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Effect of Emotional Speech Tone on Driving from Lab to Road: fMRI and ERP Studies

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ABSTRACT

Evoked Response Potential (ERP) and functional Magnetic Resonance Imaging (fMRI) recordings in this study shed light on underlying neural mechanisms for higher cognitive processes and attention allocation during multitasking of cell phone conversations and driving. Behavioral results indicated that hands-free cellular phone conversations caused statistically significant but small reaction time effects for visual event detection during simulated and on-road driving. The validated *Static Load* driving paradigm gives rise to high correlations of red light reaction times between lab and on-road. Both ERP and fMRI findings suggested that cognitive distractions are correlated with increased cognitive load and attentional distribution. The novel contribution of this ERP and fMRI study is that adding an angry emotional valence to the speech increased the alertness level, resulting in reduced driver distraction, likely via increases in right frontoparietal networks and dampened or desynchronized left frontal activity.

Keywords

Driver performance; voice interfaces; cell phone conversations; emotion effect while driving; emotional prosody; distraction.

1. INTRODUCTION

Driving is commonly referred to as a single task. But driving is really complex multitasking, involving sensory, motor, and higher-level cognitive components. These play out over different levels of functional hierarchy, on different timescales, and often concurrently [1,2]. Multitasking experiments give cognitive neuroscience researchers a unique platform for viewing language use in one of its most natural forms – in a multisensory processing environment. By seeing how the brain allocates resources for conversation while engaged in a driving task, we can find what the shared anatomy and networks are for language, executive functions, and general perceptual processing.

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Many investigations into human performance involve the use of driving simulators. What is often lacking is a validation of these simulators using on-road data. In this study, we investigated the effects of conversation and emotional speech on multitasking performance in the validated *Static Load* driving paradigm [5], an enhanced Peripheral Detection Task. Behavioral validation studies for predicting event detection on the road from lab data have recently shown excellent results, with correlations of 0.9 for brake reaction times to visual events [5]. Validation is especially important given the cognitive complexity of a real-world driving task and the public policy implications of driver performance research. Our group is the first to apply neuroscience measures to a validated driving simulation paradigm.

Previous research suggests that emotion can influence perceptual processing. We here ask whether emotion interacts with the use of a cellular phone in influencing visual event detection during driving.

Phelps et al. (2006) demonstrated that contrast sensitivity functions are enhanced when cued by an emotional stimulus, suggesting early visual processes may be modulated by emotion. Zeelenberg et al. (2006), using a perceptual identification task, teased apart the effects of enhanced processing from emotional perceptual bias, stating that it is likely that perceptual bias may underlie enhanced performance in emotional tasks.

One mechanism by which emotion may facilitate processing is via early negativity in Event Related Potentials (ERPs) at posterior brain sites. Schupp et al. (2004) observed increased negativity early in ERPs over temporal-occipital sites during the presentation of emotional visual stimuli. How might this effect operate in a multitasking situation, when emotional stimuli are paired with non-emotional visual targets?

The goal of this project was to examine the interplay between driving performance and emotion during a multitasking scenario using ERPs and functional Magnetic Resonance Imaging (fMRI).

2. METHODS

2.1 Tasks

Lab Testing

The primary task for subjects was the *Enhanced Static Load Task* (ESLT) [5]. Participants watched a video of a real driving scene, used a steering wheel to keep a pointer centered over their lane, and responded with the brake pedal to visual targets (red circles). They were told to respond as fast as possible, while inhibiting responses to non-targets (green circles).

Subjects also performed hands-free phone conversations during simulated driving. Four different calls were received (each lasting 1 minute) per 9-minute test block. Each experimental run contained 2 conversations each with angry and neutral speech stimuli.

In the angry speech condition, simple questions were asked using an *angry* speech tone (only stimuli that were consistently rated as *angry* in a preliminary rating task were used). In the neutral speech condition, simple questions were asked using a *neutral* speech tone. Each participant completed 3 runs (4 conversations each), and a baseline run (*just driving* with no conversation).

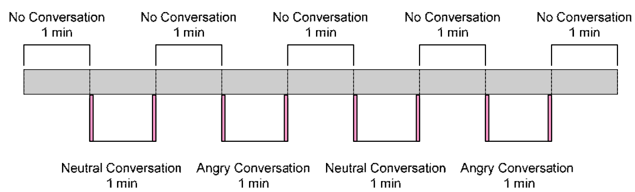

Figure 1. Task Paradigm.

On-Road Testing

On-road testing was conducted at the University of Michigan Transportation Research Institute (UMTRI) in Ann Arbor, Michigan. Rather than monitoring a video screen, drivers in the on-road task monitored the roadway, as in normal driving. The in-vehicle target detection task used two pairs of red and green high-output light emitting diodes (LEDs), one pair positioned in the straight-ahead direction (approximately 6 degrees down) and the other pair near the driver-side rear view mirror (35 degrees left, 12 degrees down), imitating the previously described laboratory presentation. The LEDs were located approximately 75 cm from the Cyclopean eye position.

Participants pressed a button to answer calls, and the same button to end calls. While performing this task, subjects drove a test vehicle on real roads. Figure 2 shows the on-road vehicle set-up, with targets. As in the lab, they engaged in simulated cell phone calls while completing the primary task of driving while responding to the LEDs.

Figure 2. Layout of the instrumented vehicle for on-road testing.

2.2 EEG and MRI Brain Imaging

Electroencephalography (EEG) data were recorded from 20 subjects using a 64-channel Waveguard cap. Data were bandpass filtered at 1-30 Hz, corrected for artifacts using Independent Components Analysis, averaged with artifacts removed, and corrected for baseline differences. EEG signals from 22 central electrodes were organized by position – front, middle, and back – into a three level factor for statistical analysis purposes. Within-subject ANOVAs were computed on minimum (N200) and maximum (P300) amplitude using position and condition as factors. Effects were assessed within 200 msec blocks (N200 = 150 – 250 msec post stimulus onset; P300 = 250 – 350 msec). Interaction terms indicate changes in effects across the scalp.

N200 and P300 are components of event-related potentials (ERPs) time-locked to the onset of a stimulus. In our studies, that stimulus was the visual target. Changes in N200 and P300 magnitude have been found to reflect changes in various aspects of cognitive processing, such as target anticipation, By observing differences in these components over different scalp sites, we can hypothesize about the timing of various cognitive processes that may be interfering between secondary and primary tasks.

We collected functional Magnetic Resonance Imaging (fMRI) data from 10 participants using a 3T GE MRI at Henry Ford Hospital. Due to the restraints of the scanner, the visual angle from the center light to the left light was reduced from 20 degrees to 12 degrees. Participants steered using a handheld controller with two buttons, and again responded to red targets using a foot pedal.

Figure 3. EEG (left) & MRI (right) imaging of Simulated Driving.

2.3 Metrics

- Response time (secs) to target red lights
- Percent missed red lights
- Event Related Potentials based on EEG brain waves
- Functional MRI brain activations associated with experimental conditions.

3. RESULTS

3.1 Behavioral Performance

Behavioral results showed longer visual reaction times during a concurrent speech task (purple bars) than with no speech (blue bars) in lab and car (See Fig. 4), with no statistical interaction between the sites. However, this effect was moderated by presenting speech questions in an angry voice (yellow bars). No significant differences were found in miss rates between experimental conditions and between testing sites. Same behavioral effects during fMRI (see Fig. 5).

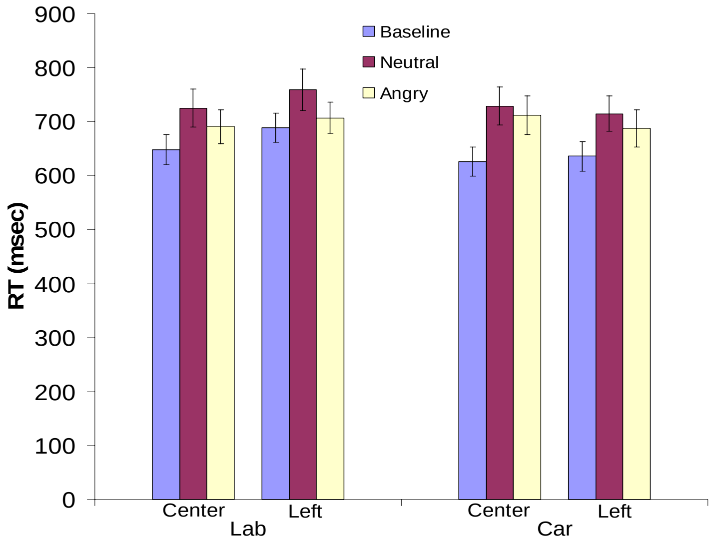

Figure 4. Conversation and Emotion Effects on Visual Event Detection during Driving in the EEG Lab and On-Road (Behavioral Reaction Times). Blue bars = baseline, red = neutral, yellow = angry condition.

3.2 EEG findings

Across-scalp peak evoked amplitude differences were significant. The N200 (top) varied across position and condition (p < .001). The P300 (bottom) also varied across position and condition (p < .05) in Fig. 6. While neutral speech peaks were larger than no speech peaks across scalp, the pattern changed with angry speech, showing larger mid-peaks (orange) at N200 and larger posterior peaks (brown) at P300.

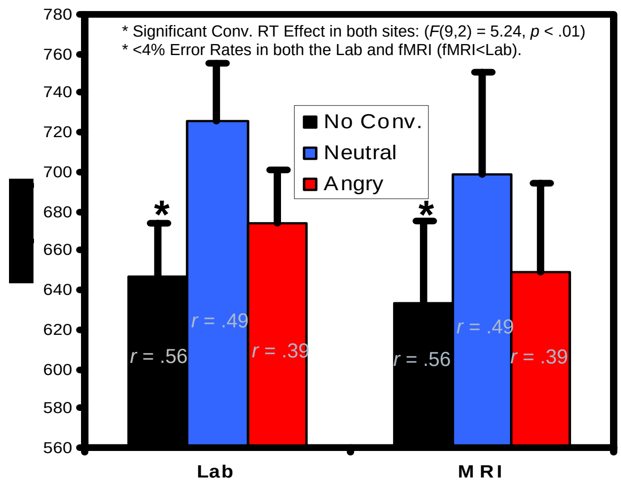

Figure 5. Conversation and Emotion Effects on Visual Event Detection during Driving in the EEG Lab and MRI center (behavioral Reaction Times). *Lab* refers to EEG testing while sitting in the lab, and *MRI* to fMRI testing in the fMRI magnet.

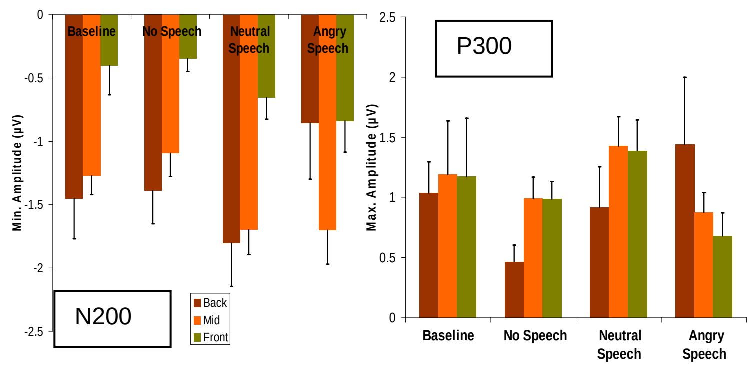

Figure 6. ERP Results of Conversation and Emotion Effects during Simulated Driving in the Lab (based on EEG brain signals). The colored bars show back, mid, and front electrodes.

3.3 fMRI brain activations

The fMRI analysis indicated increased activations ($t > 3.2$; $p < 0.002$) associated with both neutral and angry speech tasks, compared to no speech, in the bilateral temporal lobes, the left inferior frontal gyrus, and the left middle frontal gyrus; and decreased activations in the right inferior parietal lobe and the right cuneus (Fig. 7).

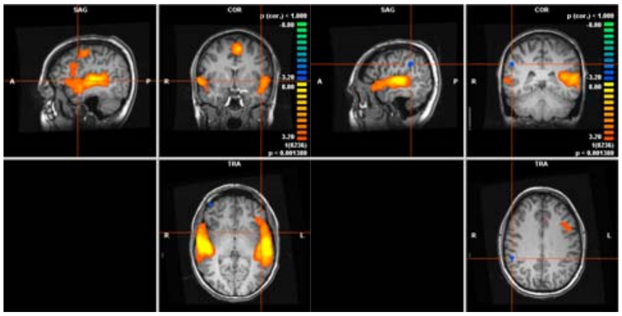

Figure 7. fMRI findings on conversation effect while driving.

Figure 8 shows direct comparisons between angry and neutral speech tasks with increased activations ($t > 2.8$; $p < 0.006$) in the right prefrontal gyrus, the right middle frontal gyrus (BA10), the right insular, the right superior temporal gyrus, the right paracentral lobule (BA5), the right claustrum, and the right inferior parietal lobe (BA40). Decreased activations were found in the left frontal operculum, the left lingual gyrus (BA18), and the left parahippocampal gyrus (BA28).

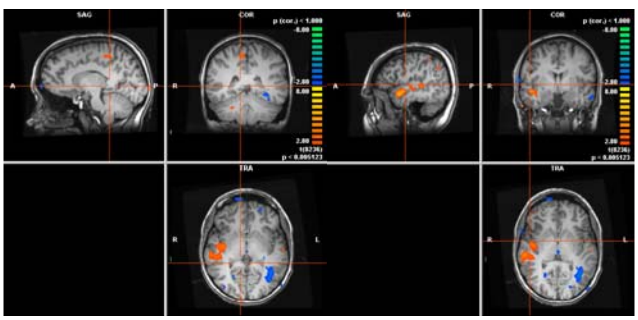

Figure 8. fMRI findings on emotional speech effect while driving.

4. DISCUSSION

These results confirm well-known previous findings that speech compared to no speech gives rise to slightly longer behavioral reaction times. We also confirm with our ERP and fMRI metrics that speech increases brain activation in language and attention areas. The novel finding is that an angry emotional tone improves behavioral reaction time performance compared to a neutral tone, while eliciting the right frontoparietal networks and either desynchronizing or dampening the left frontal activity.

5. CONCLUSIONS

We conclude that an emotional stimulus such as angry speech provides a processing advantage. The neural mechanism may be linked to an early central negativity and later posterior positivity, or an enhanced "readiness to respond" in central and posterior cortical regions linked to attention. The fMRI and EEG findings in this paper could have significant impact on the testing and design of in-car speech interfaces.

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