SUBSTITUTING THE AUDITORY AND TACTILE MODALITIES FOR THE VISUAL WHEN THE DRIVER'S VIEW OF THE OUTSIDE WORLD IS OBSCURED

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ABSTRACT

Currently, several technologies are being integrated into a single system that provides the driver of a specialty vehicle with a virtual representation of the view out the windshield via a head-up display (HUD). As part of the development of this system, we are exploring perceptual issues in a series of alternating simulation experiments and field studies. Here, we discuss a field study conducted on a closed track. We used a snowplow equipped with a HUD, a differential global positioning system, and digital geo-spatial databases. In the field study we investigated the effectiveness of lane departure warnings given in three modalities—visual, auditory, and tactile (via the driver's seat). The participants were expert snowplow operators. During the field study it became apparent that the HUD was not useful on sharp corners; rather, the visual and tactile modalities became the primary means with which operators navigated the corners. The information obtained during the field study will feed into the next field operational test stage of the program.

In his foundation work on psychophysics, Fechner (1860) proposed the experimental approach that led to the scientific determination of the relationship between mind and body. Fechner devised experimental paradigms for defining the relationships between physical stimuli and conscious sensations. These paradigms were subsequently utilized and refined by the many scientists that followed. A hundred and forty years later, the ramifications of Fechner's work have spread far beyond the study of psychophysics and the determination of thresholds.

Among the many areas explored by Fechner was that of transference (and interference). In 1858, his observations on the bilateral transfer of motor skills appeared with a longer paper by his colleague (and brother-in-law) A. W. Volkmann. Volkmann and Fechner conducted experiments on tactile discrimination. They showed that increases in skin sensitivity in a stimulated area on one hand of a subject resulted in similar improvements in the identical area on the other hand. Because of the specificity of the transfer, Volkmann inferred that this was a central effect in the brain, rather than a peripheral effect in the skin.

Later scientists — like Stevens (1951) — showed that it is possible for subjects to transfer and match the intensity of stimuli occurring in one modality to responses in another. There are many practical applications of transfer — like that of White, Saunders, Scadden, Bach-y-Rita and Collins (1970) who developed a visual substitution system in which images provided by a television camera scanning a visual scene were converted into patterns of vibrating points on the skin of the back of a subject. White et al.'s system, like the real-world application described here, is a very long way down the road on which Fechner and Volkmann set off in the mid-eighteenth century.

The current work reported here involves developing a driver assistive system (DAS) that allows drivers of specialty vehicles (snowplows, ambulances, and patrol cars) to drive in conditions of limited visibility (e.g., snow, fog, heavy rain). The DAS operates in three modalities — visual, auditory, and tactile (via the driver's seat) — it delivers visual navigation information, lane departure warnings, and collision avoidance warnings. (Only the visual navigation information and lane departure warnings developed for the DAS are discussed here.) The objective of this study was to determine whether expert snowplow operators could drive in real world conditions of zero visibility, using the DAS interface developed by implementing findings from two previous experiments conducted in a driving simulator.

In order to test this objective in the real world, we asked the snowplow operators to drive on snow-covered narrow roads with their view of the outside environment completely occluded. We used a snowplow equipped with a head-up display (HUD), a differential global positioning system (DGPS), and digital geo-spatial databases. In the field study, we investigated the effectiveness of lane departure warnings given in three modalities — visual, auditory, and tactile (via the driver's seat). Because the driver's view of the road was completely occluded, his or her only source of information was the lane markings on the HUD and the lane departure and collision avoidance warnings.

METHOD

Participants

Participants were 13 Mn/DOT snowplow operators from the Minneapolis/St. Paul, Minnesota, USA metropolitan area. Their participation was voluntary.

Apparatus

Visual navigational information inside the snowplow was conveyed via the HUD developed by the Intelligent Vehicles Lab, at the University of Minnesota. Images on the HUD were projected from a 10.4 in (266 mm) Mobile VU projector (Litton Systems #46830-1, San Diego) mounted just to the right of the driver's headrest. The roadway markings were generated by the Differential Global Positioning System. Each subject saw the lane markings (provided by DGPS via the projector) on the HUD.

The combiner surface used in the HUD was vertically and horizontally planar convex. In normal use, when the driver looked forward, he or she was able to see both the imagery on the combiner and the outside environment. (In this field study, in all but the familiarization trial, the view out of the windshield and side windows was occluded.) The combiner was mounted on an adjustable frame so that it could accommodate drivers of different heights. The combiner measured 11.5 in (294.9 mm) wide and 6 in (153.8 mm) high and was framed with clear 0.75-inch (19.2 mm) polycarbonate.

Test Site

The field study was conducted on a test track at the University of Minnesota's Agricultural Research Extension Station. The track, shown in Figure 1 below, was 4 mi (6.44 km) long. It consisted of three legs: the first was a two-lane-wide road; the second was a three-lane-wide road; and the last leg was a single lane. All three legs were unpaved. In the first leg, soon after the start point, there was a gentle left bend. Between the first and second legs there was an oblique approximately 120-deg left turn. Between the second and third legs there was a 90-deg short radius left turn. Then in the middle of the third leg there were two 90-deg short radius turns, the first to the left and the second to the right.

The experiment was run in December 2000 and January 2001 a time during which the temperature varied between 30 deg and minus 18 deg F with wind chills that were sometimes as low as minus 50 deg F. On all test runs, the track was snow covered. If necessary, the track was plowed at the start of each day. Atmospheric visibility was
excellent on all days.

Design and Procedure

On arrival at the test facility participants signed an informed consent form. An experimenter drove them from the assembly point to the snowplow at the start of the course. When seated in the snowplow subjects were asked to adjust the HUD combiner by centering its lane markings in the middle of the road. They also made an azimuth adjustment to assure that the vanishing point of the HUD lane markings coincided with the vanishing point of the road. Then they listened to taped instructions.

Before starting the first test run the experimenters checked with the traffic controllers to ensure that no other traffic was present on the course and to block any traffic from turning onto it. Following clearance from all six traffic control points, shown in Figure 1 below, participants began driving.

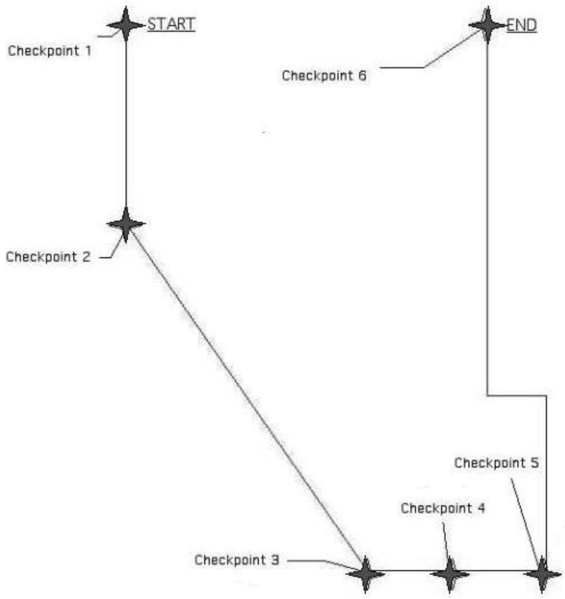

Figure 1. The field study test track showing the course and the six checkpoints for traffic control.

Run Number 1:

During the first run the drivers were asked to pay attention to the lane markings on the HUD through which the actual roadway was clearly visible. They also were invited to sample the lane departure warnings. (If the snowplow departed the lane to the right, a red line appeared over the right lane marking on the HUD, an auditory warning resembling the sound of a rumble strip was heard on the right side of the cab, and the driver felt a vibration under his or her right thigh. If the snowplow left the lane to the left all three warnings were given on the left side.) At Turn Number 1, which is an approximately 120-deg oblique angle they turned left onto the next stretch of road. During the turn, subjects were instructed to attend to the HUD and to their speed. They were told that during the conditions in which their view of the actual road would be completely occluded the lane markings on the HUD would disappear and that they "should proceed to turn cautiously at a speed that did not exceed 3 to 4 mph." (The reasons for this are discussed below.) At turn 2, which was a sharp 90-deg turn to the left, onto a single lane road each subject was again cautioned to turn slowly and cautiously because on sharp turns the HUD's lane markings completely disappeared. They were told that the best way to navigate the curve was with a foot over the brake and not on the accelerator. This guidance was useful to them in preparation for test runs during which their view of the actual roadway was occluded by opaque curtains covering the inside of the windshield and side windows. They were told that when negotiating the sharp 90-deg turns they would need to rely on the auditory and active seat warnings for guidance. At turns 3 and 4, a sharp 90-deg left turn and sharp 90-deg right turn, respectively, subjects were again cautioned to proceed around the turns "at a speed of approximately 3 to 4 mph." They were again told that the lane markings on the HUD would disappear on the tight turns. At the end of the course they were asked to stop at the point on the track where they would be asked to stop on subsequent runs. Subjects were encouraged throughout the run to comment on their perception of the HUD and lane departure warnings.

Runs Number 2 - 5:

During the second through fifth runs, subjects drove with opaque curtains drawn across the windshield and side windows. They were asked to drive the course by using only the lane markings projected on the HUD combiner and the lane departure warnings. As in run Number 1, subjects were encouraged throughout the run to comment on their perception of the HUD and lane departure warnings.

RESULTS AND DISCUSSION

The field test was treated as an expert knowledge extraction task. As mentioned earlier, the test sessions began with a trial run in which each snowplow operator familiarized himself or herself with the test track. Then, for the remaining runs, the operator drove the snowplow with the outside view of the environment completely occluded, so that their main source of external information was the DAS Interface (i.e., the HUD, the auditory display and the active seat).

As mentioned above, when sharp turns were negotiated, the lane markings on the HUD and the red line warning both disappeared, and not surprisingly the operators indicated that they had problems with the way in which turns were depicted on the HUD ($p=0.061$, Binomial test; Siegel & Castellan, 1988). This is because the lane markings shown on the HUD match the normal view of a driver with the windshield view, but this conformal view fails when the vehicle is negotiating sharp turns. When negotiating turns, *all drivers* need to look out the side window at some point in order to successfully complete the turn. At the moment, we have not determined how shallow a turn must be before it is possible to use only information obtained through the windshield. However, it is clear that for the 120-deg turn as well as the three 90-deg short radius turns that the snowplow operators experienced when driving the test track, it was necessary to look out the side window to complete them.

Everyday drivers may believe that he or she acquires the information necessary for taking sharp corners through the windshield and never through the side windows, but this view is incorrect — anyone who doubts this should try to drive his or her vehicle with the side windows occluded. The reason for such an erroneous belief may be that driving is a highly over-learned and over-practiced skill, that expert knowledge is difficult if not impossible for the expert to articulate, and that there is, as Howarth (1988) points out, “a surprising degree of dislocation […] between conscious verbally expressed behavior and tacit knowledge which guides skilled behavior.”

Although unable to use the HUD on sharp corners, the majority of snowplow operators successfully navigated the corners while using the combined auditory/active seat signal as a turn advisory ($p<0.00001$, Binomial test; Siegel & Castellan, 1988). With regard to the auditory warning and the tactile warning that was delivered via the active seat, it was clear that the operators perceived the two warnings as a single perceptual unit; in some cases, the operators were clearly unaware that the signals were separate at all. It is likely that the signal presented by the two modalities merged into a single perceptual entity because they both oscillate. The subjects were able to use this dual-modality stimulus, which provided spatial information, instead of the virtual, visual information presented on the HUD. Further, they were able to transfer from this virtual display to the spatially presented dual-modality stimulus. Clearly, this is in line with Fechner's original findings — although if he were to look down on this study it might be with some surprise and trepidation.

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