# DRIVING UNDER THE INFLUENCE OF PHONES: THE IMPORTANCE OF COGNITIVE ABILITY AND COGNITIVE STYLE ON INTERRUPTION-RELATED PERFORMANCE

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The impact of notifications on driving performance is a critical safety concern (Lee & Strayer, 2004). This study examined how interruptions (including phone calls) impair simulated driving performance, and how individual differences mediate the effect of those interruptions. Consistent with our hypothesis, field dependent participants answered phone calls more quickly and with less consideration of the difficulty of the current driving situation than more field independent participants. Further, a post-hoc analysis showed that, on average, field dependents with small operating spans crashed twice as often as the other drivers. Thus the detrimental effect of a field dependent style on managing interruptions while driving is likely worsened for people with low working memory capacity. It is suggested that future research should investigate the safety implications of individual differences in interruption handling ability. Such research is needed to support ongoing efforts to develop guidelines and legislation concerning the use of distracting information technologies (such as cell phones) in automobiles.

## INTRODUCTION

Driving is a task in which minor fluctuations of attention result in important performance impacts such as crashes. Since usage of personal technologies such as PDAs and cell phones is growing, the impact of notifications on driving performance has become a critical safety concern (Lee & Strayer, 2004). Underscoring the prevalence of cell phone use while driving, the U.S. National Highway Transportation Safety Administration estimated that, at any given time during daylight hours, around one in twelve of drivers on U.S. roads are using their cell phone (Glassbrenner, 2005).

Cell phone use has been shown to impair driving performance in a number of studies. For instance, Strayer et al. (2006, p. 386) found that cell phone use was associated with more rear-end collisions, delayed reaction to lead vehicle braking by 9%, and increased variability in following distance by 24%, relative to baseline.

The distracting effect of cell phones is not due to the need to hold a handset or view its display. This suggests that distraction due to cell phone use is more centrally based, likely involving attentional mechanisms.

Cell phone use can be divided into different sub-activities, beginning with call notification, initiating dialogue, carrying out the conversation (including listening, thinking and talking), terminating the dialogue, and recovering from the interruption/call. In particular, call notification is of interest as it is known that auditory interruptions tend to capture attention at the expense of an ongoing visual task (e.g., Wickens and Liu, 1988; Wickens et al., 2005). Once the driver's attention is captured by the ringtone of a cell phone she then has to decide if and when to answer the call. Baran and Chignell (2006) found that personality variables have a mediating effect in determining how much simulated driving performance is affected by cell phone use. They found that a field dependent cognitive style (a measure of information processing style) and lower operating span (a measure of working memory) led to more impairment of driving performance due to cell phone use. Conversely, in the high risk situation of being on-call and on a curve in the road, they found that those with a higher operating span engaged in safer driving behavior by maintaining a larger time to collision (i.e., a greater distance from the vehicle in front).

In the research reported in this paper, cognitive style (cf. Goodenough, 1976a) and operating span are explored with respect to how they mediate the effect of interruptions while driving. Operating span is of interest because, during a dual task (such as cell phone use while driving) attentional resources are allocated between the primary and secondary tasks, creating a load on working memory. Thus, larger working memory capacity should contribute to better performance on both tasks. The effects of working memory have been studied in the driving context: Guerrier et al. (1999) found that the size of working memory was significantly related to decision time and gap choice in a left hand turning task. Cognitive style or field independence (Witkin et al., 1977) has also proven to have a significant effect in divided attention tasks, or interruptions. For example, during a fast-paced envelope stuffing task, Jolly and Reardon (1985) found that field dependents switched more of their attention to interruptions, resulting in poorer primary task performance. Goodenough (1976b) concluded from a survey of relevant literature that field dependent individuals tend to be involved in more accidents than field independent individuals. More recently, a research report by the United States Department of Transportation (1997) on improving transportation for an aging listed field dependence (cognitive style) as a potential factor that may be related to age and driving ability. Thus there is strong evidence that field dependence may be a risk factor when driving, and that switching between driving and responding to interruptions is a task where salient characteristics of the environment, such as audio alerts, compete with attention paid to the road.

We chose to extend Baran and Chignell's (2006) work by examining the effect of different types of interruptions in more detail. A within-subjects interruptions factor with three levels was used. The interruptions factor consisted of the following levels: 1. immediate (no-ringing, simulating a "push-to-talk" style of interaction; 2. a phone call notified with a typical ("ringing") ringtone; 3. A pager style notification with standard beeping. Note that the participant could choose when to interact in levels 2 and 3 ("negotiated" interaction), whereas the user had no control over when the other party started talking in the first ("direct") condition.

## METHODS

A mixed (between/within) experimental design was used to compare participants based on (between subject) individual differences and (within subject) different types of notifications. During a 30-minute driving task, participants were interrupted 30 times either directly (by someone talking to them without prior notification), or by phone and pager calls where a mathematical question was asked. Thus, the three types of interruptions used in the study were: immediate (or direct vocalization of the math question), phone (math question preceded by up to 10 rings) and pager (similar to phone, except beeps instead of rings). Interruptions consisted of mathematical questions that, when answered correctly, provided financial remuneration.

An STISIM driving simulator (Systems Technology Inc.) was used to capture driving performance. The setup included three monitors for the driving scene, the accelerator and brake pad, the steering wheel and the response set-up for notification receipt, which was a mouse affixed to the centre of the steering wheel (Figure 1). The driving-related dependent measures were: number of crashes, minimum time to collision (TTC) and other performance indicators, such as lateral and longitudinal acceleration. The driving-related measures were collected during notification time (e.g., when the phone was ringing), during question response times, and in between. The dependent measures collected during interruptions were: response time to ringing/beeping, response time to math questions, and accuracy of math responses.

Figure 1. Experimental Set-up

Participants ranged between 19 and 33 years of age with a mean age of 23.5 years. 15 of the 20 participants were male. 11 of the participants had English as their first language. The remaining participants were fluent in English and had no difficulty in understanding the experimental instructions. On average, participants had between 4 and 6 years driving experience, and at the time of the study drove less then one hour per day. The mean length of time that participants had owned a cell phone was 3.29 years, with the participants reporting that they spoke on their cell phones an average of 19 minutes per person per day.

Participants first completed a background questionnaire. They then completed two standardized tests: a mixed numeric and verbal test presented on a PC to measure Operation Span using the OSPAN procedure of Conway & Engle (1996), and the group embedded figures test (GEFT) for field dependence (Witkin et al., 1971; Figure 2). Participants were then given 10 minutes of driving practice, five of which included interruptions. This was followed by the study session, consisting of 30 minutes of driving with one interruption initiated at a random point during each minute (30 interruptions total, consisting of 10 direct, 10 'phone' ringtones and 10 'pager' ringtones). Interruptions had up to 4 phases: hearing the ringing or beeping, listening to the mathematical question (named 'listening' phase), answering the question (named 'answering' phase) and a 15 second recovery period (named 'recovery').

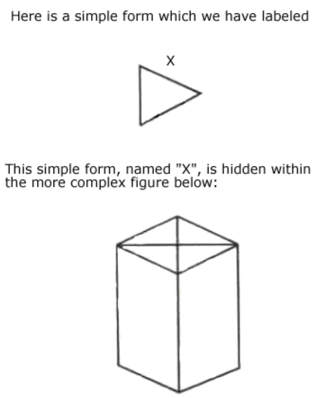



Figure 2. Example of GEFT item

Statistical relationships between driving performance and individual differences were analyzed in order to assess the effects of individual differences, interruption type, and interruption phase on driving performance. The individual difference factors (cognitive style and working memory) were each dichotomized into two levels for the analysis by dividing the sample around the median into high and low groups. Pearson's correlations were used to detect relationships between variables. ANOVAs were conducted to assess the effects of the experimental factors.

## RESULTS

### Handling Notifications

As expected, the field dependents answered ringing and beeping (phone and pager interruptions) more quickly (2.18s vs 2.88s; $F[1,394]=17.47$, $p<.001$) than did the more field independent participants. In addition, this was not due to field dependents being quicker to respond in general, since on average they answered the math questions more slowly (4.00s vs 3.47s; $F[1,567]=5.30$, $p=.022$) than field independents. There was also a trend for field dependents to have more collisions ($r=-.421$, $p=.065$) as was also found by Baran and Chignell (2006).

Those with large operating span answered ringing and math questions more quickly (2.30 s vs 2.83 s; $F[1,392]=10.90$, $p=.002$; 3.48 s vs 3.93 s; $F[1,567]=3.89$, $p=.049$) when compared with those with smaller operating spans.

Across all participants, the average response time to math questions was faster for negotiated interruptions (3.50 s vs 4.05 s; $F[1,567]=4.56$, $p=.033$) than it was for immediate interruptions.

### Interruptions and Driving Performance

The driving performance of field dependents was more sensitive to different phases of the interruption task ($F[2,26]=5.98$, $p=.007$; Figure 3). With respect to lateral acceleration, field independents used similar levels of lateral acceleration regardless of the phase of the secondary task, whereas field dependents used less lateral acceleration when listening to ringing or beeping and talking, but more when there was no interruption (secondary task) to deal with.

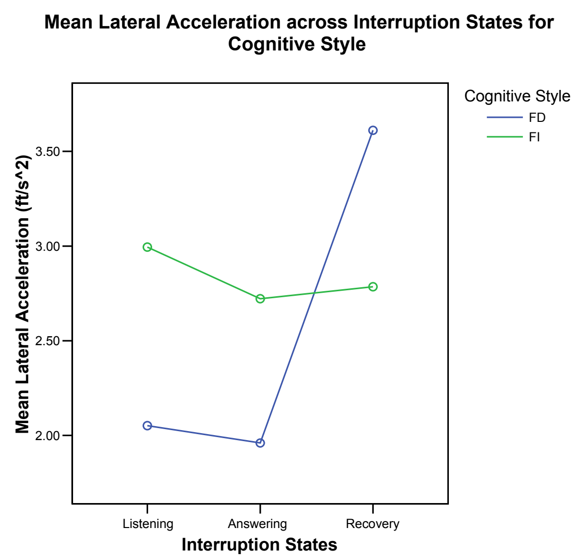
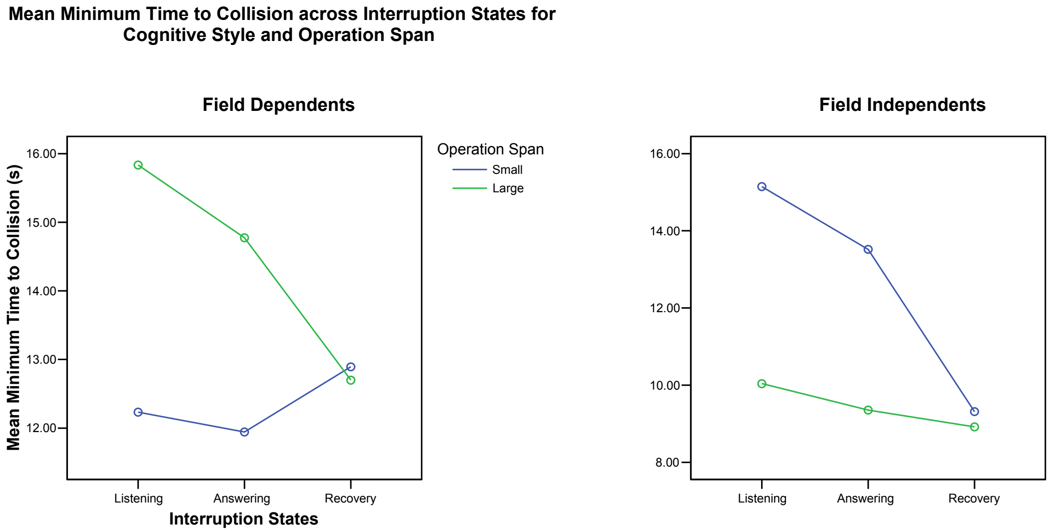



Figure 3.

There was a three-way interaction between cognitive style, working memory, and task phase ($F[2,26]=3.468$, $p=.046$; Figure 4a, 4b). Time to collision tended to be low for people who were field independent and had higher working memory, and also for people who were field dependent and had lower working memory




Figures 4a, 4b.

during the listening and answering phases of the task.

A post-hoc analysis then examined high and low risk groups. The sample was divided into two groups based on median values: one group contained field-independent and high operating span (n=11) participants, and was labeled as low risk, with the remaining participants being labeled as high risk (n=9). There was a significant difference in terms of number of collisions (m low-risk=7, m high-risk=14; F[1,18]=5.88, p=.026) between the groups.

## DISCUSSION

As has been found in previous research (McFarlane, 2002), negotiated interruptions yield better performance than immediate interruptions. The research reported in this paper extended the earlier work by showing that individual differences mediate the impact of different types of interruptions.

Previous driving research has investigated the general presentation of warning signals (e.g., Kantowitz et al, 1997; Deatherage, 1972) and found that audio signals should precede instructions for a necessary impending action.

In this study, field dependents chose to answer the ringing or beeping more quickly and math questions more slowly. This indicates that they were reactive to the salient audio cue of the notifications, and then switched their attention back to the driving task once the audio notification stopped. This strategy is not ideal for attentionally critical tasks such as driving, where drivers need to focus their attention based on relevance to safety and not on perceptual salience. As a result of their interruption-related strategies, this group suffered poorer driving performance in terms of collisions, and greater instability in lateral acceleration.

As with past research, we found that higher working memory participants showed better performance, answering ringing and math questions quickly while maintaining safer driving in terms of fewer collisions.

Minimum time to collision (TTC) represents a safe ‘buffer’ zone between one’s own vehicle and surrounding vehicles. During interruptions, field independents with large operating span and field dependents with small operating span kept a small TTC, when compared to field independents with small operating spans and field dependents with large operating spans. For the field dependents with small operating spans, this behaviour was maladaptive and led to more crashes, while for the former group, it was associated with fewer crashes. This effect implies that the intersection of field independence with large operating span lends itself to less need for a large buffer safety zone. In other words, field independents with a large operation can handle safe driving with lower minimum time to collisions (as shown by no greater tendency towards collisions).

## CONCLUSIONS

The results from this study may be useful to inform the design of in-vehicle systems that can accommodate individual differences safely and effectively. For example, a GPS navigation aid that announces directions such as “left turn up ahead” should use an audio warning tone. All cognitive types appear to benefit from this type of warning signal. Moreover, non-critical messages could be presented with a negotiated warning signal (involving a driver response to hear the message), and critical messages could be proceeded with an appropriate tone.

Knowledge of individual differences may also be useful in setting default configurations for in-vehicle systems. For instance, since field dependents had a tendency to answer the notification instantaneously regardless of the driving situation, they could benefit from a filter for incoming messages. However, such a filter would not be as useful for field independents, in particular those with large working memories.

Perhaps the most important implication of the research reported in this paper is that information technologies that provide distractions to the driving task may be dangerous for field dependent drivers with low working memories. While this is not a surprise given relevant earlier research findings, this research, along with that of Baran and Chignell (2006), shows how working memory and field dependence interact with each other in determining the effect of in-vehicle interruptions on driving performance. Unfortunately since most engineers tend to be field independents with high working memory, the dangers of using distracting technologies within cars may not be readily apparent to them unless extensive testing is carried out with samples that include a significant proportion of field dependent people with low working memory.

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## REFERNCES

Baran, M., & Chignell, M. (2006). Difference in cognitive ability and preference mediate effects of interruptions on simulated driving performance. *In Proceedings of the Human Factors and Ergonomics Society 50 th Annual Meeting.* 2008-2013.

Conway, A.R.A., & Engle, R.W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory 4*, 577-590.

Deatherage, B. H. (1972). Auditory and other sensory forms of information presentation. In H.Van Cott & R. Kinkade (Eds.), Human engineering guide to equipment design (revised ed., pp. 123-160). Washington: U.S. Government Printing Office

Glassbrenner, D. (2005). Driver cell phone use in 2004 – Overall results. In *Traffic safety facts: Research note*( DOTHS 809 847). Washington, DC: U.S. Department of Transportation.

Goodenough, D.R. (1976a). The role of individual differences in field dependence as a factor in learning and memory. *Psychological Bulletin, 83*, 675-694.

Goodenough, D.R. (1976b). A review of individual differences in field dependence as a factor in auto safety. *Human Factors*. *18(1),* 53-62

Guerrier, J.H., Manivannan, P., & Nair, S.N. (1999). The role of working memory, field dependence, visual search, and reaction time in the left turn performance of older female drivers, *Applied Ergonomics, 30*, 109-119.

Jolly, E. J., Reardon, R. (1985). Cognitive differentiation, Automaticity, and Interruptions of Automatized Bevaviors, *Personality and Social Psychology Bulletin, 11(3),* 301-314.

Kantowitz, B. H., Hanowski, R. J., Kantowitz, S. C., & Garness, S. A. (1997). Development of human factors guidelines for advanced traveler information systems and commercial vehicle operations: Display channels. Washington, DC: Federal Highway Administration (FHWA-RD-96-148).

Lee, J., & Strayer, D. (2004). Preface of special issue on driver distraction. *Human Factors. 46(4),* 583-586.

McFarlane, D. C. (2002). Comparison of four primary methods for coordinating the interruption of people in human-computer interaction. *Human-Computer Interaction, 17 (1),* 63-139.

Strayer, D. L., Drews, F. A., & Crouch, D. L.(2006). A comparison of the cell phone driver and the drunk driver. *Human Factors: 48(2)*, 381-391

United States Department of Transportation (1997). Improving transportation for a maturing society. Report number DOT-P10-97-01.

Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cox, P. W. (1977). Field dependent and field independent cognitive styles and their educational implications. *Review of Educational Research, 47,* 1-64.

Wiktin, H.A., Oltman, P.K., Raskin, E., & Karp, S. A. (1971). *Group Embedded Figures Test Manual.* Palo Alto, CA: Consulting Psychologists Press.

Wickens, C., Dixon, S., & Seppelt, B. (2005). Auditory preemption versus multiple resources: Who wins in interruption management? In *Proceedings of the Human Factors and Ergonomics Society 49 th Annual Meeting*. 463-467.

Wickens, C.D. & Liu, Y. (1988). Codes and modalities in multiple resources: A success and a qualification. *Human Factors, 30(5),* 599-616.