The use of EMG and video to decompose driver crash avoidance and bracing response

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While a number of physiological variables are used to assess driver performance, the use of electromyography (EMG) to examine onset and amplitude of response has been relatively rare. In this study, surface EMG was used to complement a frame-by-frame video analysis of driver posture in a simulated head-on crash. To determine how EMG adds to the overall understanding of the pre-crash bracing response, five females and five males (mean age =35.4; SD = 7.7) participated in a motion-base driving simulator experiment in which they experienced an unexpected head-on crash with a semitruck. The onset and amplitude of muscular response in the finger flexors, mid cervical extensors, and trapezius muscles were collected at 1000 Hz and integrated into driving simulator data. A frame-by-frame analysis was also completed to decompose driver posture and bracing. A probability analysis among non-vehicle control parameters (e.g., acceleration, braking, steering) revealed that 100% of the drivers had some element of head withdrawal away from the frontal crash. The results also showed that EMG data were robust at showing onset of driver response to a simulated head-on crash. Because driving simulation environments are rich in electronic noise from projectors, actuators, and other electronic equipment, special consideration for shielding EMG is required.

Introduction

A variety of physiological measures have been used to assess driver performance (Lenneman, Shelley, and Backs, 2005; Michalski and Blaszczyk, 2004). Few studies, however, have examined muscle activity in relation to emergency driver response in actual or simulated crashes. Surface electromyography (EMG) has previously been used to study muscle fatigue (Katsis, Ntouvas, Bafas, and Fotiadis, 2004) and comfort issues in driving (El Falou, Duchene, Grabische, Hewson, Langeron and Lino, 2003). Because EMG can capture onset and amplitude of muscle response, it may add useful information to other driver response data collected via vehicle sensors (e.g., accelerator release, steering position, etc.). This is particularly true when the goal is to measure pre-impact posture.

In the field of crash injury control research, the use of human surrogates in the form of crash dummies and cadavers continues to be the ‘gold’ standard for injury prediction research. Such surrogates, however, are incapable of active musculature, and thus function in crash tests essentially as projectiles. The difference between a static crash dummy and a live human bracing in or out of position could make a substantial difference in injury prediction. Furthermore, it could have dramatic implications for injury biomechanics, crash worthiness and supplemental restraint researchers who currently must model driver biodynamic response and performance with the driver out-of-the-loop. Pre-impact bracing information could be vitally important to the integration of airbag deployments and advanced seatbelt pre-tensioning. While position sensors for intelligent airbag deployments are now in limited production, they are largely based on static dummy models and do not consider reactive postures, hand/arm position on the steering wheel, or foot position/placement. It is obviously unethical to place live humans into situations in which severe unalerted impacts occur, and as a result, there is a paucity of literature that addresses pre-impact response. High-fidelity driving simulation provides a unique platform to study such pre-impact behaviors. The purpose of this study was to determine how EMG adds to the overall understanding of the pre-crash bracing response.

Methods and Procedure

Participants

Five females and five males recruited from the general public and ranging in age from 24-49 participated in the simulator study (mean age =35.4; SD=7.7). Participants received $25 compensation for the two-hour study, which included the setup of EMG instrumentation and calibration as well as the simulator drive.

Simulator

The primary apparatus employed in this study was the University of Minnesota HumanFIRST program driving simulator, which is composed of SCANeR II software, a 1995 Saturn SC2 vehicle, and Epson 760 projectors presenting a 5-channel forward field of view of 210º (2.5 arcmin per pixel) and a single-channel rear field of view of 58º (3.0

arcmin per pixel). In addition, two side mirror LCD displays each provide a 19º field of view (1.8 arcmin per pixel). A 3D surround sound system, subwoofer, car body vibration units, a three-axis electric motion system (roll, pitch, Z-axis), and a high frequency vibration unit attached to the bottom of the vehicle provide auditory and physical feedback regarding the roadway surface, vehicle dynamics, and other traffic. The data sampling rate was set at 20 Hz.

EMG

Participants were instrumented with six surface EMG electrodes bilaterally over the finger flexors (to measure steering wheel grip), mid cervical extensors of the neck (to measure cervical withdrawal), and upper trapezius muscles (also to measure cervical withdrawal). Standard electrode locations were used (Zipp, 1982) to ensure proper placement of each electrode (Figure 1a). Electrodes were attached to an EMG data acquisition system (Therapeutics Unlimited EMG Amplifier, Iowa City, Iowa; Spike 2, Cambridge, England).

Figure 1a. Measurement of muscle groups for electrode placement; Figure 1b. Mid cervical extensor EMG electrode placement.

After the electrodes were attached, each participant went through a series of submaximal muscle contractions and rest sequences to calibrate (or "normalize") the EMG. This process allows comparisons of muscle activity between individuals.

To calibrate the finger flexors, each participant placed their arm in a standard position and gripped a hand dynamometer until 20 foot pounds / inch^2 (4.2859122 kg/mm) was achieved (Figure 2a). To calibrate the upper trapezius muscles, participants elevated their arms out to the side while a five-pound weight (2.3 Kg) was placed on top of the each hand (Figure 2b). To calibrate the mid-cervical extensors, participants lay prone on a padded table. They hung their heads over the edge of the table and a 10 lb. weight (4.6 Kg) was suspended from their heads (Figure 2c). For all muscle groups, the calibration contraction was held for 20 seconds.

The raw EMG signal was root-mean-square (RMS) processed. The mean RMS amplitude of the middle 10 seconds of EMG was used for analysis. Baseline muscle activity during rest was also recorded. Muscle group contractions were rotated among the muscle groups so that there would be adequate rest between measurements.

Figure 2a. Hand dynamometer used for finger flexors calibration contractions; Figure 2b. Trapezius calibration contractions and hand weights; Figure 2c. Mid-cervical extensor calibration contraction measured in prone position.

Video analysis

In order to capture driver posture, positional information, and emotional response, video angles that captured the forward view, straight-on face, side profile, and foot position were also recorded (Figure 3).

Figure 3. Quad multiplex video image

Simulator drive

The simulated environment through which participants drove was a 15-kilometer long undivided rural highway. Each lane was 3.6-meters wide, depicted standard roadway markings, and was both flat and straight. The scenario also included a 1.8-meter paved shoulder, an additional 6 meters of flat grass beyond the edge of the shoulder, and beyond that, fields and occasional farms. Approximately 300 meters from the point at which participants began their drive there appeared on the right edge of the participant's lane a concrete jersey barrier that prevented the driver from moving right onto the shoulder of the roadway. Opposing lane traffic consisted of a mix of small and large vehicles (i.e., compact cars, sedans, pickup trucks, and semi-tractors) spaced approximately 500 meters apart from each other and traveling at approximately 90 kph. This oncoming traffic was included to reduce the likelihood that participants would steer left into the oncoming lane.

Each participant's task was to start the vehicle when instructed and drive down the roadway in their lane at the posted speed limit (i.e., 90 kph). As the 21st oncoming vehicle, a semi-tractor, approached the participant (approximately 180 seconds into the scenario) it suddenly and without notice swerved into the participant's lane. There were two parameters that influenced the event. First, the semi-tractor moved into the participant's lane at 1.8 seconds time-to-contact as calculated between the participant and event vehicle speeds. Second, time-to-center, the time it would take for the left edge of the semi tractor to reach the center of the participant's lane, was fixed at 1.8 seconds. Muscle activity was recorded during the entire simulated driving task.

Results

Each of the videos was scored manually frame-by-frame in a time series to decompose the pre-impact driver actions and behaviors. Frequency counts were tabulated for each set of behaviors in a time series. Probabilities for each behavior were then calculated. For the sake of brevity in this paper, only behaviors considered 'defensive' in nature are considered (non-vehicle control parameters such as steering and braking). Of particular interest was the observation of any behavior that was defensive in nature (e.g., moving head back or away from the danger of the head-on crash). It is especially significant that a head withdrawal occurred with all of the participants—having a probability of 1. Squinting/closing of the eyes was also a central feature of the non-vehicle control-related response, occurring 80% of the time, while mouths of the participants opened 65% of the time.

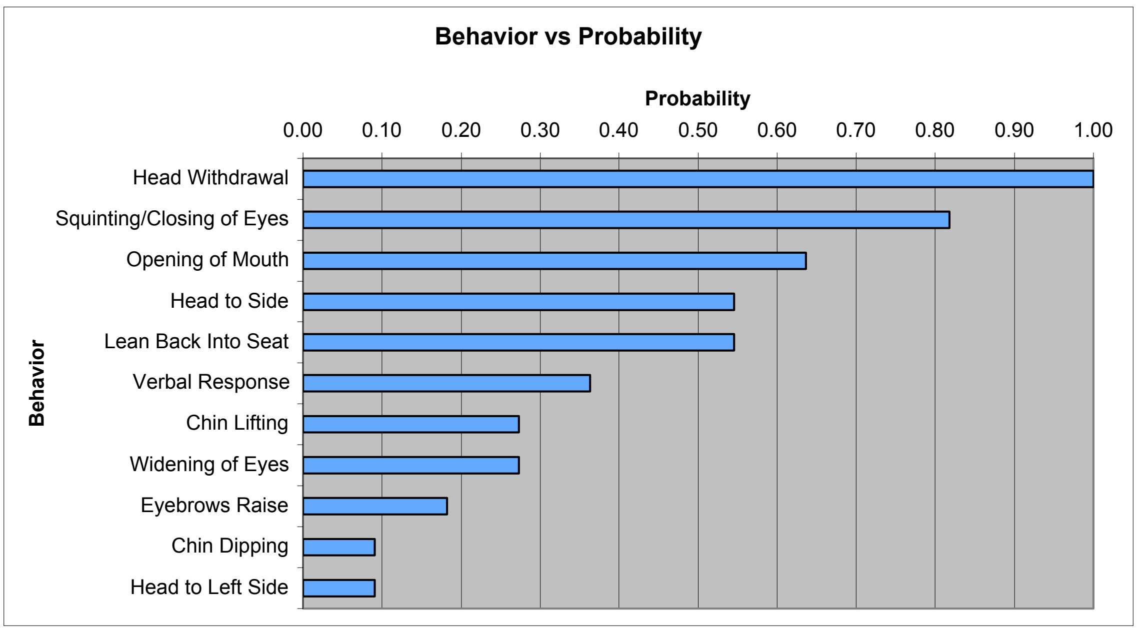

Figure 4. Probability of defensive action

Multi-faceted action causality visualized

Driver actions occur in sequence and should therefore be visualized and analyzed in such a way that the causal structure is not masked. Understanding the causality of activity components is critical for establishing computational models of human action generation, as well as for designing systems that can recognize what action a driver is taking or not taking. This will ultimately allow for the design of systems that can optimally aid drivers. In order to understand the underlying mechanisms and key behavioral signatures that are present in a particular response, it is necessary to visualize all relevant data in a manner that enables researchers to see patterns that can guide model and/or support system development.

The emergency response targeted in this paper was captured by a number of sensors that fed into different data recording systems. We had three main data records:

1. Videos of driver actions from multiple vantage points. These videos of foot movements, facial expressions, hand positioning, and body posture changes were all combined into a quad image to assure that the four videos were synchronized.

2. Driver actions, absolute vehicle state (e.g., speed, yaw rate, etc.), and the vehicle state relative to the environment (e.g., lateral position, distance to lead vehicle, etc.) were all stored in a large, time-stamped ASCII file. Each row represented a new time sample (20 Hz) and each variable was stored in a separate column.

3. EMG data was recorded by a separate computer and stored at a much higher sampling rate (1000 Hz) into a separate file.

Further, the video was manually encoded so that for each labeled relevant driver activity/expression/state, a data record was created including the starting and ending time for each labeled activity. The experiment produced three time-stamped files (video annotation (VID_ANOT), simulator driving record (SIM_DRV), and EMG recordings (EMG_REC)); information from these files then needed to be visualized in an integrated manner.

Unfortunately, the time stamps on the SIM_DRV and the EMG_REC could not be assumed to be identical because the computer clock could not be perfectly synchronized. To ensure that accurate synchronization would be possible, the raw steering signal from the simulator (a voltage off the steering angle sensor) was fed into the EMG recorder as if it were a muscle signal. This way, the steering signal occurred in the SIM_DRV files as well as in the EMG_REC files. In order to determine what time sample in the EMG_REC corresponded with what sample in the SIM_DRV, the following steps were performed:

1. The steering signal from the SIM_DRV was sub-sampled from 20 Hz to 1000 Hz so the two steering signals had the same time-step interval.
2. The cross-correlation function was computed between the two steering signals. This resulted in a signal with correlation coefficients between the SIM_DRV steering signal and a time-shifted version of the EMG_REC steering signal. The maximum correlation value occurs at the time shift that makes the two steering signals as similar as possible. This optimal time shift was used to then shift the EMG data so that it optimally aligned with simulator data. Note that units do not matter in computing a correlation as long as the steering units used in the SIM_DRV and EMG_REC files are linearly related.

This synchronization process ensured that EMG signals were synchronized with driver actions and vehicle state (SIM_DRV) to 50ms, or the sampling interval of the simulator. The SIM_DRV and EMG_REC steering signals are shown in the 3rd panel in Figure 5 in red and yellow, respectively. It is clear that good synchronization was achieved with the adopted method.

The video data was used to obtain detailed, time-stamped records of driver actions (e.g., head withdrawal and facial expressions) that indicate not only different stages of information processing, but also whether the driver was feeling in control or was panicked and fearing a crash. The video frame numbers were recorded in the SIM_DRV file so that frame-rate synchronization between driver actions and vehicle state from SIM_DRV and video annotation was possible. To facilitate quick annotation, only the portion of the video surrounding the crash was cut out of the large video stream. Unfortunately, the frame number of the first clip frame was in the original video was not recorded. This, together with the fact that the video titler only wrote time in 0.1s resolution, caused the video annotations to be only synchronized to within 0.1s. After frequent viewing and annotating of the crash video clips, 21 labeled actions emerged. Each video was then reviewed, and occurrences of these actions were recorded in an ASCII file as the action name followed by the start time of the action followed by its duration. The times were obtained from the 0.1s resolution video titler.

To visualize these video, simulator, and EMG data, many different composite graphs can be constructed. The final version selected is shown in Figure 5. The software was developed by LUEBEC and written in Matlab. Given that the focus in this sub-study was on EMG and the video coding, it was decided that each EMG signal (from a different muscle group) should be displayed (blue) in a separate panel, but that all panels would share the same time axis. Given the large number of video-coded action labels, it was decided that they would be placed in groups of four to the left of the event start time (defined as the first lateral movement of the oncoming truck and set to zero) to avoid cluttering the relevant data. Colored bars are used to show when a particular video coded action was being performed. Finally, the driver control action signals from the simulator records are shown as non-blue signals overlaying the blue EMG signals. These signals are scaled in magnitude to fit within the EMG range. Gas pedal depressions are shown in the top panel, brake pedal depressions in the 2nd panel, and steering angle in the 3rd panel. Additional signals, such as visual angle of the looming truck or the visual angle expansion rate of the oncoming truck, could easily be added to the 4th to 6th panels. The specific choice depends on the research question at hand.

The adopted visualization has yielded many interesting patterns that could not be observed as readily in a set of separate plots. For example, the data show clearly that: i) accelerator pedal release is generally the first action drivers take (at least in a head-on collision situation) even before protective mechanisms such as head withdrawal, ii) verbal responses and open mouth often occur a whole second after gas pedal release, and often also after the brake pedal has been depressed, and iii) EMG signals clearly correlate with the driver's pedal and steering actions, as well as with the withdrawal actions observed in the video.

Figure 5 presents causality-preserving, time-synchronized visualization of driving control actions (SIM_DRV), vehicle state (SIM_DRV), muscle activity (EMG_REC), and time-stamped post-drive video annotations (VID_ANOT). The six panels show the EMG of a different muscle group (blue lines).

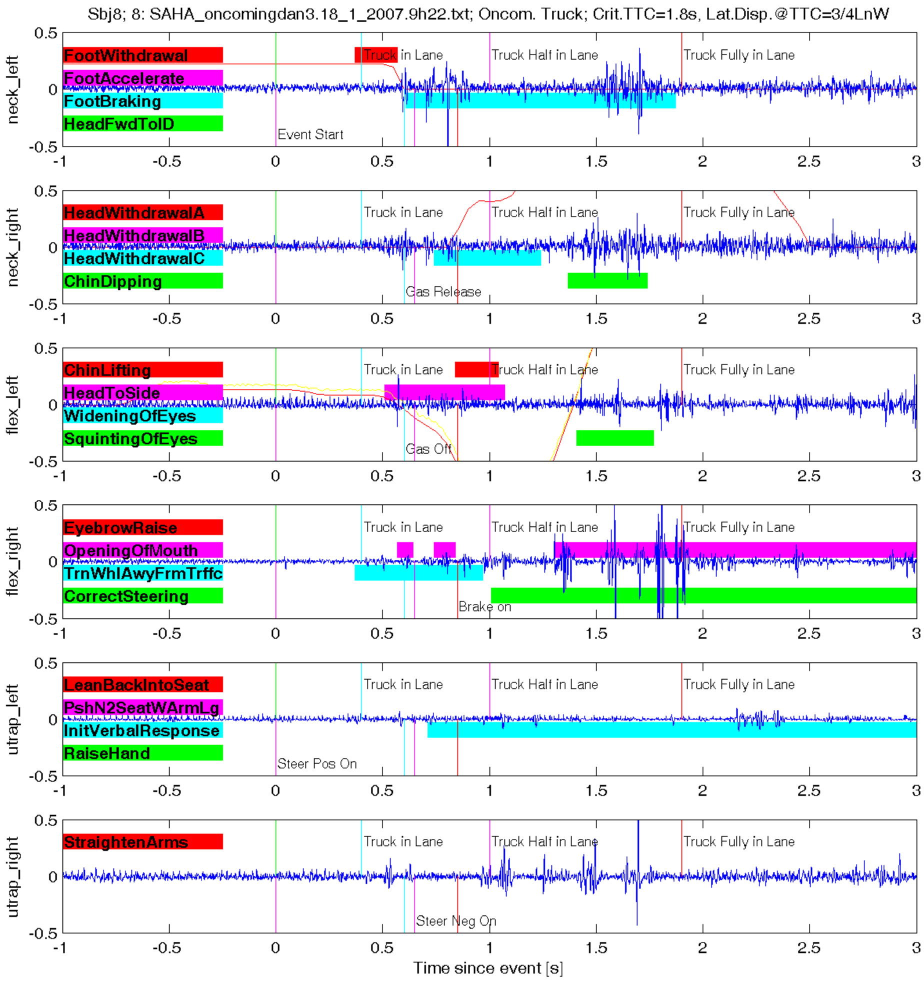

Figure 5. Times series data visualization of EMG, driver response and subject vehicle.

A number of vertical lines show key events, such as when the oncoming truck was half in the subject's lane, or when the subject released the gas pedal, or initiated a steering action. These vertical lines are shown in each panel but labeled in only one to minimize text clutter that would mask the data (the labels appear immediately to the right of the vertical event marker line). The non-blue signals in the various panels show different driver actions. The red signal in the top panel represents accelerator pedal depression. The red signal in the 2nd panel from the top shows brake depression. The red signal in the 3rd panel is the steering angle as recorded in the SIM_DRV file. The yellow signal in the 3rd panel is the steering angle as recorded in the EMG_REC file (scaled to match the magnitude of the red SIM_DRV steering signal). Note the tight correlation between the red and yellow steering signals indicating that the EMG signals are well synchronized with the simulator records. The actions coded from the crash video clips are shown in labeled colored bars to the left of each panel. If a smaller bar of the same color appears after event start time 0, this indicates activity during the time window the small bar spans (e.g., subject 8 lifted his chin about 0.8s after event start for about 0.2s, as indicated by the short red bar in the 3rd panel).

Conclusions

This study's goal was to capture EMG data, and to track posture and other physical responses during a sudden emergency head-on crash. The driver behavior and response decomposition yielded some interesting response sequencing from drivers—most notably that they respond first by releasing the accelerator pedal, and then by withdrawing their neck and head away from the frontal impact. Such a result has important implications for understanding pre-crash posture and biodynamics. One implication for the head and neck withdrawal is that drivers's posture becomes more upright at the point of the primary crash pulse. One disadvantage of this reaction, however, is that such withdrawal may cause the shoulder belt to slip off slightly and thus transfer more crash energy into the lap belt—causing a fulcrum effect on the lower spine.

The EMG data collected as part of this study was a useful complement to the other positional data. However, electronic noise from the simulator should be shielded from the EMG instrumentation to minimize electronic noise artifacts. Future studies should also examine lower extremity EMG. Additional camera angles and seatbelt position indicators should also be used.

Acknowledgments

The authors wish to thank Nissan Motor Co. LTD for funding this pilot research. Curt Olson and Peter Easterlund from the University of Minnesota HumanFirst Program programmed the scenes and scenarios for the experiment.

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