Article Title: Assessment of driving-related performance in chronic whiplash using an advanced driving simulator

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This study was cleared by the institutional human medical ethics committees of The University of Queensland and The Queensland University of Technology.
1. INTRODUCTION

Individuals with chronic whiplash associated disorders (WAD) commonly report difficulties in driving (Hoving et al. 2003, Pereira et al. 2008, Takasaki et al. 2011). Chronic WAD is associated with a variety of physical, psychological and cognitive symptoms (Radanov et al. 1995, Dall'Alba et al. 2001, Öhberg et al. 2003, Treleaven et al. 2005, Pereira et al. 2008, Takasaki et al. 2012) that may directly or indirectly negatively affect the motor skills, visual perception and cognitive skills required for safe driving (Austroads 2003). It is possible that individuals with chronic WAD may have impaired driving-related performance and on-road safety. However, no studies have objectively quantified driving-related performance in individuals with chronic WAD to determine if they are fit to drive safely.

The gold standard for objective assessment of driving-related performance is an on-road assessment. On-road assessments are less than ideal for research purposes. Firstly, the outcomes of an on-road driving test cannot be compared between individuals because road conditions cannot be standardized for all subjects. Secondly, challenging traffic situations are needed to investigate driving safety comprehensively. Inherent in providing challenging on-road traffic situations is the risk of being involved in a car crash (Rizzo 2004). An alternative is the use of driving simulators which allow manipulation of driving environments to deliver standardized, repeatable and challenging driving scenarios in a safe and controlled environment. A number of studies have used driving simulators for the assessment of driving-related performance (Ku et al. 2002, Lew et al. 2005, Yuen et al. 2007, Crizzle et al. 2012) and the use of a driving simulator is regarded as a valid alternative to the on-road assessment (Lew et al. 2005, Shechtman et al. 2009). It is thus preferable, at least for research purposes, to use a driving simulator to study driving-related performance in individuals with chronic WAD.
1.1. Purpose

The purpose of this study was to investigate whether driving-related performance in individuals with chronic WAD was sufficiently impaired to require future consideration of fitness to drive assessment. Driving-related performance was assessed using an advanced driving simulator and compared between individuals with chronic WAD and asymptomatic healthy controls.

2. METHODS

2.1. Study design

This cross-sectional study included persons with chronic WAD and asymptomatic healthy control subjects of similar ages, gender and driving experience. This study was cleared by the institutional human medical ethics committees of The University of Queensland and The Queensland University of Technology. All subjects provided written informed consent prior to data collection.

2.2. Subjects

Subjects were recruited via community advertisements. WAD subjects were also recruited from a university whiplash research clinic. General inclusion criteria were; 1) current drivers aged between 20 and 60 years, 2) residing in Brisbane, 3) no history of cervical fracture or dislocation, concussion or neurological disorders (eg, multiple sclerosis, stroke), 4) no medical problems affecting driving (eg, upper or lower limb fractures/injuries, cardiovascular problems, respiratory and visual disorders), and 5) not prone to motion sickness. Further inclusion criteria for the WAD group were ongoing neck pain of between three months and six years duration related to a whiplash injury and a score of ≥8/100 on the Neck Disability Index (NDI) (Vernon and Mior 1991) as a lesser score is regarded as recovered (Sterling et al. 2003a, Sterling et al. 2003b, Sterling et al. 2006). Further
inclusion criteria for the control group were; 1) no history of whiplash, 2) no current headache or neck pain, and 3) no diagnosed psychological problems.

2.3. Driving simulator

This study used an advanced driving simulator (OKTAL, Paris, France), housed at The Queensland University of Technology, Australia. A real car without an engine was mounted on a motion platform (Emotion 1500, REXROTH, Boxtel, Netherlands) with six-degrees of freedom, which allowed the car to move and twist in three dimensions in order to provide simulated motion appropriate to the driving situation (Figure 1). A virtual environment was generated using eight computers. Virtual sceneries were projected onto three flat screens (4m wide × 3m high) with 180° horizontal and 40° vertical forward field of view, and onto side and rear view mirrors, which were replaced by LCD monitors (side mirrors, 15cm × 9cm; rear view mirror, 24.5cm × 8cm). The angles of the mirrors relative to the straight line ahead were left 61.7° for the left side mirror, left 32.5° for the rear view mirror and right 35.5° for the right side mirror. Surround sound for engine and environmental noise were also generated. All computers were controlled by SCANeR™ studio ver.1.0 software (OKTAL, Paris, France). The refresh rate of the visual virtual environment was 60Hz. Feedback was provided by a force feedback system (SENSO-wheel SD-LC, SENSODRIVE, Weßling, Germany) on the steering wheel and motion platform to provide a realistic driving experience. All parameters while driving were recorded at a sampling frequency of 20Hz.

2.4. Driving scenarios

This study examined driving-related performance in three driving scenarios (freeway, residential area and central business district (CBD)). The CBD was a replicate of Brisbane, Australia. These were preceded by a 5min-familiarization scenario, in which data were not
collected. Each scenario was designed to replicate as closely as possible the local road conditions and environment. Vehicles are driven on the left side of the road in Australia. Each scenario was timed for five minutes to minimize the possibility for motion sickness. The order of scenarios was not randomized and all subjects drove the freeway scenario first, followed by the residential and then CBD scenario. This order was chosen to reduce drop-outs due to motion sickness. Based on our pilot trials, the probability of being motion sick was least when driving on a straight road. Before commencing each driving scenario, subjects were instructed to remain within the posted speed limits and within the one lane unless instructed to do otherwise by pre-recorded voice instructions. Instructions for each driving task (eg, changing lanes and turning at intersections) were also given by pre-recorded instructions. Crash sounds were produced, without any car motion reactions, when there was a collision with any vehicle (car, cyclist and pedestrian).

2.4.1. Freeway scenario

The road map for this study was a two-way freeway with two lanes in each direction. In keeping with local road conditions, lane widths were 4m (leftmost lane) and 4.55mm (centre lane) and the speed limit was 100 km/h throughout the scenario. The road map curved slightly to the right (Figure 2) but the radius of curve was 10000m and therefore was considered as a straight road. Three driving tasks were included; merging onto the freeway, changing lanes and sudden braking as these were identified as troublesome in a previous study of chronic WAD (Takasaki et al. 2011).

The first driving task of merging onto the freeway had all cars on the freeway in the right hand lane. This ensured consistent driving conditions between subjects and avoided differences in the timing of subjects’ merging.

The second driving task was changing lanes (Video 1). The driving simulator permitted subjects to drive at their self-paced speed to simulate their usual driving. The
speed of other cars was controlled based on the subject’s speed to simulate a realistic lane change. Freeway speed limits are 100km/h. In our pilot trials, the maximum speed driven by a participant was 120 km/h. Changing lanes and sudden breaking on the freeway were programmed to cater for participants’ driving speeds between 120 and 70km/hr, The other cars in the programmed scenario reacted appropriately within this speed range. If the subject drove <70km/h when changing lanes in the main study, the simulation was stopped and the subject was encouraged to drive faster and keep to the speed limit. The simulation was then restarted. The details of this task are described in Box 1.

The third task was sudden braking (Video 2), and was one of five critical events potentially resulting in a collision (critical event). An accident site was created and two vehicles in front of the subject (Cars B and C) were programmed to brake quickly. The distance between the subject and Cars B and C was 60m to simulate a situation requiring sudden braking from pilot trials (see Box 2 for details).

2.4.2. Residential scenario

The road map used in the residential scenario was a two-way street with one lane (5m width) in each direction, with the exception of the fourth driving task where the road became two lanes. As per local road conditions, the speed limit was 60km/h throughout this scenario. The scenario included straight and curved roads and two intersections (Figure 3). The proportion of straight or curved roads was equal. The curved roads were gentle (radius = 70m or 300m) as sharp curves do not have sufficient validity when driving at moderate speed in the simulator (Fitzpatrick et al. 2000). Four driving tasks found troublesome in chronic WAD were included in this scenario; sudden braking, turning at intersections (with and without traffic signals) and changing lanes (Takasaki et al. 2011).

The first task was sudden braking (Video 3), the second critical event. The road map was a two-way street with one lane in each direction. The lane width on the side of the
driven car was 5m and 5m on the opposite side. A parked car (Car D) was designed to
suddenly pull out into the subject's lane, accelerating from stationary to 60km/h over five
seconds, when the distance between the subject and Car D was 38m. Sudden braking was
necessary to avoid a collision. In approaching this event, three cars were on the side of the
road to lessen subjects’ anticipation of this critical event. Approximately 200m further on,
Car D was parked in front of a large multi-passenger vehicle (Car E), which hid Car D to
generate a realistic and challenging traffic situation. The oncoming lane was programed to
have seven cars following each other closely so that braking was the subjects’ only choice
to avoid a collision with Car D.

The second task was turning left at the first intersection, the third critical event.
The traffic signal was always green. A child and adult were placed on the sidewalk at the
intersection (Figure 4). The child begins to run across the intersection when the distance
between the subject and the child was 8m (Video 4). The subject was required to anticipate
the potential hazard, turn at the intersection slowly and brake suddenly when the child ran
across the intersection to avoid hitting the child. Pilot studies with individuals both with
and without neck pain revealed that only half of them avoided a collision at a distance of
8m, thus this distance was selected in order to simulate a very challenging traffic situation.

The third task was turning right at a second intersection (T-intersection) without
traffic signals. Vehicles in the subject's lane had the right of way, indicated by a stop sign
and lane marking on the other lane.
The next task was changing lanes (Video 5), the fourth critical event. The road map
was a two-way street with two lanes in the each direction. The lane widths were 3.15m
(leftmost lane) and 3.35m (centre lane). To change from the left to the right hand lane
safely, the subject needed to appreciate the cars and space in the right lane, let the car on
the right go ahead and then change to the right hand lane. Box 3 presents the details of this
task.
2.4.3. CBD scenario

The CBD scenario was developed to replicate a real traffic road map of the Brisbane CBD. The width of one lane was 3.5m (majority of road network) or 3.35m and the speed limit was 40km/h. The CBD scenario included turning at four intersections with traffic signals and a sharp curve (radius=11.8m). The fifth critical event was programed when turning left at the first intersection (Video 6). A cyclist riding on the sidewalk crossed the intersection two seconds after the traffic light changed from red to green. A mood disturbing event, where the subject was honked by a car approaching from the behind (Box 5), was programed at the final intersection (Video 7).

2.5. Outcome measures

A questionnaire was used to record subject characteristics; age, gender, years holding a driver license, self-reported kilometers driven per week and days driven per week. The length of history of neck pain related to WAD, self-reported neck pain and disability (NDI) was recorded for the WAD subjects. The validity and reliability of the NDI have been established in the chronic whiplash population ($\alpha=0.87$) (Hoving et al. 2003, Nieto et al. 2008). Any symptoms related to motion sickness during testing was measured in both groups with the Modified Motion Sickness Assessment Questionnaire (M-MSAQ) (Brooks et al. 2010).

Driving performance was evaluated with the Simulator Performance Index (SPI). Responses in the divided attention tasks and the number of collisions in the five critical events were collated to consider driving safety. In addition, subjects’ reactions to the mood disturbing event in the CBD scenario (car behind honking the horn) were recorded.

2.5.1. The SPI
The SPI is an established measure of driving performance (Lew et al. 2005). It includes 12 measures with two domains; speed control (five measures) and direction control (seven measures). The speed control domain includes; speed (percent of time exceeding the posted limit); standard deviation (SD) of speed variability; SD of acceleration variability; SD of the throttle speed; and the number of red-light violations. The direction control domain includes; the mean absolute value of lane position error on straight roads; SD of lane position variability on straight roads; mean absolute value of lane position variability on curved roads; SD of lane position variability on curved roads; SD of steering wheel speed; the number of collisions; and the number of deviations off-road. All measures were calculated with a custom developed MATLAB® program (The MathWorks Inc., Natick, MA, USA). Data from specific driving tasks (eg, merging onto the freeway, changing lanes, sudden braking and turning intersections) were not included in SPI calculations but the number of collisions were included. The z-scores for each domain and the overall SPI score were calculated and compared to the control group. A z-score of ≤-2.0 indicates a failing grade (Lew et al. 2005). Good internal consistency in each domain (the speed control domain, α=0.9; the direction control domain, α=0.8) and the overall score (α=0.9) was reported by Lew et al (2005).

2.5.2. Divided attention tasks

Three divided attention tasks were included in each of the three driving scenarios (Figures 2-4). A red dot (7.5cm diameter) appeared on a side or rear view mirror while driving. The subject was instructed to flash high beam as soon as they saw the dot. Reaction time was measured in milliseconds and the dot disappeared when the subject responded. If the subject failed to flash high beam within five seconds, the dot automatically disappeared, reaction time was recorded as five seconds and a miss was noted. Reaction time and missed response ratio were computed for each divided attention task.
2.4. Statistics

This study’s aim was to investigate whether driving-related performance was sufficiently impaired in chronic WAD to warrant assessment of fitness to drive. The minimum sample size was therefore based on the failing grade of the SPI (ie, $z$-score=$-2$) (Lew et al. 2005). G*Power 3.1.3 (Faul et al. 2007) demonstrated that a sample size of 16 (eight in each group) would provide 95% power to detect the failing grade of the SPI with an $\alpha$ level of 0.05. However, a larger sample size reduces the chance of a type-II error, which is more important than the type-I error given the purpose of this study. Our pilot studies indicated that withdrawals due to motion sickness were likely in the simulator in this study. Considering these two factors, we aimed to recruit approximately 25 individuals in each group.

Descriptive statistics (mean±SD) were used to summarize variables. Data for the SPI were tested for normal distribution (Shapiro-Wilk tests). Speed variability and throttle speed data were normally distributed and therefore the raw data were used to calculate $z$-scores. All other SPI data were normalized using logarithmic transformations (Lew et al. 2005), allowing parametric statistical tests. Independent samples t-tests were used to compare mean $z$-scores in all SPI measures between the groups (Lew et al. 2005). Negative $z$-scores meant below-normal performance. In each scenario, $z$-scores were computed for subjects who completed the scenario. Fifteen SPI measures, including the 12 SPI parameters, speed control and direction control domains and overall SPI score, were compared between the WAD and control groups. For assessment of overall driving-related performance, $z$-scores of the SPI in each scenario were averaged and compared between the groups using Independent samples t-tests. Independent samples Mann-Whitney U tests and Fisher tests were used for comparisons of other measures including demographic data between the groups. All statistical analyses were performed by SPSS version 20.0 (IBM Corporation, New York, USA). Significance level was set at $P<0.05$. 


3. RESULTS

Subjects were recruited from April 2011 to May 2012. Figure 6 displays the flow of subjects through the study. Seventeen subjects with chronic WAD and 26 controls entered the study and commenced the assessment in the driving simulator but three WAD subjects and nine control subjects failed to complete the three scenarios because of motion sickness.

Table 1 presents demographic data for the 17 WAD subjects and the 26 controls who commenced the study and the 14 WAD and 17 controls who completed all scenarios. There were no significant differences in demographics between the WAD and control groups (All $P>0.05$). There was no significant difference in withdrawal rates in each scenario between the groups ($P>0.05$). There was a relatively equal distribution of WAD subjects with milder (NDI<30) or moderate to severe (NDI>30) self-reported pain and disability (Vernon and Mior 1991, Sterling et al. 2003a, Sterling et al. 2003b, Sterling et al. 2006) within the WAD group who commenced (milder WAD=47%, moderate/severe WAD=53%) and who subsequently completed all scenarios (milder WAD=50%, moderate/severe WAD=50%). The freeway scenario was restarted for three subjects in each group as they drove $<70\text{km/h}$. and these proportions were not significantly different between the WAD and control groups ($P>0.05$).

Table 2 presents the mean SPI z-scores for the WAD group. There were several negative values indicating poorer driving performance, but few reached significance when compared to the control group. The WAD group had statistically ($P<0.05$), poorer overall driving performance ('overall SPI'). There was statistically poorer performance in 'speed control', and 'speed variability' over the three scenarios, poorer 'lane position' in the freeway scenario, and poorer 'speed control domain', 'speed', and 'speed variability' in the CBD scenario. Notably, no measure approached or met the failing grade of the SPI ($\leq-2.0$).
Table 3 presents the mean reaction time and missed response ratio in each divided attention task. There was no significant difference in any measure of divided attention between the WAD and control groups (All $P>0.05$). However, WAD subjects detected the red dot in the left mirror more frequently than control subjects in all scenarios, but the difference was not significant.

Table 4 presents the number of subjects who had a collision at each critical event. Collisions in most events were rare with no significant differences between the WAD and control groups (All $P>0.05$). The exception was in the residential area where participants had to turn left and confronted a pedestrian. Approximately 60% of both WAD and control subjects hit the pedestrian.

Review of participants’ reactions to the mood disturbing event in the CBD scenario (a car behind honking their horn), revealed that 28 of the 31 subjects stopped at the intersection. One WAD and one control subject crossed the intersection even though the traffic light changed from amber to red. They reported that they thought that their speed was too fast to stop at the intersection and sudden braking was dangerous with the car behind honking and following closely. Another WAD subject moved to the opposite lane to avoid a collision when the car honked.

We questioned, post-hoc, whether higher disability level could influence driving ability and therefore compared the 15 SPI measures averaged across all scenarios, reaction time and missed response ratio in the divided attention tasks between the two WAD groups (milder WAD vs moderate/severe WAD). It was found that the milder WAD group had statistically poorer performances in three of the 15 SPI measures; 'variance speed', 'variance acceleration' and 'speed control domain' ($P<0.05$). There were no significant differences in any divided attention measures between the two WAD groups (All $P>0.05$).

4. DISCUSSION
This study compared driving-related performance between individuals with chronic WAD and healthy controls and determined that the majority (74%) of WAD group’s SPI z-scores were negative and 12% of all possible SPI measures were statistically inferior, indicating poorer driving performance in the WAD group. However, no SPI measure met the established failing criteria (z-score ≤ -2.0), indicating that driving impairments were negligible or at least mild. The average overall SPI z-score for the WAD group was -0.3±0.3, which contrasts markedly to the overall SPI of -4.6±4.7 determined by Lew et al (2005) when investigating driving performance in persons with traumatic brain injury. In addition, there were no differences between WAD and control groups in reaction times, missed response ratios in divided attention tasks and the number of collisions in each critical event. Thus, this study indicates that driving-related performance of persons with chronic WAD is not impaired to the extent that would require specific consideration of their fitness to drive.

Pain in itself may be an important predictor of involvement in a car crash (Lagarde et al. 2005) and many studies report the negative impact of chronic pain on driving (Jones et al. 1991, Duong et al. 2005, Veldhuijzen et al. 2006, Pereira et al. 2008, Nilsen et al. 2011, Fan et al. 2012). Pain can also impact negatively on cognitive skills (Kuhajda et al. 2002, Pais-Vieira et al. 2009, Thompson et al. 2010, Takasaki et al. 2012). We therefore explored post-hoc, whether WAD subjects with self-reported moderate/severe levels of pain and disability had either poorer driving-related performance or poorer abilities in the divided attention tasks than those with milder symptoms. However, the moderate/severe WAD group did not have poorer performance in either SPI measures or divided attention performances. Unexpectedly poorer performance in the milder WAD group was identified in three of 15 SPI measures analyzed. Thus the magnitude of pain and disability did not have a substantive impact on driving-related performance in our WAD cohort. Neck rotation is important for driving (Hunter-Zaworski 1990, Marottoli et al. 1998, Barry et al. ...
but the intensity of neck pain is not always associated with the magnitude of limitation in neck rotation (Howell 2011), which could explain our observations. Our previous study found that 50% of WAD patients with perceived reduction of driving ability after a whiplash reported now driving more cautiously (Takasaki et al. 2011). Interestingly, WAD subjects responded more frequently than control subjects (albeit not statistically) to the divided attention task on the left mirror in all scenarios, which could support the notion of hyper-vigilance or cautiousness in driving. Further research is needed to compare head movement while driving between individuals with chronic WAD and healthy controls to better understand any compensation strategies used by persons with chronic WAD to maintain their driving safety.

Critical and mood disturbing events were programed into the driving scenarios based on driving tasks nominated as troublesome by individuals with chronic WAD (Takasaki et al. 2011). We attempted to program critical events with different levels of difficulty as it is unknown what level of difficulty is critical in chronic WAD. The critical event where the child ran out onto the road at an intersection was designed as the most challenging task during our relatively short period of driving time. As anticipated by our pilot trials, over half of the subjects (60%) had a collision. There were no critical events where all subjects crashed and conversely there was none without a crash. There were three overt reactions to the mood disturbing event. This suggests that the critical and mood disturbing events were sufficiently realistic for the purposes of this study. There were no significant differences between the WAD and control groups in the numbers of collision in any critical event. However, no WAD subject, but rather two control subjects, had a collision in the sudden braking task in the residential scenario. This may reflect self-reported modification of driving behavior after a whiplash injury (eg, more cautious driving). Interestingly two WAD subjects had a collision when changing lanes in the residential scenario while the count for the control group was nil. Nevertheless,
interpretation is limited as the sample size in this study was small and precise prediction of accident risk using a driving simulator is limited (Rudin-Brown et al. 2009). However, changing lanes might be an important task in future research investigating driving safety in people with neck pain. Other critical events could also be developed to test the driving safety of persons with WAD.

Closer examination of the SPI measures revealed that three of five measures of speed control in the CBD scenario were statistically lower for the WAD group. Reasons for the difference are not clear. There could be some increase in anxiety and nervousness while driving in the CBD scenario, where there were several parked cars and potential hazards. This may be associated with the finding of increased speed variability (ie, braking and acceleration). Certainly, anxiety and nervousness were nominated as features by 54% of the cohort in our previous study of self-reported reduction of driving ability after a whiplash injury (Takasaki et al. 2011).

This study attempted to recruit approximately 25 subjects with chronic WAD but only 17 subjects entered the study due to recruitment constraints and 14 completed all scenarios. Considering all subjects (WAD and control), 28% (12/43) withdrew at various stages due to motion sickness (Figure 6) even though all participants were screened and excluded from the study if they were prone to motion sickness. It is considered that these withdrawals during testing had negligible impact on results as; 1) characteristics were comparable between the WAD and control groups in each scenario, 2) the control group had a larger sample size than the WAD group, giving stable reference values, and 3) the number of subjects who completed all scenarios was greater than the minimum sample size required to accomplish the primary aim of the study. Mullen et al (2010) demonstrated no association between driving performance and susceptibility to motion sickness, which further supports the suggestion of a lack of substantive impact of withdrawals due to motion sickness on findings of this study.
4.1. Limitations

This study has limitations. This study did not investigate driving-related performance with prolonged driving, which patients with chronic WAD report as problematic. They also report a reduction in concentration while driving (Takasaki et al. 2011). Poorer abilities in divided attention tasks might be more evident over longer driving times. Nevertheless, it would be difficult to investigate driving-related performance over longer times especially in the important residential or CBD areas in light of the number of subjects who experienced motion sickness in these scenarios. Further technological progress will be needed to counter this problem. We used only five critical events from potentially innumerable critical situations due to limited testing time, and more or alternate events may have been warranted to detect differences between WAD subjects and healthy controls. Notably, the skill of reversing was not tested for technical reasons, despite it being one of the most troublesome driving tasks for persons with chronic WAD (Takasaki et al. 2011). A totally different experimental setting is required to investigate performance in reversing tasks. Finally, the sample size tested was adequate but a larger sample size could reduce any potential for a type-I error.

5. CONCLUSION

This study compared driving-related performance between individuals with chronic WAD and healthy individuals in freeway, residential and CBD scenarios over 15 minutes of driving in an advanced simulator. This study determined that driving-related performance in individuals with chronic WAD was not substantially different to healthy control subjects and there appears to be no basis to recommend a need for fitness to drive assessment in persons with chronic whiplash associated disorders.
1 ACKNOWLEDGMENTS

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REFERENCES


methods for two-lane rural highways. Texas Transportation Institute: The Texas A&M University System, College Station.


Figure 1. An advanced driving simulator

Figure 2. Road network of the freeway scenario
1: The start point of this scenario
2: The first driving task, merging onto freeway
3: The first divided attention task (a red circle on the right side mirror)
4: The second driving task, changing lanes
5: The third driving task, sudden braking (the first critical event)
6: The second divided attention task (a red circle on the rear view mirror)
7: The third divided attention task (a red circle on the left side mirror)
8: The end point of this scenario

Figure 3. Road network of the residential scenario
1: The start point of this scenario
2: The first driving task, sudden braking (the second critical event)
3: The first divided attention task (a red circle on the right side mirror)
4: The second driving task, turning left at an intersection (the third critical event)
5: The second divided attention task (a red circle on left side mirror)
6: The third driving task, turning left an a T-intersection
7: The fourth driving task, changing lanes (the fourth critical event)
8: The third divided attention task (a red circle on the rear view mirror)
9: The end point of this scenario

Figure 4. Turning left at the first intersection in the residential scenario.

Figure 5. Road network of the Brisbane CBD scenario
The course is presented with white arrows and numbers. The simulated Mary Street is a two-way street with two lanes in each direction, the simulated Albert Street is a two-way street with two lanes in one direction and one lane in the other direction, and the simulated Margaret, Edward and Alice Streets are all one way streets with four lanes.

1: The subject drives on Mary Street, stops at an intersection between Mary street and Albert street, and then turns left into Albert Street (the fifth critical event).

2: On Albert street, a stationary car with flashing hazard signals is located in the right lane. The subject is required to drive in the left lane in Albert Street.

3: The subject is instructed to turn left at the intersection of Albert and Margaret Streets and drive in the second lane from the right. The traffic signal is green. On Margaret Street, cars are stationary in the first, third and fourth lanes and therefore the subject can drive only in the second lane from the right.

4: At the intersection of Margaret and Edward Streets, the subject is instructed to turn right into Edward Street and keep to the second lane from the right. The traffic signal is green.

5: Edward Street changes to Alice Street after a sharp curve (radius = 11.8m).

6: The subject is instructed to turn right at the intersection of Alice and Albert Streets. The traffic signal is green. On Albert Street, the subject is instructed to go straight for two blocks. At the intersection of Albert and Margaret Streets, a mood disturbing event is programmed where the participant is honked by a car approaching from the behind.

The first red circle-dot of the divided attention task is generated on the right side mirror in Mary Street, the second on the left side mirror in Margaret Street and the third on the rear view mirror in Alice Street.

**Figure 6.** Flowchart of subjects

Abbreviations: WAD, whiplash associated disorders; M-MSAQ, Modified Motion Sickness Assessment Questionnaire; CBD, Brisbane central business district.
Figure 4
WAD-Interest in participating (n=65)

Excluded (n=48)
- Not meeting inclusion criteria (n=10)
  - NDI<8 (n=2)
  - Not currently driving (n=1)
  - Prone to motion sickness (n=7)
- Declined to participate (n=38)
  - Anxiety re driving in the simulator (n=1)
  - Fear of symptoms aggravation by testing (n=1)
  - Lack of time to participate (n=25)
  - No response after providing information (n=11)

Tested (n=17)

Freeway scenario (n=17)
  - Completed freeway scenario (n=17)

Residential scenario (n=17)
  - Completed residential scenario (n=16)
  - Withdrew due to motion sickness (n=1)
    - M-MSAQ=3.8

CBD scenario (n=16)
  - Completed CBD scenario (n=14)
  - Withdrew due to motion sickness (n=2)
    - M-MSAQ=6.2 4.3

Control-Interest in participating (n=32)

Excluded (n=6)
- Not meeting inclusion criteria (n=4)
  - NDI>0 (n=1)
  - Prone to motion sickness (n=3)
- Declined to participate (n=2)
  - No response after providing information (n=2)

Tested (n=26)

Freeway scenario (n=26)
  - Completed freeway scenario (n=26)

Residential scenario (n=26)
  - Completed residential scenario (n=23)
  - Withdrew due to motion sickness (n=3)
    - M-MAQ=5.5 1.1

CBD scenario (n=23)
  - Completed CBD scenario (n=17)
  - Withdrew due to motion sickness (n=6)
    - M-MSAQ=3.6 2.8
Table 1. Characteristics of subjects who commenced the study and subjects who completed all scenarios.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Commenced the study</th>
<th>Completed all scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WAD (n=17)</td>
<td>Control (n=26)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>35.1±12.0</td>
<td>36.7±10.4</td>
</tr>
<tr>
<td>Female (n [%])</td>
<td>11 [65]</td>
<td>19 [73]</td>
</tr>
<tr>
<td>Driving experience (years)</td>
<td>12.2±9.7</td>
<td>16.8±12.5</td>
</tr>
<tr>
<td>Driving frequency per week (days)</td>
<td>5.6±2.2</td>
<td>5.5±2.2</td>
</tr>
<tr>
<td>Total kilometers driven per week (km)</td>
<td>165.4±185.5</td>
<td>178.3±135.7</td>
</tr>
<tr>
<td>Symptom duration (months)</td>
<td>32.1±23.9</td>
<td>NA</td>
</tr>
<tr>
<td>NDI (%)</td>
<td>28.8±13.6</td>
<td>NA</td>
</tr>
</tbody>
</table>

No significant differences in measures between and within the WAD and control groups who commenced the study and who completed all scenarios (All *P*>0.05).
Table 2. Mean z-scores of the SPI in the WAD group.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Freeway scenario(^b) (n=16)</th>
<th>Residential scenario(^c) (n=15)</th>
<th>CBD scenario(^d) (n=13)</th>
<th>Average(^e) (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall SPI</td>
<td>-0.1±0.4</td>
<td>-0.2±0.5</td>
<td>-0.3±0.5</td>
<td>-0.3±0.3</td>
</tr>
<tr>
<td>Speed control</td>
<td>-0.1±0.7</td>
<td>-0.3±0.8</td>
<td>-0.6±0.8</td>
<td>-0.4±0.5</td>
</tr>
<tr>
<td>Speed (time over posted limit)(^a)</td>
<td>0.0±1.0</td>
<td>-0.3±0.9</td>
<td>-0.8±0.7</td>
<td>-0.5±0.6</td>
</tr>
<tr>
<td>Speed variability</td>
<td>-0.2±1.4</td>
<td>-0.2±1.1</td>
<td>-1.0±1.5</td>
<td>-0.6±0.7</td>
</tr>
<tr>
<td>Acceleration variability(^a)</td>
<td>0.4±1.5</td>
<td>-0.4±1.3</td>
<td>-0.9±1.7</td>
<td>-0.5±1.0</td>
</tr>
<tr>
<td>Speed jerk</td>
<td>-0.5±1.4</td>
<td>-0.4±1.3</td>
<td>-0.6±1.4</td>
<td>-0.6±1.2</td>
</tr>
<tr>
<td>Red-light violations</td>
<td>NA</td>
<td>0.0±0.0</td>
<td>-0.1±1.1</td>
<td>0.0±0.6</td>
</tr>
<tr>
<td>Direction control</td>
<td>-0.1±0.4</td>
<td>-0.1±0.6</td>
<td>-0.1±0.6</td>
<td>-0.2±0.4</td>
</tr>
<tr>
<td>Lane position (straight road)(^a)</td>
<td>-0.6±0.7</td>
<td>0.2±1.8</td>
<td>0.3±1.1</td>
<td>-0.1±0.8</td>
</tr>
<tr>
<td>Lane position (curved road)(^a)</td>
<td>NA</td>
<td>-0.5±1.1</td>
<td>0.2±0.8</td>
<td>0.2±0.8</td>
</tr>
<tr>
<td>Lane position variability (straight road)(^a)</td>
<td>0.0±0.9</td>
<td>0.0±1.1</td>
<td>-0.3±1.4</td>
<td>-0.3±0.9</td>
</tr>
<tr>
<td>Lane position variability (curved road)(^a)</td>
<td>NA</td>
<td>0.1±1.3</td>
<td>-0.3±1.1</td>
<td>-0.1±1.0</td>
</tr>
<tr>
<td>Steering jerk(^a)</td>
<td>-0.3±1.7</td>
<td>0.1±1.0</td>
<td>-0.5±1.1</td>
<td>-0.4±0.9</td>
</tr>
</tbody>
</table>
Collisions\(^a\) & 0.1\(\pm\)0.9 & -0.4\(\pm\)1.1 & 0.4\(\pm\)0.0 & 0.0\(\pm\)0.5 \\
Deviations off road\(^a\) & -0.4\(\pm\)1.0 & -0.2\(\pm\)1.4 & -0.6\(\pm\)0.9 & -0.5\(\pm\)0.6 \\

Abbreviation: NA, not applicable.
Values are normalized z-scores relative to the control group; negative values indicate below-normal performance. Z-scores with \(P<0.05\) are presented in bold.

\(^a\)Data is transformed using logarithmic transformation.

\(^b\)Values are normalized z-scores relative to the control group (n=26). Statistical significance is by t-test (40 degrees of freedom).

\(^c\)Values are normalized z-scores relative to the control group (n=23). Statistical significance is by t-test (36 degrees of freedom).

\(^d\)Values are normalized z-scores relative to the control group (n=17). Statistical significance is by t-test (28 degrees of freedom).

\(^e\)Z-scores of the WAD group who completed all scenarios (n=13) are averaged.
Table 3. Reaction time and incorrect response ratio in divided attention tasks.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Location of a dot</th>
<th>Reaction time (seconds)</th>
<th>Incorrect response ratio (n [%])</th>
<th>Reaction time (seconds)</th>
<th>Incorrect response ratio (n [%])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway</td>
<td>Left</td>
<td>3.3±1.6</td>
<td>6 [35]</td>
<td>3.4±1.7</td>
<td>13 [50]</td>
</tr>
<tr>
<td>scenario^a</td>
<td>Centre</td>
<td>2.3±1.6</td>
<td>4 [24]</td>
<td>2.0±1.4</td>
<td>2 [8]</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>1.8±1.3</td>
<td>2 [12]</td>
<td>1.4±0.8</td>
<td>1 [4]</td>
</tr>
<tr>
<td>Residential</td>
<td>Left</td>
<td>3.8±1.6</td>
<td>8 [50]</td>
<td>4.1±1.4</td>
<td>15 [65]</td>
</tr>
<tr>
<td>scenario^b</td>
<td>Centre</td>
<td>2.0±1.6</td>
<td>3 [19]</td>
<td>1.9±1.4</td>
<td>3 [13]</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>1.8±1.2</td>
<td>1 [6]</td>
<td>1.3±0.8</td>
<td>1 [4]</td>
</tr>
<tr>
<td>CBD</td>
<td>Left</td>
<td>4.3±1.4</td>
<td>11 [79]</td>
<td>5.0±0.1</td>
<td>16 [94]</td>
</tr>
<tr>
<td>scenario^c</td>
<td>Centre</td>
<td>2.7±1.8</td>
<td>4 [29]</td>
<td>3.3±1.9</td>
<td>9 [53]</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>2.0±1.6</td>
<td>3 [21]</td>
<td>1.7±1.3</td>
<td>2 [12]</td>
</tr>
</tbody>
</table>

Abbreviations: Left, left side mirror; Centre, rear view mirror; Right, right side mirror.

No significant differences in each measure between the WAD and control groups (All $P>0.05$).

^a17 WAD subjects and 26 control subjects.
16 WAD subjects and 23 control subjects.

14 WAD subjects and 17 control subjects.
Table 4. The number of collisions in each critical event.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Critical event</th>
<th>WAD</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway scenario</td>
<td>Sudden braking</td>
<td>1/17</td>
<td>2/26</td>
</tr>
<tr>
<td></td>
<td>Sudden braking</td>
<td>0/16</td>
<td>2/23</td>
</tr>
<tr>
<td>Residential scenario</td>
<td>Hitting a child running out onto the road at an intersection</td>
<td>10/16</td>
<td>14/23</td>
</tr>
<tr>
<td></td>
<td>Changing lanes</td>
<td>2/16</td>
<td>0/23</td>
</tr>
<tr>
<td>CBD scenario</td>
<td>Turning left at an intersection</td>
<td>1/14</td>
<td>3/17</td>
</tr>
</tbody>
</table>

No significant differences between the WAD and control groups in any events (All $P>0.05$).
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