatigue effects. Further analysis is to take place to separate these effects. A laboratory test room has been constructed to simulate wind-induced building motion on a shake table.

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References

1. ISO 6897 – 1984 Guidelines for the evaluation of the response of occupants of fixed structures, especially buildings and off-shore structures, to low-frequency horizontal motion (0.063 to 1 Hz*)*, 1st edition, International Organization for Standardization, 1984.

2. Jeary, Morris and Tomlinson, Perception of vibration – tests in a tall building, *JWEIA, 29, 1988, pp.361-270.*

3. Denoon, Letchford, Kwok and Morrison. Wind-induced motion of two air traffic control towers and motion perception of their occupants, *to be presented at ASEC 98.*

4. Denoon and Kwok, Full-scale measurements of wind-induced response of an 84 m high concrete control tower, *JWEIA, 60, 1996, pp155-165.*