# THE IMPACT OF AUDITORY

# TASKS

# (AS IN HAND-FREE CELL PHONE USE)

# ON DRIVING TASK PERFORMANCE

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**SAFETY RESEARCH**
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# THE IMPACT OF AUDITORY TASKS (AS IN HANDS-FREE CELL PHONE USE) ON DRIVING PERFORMANCE

## 1. Background

From October, 1999 to February, 2000 the Insurance Corporation of British Columbia (ICBC) conducted closed-course driving experiments at Boundary Bay Airport (the Pacific Education Centre site) intended to test the impact of in-vehicle telephone use on driving performance.

Previous studies reported in the literature (notably Redelmeier and Tibshirani, 1997) have suggested a link between in-vehicle telephone use and driving safety, not just in terms of the physical task of operating the phone but – most importantly – in relation to the competing cognitive requirements of driving and conversing. With the recent proliferation of cell phones and their use by drivers to transform cars into secondary work environments, a legitimate concern has been raised as to the potential impact on crash risk due to distraction from the driving task.

Research in the area of attention - switching has shown that task complexity plays a key role (Ranney et al, 2000; Lee et al, 2000). If the primary task (Eg. related to driving) is not very complex, then a certain amount of attention can safely be diverted to a secondary cognitive task (such as listening and responding to messages) without significantly impairing performance in the primary. For example, Noy et al (1999) found no effect of cell phone use on driver ability to maintain lateral position under normal traffic conditions.

But what about situations requiring critical choices? Some traffic situations require fairly complex and quick decision-making on the part of the drivers (making left turns through gaps in on-coming vehicle streams, for example). How might performance in such situations be affected by talking on a cell phone, and could crash risk increase as a result?

## 2. Research Methodology

ICBC researchers, together with engineers from MacInnis Engineering Associates limited, designed an 807m. elongated closed-course driving circuit to address the above questions. Three different driving tasks were set up. First was a commonly-encountered traffic light situation where a 3.5 second amber light was triggered from one of two vehicle positions vis-à-vis the stop line location: the closer position made it easier for the vehicle to run through the amber light (prior to the light turning red) than did the farther position. Second, offset pop-up targets were activated on one of the straight legs of the circuit in such a way as to create the need to weave between them. Two cases were presented: a short weave space and a longer space. And third, a left-turn task was set up which required the subjects to press the accelerator pedal of their appropriately-positioned but immobilised vehicle so as to indicate which gaps in an approaching vehicle stream (eight other vehicles continuously looping around the circuit) they would accept.

The subjects were exposed to activation of the first two tasks on a periodic basis as they drove at an average of about 50km/h. around the circuit. They were also required to respond verbally to taped messages which played in the vehicles and which were triggered so as sometimes to coincide with the physical driving task activations and sometimes not. Each subject completed both the signal and weave tasks 12 times while exposed to the messages and 12 times when no messages were playing. For the left-turning test, the message sequences were initiated randomly and subjects were presented with about 50 gaps during message presence and about 50 when no messages were being played.

The messages were of two types: verbal/ semantic and spatial/ imagery. The later required subjects to visualize the elements involved while the former required more abstract associations. In each taped message (following a brief instructional section) a criterion or contextual statement was presented (Eg. "means happiness" or "smaller than a dime"), followed by a string of target words separated by a 1.0-1.5 second gap. During this gap the subjects were required to state ("yes" or "no") whether or not the word met the criterion defined in the contextual phrase. Their responses were recorded automatically and the initial audio was activated by triggering switches installed on the test course pavement (similar to those which were used to activate the signal light and targets) so the message operation was entirely "hands-free" from the subjects' perspective.

In order to ensure that subjects always attempted both the driving and message tasks to the best of their ability and in the best possible time, they were informed that their scores in both would be tallied and their overall results would give them an equivalent number of chances to win a $1,500 draw. Since only 41 subjects were tested (30 male, 11 female, 7 aged 19-24, 25 aged 25-44, and 9 aged 45-70) the chances of winning with a high score were very good and thus the subjects should have been highly motivated to perform.

The test vehicle (a 1991 Honda Accord) was fully instrumented to record brake and acceleration pedal movement, and continuous speed over time. A number of performance-related measures relevant to each driving situation were defined (such as average deceleration/ acceleration, reaction time from event trigger to brake or accelerator pedal movement, etc.). Each of these were employed as dependant variables in a series of repeated measures analyses (using the SAS GLM proc.) where items such as driver age and gender, and weather/ road condition were utilized as independent variables. The F-test statistic was used as a measure of significance level ($p < .05$).

## 3. Results

The results presented below represent only those specifically concerning the presence/ absence of messages in relation to driving performance measures. Other significant main effects of such things as driver age and gender are not covered in this report.

## 3.1 Traffic Signal Task

Table 1 presents the significant ($p < .05$) main and interaction effects of message presence/absence from the repeated measures analysis.

Where subjects decided to "run" the short-trigger light (as opposed to stopping) they (and especially the females) appeared to require a greater initial speed to precipitate the decision when the message was present than when it was not. They were more likely to stop (62.6%) when attending to the message than when not (47.9%). Also, once the decision had been made to go through the amber, the subjects accelerated harder in the message than in the non-message situation thus giving themselves more of a time cushion in avoiding the red light. The interaction of this "clearance time" with surface condition (wet vs. dry) seemed to suggest more precautionary behaviour in the presence of the messages.

For subjects attempting the more difficult task of running the long-trigger light, the principal effect of the messages related to the initial decision speed as differentiated by subject age. While older drivers made the "run" decision at higher initial speeds when dealing with the messages (i.e. they were more likely to make the conservative "stop" decision), young drivers exhibited significantly riskier behaviour.

Where subjects decided to stop for the long-trigger amber light, the presence of the messages had the effect of producing lower average deceleration owing partly to a faster brake reaction time. The result was a longer estimated "arrival time" (the time to reach the stop line based on maintenance of the initial speed prior to braking – also known as the "time-to-collision" or TTC – see Tijerina, 2000). When deciding to stop for the short-trigger light, there was similar evidence for precaution or anticipation on the part of the young and middle-aged subjects who recorded shorter brake pedal reaction times when the messages were present than when they were absent. But the older subjects displayed a markedly longer reaction time under the message conditions. This is consistent with expectations from the literature concerning the increased negative effect of distraction on older drivers.

The net effect of the messages on subject driving performance in the traffic signal task seemed to be most often to encourage conservative or anticipatory behaviour. This is consistent with drivers acting according to expectations concerning the primary task (Tijerina, 2000). But there was an indication at least in the case of subjects choosing to run the long-trigger light, that such over-compensation was not operative for young drivers, as Figure 1 illustrates.

## 3.2 Pop-up Target Task

Table 2 presents the significant ($p < .05$) main effects of message presence/ absence from the repeated measures analysis.

The results for the target tests were very straightforward. The presence of the messages had a highly significant impact on deceleration prior to and, speed through, the weave manoeuvre. With the messages playing, subjects confronted with the more critical – short space – weave situation reduced their speed markedly less than they did when not having to divert attention to the auditory task. While there was no adjacent traffic flow to restrict how widely the vehicles could swerve in completing the manoeuvre, nevertheless it was apparent that the subjects in “real life’ would have been dealing with a lower factor of safety for adjacent lane encroachment during the divided attention conditions.

There were no significant interactions of message presence/ absence with subject/ environment variables in explaining driving performance variable values. But, even though short of statistical significance, the most pronounced difference in weave speed in relation to presence/absence of the messages occurred under wet pavement conditions. Figure 2 illustrates the overall significant main effect of message presence on weave speed, separated into dry and wet surface conditions. The comparison is suggestive of a lack of compensation for reduced manoeuvring capability - an issue which arises more evidently in the left-turn task results.

### 3.3 Left-Turn Task

Table 3 presents the significant (p, .05) effects of message presence/ absence from the repeated measures analysis.

The most important outcome of the left-turn task was that, when the pavement was wet, subjects exposed to the messages accepted significantly shorter gaps (both in terms of distance and time) than they did when not exposed. This translated into a shorter through-vehicle arrival time (TTC) associated with the messages which has implications for crash risk. The difference in arrival time for the trailing through vehicle would have reduced the lag or “space cushion” available between this and the turning (subjects’) vehicle by close to 3.5 metres – a difference which could be important in determining whether or not a collision occurs if the through vehicle does not react in time.

Figures 3 shows the difference in accepted gap time that the presence of messages made for the left-turning subjects under dry and under wet surface conditions. Without the distraction from the messages, subjects appeared able to factor-in adverse surface friction for through vehicles so as to wait for substantially larger gaps when the pavement was wet. But absolutely no adjustment was apparent when the messages were playing.

## 4. Discussion

The overall effect of the messages in the cases of the traffic signal task was generally to produce a more conservative response on the part of subject drivers. With the message listening/response task activated, the drivers were more likely to stop (as opposed to running the light) than when no message was presented in the short-trigger situation where the choice was more ambiguous than it was for the long-trigger. Similarly, a higher initial speed was associated with the decision of subjects under these conditions (message on, short-trigger) to run the light than was the case when no message was playing. This can reasonably be interpreted as a conservative response if drivers under the message-on condition felt they needed more of a speed "cushion" to support their decision to run the light than was the case when no message was playing.

Similarly, when the signal light activation situation heavily favoured one choice alternative (i.e., stopping under the long-trigger situation), drivers who stopped while under exposure to the cell message tended to react earlier than they did when stopping and not exposed. This enabled lower average deceleration and greater "arrival time" (less chances of pedestrian "conflict"). Such a result could imply anticipation of the event and predetermination of response strategy.

The effect of the secondary (message) task on the traffic signal response was consistent with the driver acting according to expectations concerning the primary task (as per Tijerina, 2000). The traffic signal task modelled a situation encountered by drivers dozens of times every day and for which they have undoubtedly established workable coping strategies which allow them to successfully "multi-task". It is easy to see how drivers could make an a-priori decision to favour stopping as opposed to running an amber light, in order to divert some attention to responding to a cell phone, although such a strategy cannot be taken to mean that phone use has an inherent safety benefit.

But when the driving task moved away from the familiar and towards the more demanding, the effect of the cell message intervention on driver performance changed. In the more critical short-trigger weave situation (short spaces between targets), drivers took more time to respond in easing-up on the accelerator pedal when the messages were playing than they did under the no-message condition. They then made significantly less speed adjustments and ended-up going substantially faster through the weave manoeuvre than they did when not exposed to the messages. Thus the margin of safety in the short-weave task can be said the have been significantly reduced by the addition of the secondary "cell-phone" message task.

However, the most clear-cut impact of the messages was found in the left-turn task as had been anticipated based on the literature review. Listening and responding to the messages was associated with significantly riskier decision making (shorter accepted gaps) on the part of the subjects when the ambient test conditions reflected slippery road conditions. Drivers adjusted their gap acceptance decision-making significantly for wet conditions (i.e., gaps increased in size and time) when not subjected to the message task but did not do so when attending to the messages. The necessity to factor-in lower approach vehicle speed change potential as a result of reduced road/tire friction levels would logically add a substantial degree of difficulty to the decision process. This additional mental demand seemed to be impaired by the attention required for listening/responding to the messages, with the result that safety margins were significantly degraded.

## 5. Conclusions

Listening and responding to relatively complex messages, as might occur when using a hands-free cellular telephone to conduct business or deal with important domestic issues, was found to significantly degrade driving performance in a series of driving tasks. The extent to which this degradation occurred seemed connected to the complexity of the driving manoeuvre. Commonly encountered traffic signal-related choices tended to elicit conservative decision-making in the presence of the messages but the somewhat less common events of weaving and left turning demonstrated a significant negative impact of message attention.

Most importantly though, there was evidence that the problems associated with divided attention (driving and message attention/response) were exacerbated by adverse driving conditions. Attention to the secondary message task seemed to prevent the normal adjustment by drivers for potentially slippery road conditions in their decision-making.

While it was not possible to make a direct connection to crash risk from the experimental results, the nature of the driving performance degradations measured in relation to the presence of the message task clearly point to potential safety-related problems associated with such things as phone use while driving – even if such use does not involve physical manipulation of the device.

## 6. References


- Lee, J.D., Caven, B., Haake, S., Brown, T.L., 2000. Speech-based interaction with in-vehicle computers: the effect of speech-based E-mail on drivers' attention to the roadway. Internet Forum on Driver Distraction, NHTSA.

- Noy, I., Cassidy, H., Brown, C.M., 1999. Quality of Driving with Cellular Telephones. Technical Memorandum TME 9901, Road and Motor Vehicle Regulation Directorate, Transport Canada, Ottawa.

- Ranney, T.A., Mazzae, E., Garrott, R., Goodman, M.J., 2000. NHTSA driver distraction research: past, present and future. Internet Forum on Driver Distraction, NHTSA.

- Redelmeier, M.D., Tibshirani, R.J., 1997. Association between cellular-telephone calls and motor vehicle collisions. The New England Journal of Medicine, 336 (7), 453-458.

- Tijerina, L., 2000. Issues in the evaluation of driver distraction associated with in-vehicle information and telecommunications systems. Internet Forum on Driver Distraction, NHTSA.

**Table 1**

Significant Differences in Outcome Measures Related to Message Presence / Absence During Traffic Light Tests

| Condition | Significant Effect | Message Absent N | Message Absent mean | Message Present N | Message Present mean |
|---|---|---|---|---|---|
| stop long-trig. | deceleration | 33 | 0.34 | 33 | 0.32 |
| | arrival time (TTC) | 33 | 2.67 | 33 | 2.73 |
| | dry surface | 17 | 2.51 | 17 | 2.51 |
| | wet surface | 15 | 2.36 | 15 | 2.44 |
| stop short-trig. | time to brake contact | | | | |
| | age 19-24 | 5 | 1.00 | 5 | 0.97 |
| | age 25-44 | 19 | 1.01 | 19 | 0.87 |
| | age 45-70 | 8 | 1.05 | 8 | 1.21 |
| run long-trig. | initial speed choice | | | | |
| | male | 9 | 51.77 | 9 | 51.91 |
| | female | 7 | 53.30 | 7 | 53.36 |
| | dry surface | 7 | 52.78 | 7 | 52.63 |
| | wet surface | 9 | 52.18 | 9 | 52.48 |
| | age 19-24 | 2 | 54.61 | 2 | 51.63 |
| | age 25-44 | 10 | 52.43 | 10 | 52.77 |
| | age 45-70 | 4 | 51.38 | 4 | 52.43 |
| run short-trig. | initial speed choice | 24 | 51.96 | 24 | 53.12 |
| | male | 17 | 51.84 | 17 | 52.40 |
| | female | 7 | 52.26 | 7 | 54.85 |
| | acceleration | 24 | 2.12 | 24 | 2.24 |
| | red light clearance | | | | |
| | dry surface | 9 | -0.35 | 9 | -0.34 |
| | wet surface | 15 | -0.24 | 15 | -0.32 |

**Table 2**

Significant Differences in Outcome Measures Related to Message Presence / Absence During Pop-up Target Tests

| Condition | Significant Effect | Message Absent N | Message Absent mean | Message Present N | Message Present mean |
|---|---|---|---|---|---|
| widely-spaced | arrival time (TTC) | 36 | 1.73 | 36 | 1.50 |
| closely-spaced | deceleration | 35 | 0.36 | 35 | 0.33 |
| | speed through targets | 35 | 23.45 | 35 | 25.90 |
| | speed change | 35 | -27.66 | 35 | -25.14 |

**Table 3**

Significant Differences in Outcome Measures Related to Message Presence / Absence During Left-Turn Tests

| Condition | Significant Effect | Message Absent N | Message Absent mean | Message Present N | Message Present mean |
|---|---|---|---|---|---|
| left-turn | average gap size acc. | | | | |
| | dry surface | 23 | 57.13 | 23 | 56.00 |
| | wet surface | 18 | 59.18 | 18 | 55.76 |
| | average gap time acc. | | | | |
| | dry surface | 23 | 3.93 | 23 | 3.90 |
| | wet surface | 18 | 4.10 | 18 | 3.90 |
| | arrival time (TTC) | | | | |
| | dry surface | 23 | 4.32 | 23 | 4.28 |
| | wet surface | 18 | 4.37 | 18 | 4.17 |

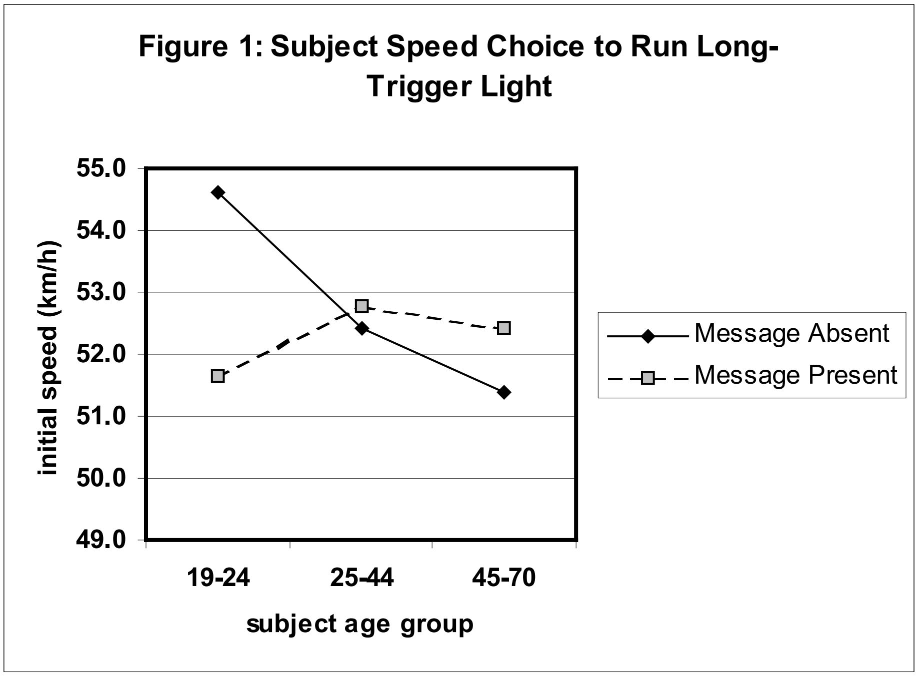
Figure 1: Subject Speed Choice to Run Long-Trigger Light
55.0
54.0
53.0
52.0
51.0
50.0
49.0
initial speed (km/h)
19-24
25-44
45-70
subject age group
Message Absent
Message Present

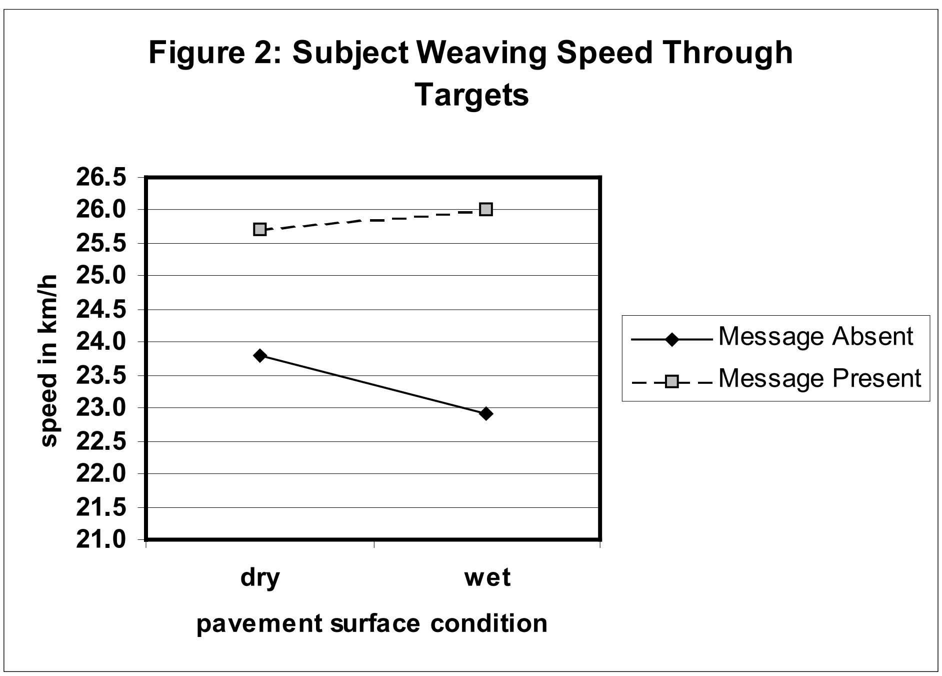
Figure 2: Subject Weaving Speed Through Targets
26.5
26.0
25.5
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
21.0
speed in km/h
dry
wet
pavement surface condition
Message Absent
Message Present

**Figure 3: Left-Turning Gap Time Accepted by Subjects**