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Effects of Wind-Induced Tall Building Motion on Cognitive Performance

Research Report No R804

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ABSTRACT

Field and laboratory experiments were conducted to investigate the effects of wind-induced building motion on cognitive performance. This was done with particular reference to determining whether there was a decrement in the performance of air traffic controllers due to motion in air traffic control towers.

Field experiments were unsuccessful due to a lack of control of environmental factors. A laboratory motion simulator was designed and constructed. The laboratory experiments found no evidence of simulated wind-induced building motion affecting cognitive performance. Any effects which do exist are much smaller than inter- and intra-subject variability.

CONTENTS

1 INTRODUCTION

Most investigations into the acceptability of wind-induced building motion, and all design criteria to date, have concentrated on perception and tolerance of motion. A number of researchers, such as Goto (1975, 1990) and Irwin (1981, 1988) have investigated the effects of motion on task performance and walking ability. The amplitudes at which significant effects were found were well beyond the amplitudes considered acceptable for general occupation. Thus, as the effects of motion on manual performance occur only well above levels that impact on occupant comfort, these performance factors are not of interest for most normal structures. However, effects of motion on cognitive performance have not been investigated. It is easily envisaged that if wind-induced building motion in an office environment impacts on cognitive performance, it results in a loss of productivity to the tenant with consequent financial implications. Similarly, a cognitive performance deterioration in air traffic controllers during strong winds, which are some of the most stressful work times, could lead to a greater chance of errors being made.

This research report describes field and simulator experiments to measure the effects of wind-induced tall building motion on cognitive performance.

2 FIELD TEST LOCATIONS, MOTION SIMULATOR DESIGN AND THE CDR SOFTWARE PACKAGE

2.1 Brisbane Airport Control Tower

Brisbane Airport Control Tower (Fig. 1) is a 71 m high reinforced concrete control tower with an 18 faceted polygonal cross-section. The control level is located at a height of 63.2 m. The tower's first mode natural frequency of 0.54 Hz and first mode structural damping of around 0.5 % of critical damping were identified using forced excitation by synchronised human movement (Denoon, Letchford & Kwok 1997).

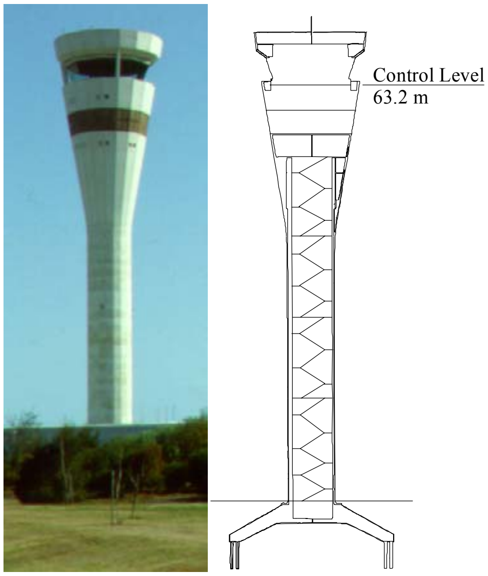


Fig. 1 Brisbane Airport Control Tower

The tower was instrumented with an orthogonally mounted (E-W & N-S or x & y) pair of accelerometers and a propeller-vane anemometer. The accelerometers were located in the crawl space directly below the floor of the control cabin. The accelerometers used were high output Lucas NAS-002G models and were connected to custom-built signal conditioners which amplified the signal and low-pass filtered the output with a cut-off frequency of 10 Hz. The accelerometers and data logging equipment are shown in Fig. 2.

Fig. 2 Accelerometers, signal conditioning and data logging equipment, Brisbane Airport Control Tower

Data logging and storage was carried out in a similar routine to that used by Denoon & Kwok (1996). Data was gathered by personal computer for 14 minutes and 50 seconds using a routine based on the VIEWDAC data acquisition package in combination with a Burr-Brown analogue to digital conversion board, reduced to summary information and then stored as summary information with raw data stored if acceleration or wind speed thresholds were exceeded.

2.2 Sydney Airport Control Tower

Sydney Airport Control Tower is a 43 m high composite concrete and steel structure of very unusual design, as shown in Fig. 3. The tower consists of a concrete core which is connected to the turret by a cylindrical steel section. A steel framed lift shaft is attached to the core. The structure is guyed in three directions by pairs of stays. One stay of each pair is connected directly to the turret while the other is connected to the top of the concrete section of the core. A further steel member connects these two attachment points. There is also a fire escape stairway which spirals from the turret to the ground, and connects to the core by way of a bridge at approximately mid-height between the ground and the turret.

The tower's first mode natural frequency of 0.95 Hz and first mode structural damping of around 0.75 % of critical damping were identified using forced excitation by synchronised human movement (Denoon et al. 1997).

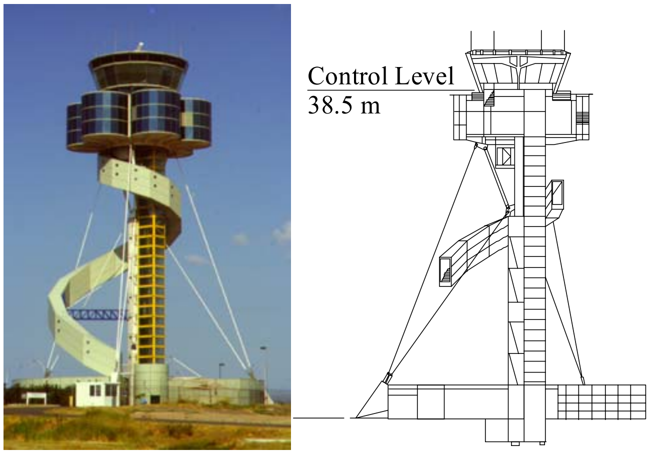


Fig. 3 Sydney Airport Control Tower

The tower was instrumented in a similar fashion to Brisbane Airport Control Tower but instead of a single pair of accelerometers and a single anemometer, two pairs of orthogonally mounted accelerometers and two anemometers were installed. The accelerometers were mounted below the false floor of the control level with one pair of accelerometers at the centre of the floor and one pair at the perimeter. This was to allow the detection of torsional components of the motion.

Data from the above instrumentation were analysed and stored in an almost identical manner to that used at Brisbane Airport Control Tower.

2.3 Port Operations and Communications Centre

The Port Operations and Communications Centre (POCC) is located close to the Sydney city centre on the eastern edge of Darling Harbour. The tower was opened in 1974 to control all shipping movements within the Port of Sydney. The tower consists of a 9.8 m diameter stainless steel clad turret mounted on top of a 4.9 m diameter reinforced concrete shaft. The space frame roof on the turret has a diameter of 14.7 m. The tower is illustrated in Fig. 4. The tower has a first mode natural frequency of 0.39 Hz and first mode structural damping ratio of around 0.8 % of critical damping (Denoon & Kwok 1996).

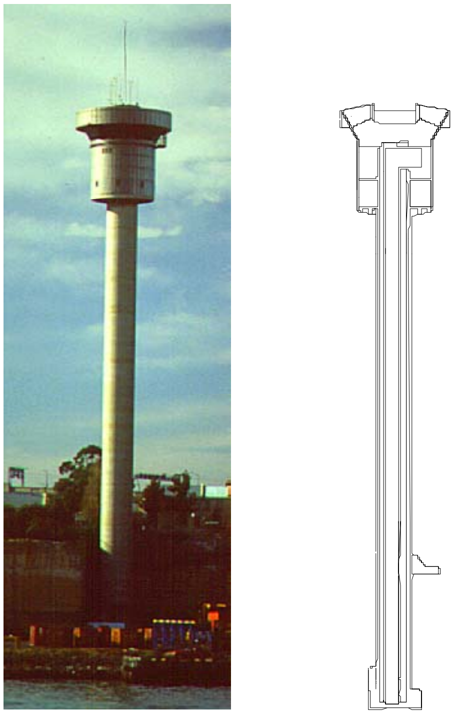


Fig. 4 The Port Operations and Communications Centre

The POCC was used for a field study of the effects of tall building motion on cognitive efficiency. For this, it was instrumented with a pair of orthogonally mounted accelerometers to measure horizontal accelerations. These were linked to a data logging computer using the data acquisition sequence described in Denoon & Kwok (1996). No measurements of wind speed were made for this project, although the tower had been the subject of a previous long-term investigation of its wind-induced dynamic response (Denoon 1994).

2.4 National Facility for Dynamic Testing and Research

A motion simulator was constructed by the University of Sydney for the purposes of investigating the effects of wind-induced building motion on cognitive performance. The simulator was necessary in order to be able to expose a large number of subjects to repeatable motion experiences. This simulator used the shake table at the National Facility for Dynamic Testing and Research as the driving mechanism. The following sections describe the design and capacities of this simulator, the exterior of which is shown in Fig. 5.

Fig. 5 The University of Sydney motion simulator

2.4.1 Simulation Requirements

Ideally, a building motion simulator should be able to reproduce not only a building's wind-induced motion, but also other factors relating to and affecting the perception of building motion. These factors might include aural, visual and postural environments encountered in the field. This, however, is an impossible 'wish list' and any laboratory simulation must necessarily contain some compromises whether as a result of practicality or available finances. The major requirements are discussed below in relation to the experiment reported here.

2.4.2 Motion Simulation

When tall buildings move in the wind, they move in one or more of three directions: along-wind, cross-wind and torsion. In a simulator, however, it is not these motions which are of interest but motions relative to the axes of the body. These may be thought of as fore-aft, transverse and yaw. In a building, away from the centre of rotation of the building, torsional motion is not felt as yaw by an occupant but is felt as either fore-aft or transverse or a combination of the two. For building motion perception purposes, a simulator should be able to reproduce fore-aft and transverse motions but it does not need to reproduce torsional motion. In the case of the experiments described here, where motion perception or discomfort is not a primary aim, a single degree of freedom simulator may be expected to produce the required effects on cognitive performance. It would be unlikely that dual-axis motion would produce an effect on cognitive function which was not produced by single axis motion. It may be conceded, however, that the magnitude of the effects may vary. As this was an initial investigation, and a single axis shake table was available, single axis motion was used for the experiments.

Wind-induced tall building motion is generally narrow band random motion with predominant frequencies at the natural frequencies of the building. Such a response is generally Gaussian in form, with a peak (or crest) factor of around 3.5. However, most simulator experiments in building motion research have used sinusoidal motion which has a peak factor of $\sqrt{2}$. This may potentially result in different responses being elicited from the subjects. Hence, the motion reproduced by the simulator should be similar to that experienced in the field. This may be achieved either by using field data directly or by using simulated data, as may be generated from an appropriate power spectrum.

For the experiments described in this thesis, data records from the POCC were used, being scaled appropriately to achieve the desired acceleration levels. Thus, all experiments were conducted using narrow band random excitation with a dominant natural frequency of 0.39 Hz.

2.4.3 Aural Environment

Aural cues in a building can significantly lower the threshold of perception of motion and significantly increase feelings of discomfort. Aural cues may include wind noise, lift cables slapping or structural creaking. As these cues may be specific to each environment, the simulator should, for most purposes, avoid providing aural cues to motion. The simulator environment should also, thus, be free of aural cues to movement from its driving mechanisms. The intensity or pitch of such noises is often related to the amplitude and/or frequency of the motion, thus significantly affecting any results gained under such conditions. The simulator may avoid such audible motion cues by sound insulation or provision of masking white noise or a combination of these.

Shake table noise was initially clearly audible in the University of Sydney simulator. To counter this, thick carpet with underlay was fitted and an air conditioner was installed. Following minor mistreatment of the air conditioner, shake table noise was adequately masked.

2.4.4 Visual Environment

As with aural cues, visual cues in a building have the potential to significantly lower the threshold of perception of motion and increase feelings of discomfort. Visual cues in a building may include swinging cables or lights, fluid surfaces moving or doors swinging to and fro. Views from windows are often cited as visual cues. Views will not provide a visual cue of translational motion but, due to the sensitivity of the eye to lateral movement, may provide a cue to torsional motion. This is the main reason that torsion is sometimes considered separately when designing for wind-induced motion in tall buildings. A simulator should be designed to allow the introduction or removal of visual cues.

All visual cues in the University of Sydney simulator were removed. The twin fluorescent light was firmly affixed to the ceiling. The window in the simulator was covered with opaque white paper. Cables from computers were bundled and taped either to the rear of the machines or to the desks.

2.4.5 Postural Environment

Posture has a significant effect on the perception of motion, and also on the performance of cognitive tasks. It is important in a simulator experiment to have a standardised seating arrangement which leads, as far as possible, to a uniform posture. This is generally best achieved by aiming for a fairly erect posture.

During the experiments described in this thesis, subjects sat on small foam topped stools while completing computer based tasks. The stools were 540 mm high including a foam squab depth of 40 mm. The computers were on desks which were 710 mm high. Subjects sat with their feet on the stool rails to reduce transmissibility of occasional high frequency vibration emanating from the shake table. The thick carpet and underlay also assisted in reducing the transmissibility of any high frequency vibrations. The response buttons for the testing sat on the front of the desks, with buttons pushed using either forefingers or thumbs, a consistent technique being encouraged. The seating arrangements are shown in Fig. 6.

Fig. 6 Stool, desk and computer arrangement in motion simulator

2.4.6 Other Environmental Factors

Other environmental factors which may influence perception of motion in the field include the length of exposure to the motion and comments on the motion from other inhabitants of the building. In a simulator experiment, length of exposure is easily regulated while subjects may either be tested individually or be forbidden to discuss the motion or make comments during testing.

2.4.7 Shake Table and Motion Record

The shake table at the National Facility for Dynamic Testing and Research is located at the University of Technology Sydney. It has a 3 m by 3 m platform and can handle test specimens of up to 10 tonnes. The shake table is shown in Fig. 7, with the control room behind. It is a single degree of freedom servo-hydraulic shake table.

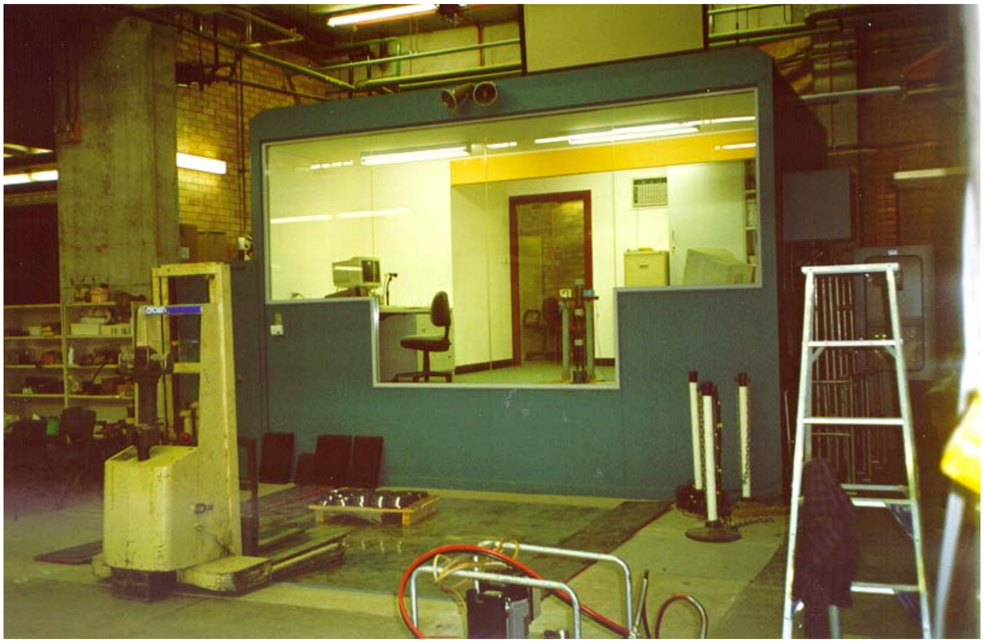


Fig. 7 Shake Table at the National Facility for Dynamic Testing and Research

2.5 THE CDR SOFTWARE

The cognitive tasks which were completed by the subjects were part of a computer based package developed by Cognitive Drug Research Ltd. (CDR). The package was supplied free of charge under a collaborative research agreement. The tasks were designed such that no knowledge of computers was required and all responses to tasks were made using ‘yes/no’ buttons which can be seen in Fig. 8.

Fig. 8 Test set-up as used at POCC showing computers, stools and response buttons

The tasks that were employed were as follows:

1. Simple reaction time – measures pure reaction time. This 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.

A full description of the task battery was given by Wesnes (1985) and a review of fifteen years of its use given by Ward and Wesnes (1999). It can be seen that the above range of tasks cover a wide spectrum of cognitive processes relevant to everyday work.

3 FIELD EXPERIMENTS TO MEASURE THE EFFECTS OF TALL BUILDING MOTION ON COGNITIVE PERFORMANCE

This section describes three field experiments using the CDR system. These took place (in chronological order) at Brisbane Airport Control Tower, Sydney Airport Control Tower and the Port Operations and Communications Centre in Sydney.

3.1 Brisbane Airport Control Tower

A laptop computer installed with the CDR software and response buttons was installed in Brisbane Airport Control Tower in late 1996. The computer was installed adjacent to the strip-writing desk behind the main console. 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, the disks of fifteen subjects remained. 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 (Denoon, Letchford & Kwok 2000), it is unlikely that, performing 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.

3.2 Sydney Airport Control Tower

A different approach was adopted to CDR testing at Sydney Airport Control Tower. Here, 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.

3.3 Port Operations & Communications Centre

The final full-scale experiments utilising the CDR system were conducted at the Port Operations and Communications Centre (POCC) in Sydney. 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 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. These perception surveys have been reported in Denoon, Roberts, Letchford & Kwok (2000). The tests were undertaken during a range of motion conditions with peak accelerations from close to zero up to 9.5 milli-g (see Fig. 9).

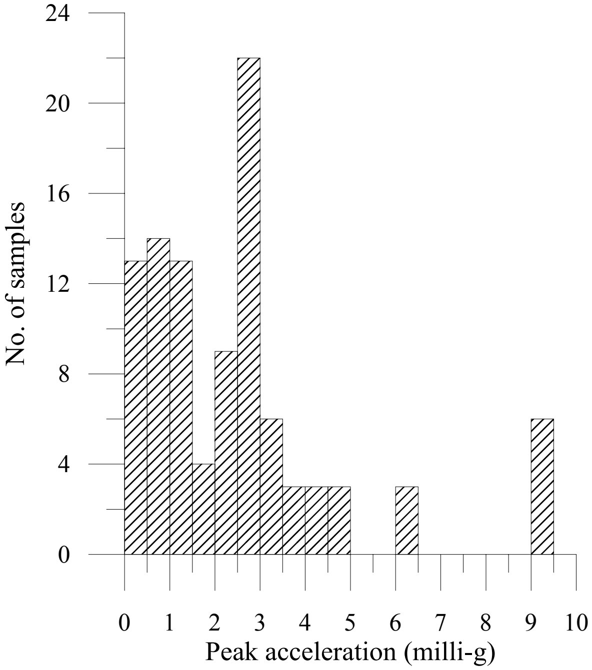


Fig. 9 Peak acceleration distribution during CDR testing at POCC

The computers were installed in front of a small window to give the opportunity for an external visual reference and there were no other visual cues to motion. In fact, it was apparent that visual detection of motion did not occur from the window view. From the test seating it was not possible to see anything other than sky from the window, and as the tower underwent only translational motion no motion cues were visible from other vantage points. The only auditory cue to motion was wind noise. The primary cues to motion were, therefore, kinaesthetic.

Analysis of the results showed very high variability: both inter- and intra-subject. These variabilities were unrelated to the motion. This is illustrated in Figs. 10 and 11, which show reaction times and accuracies in each of the tests versus peak accelerations. Each point on each of the graphs in Fig. 10 represents the mean reaction time for the specified task for each subject on each session at the POCC. Similarly, each point on each of the graphs in Fig. 11 represents the accuracy of responses for the specified task for each subject on each session at the POCC. The graphs do not include data from the first four training sessions which were used to familiarise the subjects with the system.

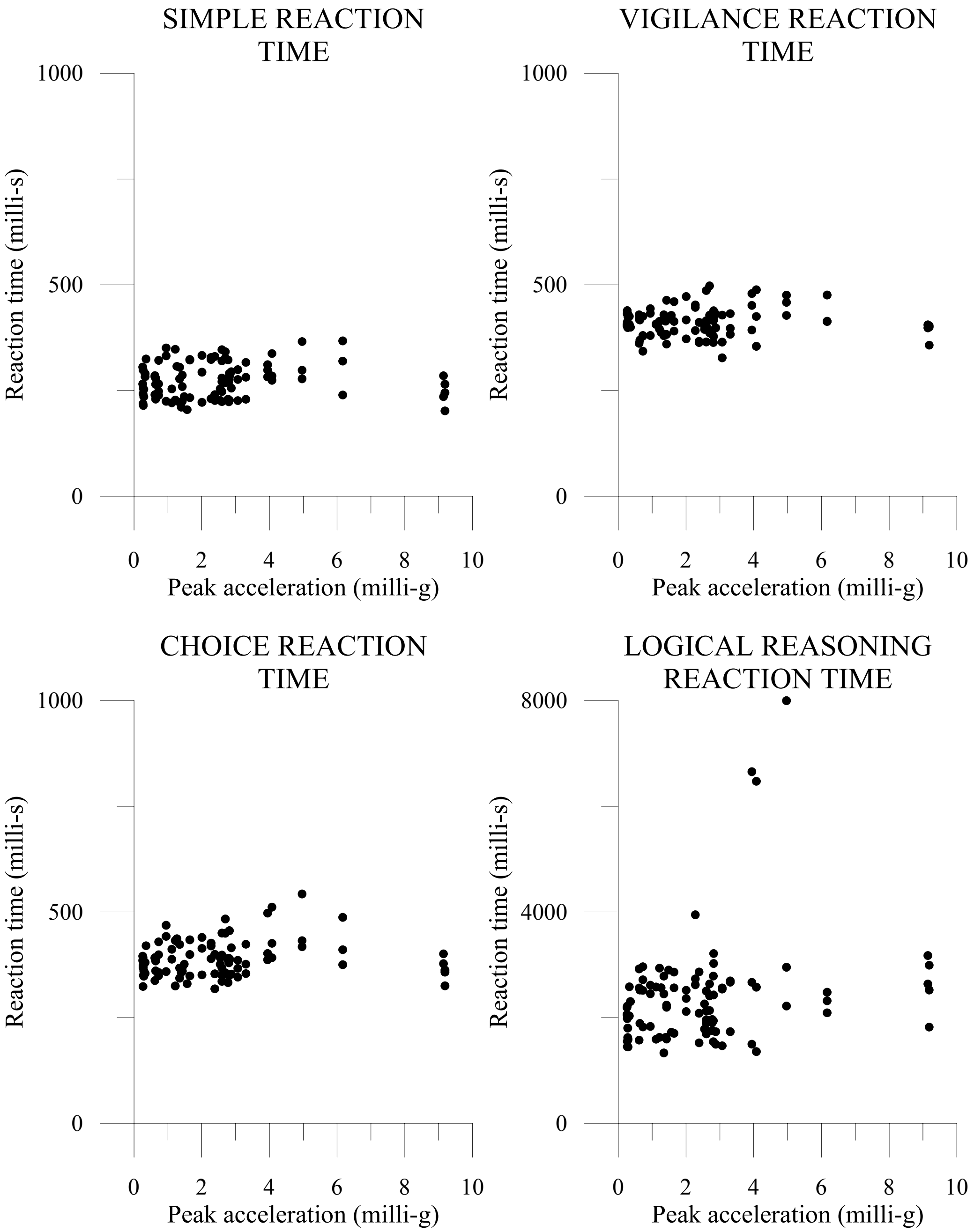


Fig. 10 Mean reaction times on CDR performance battery from POCC experiment

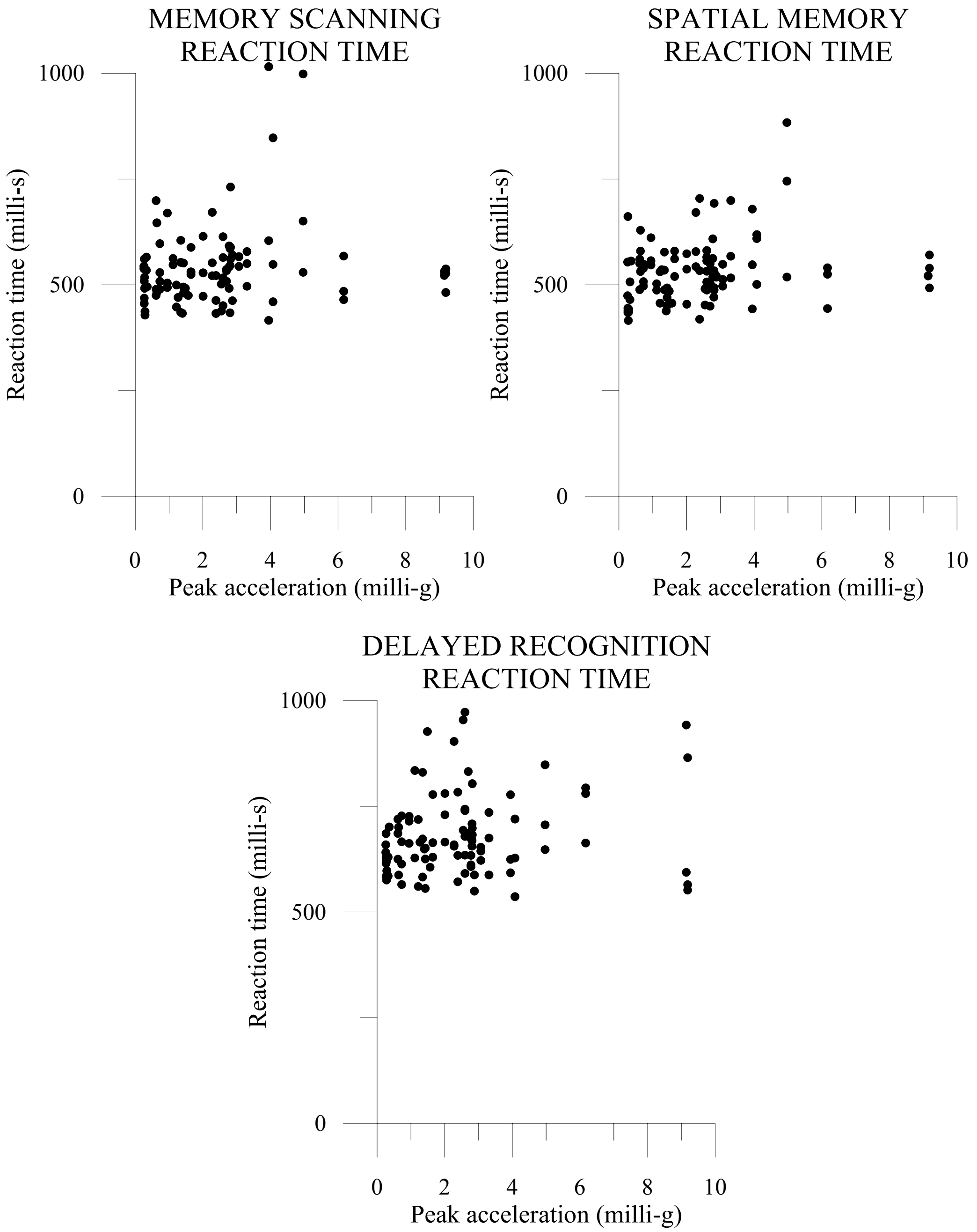


Fig. 10(cont.) Mean reaction times on CDR performance battery from POCC experiment

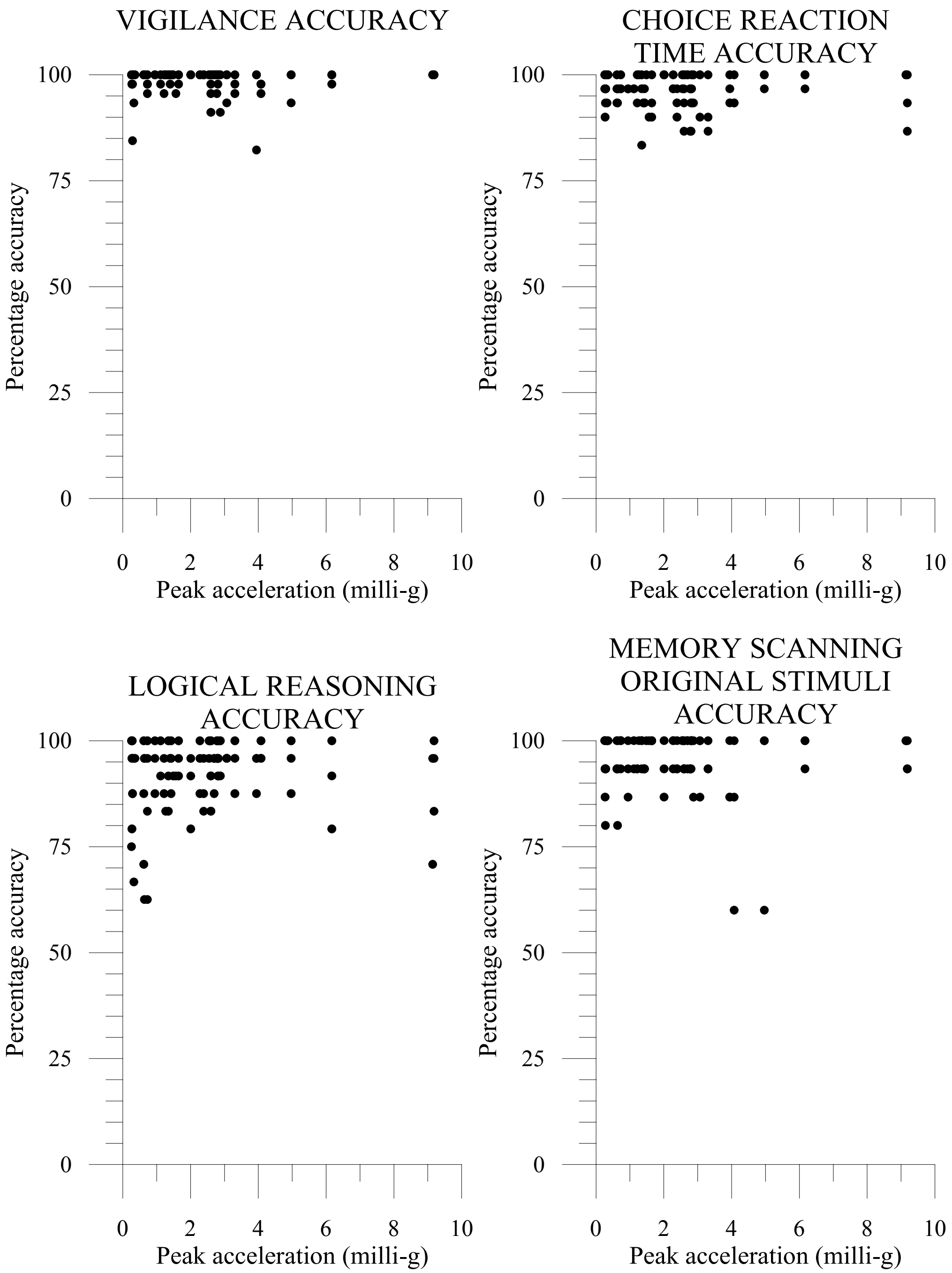


Fig. 11 Accuracies on CDR performance battery from POCC experiment

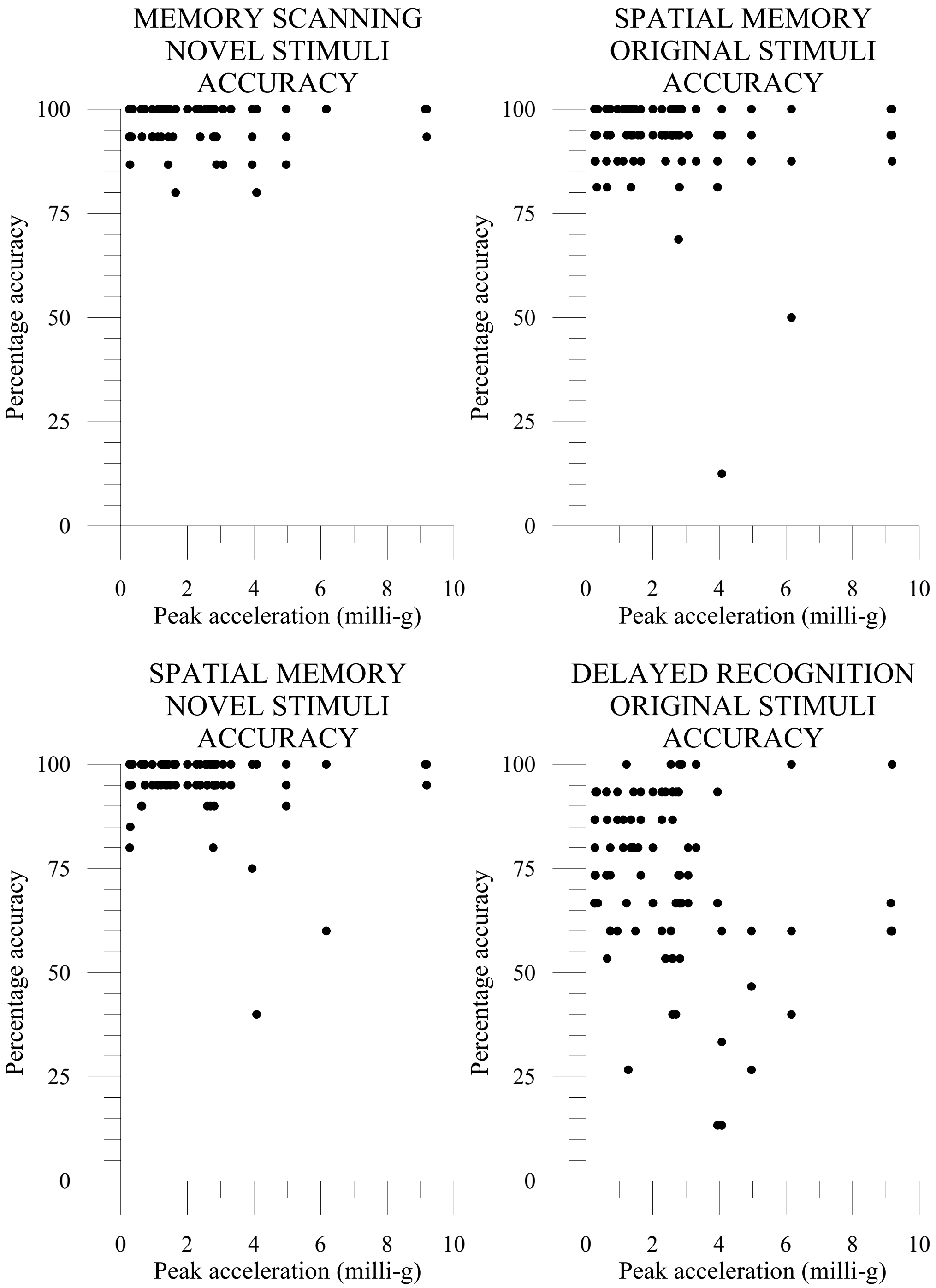


Fig. 11(cont.) Accuracies on CDR performance battery from POCC experiment

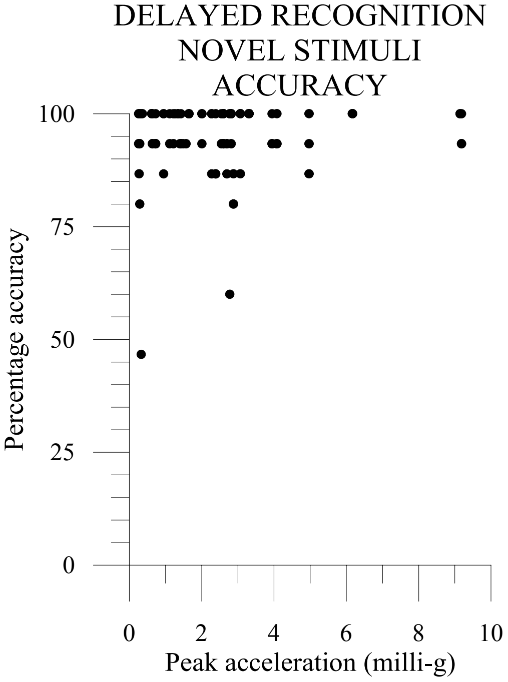


Fig. 11(cont.) Accuracies on CDR performance battery from POCC experiment

It can be seen from Fig. 10, that there are very wide variations in mean reaction times. Fig. 11 illustrates, by the number of results at the 100% ceiling of accuracy, that for the population sample used, reaction times are likely to provide the most sensitive measure of motion effects on cognitive performance. However, the wide scatter in the data demonstrates that for statistically reliable measures to be achieved, a much larger population sample would be required. In fact, analysis of the data from this experiment showed no significant correlations between amplitude of motion and any cognitive performance measure.

Due to the nature of this experiment, it would not be feasible to test a large population sample. The subjects used were required to be available at very short notice to leave work, be transported from work to the POCC and complete three CDR sessions. This was also dependent on wind conditions. To arrange a large population sample of this flexibility would be near impossible. This design of experiment also introduced a large number of uncontrolled variables such as subject fatigue, time of day and subject well-being. It was also not possible to control the tower motion or predict it well in advance, the decision to conduct testing being on the basis of observed wind conditions at the University of Sydney and the availability of the subjects. The experiment using 8 subjects took nearly 3 months to complete four visits to the tower for each subject.

3.3.1 Summary of field experiments

Three different experiments to measure the impact of wind-induced building motion on mental efficiency have been described. Two of the experiments yielded no useful data, while the third yielded only limited data. The primary restrictions on conducting this type of research in the field are the availability of subjects and the availability of a structure with sufficient and regular wind-induced motion to allow completion of the investigation in a timely manner. Both of these requirements are extremely difficult to fulfil, rendering this approach to the problem unviable. It thus becomes clear that the only viable approach to the problem is the utilisation of a controllable motion environment while limiting the participation of the subjects to well-defined and short periods of time. The following sections describe motion simulator experiments designed and conducted to overcome the limitations of the field experiments.

4 A SIMULATOR EXPERIMENT TO MEASURE THE EFFECTS OF WIND-INDUCED TALL BUILDING MOTION ON COGNITIVE PERFORMANCE

Due to the inability of the field experiments to measure effects of wind-induced tall building motion on cognitive performance, a simulator experiment was devised to conduct the research in a controlled fashion. The simulator has already been described in Section 2.4. The following sections will describe the test protocol and results from this experiment.

4.1.1 Test protocol

The simulator described in Section 2.4 was equipped with 6 identical computers installed with the CDR test battery. Furniture consisted of 6 desks and 6 stools. The layout of the test room is shown in Fig. 12 with all dimensions shown in millimetres.

18 subjects from the Department of Civil Engineering at the University of Sydney volunteered to take part in the testing. The volunteers were aged between 18 and 63 with a median age of 29. 17 volunteers were male and 1 was female. Subjects were provided with subject information statements (Appendix A) and were free to withdraw from the experiment at any time.

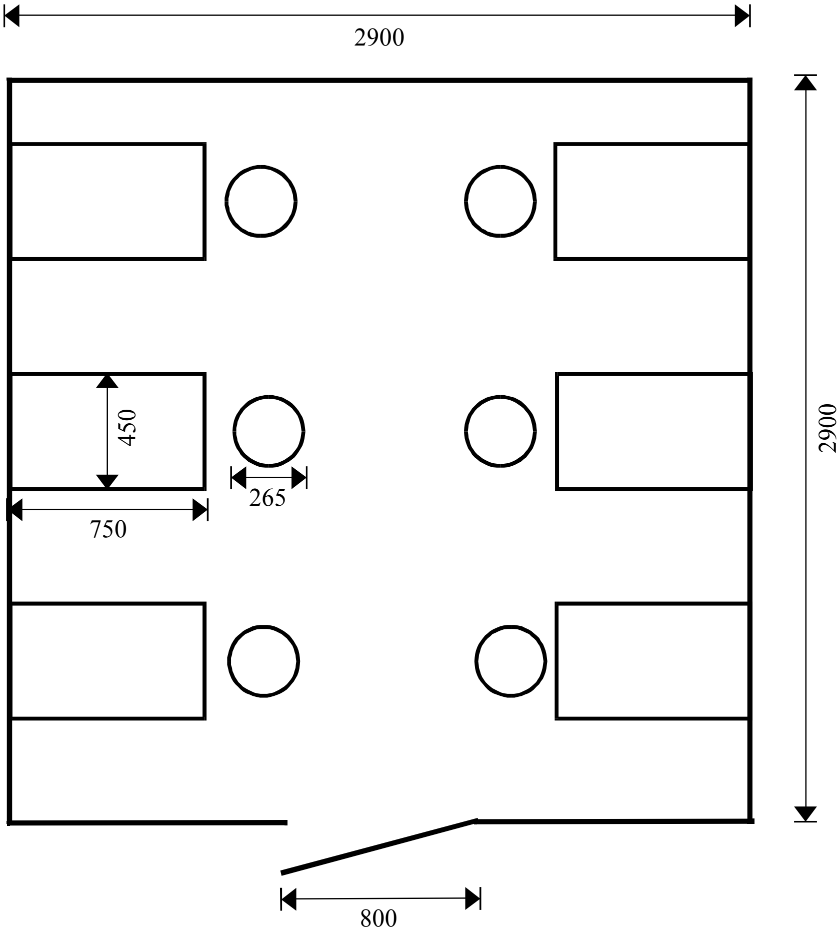


Fig. 12 Layout of test room for simulator experiment to determine the effects of wind-induced tall building motion on cognitive performance

Subjects each attended testing on 5 days. Each subject attended at the same time each day to minimise fatigue effects. At each visit, three test sessions were completed, with a 15 minute break between each session. Subjects were free to leave the test room during the breaks and light refreshments were provided. Caffeinated drinks were not available as refreshments and subjects were asked to avoid the consumption of such drinks for a couple of hours before testing. The test room was not vibrated during the breaks.

Two motion records were used to drive the simulator. One was a large amplitude motion with a standard deviation acceleration of 8.15 milli-g. and the other was a very small amplitude motion with a standard deviation acceleration of 0.66 milli-g. The current ISO6897-1984 serviceability acceleration criterion for 0.39 Hz and a return period of 5 years is approximately 3.9 milli-g. It can thus be seen that the large acceleration record used for testing was twice that which might occasionally be expected in tall buildings of a similar frequency. The small acceleration record was used instead of a no motion condition. This allowed any background noise from the system hydraulics to remain consistent across both amplitude levels. The small amplitude level was well below serviceability levels and much smaller than could reasonably be designed for in a tall building. Both drive records were derived from the same full-scale data record obtained from the POCC. The form of these data records are shown in Figs. 13 and 14.

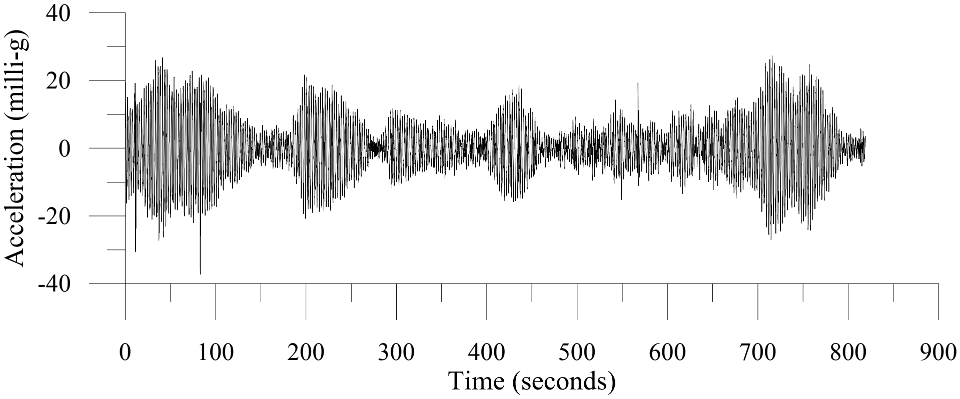


Fig. 13 Large motion data record used in first simulator experiment

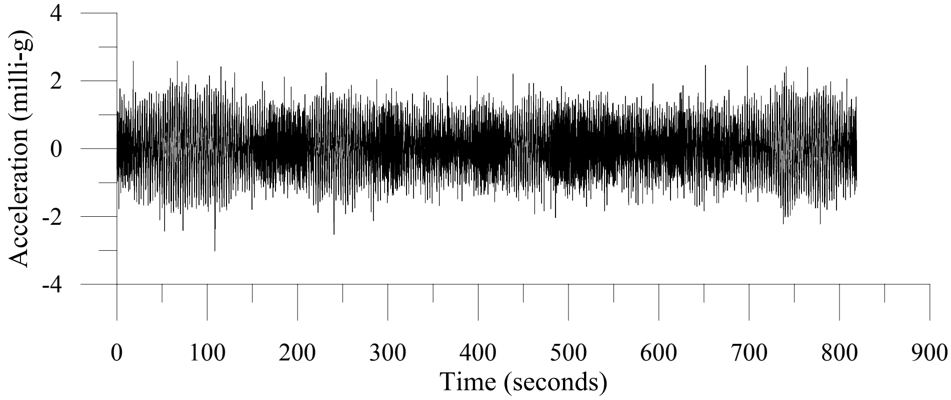


Fig. 14 Small motion data record used in first simulator experiment

A few spikes can be seen in the data records. These occurred due to the drive mechanism of the shake table. The shake table ran much more smoothly on displacement control than on acceleration feedback control. In order to run the table on displacement control, the acceleration record from the POCC was used as a displacement record. This approach was possible due to the nature of the vibration at the POCC with only one significant frequency contributing to the dynamic response. By closely band-pass filtering around this frequency, it was possible to use a scaled acceleration record as a drive record. However, the band-pass filtering software incorporated in the drive software for the shake table occasionally resulted in an excessively steep gradient in the record. It was not possible to remedy this in the time scale available for preparation of the tests and hence the occasional spike in the data record. However, for the purposes of investigating the effects of the motion on cognitive performance, the few spikes were relatively insignificant as the standard deviation of motion over the duration of the test battery was of more importance (Sherwood, 1992).

Test sessions were counterbalanced in the order of presentation of motion conditions as follows:

Day 1	Small – Large – Small
Day 2	Large – Small – Large
Day 3	Small – Large – Small
Day 4	Large – Small – Large
Day 5	Small – Large – Small

This was the case for all but 3 of the subjects who were absent for one day’s testing and had to do an extra session on a sixth day.

At the first test session, subjects were read the instructions in Appendix A. At this and all further test sessions, subjects completed a task and then sat quietly until instructed by the investigator to begin the next task. The reason for this approach was to minimise distraction from button clicks from other subjects engaged on different tasks which necessitated different rates of button pushing. Subjects were asked to sit with their feet on the stool rails in order to minimise transmission of some higher frequency vibration from the floor of the test room. Various shake table tunings and test room mounting configurations failed to minimise the transmission of this vibration to the investigator’s satisfaction.

Following completion of each test session, subjects were asked to fill in the questionnaire shown in Appendix A. This questionnaire was designed to closely mirror information gathered by means of push-button and survey data at Sydney and Brisbane Airport Control Towers and the POCC. It was also designed to investigate the validity of an approach to interviewing for prediction of motion acceptability used by previous investigators in the field of perception and acceptability of tall building motion (Hansen et al. 1973). It has already been shown by Denoon, Roberts, Letchford & Kwok (2000) that perception of motion is driven by peak accelerations, which in the simulator were caused by the spikes. The relationships between peak and standard deviation accelerations in determining comfort are less clear. As the simulator motion did not closely mimic the type of motion found in the field, the results of this survey were invalidated and are not presented.

4.1.2 Results

Of the 18 subjects who participated in the test programme, 16 completed the whole series of tests. Two subjects withdrew from the testing due to nausea resulting from the motion.

As discussed for the POCC project, reaction times on the tests are more reliable performance indicators than accuracies for the population sample used. The reaction times on each of the tests for each subject are shown in Fig. 15. Two points have been plotted for each subject: one for median performance under low motion conditions and one for median performance under high motion conditions. Median measures have been used to reduce the significance of any outliers on the aggregate data. The error bars represent +/- one standard deviation of the six data points from which each median values is derived. The thicker error bars are related to the high motion data points.

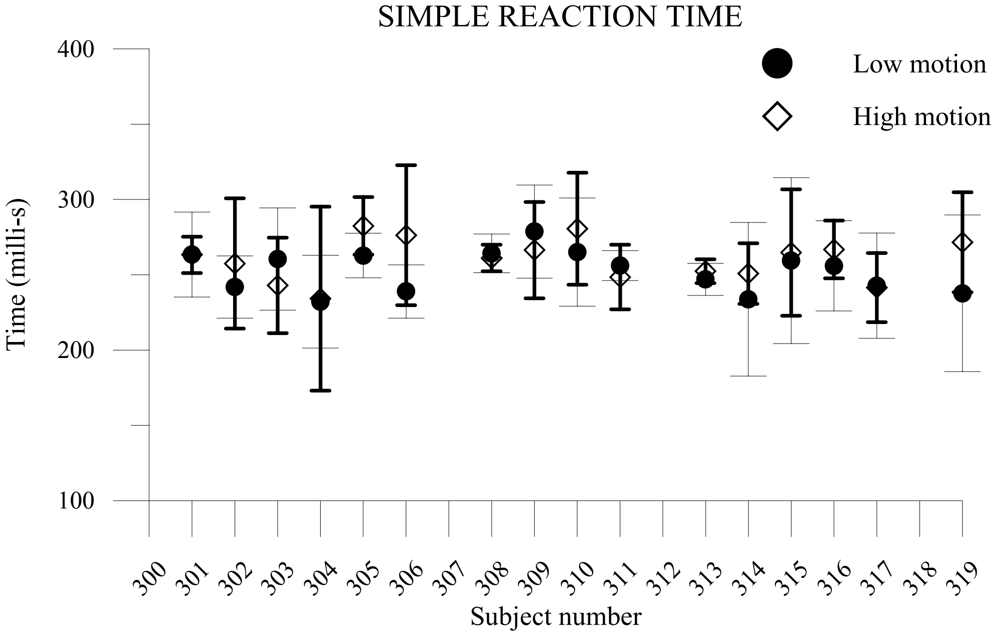
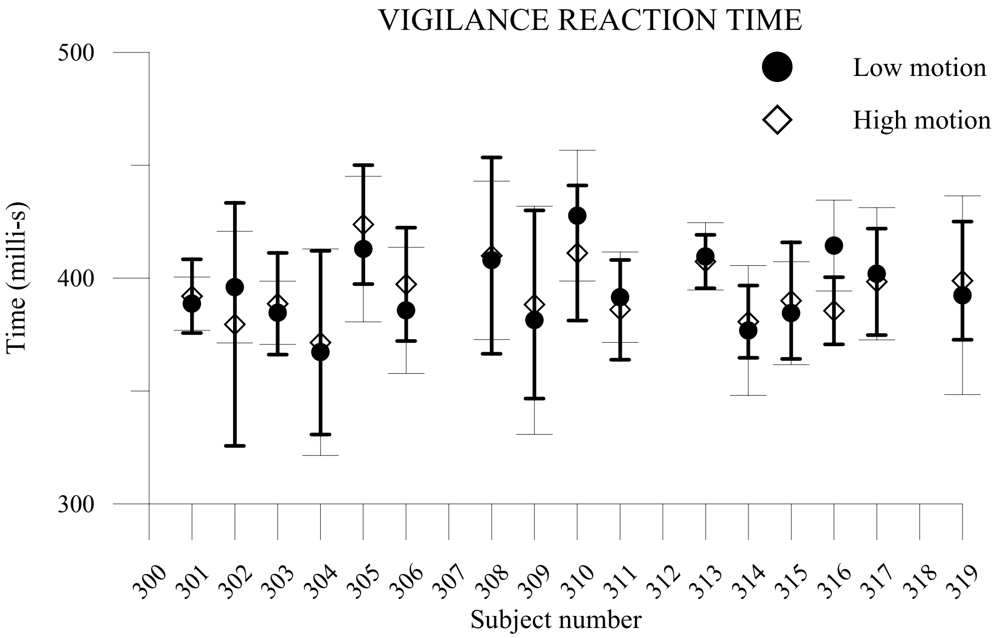


Fig. 15 Median responses for each subject under low and high motion conditions for each test in CDR performance battery



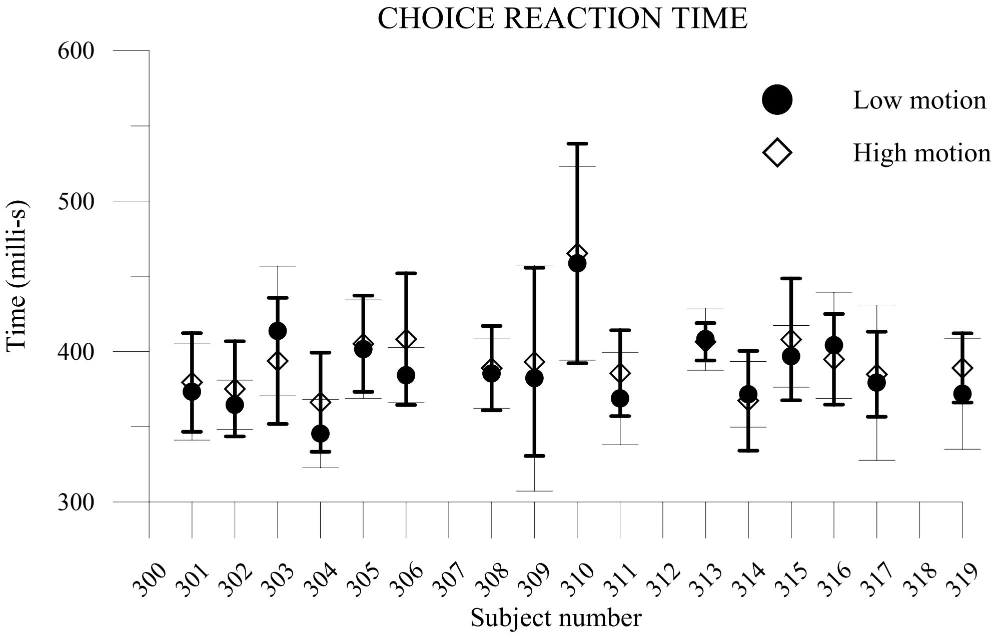
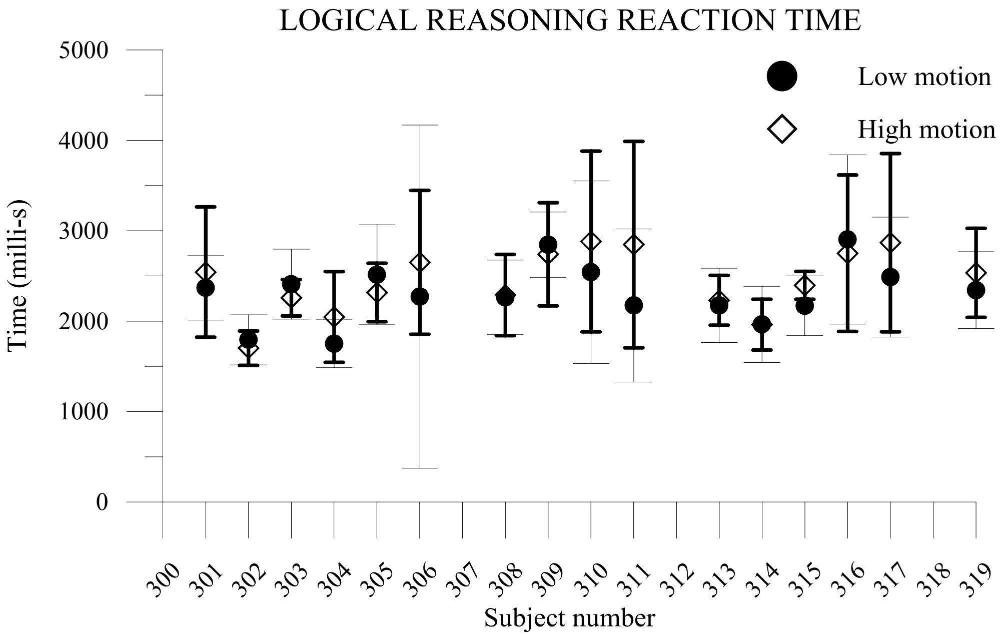


Fig. 15(cont.) Median responses for each subject under low and high motion conditions for each test in CDR performance battery



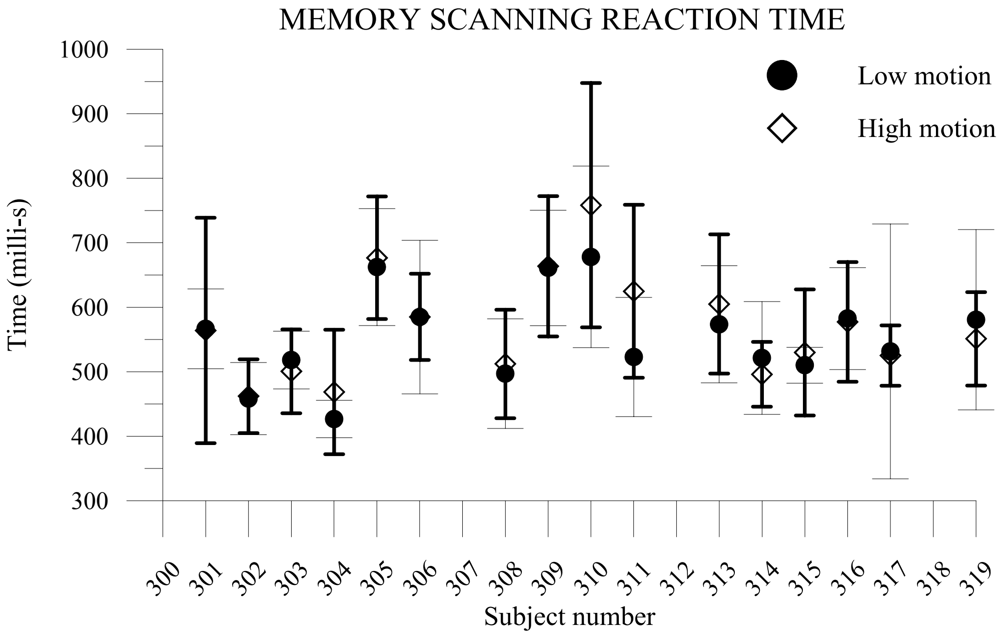
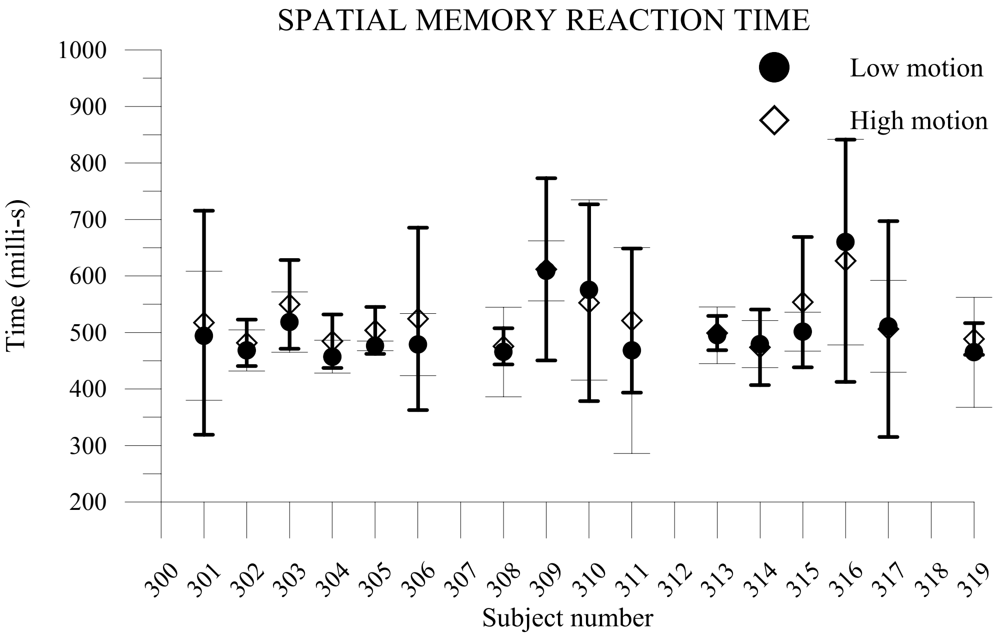


Fig. 15(cont.) Median responses for each subject under low and high motion conditions for each test in CDR performance battery



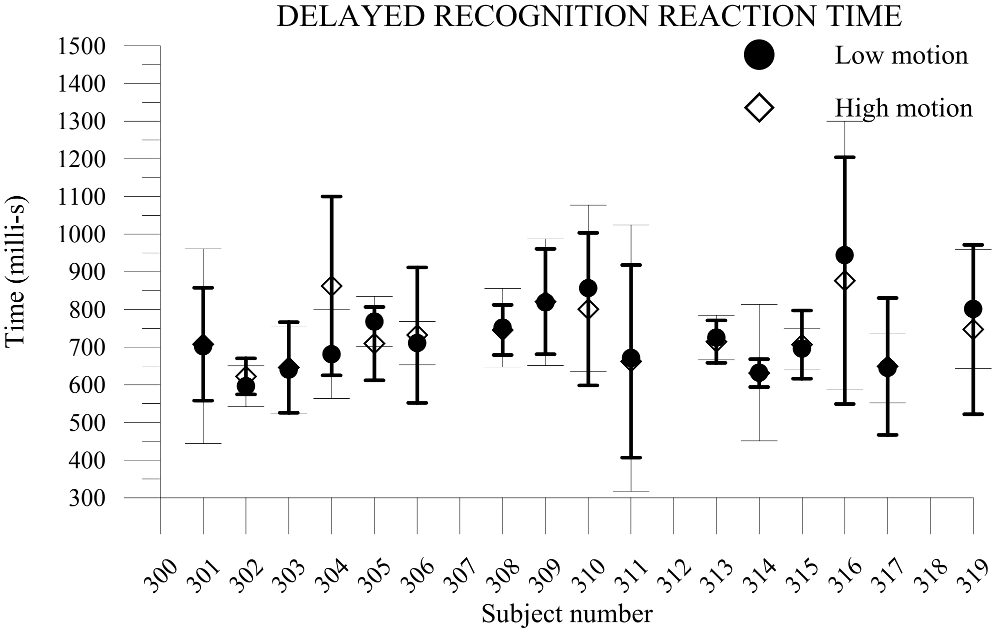


Fig. 15(cont.) Median responses for each subject under low and high motion conditions for each test in CDR performance battery

A number of trends are apparent in the data presented in Fig. 15. Firstly, it can be seen that there is significant inter-subject variability on each of the tests. Secondly, the differences between performance on the tasks under high and low motion conditions is generally very small. The effect of the motion on performance is irregular with a near equal distribution between apparent performance improvements and performance deteriorations. Finally, the standard deviation of each of the subjects' responses can be seen to be several times the apparent performance change. These three factors in combination would intuitively suggest that no real performance change was measured as a result of the motion.

The mean results of each test under motion and no motion conditions were investigated by *t*-tests, the results of which are presented in Appendix B. These tests returned no significant *t*-statistics, indicating no statistically significant difference between the mean performances of each test under motion and no motion conditions.

5 A SIMULATOR EXPERIMENT TO MEASURE THE EFFECTS OF WIND-INDUCED TALL BUILDING MOTION ON COGNITIVE FATIGUE

Having determined that motion has no measurable immediate effects on cognitive performance it was decided to investigate one other area of interest to the building designer: does building motion affect cognitive fatigue over the course of prolonged exposure?

5.1.1 Test protocol

The test procedure was to subject volunteers to 8 hours of continuous motion, the volunteers performing the CDR test battery once every 45 minutes. The performance of these volunteers was then compared with that of an equally sized control group who completed the tasks in the same environment but under no motion conditions.

The simulator described in Section 2.4 was equipped with 2 identical computers installed with the CDR test battery. Furniture consisted of 2 computer desks, 2 stools, 2 normal desks, an office chair, 2 easy chairs, a coffee table and a television and video. The layout of the test room is shown in Fig. 16 with all dimensions shown in millimetres.

Thirty subjects from the Department of Civil Engineering, The University of Sydney volunteered to take part in the testing. The volunteers were aged between 19 and 74 with a median age of 30. 27 volunteers were male and 3 were female. Subjects were provided with subject information statements (Appendix C) and were free to withdraw from the experiment at any time.

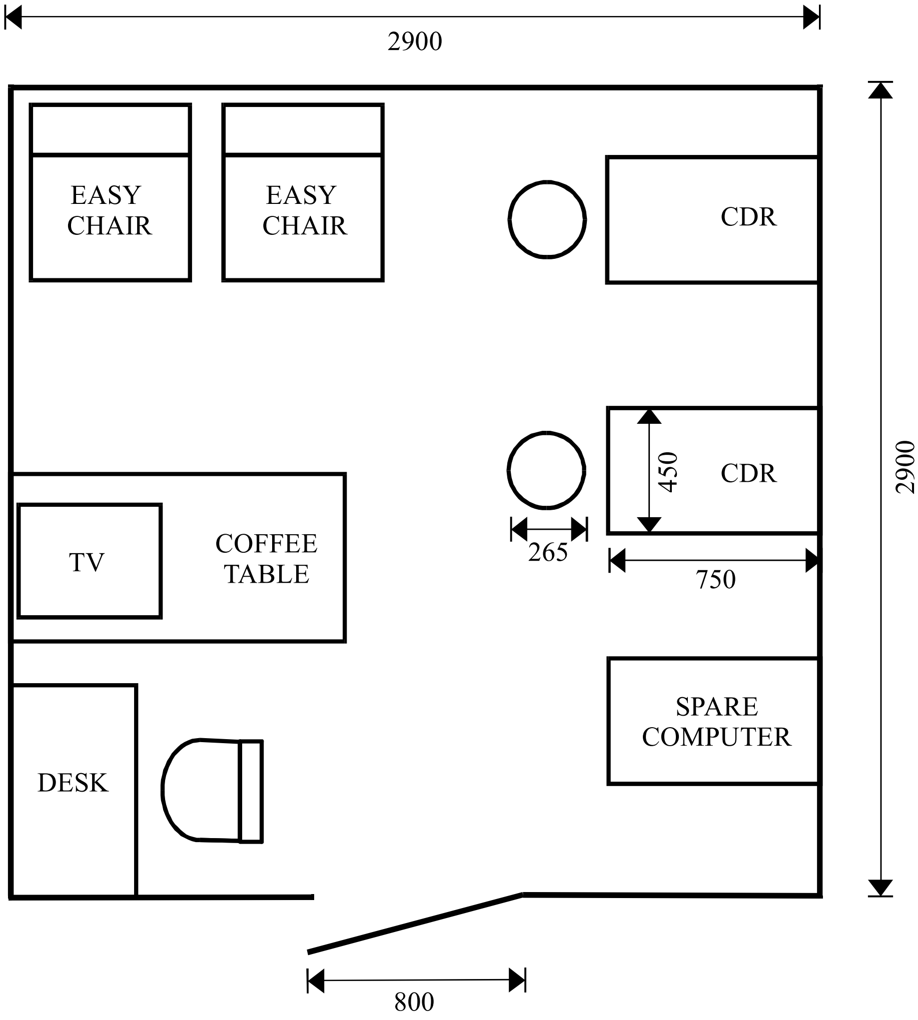


Fig. 16 Layout of test room for simulator experiment to determine the effects of wind-induced tall building motion on cognitive fatigue

Two volunteers entered the simulator at 0900 on each of the test mornings, and immediately started by completing a test battery. The volunteers remained there, completing a test battery every 45 minutes, until 11 such test batteries had been completed. During the time between test batteries, subjects were free to read, watch television or work as they desired. Food and refreshments were provided on request throughout the day, although alcoholic and caffeinated drinks were not permitted. Subjects were free to leave the test room to visit the bathroom. Simulator motion was shielded from subjects returning from the bathroom by use of screens, with subjects instructed to focus on the middle of the door as they approached the simulator. This minimised any visual cues to the simulator motion.

The motion record which was used on this occasion avoided the spikes previously encountered by removing portions of the record which were found to cause 'jerks' in the shale table motion. The response characteristics inside the test room are shown in Fig. 17. The record had a peak acceleration of 27 milli-g and a standard deviation acceleration of 8.7 milli-g. On those days when the control group was being tested under no motion conditions, the simulator room was jacked up above the shake table, and the same motion record run on the table below. This ensured that the acoustic environment was almost identical. These adjustments to the drive record and motion protocol were made on the basis of experience gained in the previous simulator experiment.

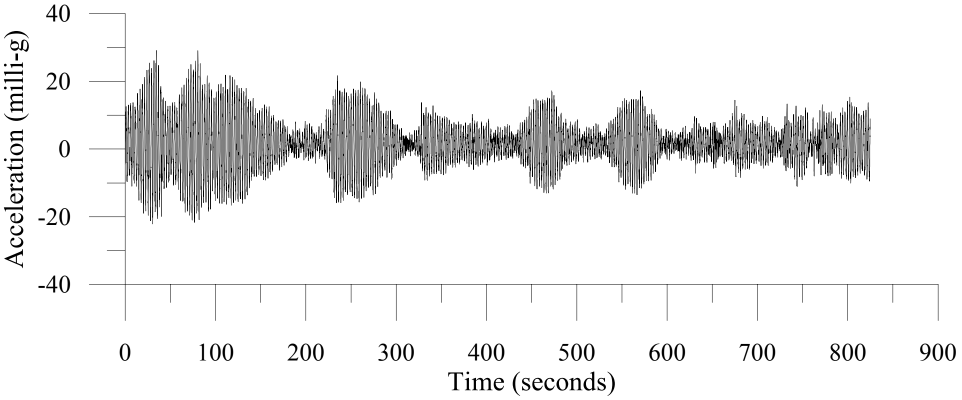


Fig. 17 Motion response of simulator during cognitive fatigue experiments

5.1.2 Results

Results of mean performances on each of the tests of the ‘motion’ and ‘no motion’ groups are presented in Figs. 18 - 27 for reaction times and accuracies.

Reaction times from the simple reaction time test are shown in Fig. 18. It can be seen that both groups show a performance deterioration during the day. As this occurs in both groups, this is not a motion effect but due to general cognitive fatigue or boredom. In both groups, there was a performance increase in the last test battery of the day, demonstrating extra effort just before ‘release’ from the test room.

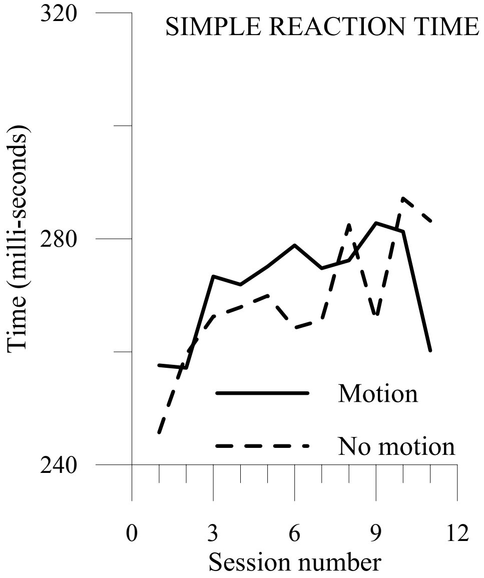


Fig. 18 Mean performances on simple reaction time task during cognitive fatigue simulator experiment

Performances on the vigilance test are shown in Fig. 19. As for simple reaction time, reaction time performance is similar for both motion and no motion groups, with a performance deterioration with increasing session number. There is a difference between the accuracy performance of the two groups, with better performance by the group undergoing motion. The difference is, however, small and may be distorted as a result of the very high performance accuracies where many subjects were performing to the 100% ceiling. This, again, is a criticism of the test battery used: the test battery was too simple for the population sample tested.

Performances on the choice reaction time task are shown in Fig. 20. Performances are similar between the groups on both reaction times and accuracies. Reaction times are seen to increase with increasing session number, but accuracies, although variable, show no discernible trend with increasing time.

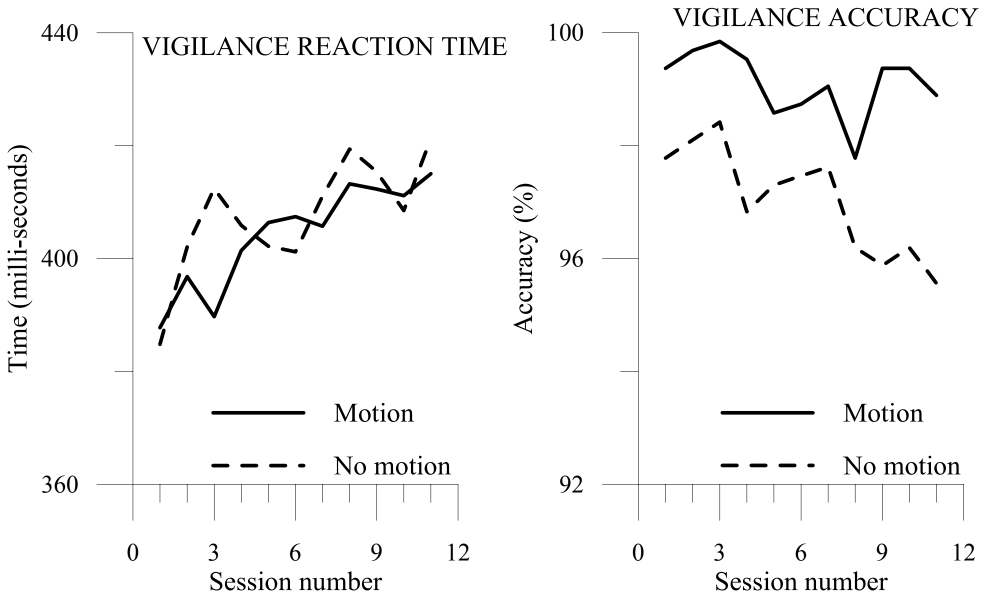


Fig. 19 Mean performances on vigilance task during cognitive fatigue simulator experiment

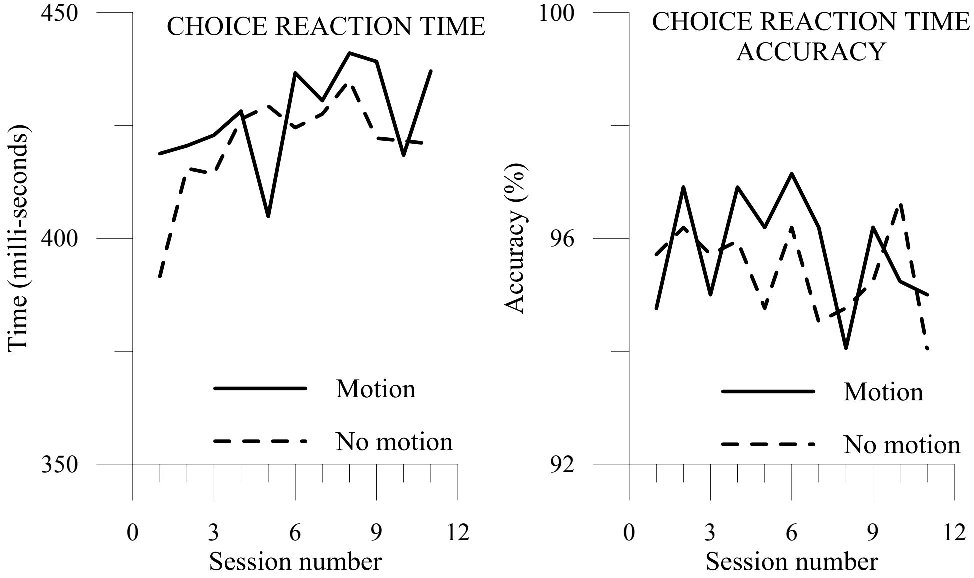


Fig. 20 Mean performances on choice reaction time task during cognitive fatigue simulator experiment

Mean performances on the logical reasoning task are shown in Fig. 21. The reaction time results on this task differ from the previous tasks in that performance improves with session number. This is evidence of a significant practice effect. This practice effect may also explain the apparent difference between the motion and no motion groups. Due to staffing constraints at the shake table, it was decided to run all the motion condition tests first. When volunteers were recruited for the testing, the first volunteers approached were those who had taken part in previous tests. Hence, the motion group had more experience of the test battery than the no motion group, thus explaining their apparently superior performance on this task. This hypothesis is supported by the fact that in the previous series of simulator tests, in which direct effect of motion on cognitive performance were investigated, no differences in the reaction times on this task were found between motion and no motion conditions. There is no discernible difference in the logical reasoning accuracies.

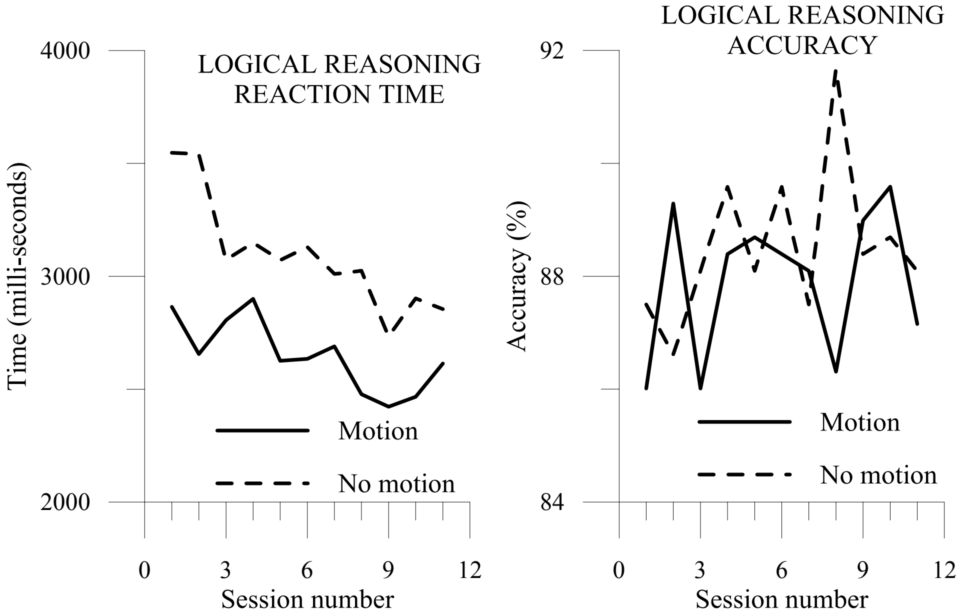


Fig. 21 Mean performances on logical reasoning task during cognitive fatigue simulator experiment

Mean performances on the working memory task show no apparent differences between the motion and no motion subject groups, as shown for both original and novel stimuli in Figs. 22 and 23.

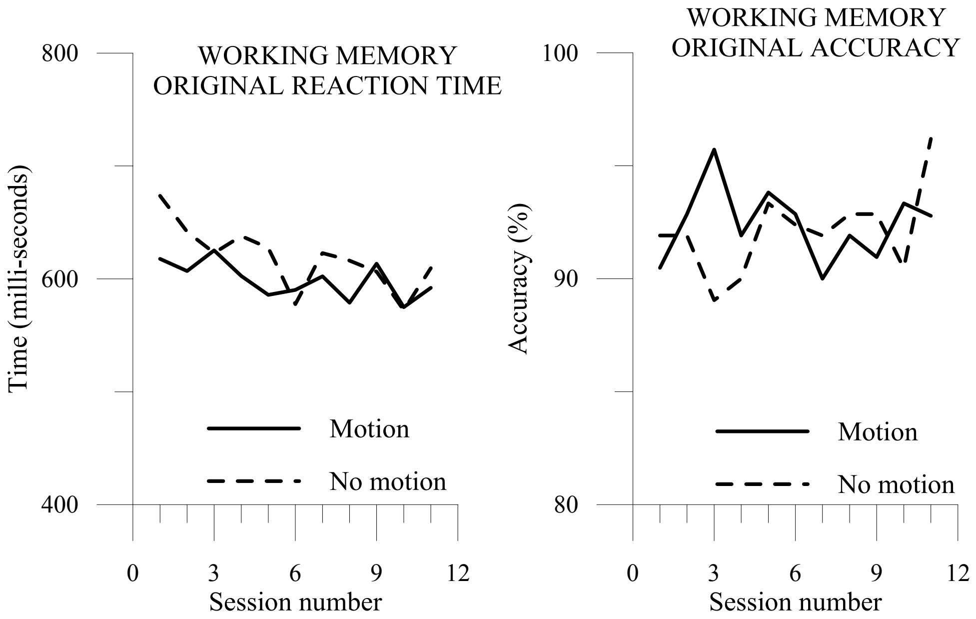


Fig. 22 Mean performances on working memory task during cognitive fatigue simulator experiment – original stimuli

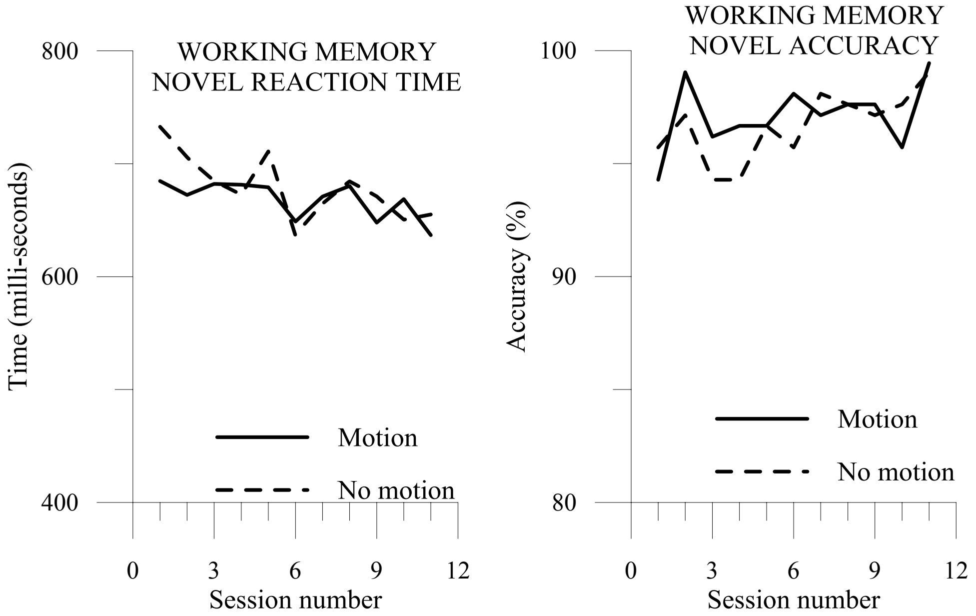


Fig. 23 Mean performances on working memory task during cognitive fatigue simulator experiment – novel stimuli

Mean performances on the spatial memory task, for both original and novel stimuli, are shown in Figs. 24 and 25. There are no obvious differences between the performances of motion and no motion groups for original or novel stimuli.

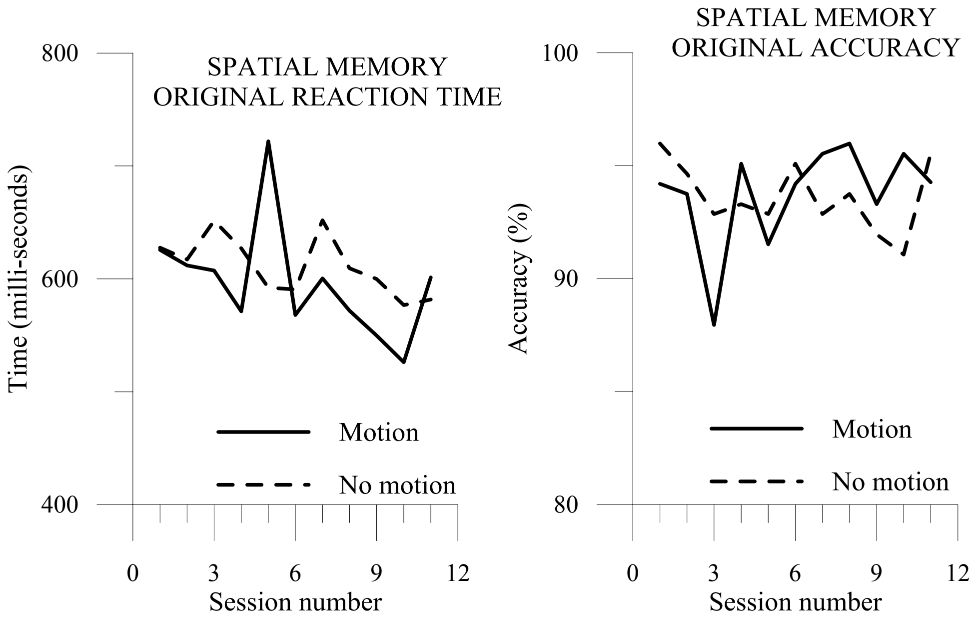


Fig. 24 Mean performances on spatial memory task during cognitive fatigue simulator experiment – original stimuli

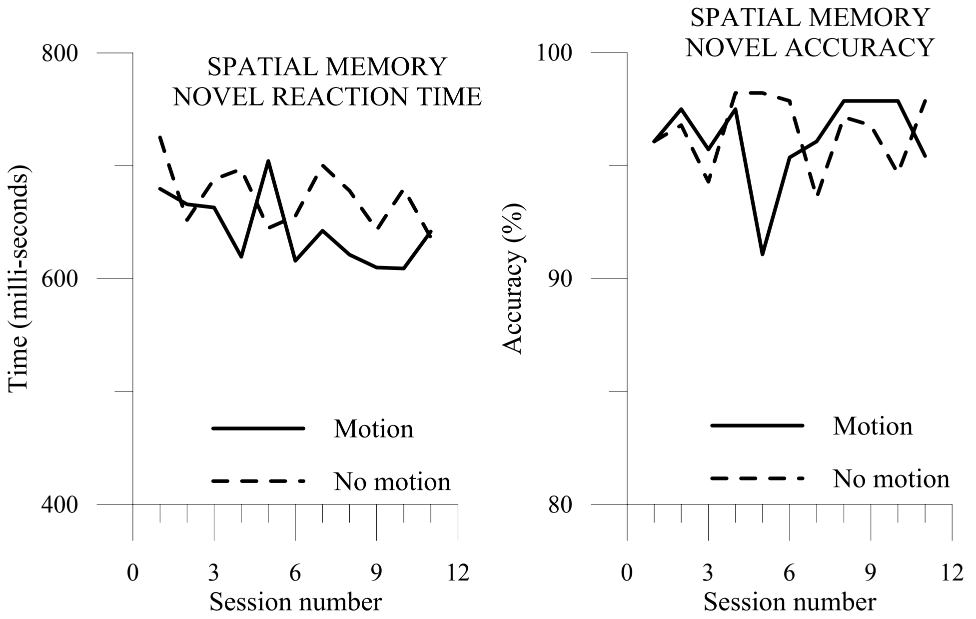


Fig. 25 Mean performances on spatial memory task during cognitive fatigue simulator experiment – novel stimuli

Examining performances on the delayed recognition task, Figs. 26 and 27, it would appear that there is little effect of motion on cognitive fatigue. There does, however, appear to be a small overall difference between the mean reaction times of the two groups. This difference, however, was not evident in the previous tests which investigated direct effects of motion on cognitive performance.

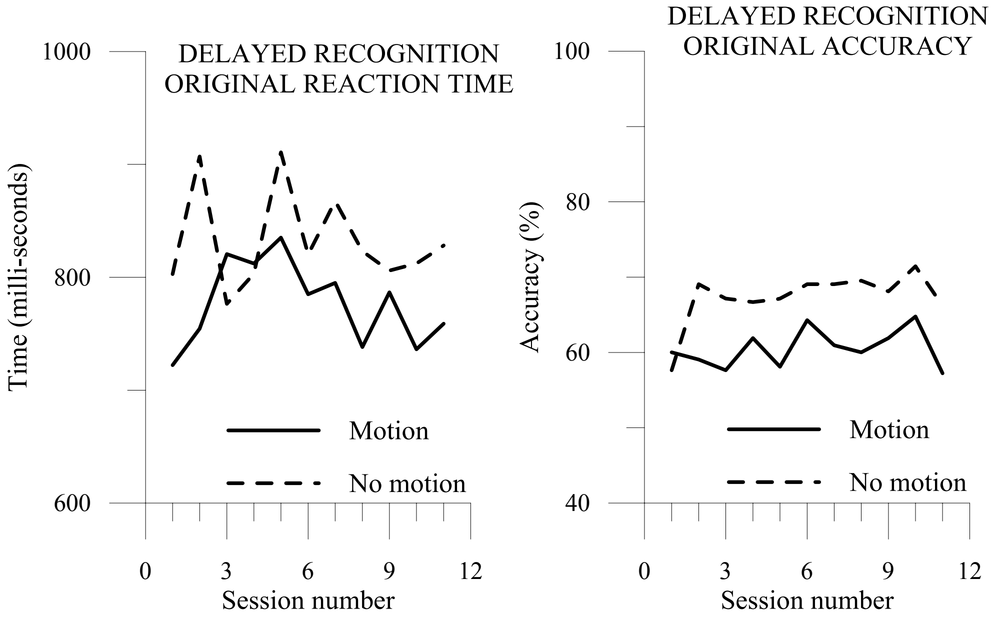


Fig. 26 Mean performances on delayed recognition task during cognitive fatigue simulator experiment – original stimuli

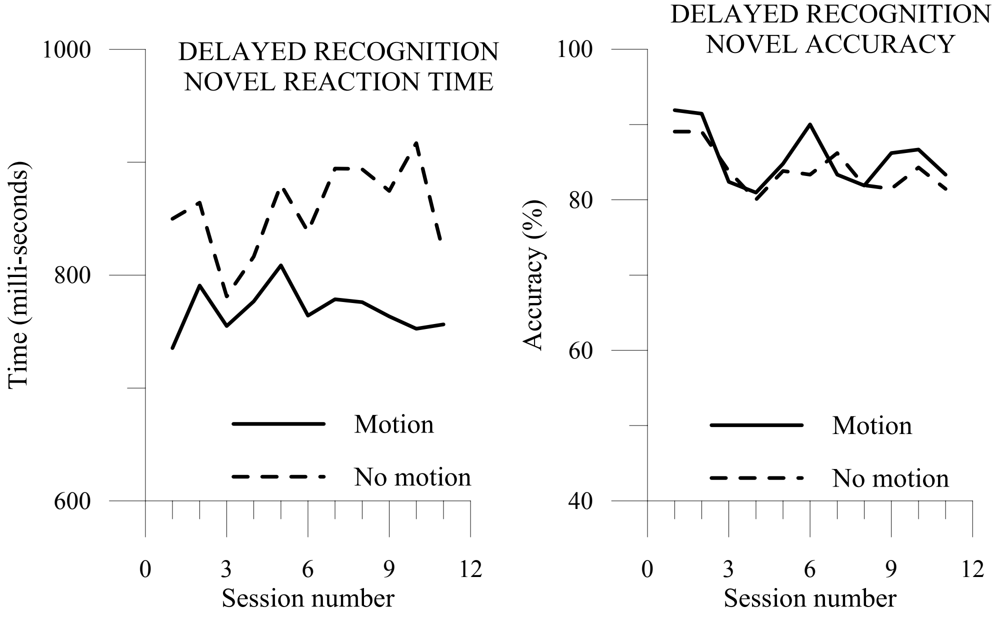


Fig. 27 Mean performances on delayed recognition task during cognitive fatigue simulator experiment – novel stimuli

The above paragraphs have discussed trends in the data which were apparent from inspection, and also determined that there were no large differences between performance of the motion and no motion groups. However, in order to investigate subtle performance differences multivariate statistical methods must be applied. To this end, a MANOVA analysis was conducted (for a standard reference on the use of MANOVA analysis see Hand & Taylor 1987). The results of this MANOVA analysis are given in Appendix D.

The MANOVA investigated the effects of both amplitude and session number. In a finding similar to the previous simulator experiment, no significant F statistics were found for the effects of amplitude. Significant F statistics were found for a number of the session number effects, indicating that performance on tasks changed with fatigue or learning effects. However, no F statistics less than 0.01 were found for interaction effects between amplitude and session number. This indicates that the motion had no measurable effects on cognitive fatigue.

6 SUMMARY OF EFFECTS OF WIND-INDUCED BUILDING MOTION ON COGNITIVE PERFORMANCE

This investigation was instigated on the hypothesis that wind-induced tall building motion may impact on cognitive performance. This hypothesis was investigated in both field and laboratory situations using a software package from CDR Ltd.

Field investigations proved to be impractical due to the lack of control over environmental variables, including motion conditions, subject availability, and subject fatigue amongst others. As a result of this, a test room was constructed and equipped to conduct cognitive testing while mounted on a shake table.

Two sets of experiments were conducted using the shake table. The first investigated direct effects of motion on cognitive performance by subjecting volunteers to a repeated measures test design during which they were exposed to both motion and no motion conditions. The second set of experiments was designed to investigate the effects of prolonged exposure to motion on cognitive fatigue. Volunteers conducted a repeated measures test design over the period of a normal working day, with half the group subjected to motion and the other half a control group. Both groups were told that motion might be expected during the day. Neither of the simulator tests detected any effects of wind-induced tall building motion on cognitive fatigue.

It can thus be concluded that serviceability acceleration design techniques do not require to take into account any cognitive performance factors.

7 ACKNOWLEDGEMENTS

The contribution of the volunteers who took part in this project is gratefully acknowledged. Without their willingness, forbearance, and co-operation, this project would not have been possible.

The testing software was generously supplied by CDR Ltd. Thanks to Gareth Ayre and Nick Hargaden for their contributions to the data analysis.

Computers for the testing were kindly donated by Reuters Australia. Thanks in particular to Mr John Murphy for supporting the project.

Technical assistance was provided by Mark MacLean, Steve Johnson, Matt Fleming, and Phil Witty.

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APPENDIX A

SUBJECT INFORMATION STATEMENT, INSTRUCTIONS READ, AND SURVEY PRESENTED TO VOLUNTEERS PARTICIPATING IN LABORATORY STUDY TO INVESTIGATE THE EFFECTS OF WIND-INDUCED TALL BUILDING MOTION ON COGNITIVE PERFORMANCE

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HUMAN PERCEPTION OF MOTION AND EFFECTS ON COGNITIVE PERFORMANCE

SUBJECT INFORMATION STATEMENT

Many modern tall buildings sway in the wind. Little, however, is known about the effects of this motion on the building occupants. This study will investigate the levels at which subjects begin to perceive the motion and the effects of the motion on mental efficiency. The project aims to develop new design codes for acceptable levels of motion in tall buildings based on both occupant comfort and occupant cognitive performance data.

Subjects will be required to attend five one and a half hour sessions at the National Facility for Dynamic Testing and Research at the University of Technology Sydney, although subjects should note that they are free to leave the study at any time. During these sessions subjects will be asked to perform simple computer based tasks, such as reaction time tasks, logical reasoning tasks and memory tasks, to assess various aspects of cognitive performance. These tasks will be carried out in a 3 metre by 3 metre test room mounted on a shake table. During some of the test sessions the room will be subjected to motion similar to that experienced in real tall buildings during strong winds. Sometimes this motion will be perceptible, and at other times it will not.

Results of the tests will be presented in peer reviewed international journals. Aggregate results only will be presented. Individuals will at all times remain anonymous with subjects being issued with subject numbers, the identities of which are known only to the project team staff: Mr Roy Denoon and Dr David Morrison.

Enquiries about the project should, in the first instance, be made to the project engineer Mr Roy Denoon on 02 9351 2187. Complaints arising from the conduct of the research should be addressed to Ms Gail Briody, IEC Executive Officer on 02 9351 4811
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INSTRUCTIONS TO BE READ AT SHAKE TABLE

Please be seated at a computer and use this same computer each day this week. Please sit in an upright posture with your feet on the rails of the stool. If you normally wear spectacles at work, please wear them and wear them to each session.

Each test session will last approximately 15 minutes. During this 15 minutes you will be asked to perform computer based tasks. At completion of each individual task, please await instruction before proceeding to the next task. Try to perform each task to your best ability each time. When all the tasks in a session have been completed, you will be asked to complete a questionnaire.

During the tasks, the room may vibrate. Sometimes, you may be able to feel this vibration, and sometimes you may not. If at any time the motion makes you feel nauseous, please feel free to leave the test room.

After each test session, there will be a break of approximately 15 minutes before starting your next test session. Light refreshments will be available at these times.

Word Presentation

This task will test your memory. Fifteen words will appear on the screen, one at a time. Try to remember as many as you can. It is important to get the words fixed firmly in your mind. Remember that there are fifteen words. I suggest that you take a few moments to work out the best way to remember them. PAUSE. Press one of the buttons to start when you are ready and watch the words carefully as they appear on the screen.

Simple Reaction Time

In this task we are measuring your reaction time – or how fast you can press the button in response to a stimulus. The word ‘YES’ will appear in the middle of the screen at irregular intervals. Every time you see the ‘YES’ appear, press the ‘YES’ button as quickly as you can. The gap between each presentation of the word "‘YES’ varies, so you know what is going to happen but you are not sure when. The word ‘YES’ will be the only thing that will appear on the screen, so get ready to press as soon as you see anything appear. Have your finger resting lightly on the ‘YES’ button so you can get the fastest reaction time possible. You only need to press the ‘YES’ button, so keep your fingers away from the ‘NO’ button.

Number Vigilance

This task will ensure how well you can maintain your concentration on a series of rapidly changing digits. A single number will appear on the right hand side of the screen and stay there. A continuous series of numbers will appear, one at a time, in the middle of the screen. Every time the number in the middle is the same as the one on the right, press the ‘YES’ button as quickly as you can, even if the number in the middle has disappeared. The numbers in the middle come up quite quickly, so you will have to keep your attention on the screen, otherwise you might miss some of them. You only need to press the ‘YES’ button in this task, so keep your fingers away from the ‘NO’ button.

Choice Reaction Time

In this task we are measuring your reaction time – or how fast you can press a button in response to a stimulus. Either the word ‘YES’ or the word ‘NO’ will appear on the screen at irregular intervals. Every time you see the word ‘YES’ press the ‘YES’ button as quickly as you can and every time you see the word ‘NO’, press the ‘NO’ button as quickly as you can. In this task, we are measuring how quickly you can react when you also have to choose the right response. Rest a finger or thumb of your right hand lightly on the ‘YES’ button and one from your left hand on the ‘NO’ button so that you are ready to press the button as soon as you see the word appear on the screen.

Logical Reasoning

This task will test your ability to think logically. A series of statements referring to the relationship between two letters will appear on the screen, one at a time. Read each statement and decide whether it correctly describes the order of the two letters which follow it. Press the ‘YES’ button if you think the statement is true and the ‘NO’ button if you think it is false. So, for example, if the statement says ‘B follows A – BA’, you should press the ‘NO’ button as the statement is false and does not correctly describe the order of the letters on the screen. Remember to answer as quickly as you possibly can. The statement has nothing to do with the order that the letters occur in the alphabet, so just think of the two letters as they appear on the screen.

Memory Scanning

In this task, we are seeing how well you can hold a short series of numbers in your memory and how quickly you can recognise them. It is a bit like remembering a telephone number for a short while. Five numbers will appear on the screen, one at a time. Concentrate on remembering these five numbers. The screen will show the message “Get ready to respond” and then a series of numbers will appear on the screen, one at a time. For each of these numbers, press the ‘YES’ button as quickly as you can if it is one of the numbers you are remembering, and the ‘NO’ button as quickly as you can if it is any other number. The numbers do not have to appear in the order in which they were originally presented, but simply be identified as being from that series or not.

Spatial Memory

The purpose of this task is to test your spatial memory – or how well you can remember where something was on the screen. A picture of a house with 9 windows, some of which will be lit up, will appear on the screen. Try to remember which of the windows in the house are lit. A series of pictures of the same house will then appear on the screen, one at a time. For each house, if the window that is lit was also lit in the original house, press the ‘YES’ button as quickly as you can, and if the window that is lit was not lit in the original house, press the ‘NO’ button as quickly as you can. Try not to spend too long making your decision – respond as quickly, but as accurately as you can.

Word Recognition

You are now going to see the words you were shown at the beginning of the session, but they will be mixed up with some new words. They will appear on the screen one at a time. For each word, if you recognise it as one of the words that was shown on the list at the beginning of this testing session, press the ‘YES’ button as quickly as you can. If you do not think the word was shown earlier, press the ‘NO’ button as quickly as you can. Remember to press as quickly as you can once you have made your decision. If you are unsure about a word, try not to spend a long time thinking about it – guess if you are really not sure.

Subject No. ____Session No. ____ Date ________ Time ______

1. Level of motion
   - Imperceptible ☐
   - Just Perceptible ☐
   - Clearly Perceptible ☐
   - Slightly Annoying ☐
   - Annoying ☐
   - Very Annoying ☐
   - Nauseating ☐

2. Temperature
   - Cold ☐
   - Cool ☐
   - Comfortable ☐
   - Warm ☐
   - Hot ☐

3. If you were in a tall building, how would you feel about this level of motion?
   - Comfortable ☐
   - Slightly uneasy ☐
   - Uneasy ☐
   - Very uneasy ☐
   - Frightened ☐

4. How long could you tolerate this level of motion in a working environment?
   - less than five minutes ☐
   - five to fifteen minutes ☐
   - fifteen minutes to half an hour ☐
   - half an hour to one hour ☐
   - one to two hours ☐
   - two to four hours ☐
   - all day ☐

5. If this level of motion occurred for half an hour to one hour in your workplace, how regularly would it have to occur before you would make a complaint to a supervisor/ building manager?
   - once every five years ☐
   - once per year ☐
   - once per month ☐
   - once per fortnight ☐
   - once per week ☐
   - once per day ☐
   - would not complain ☐

6. At what time did you start work today? ______

7. Comments

APPENDIX B

RESULTS OF *t*-TESTS TO DETERMINE EFFECTS OF WIND-INDUCED TALL BULDING MOTION ON COGNITIVE PERFORMANCE

Note: $N_1 = N_2 = 97$ for all cases
t-value for two-tailed test and 0.05 level of significance = 2.03

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	261.94	31.59
Low amplitude	258.80	32.70
t-statistic	0.445	

Table B.1 t-test results of Simple Reaction Time task

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	98.31	3.01
Low amplitude	98.28	2.98
t-statistic	0.968	

Table B.2 t-test results of Vigilance Accuracy task

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	392.02	29.96
Low amplitude	394.59	31.45
t-statistic	0.559	

Table B.3 t-test results of Vigilance Reaction Time task

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	95.02	4.67
Low amplitude	95.02	4.67
t-statistic	0.939	

Table B.4 t-test results of Choice Reaction Time Accuracy task

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	394.41	41.62
Low amplitude	389.30	43.42
t-statistic	0.370	

Table B.5 t-test results of Choice Reaction Time task

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	87.07	16.58
Low amplitude	86.94	17.05
t-statistic	0.946	

Table B.6 t-test results of Logical Reasoning Accuracy task

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	2431.74	691.62
Low amplitude	2351.56	751.76
t-statistic	0.438	

Table B.7 t-test results of Logical Reasoning Reaction Time task

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	93.95	8.45
Low amplitude	93.61	8.92
t-statistic	0.786	

Table B.8 t-test results of Memory Scanning Accuracy task – original stimuli

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	97.11	5.17
Low amplitude	97.11	4.90
t-statistic	0.967	

Table B.9 t-test results of Memory Scanning Accuracy task – novel stimuli

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	576.57	119.88
Low amplitude	566.63	113.39
t-statistic	0.494	

Table B.10 t-test results of Memory Scanning Reaction Time task

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	94.46	7.49
Low amplitude	95.17	5.81
t-statistic	0.497	

Table B.11 t-test results of Spatial Memory Accuracy task – original stimuli

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	96.55	5.42
Low amplitude	97.47	3.62
t-statistic	0.153	

Table B.12 t-test results of Spatial Memory Accuracy task – novel stimuli

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	543.67	126.79
Low amplitude	520.67	105.90
t-statistic	0.145	

Table B.13 t-test results of Spatial Memory Reaction Time task

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	68.11	22.82
Low amplitude	65.64	24.10
t-statistic	0.477	

Table B.14 t-test results of Delayed Recognition Accuracy task – original stimuli

	Mean accuracy (%)	Standard deviation of accuracy (%)
High amplitude	87.90	10.60
Low amplitude	88.32	11.30
t-statistic	0.722	

Table B.15 t-test results of Delayed Recognition Accuracy task – novel stimuli

	Mean reaction time (milli-s)	Standard deviation reaction time (milli-s)
High amplitude	746.63	174.69
Low amplitude	749.99	186.28
t-statistic	0.892	

Table B.16 t-test results of Delayed Recognition Reaction Time task

APPENDIX C

SUBJECT INFORMATION STATEMENTS PRESENTED TO VOLUNTEERS PARTICIPATING IN LABORATORY STUDY TO INVESTIGATE THE EFFECTS OF WIND-INDUCED TALL BUILDING MOTION ON COGNITIVE FATIGUE

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MOTION TOLERANCE AND ACCEPTABILITY IN TALL BUILDINGS

SUBJECT INFORMATION STATEMENT

Many modern tall buildings sway in the wind. Little, however, is known about the effects of this motion on the building occupants. This study will investigate the levels at which subjects begin to perceive the motion and the effects of the motion on mental efficiency. The project aims to develop new design codes for acceptable levels of motion in tall buildings based on both occupant comfort and occupant cognitive performance data.

Subjects will be required to attend a one hour training session and an eight hour test session at the National Facility for Dynamic Testing and Research at the University of Technology Sydney, although subjects should note that they are free to leave the study at any time. During these sessions subjects will be asked to perform simple computer based tasks, such as reaction time tasks, logical reasoning tasks and memory tasks, to assess various aspects of cognitive performance. These tasks will be carried out in a 3 metre by 3 metre test room mounted on a shake table. During some of the test sessions the room will be subjected to motion similar to that experienced in real tall buildings during strong winds. Sometimes this motion may be perceptible, and at other times it may not. There is a possibility of some subjects experiencing symptoms of motion sickness.

During the eight hour test session, two subjects will be present in the room with the test engineer. Luncheon and other light refreshments will be served throughout the day. Subjects will complete one 15 minute test session every 45 minutes. During the 30 minutes between test sessions, subjects may carry out any of their own work or relax as they wish. Subjects may leave the room to visit the bathroom.

Results of the tests will be presented in peer reviewed international journals. Aggregate results only will be presented. Individuals will at all times remain anonymous with subjects being issued with subject numbers, the identities of which are known only to the project team staff: Mr Roy Denoon and Dr David Morrison.

Enquiries about the project should, in the first instance, be made to the project engineer Mr Roy Denoon on 02 9351 2187. Any person with concerns or complaints about the conduct of a research study can contact the Manager of Ethics and Biosafety Administration, University of Sydney, on (02) 9351 4811.

APPENDIX D

RESULTS OF MANOVA ANALYSIS TO DETERMINE EFFECTS OF WIND-INDUCED TALL BUILDING MOTION ON COGNITIVE FATIGUE

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	305780.26	24	12740.84		
AMP	3431.60	1	3431.60	.27	.609

Table D.1 Tests of between subjects effects as a result of amplitude (AMP) for Simple Reaction Time task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	101542.08	240	423.09		
PRAC	22519.50	10	2251.95	5.32	.000
AMP BY PRAC	10096.77	10	1009.68	2.39	.010

Table D.2 Tests involving session number (PRAC) for within subjects effects for Simple Reaction Time task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	356084.57	24	14836.86		
AMP	61.73	1	61.73	.00	.949

Table D.3 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Vigilance task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	120267.51	240	501.11		
PRAC	17937.24	10	1793.72	3.58	.000
AMP BY PRAC	3854.93	10	385.49	.77	.658

Table D.4 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Vigilance task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	2401.99	24	100.08		
AMP	278.42	1	278.42	2.78	.108

Table D.5 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Vigilance task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	1604.74	240	6.69		
PRAC	115.51	10	11.55	1.73	.075
AMP BY PRAC	54.68	10	5.47	.82	.612

Table D.6 Tests involving session number (PRAC) for within subjects effects for Accuracy on Vigilance task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	1268968.06	24	52873.67		
AMP	9930.09	1	9930.09	.19	.669

Table D.7 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Choice Reaction Time task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	178124.33	240	742.18		
PRAC	22312.12	10	2231.21	3.01	.001
AMP BY PRAC	13487.69	10	1348.77	1.82	.058

Table D.8 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Choice Reaction Time task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	2583.84	24	107.66		
AMP	35.21	1	35.21	.33	.573

Table D.9 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Choice Reaction Time task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	3052.16	240	12.72		
PRAC	169.14	10	16.91	1.33	.215
AMP BY PRAC	85.05	10	8.51	.67	.753

Table D.10 Tests involving session number (PRAC) for within subjects effect for Accuracy on Choice Reaction Time task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	386752243.7	24	16114677		
AMP	10151853.33	1	10151853	.63	.435

Table D.11 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Logical Reasoning task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	40194851.18	240	167478.55		
PRAC	8429470.25	10	842947.02	5.03	.000
AMP BY PRAC	3167958.22	10	316795.82	1.89	.047

Table D.12 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Logical Reasoning task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	43831.86	24	1826.33		
AMP	49.46	1	49.46	.03	.871

Table D.13 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Logical Reasoning task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	8594.26	240	35.81		
PRAC	275.52	10	27.55	.77	.658
AMP BY PRAC	344.39	10	34.44	.96	.478

Table D.14 Tests involving session number (PRAC) for within subjects effects for Accuracy on Logical Reasoning task

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	19214.79	24	800.62		
AMP	25.47	1	25.47	.03	.860

Table D.15 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Working Memory Task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	13514.55	240	56.31		
PRAC	283.62	10	28.36	.50	.887
AMP BY PRAC	442.87	10	44.29	.79	.642

Table D.16 Tests involving session number (PRAC) for within subjects effects for Accuracy on Working Memory Task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	6861503.79	24	285895.99		
AMP	1404.51	1	1404.51	.00	.945

Table D.17 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Working Memory Task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	1479947.12	240	6166.45		
PRAC	94509.22	10	9450.92	1.53	.128
AMP BY PRAC	44711.84	10	4471.18	.73	.701

Table D.18 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Working Memory Task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	3675.98	24	153.17		
AMP	14.68	1	14.68	.10	.760

Table D.19 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Working Memory Task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	6300.41	240	26.25		
PRAC	446.80	10	44.68	1.70	.081
AMP BY PRAC	193.73	10	19.37	.74	.688

Table D.20 Tests involving session number (PRAC) for within subjects effects for Accuracy on Working Memory Task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	9506540.22	24	396105.84		
AMP	10799.87	1	10799.87	.03	.870

Table D.21 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Working Memory Task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	1993533.73	240	8306.39		
PRAC	116681.60	10	11668.16	1.40	.179
AMP BY PRAC	60588.75	10	6058.88	.73	.696

Table D.22 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Working Memory Task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	8331.05	24	347.13		
AMP	43.76	1	43.76	.13	.726

Table D.23 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Spatial Memory task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	15171.55	240	63.21		
PRAC	585.66	10	58.57	.93	.509
AMP BY PRAC	616.80	10	61.68	.98	.465

Table D.24 Tests involving session number (PRAC) for within subjects effects for Accuracy on Spatial Memory task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	9072811.50	24	378033.81		
AMP	41662.06	1	41662.06	.11	.743

Table D.25 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Spatial Memory task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	2605607.67	240	10856.70		
PRAC	186984.34	10	18698.43	1.72	.076
AMP BY PRAC	116205.59	10	11620.56	1.07	.386

Table D.26 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Spatial Memory task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	4244.37	24	176.85		
AMP	2.13	1	2.13	.01	.913

Table D.27 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Spatial Memory task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	9638.96	240	40.16		
PRAC	253.00	10	25.30	.63	.788
AMP BY PRAC	395.30	10	39.53	.98	.458

Table D.28 Tests involving session number (PRAC) for within subjects effects for Accuracy on Spatial Memory task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	10519401.55	24	438308.40		
AMP	75725.55	1	75725.55	.17	.681

Table D.29 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Spatial Memory task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	2294996.55	240	9562.49		
PRAC	130062.18	10	13006.22	1.36	.200
AMP BY PRAC	84608.75	10	8460.88	.88	.548

Table D.30 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Spatial Memory task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	103918.57	24	4329.94		
AMP	3692.95	1	3692.95	.85	.365

Table D.31 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Delayed Recognition task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	41332.55	240	172.22		
PRAC	1566.05	10	156.60	.91	.525
AMP BY PRAC	1178.92	10	117.89	.68	.738

Table D.32 Tests involving session number (PRAC) for within subjects effects for Accuracy on Delayed Recognition task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	16285956.27	24	678581.51		
AMP	117853.14	1	117853.14	.17	.681

Table D.33 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Delayed Recognition task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	6832221.56	240	28467.59		
PRAC	300181.77	10	30018.18	1.05	.399
AMP BY PRAC	200278.59	10	20027.86	.70	.721

Table D.34 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Delayed Recognition task with Original Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	38908.52	24	1621.19		
AMP	98.25	1	98.25	.06	.808

Table D.35 Tests of between subjects effects as a result of amplitude (AMP) for Accuracy on Delayed Recognition task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	25693.09	240	107.05		
PRAC	2857.90	10	285.79	2.67	.004
AMP BY PRAC	580.39	10	58.04	.54	.859

Table D.36 Tests involving session number (PRAC) for within subjects effects for Accuracy on Delayed Recognition task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	19547573.05	24	814482.21		
AMP	336937.07	1	336937.07	.41	.526

Table D.37 Tests of between subjects effects as a result of amplitude (AMP) for Reaction Time on Delayed Recognition task with Novel Stimuli

Source of Variation	*SS*	*DF*	*MS*	*F*	*Sig. of F*
WITHIN+RESIDUAL	5796282.39	240	24151.18		
PRAC	208261.02	10	20826.10	.86	.569
AMP BY PRAC	99816.60	10	9981.66	.41	.940

Table D.38 Tests involving session number (PRAC) for within subjects effects for Reaction Time on Delayed Recognition task with Novel Stimuli