DESIGN OF AN AGRICULTURAL DRIVING SIMULATOR FOR ERGONOMIC EVALUATION OF GUIDANCE DISPLAYS

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

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Winnipeg, Manitoba

0-612-80106-3

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

Guidance aids assist agricultural machinery operators by providing lateral error information through a display called a 'lightbar'. Anecdotal evidence from dealers indicated that operators might prefer a larger lightbar. To determine the possibility for improving the design, seven high-clearance sprayer operators were interviewed or observed, or both. It was determined that a more salient display could reduce the scanning requirements. Following a review of relevant visual attention and display literature, a larger and more luminous lightbar was created.

The effects of the larger lightbar were tested using testing apparatus and methodology designed for this purpose. The apparatus was designed to simulate the visual scanning requirements of field spraying. It consisted of a pseudo-random tracking task, a choice reaction-time task, and an agricultural operator station. Based on a review of mental workload literature, a testing methodology was devised to measure tracking and monitoring performance, subjective workload, and heart rate. The test used 22 university students in a within-subjects design and compared the larger lightbar to a lightbar modeled after a popular version. The larger lightbar reduced tracking error by 11%, and subjects felt that it reduced mental and physical demand slightly. As well, subjects preferred the larger lightbar.

Several conclusions and recommendations were created for designing guidance displays, performing simulation testing, and studying agricultural machinery operator's tasks.

ACKNOWLEDGEMENTS

First, want to thank those that provided guidance throughout the project. The most important is my thesis advisor, Danny Mann. I would also like to thank my committee members, Richard Kruk, Dean Kriellaars, and Ray Hoemsen.

Second, I want to acknowledge the financial assistance provided to this project. The Natural Sciences and Engineering Research Council of Canada (NSERC) and the Agri-Food Research and Development Initiative of Manitoba (ARDI) provided most of the funding. MacDon Industries also contributed a joystick handle for the simulator.

Third, I want to thank the parties who provided technical assistance. The Prairie Agricultural Machinery Institute (PAMI) was hired to find and refurbish the operator station for the simulator. Gerry Woods, Dale Bourns, and Layne Maciura performed much of the remaining physical construction, while Matt McDonald created all the circuitry to control the simulator.

Finally, I would like to thank all those who supported me through this project. I want to thank my parents for their tolerance and love. I also would like to thank all my friends (you know who you are). In particular, I want to thank Helsa Chow for painstakingly proofreading initial parts of the thesis. Finally, I must also thank all the staff and students of Biosystems Engineering for making the past seven years a real joy.

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1 BACKGROUND

1. 1 Land Distribution

Grains and oilseeds are farmed on over 20,000,000 ha in western Canada (Statistics Canada 2002). Most of that land is divided into square and rectangular fields (Fig. 1). The land ranges from flat to rolling, and may contain obstacles such as wet spots, gullies, or trees.

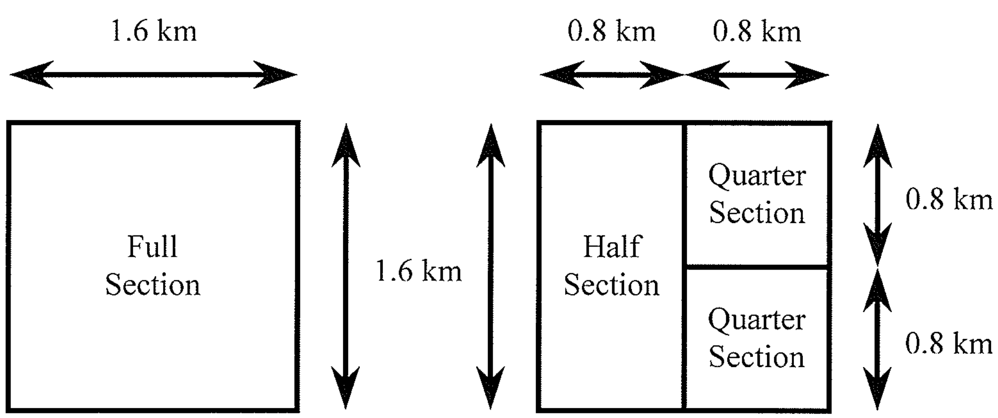


Fig. 1. Average field sizes. A full section contains 240 ha.

1. 2 Field Coverage

Farmers drive over each field with machines 2 to 12 times per season to perform the operations required to grow a crop. The most efficient way to cover a field is a series of parallel passes (Fig. 2). Optimally, no area would be missed or covered more than once during field coverage. In reality, however, equipment operators cannot guide machines optimally, and the average lateral overlap is 10% of implement width (Fig. 3) (Palmer & Matheson 1988).

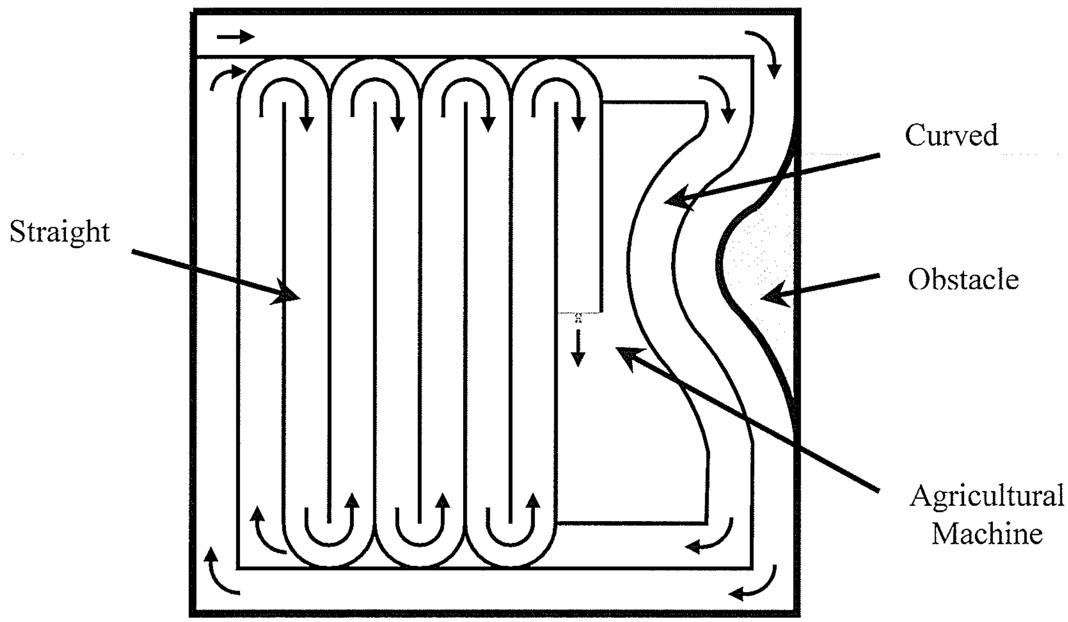


Fig. 2. Field coverage. Machine entered field from upper left corner; arrows indicate direction of travel.

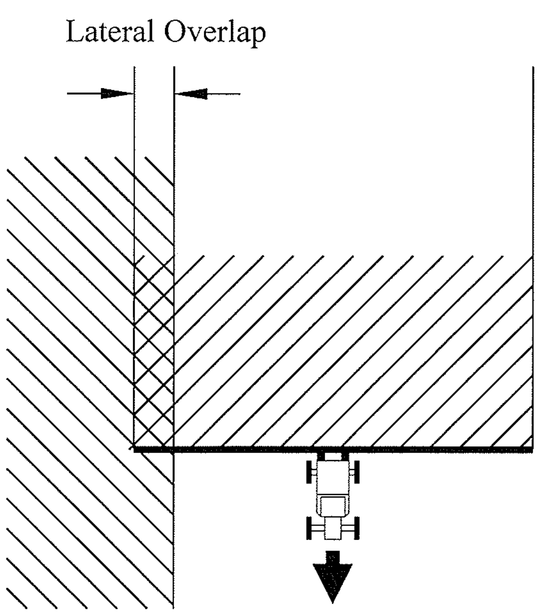
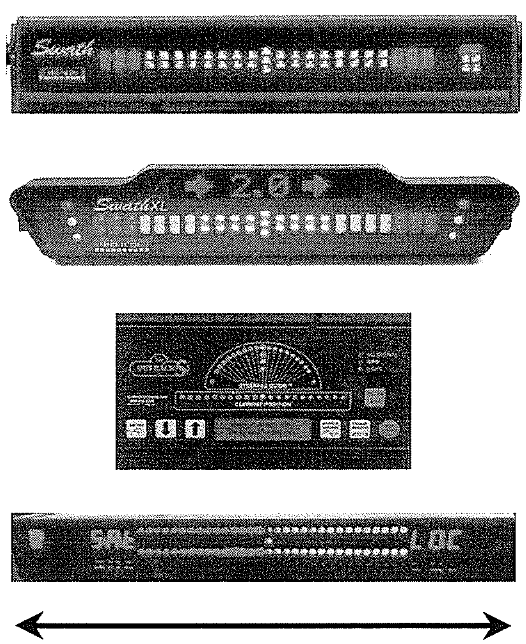


Fig. 3. Lateral overlap. Modeled after Palmer & Matheson (1988).

1. 3 Guidance Aids

Many guidance aids are available to help reduce lateral overlap (Palmer & Matheson 1988; Tang 2000), including aids based on the Global Positioning System (GPS). GPS can identify an exact location on the earth's surface by referencing a constellation of satellites in orbit around the earth. With a GPS guidance aid, an operator can program a series of parallel passes across the field, and the system will display lateral error on each pass. The operator uses this information about lateral error to help steer the machine.

The most popular display is a lightbar—a horizontal array of lighted elements (Fig. 4). When there is no lateral error, only the centre light(s) is(are) on. Lights to the left or right illuminate to indicate the magnitude and direction of lateral error. Some systems also offer a screen that shows an aerial view of the entire field, similar to Fig. 2.



350 mm

Fig. 4. Four lightbar models. Scale is approximate.

1. 4 Dealer Feedback

Although most operators like GPS guidance aids, dealers feedback has indicated potential for improvements to the system. Initial anecdotal reports indicated that operators found lightbars annoying to use. In later discussions, dealers reported that the lightbar had a large effect on how customers chose guidance aids and adapted to them, and that people were very interested in larger lightbars.

1. 5 Hypotheses and Study Plan

The dealer feedback served as the starting point for the project. The feedback indicated there was room for improvement to the lightbar, possibly improving the way guidance aids were used. One possibility was to investigate the application of peripheral vision displays, investigated previously in aviation (Stokes et al. 1990), to GPS guidance aids. A peripheral vision display provides information to the operator's peripheral vision.

The overall hypothesis for the research effort was that a peripheral vision lightbar would reduce both guidance error and operator workload. This project was intended to be an initial step toward supporting that hypothesis. There were six sections in this project. First, a preliminary task analysis was performed on sprayer operators. Second, principles of human vision and several display designs were investigated, ending in a new lightbar design. Third, a laboratory simulation was created for testing lightbars. Fourth, a testing methodology was created based on research of mental workload theory and testing. Fifth, the new lightbar design was compared to the regular lightbar using the apparatus and methodology created. Sixth, several conclusions were reached about the project, and recommendations were made for future research in this area.

2 TASK ANALYSIS

2. 1 Spraying

The first step was to investigate how operators use GPS guidance aids, and how the lightbar could be improved. High-clearance sprayers were the most popular application for guidance aids at the time, so they were the focus of the investigation.

Spraying (chemical application) is an important part of modern prairie agriculture, as chemicals are applied to crops for several reasons, and at all stages of growth. The chemical is sprayed from nozzles onto the plants as a sprayer (Figs. 5,6) is driven across the field. GPS guidance aids were first used in sprayers for several reasons. Spraying leaves no mark on the crop, so judging the edge of the last pass can be difficult. Foam markers can be used to delineate the edge of the last pass with a series of foam clumps, but foam can be blown by the wind, fall through the crop canopy, or evaporate on a hot day, resulting in a lost edge. As well, sprayers are wider and travel faster than other pieces of equipment, making steering errors more likely (Riemersma 1981; Sinden et al. 1985). Finally, the high initial cost of a GPS guidance aid is easier to justify for some sprayer operators. Custom applicators that apply chemical for a large number of people are more prevalent in spraying than in other field operations. Because these applicators spray more area than a single farmer, they can more easily afford a GPS guidance aid.

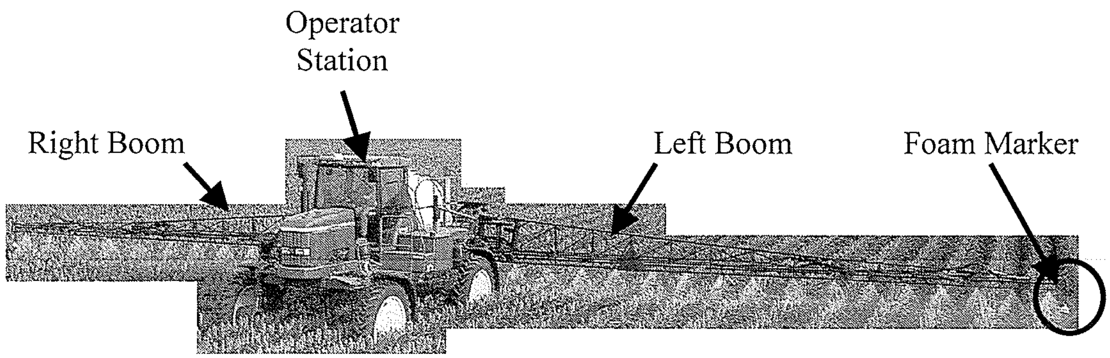


Fig. 5. High-clearance sprayer. Boom width is 18-30 m.

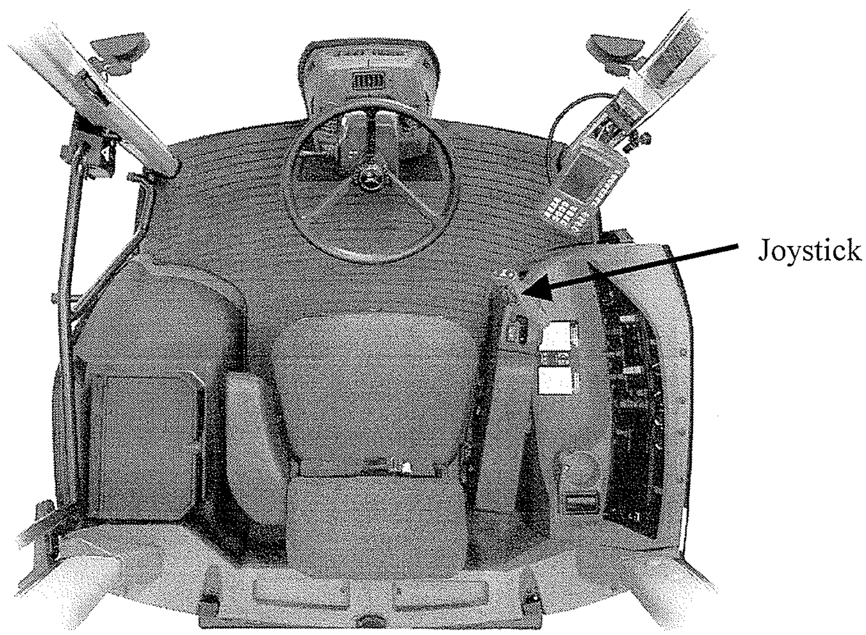


Fig. 6. Operator station of high-clearance sprayer. Joystick controls speed and several boom functions.

2. 2 Participants

Seven sprayer operators were contacted for interviews or to ride with them in the field, or both (Table 1). Full details from these encounters are shown in Appendix 1. In each interview the operator was presented with a series of questions on spraying, guidance aids, attention in the field, and their opinions of the system. During rides, the operator was observed and asked informal questions. In some cases they were also videotaped. Although a larger sample of operators was planned, weather conditions made this difficult. As well, because most operators behaved similarly, it was felt that an accurate picture of operator behaviour and lightbar usage could be constructed.

Table I. Operators used in study, and characteristics.

	GPS Brand	Lightbar/ Screen	Interview/ Ride	Lightbar Location	Terrain (Flat/Rolling)	Obstacles in Field?	Aiming Point?
A	Trimble	Lightbar	Interview	Windshield	Rolling	Yes	No
B	Trimble	Lightbar	Interview	Windshield	Flat	No	Yes
C	Trimble	Lightbar	Interview	Windshield	Flat	No	No
D	Satloc	Both	Both	End of hood	Rolling	Yes	Yes
E	Trimble	Both	Ride	Windshield	Rolling	Yes	Yes
F	Trimble	Lightbar	Ride	Windshield	Combination	Yes	Yes
G	Trimble	Lightbar	Ride	Above windshield	Flat	Yes	Yes

All operators were experienced with the GPS system, having used it for at least one season. Six used a Trimble system, the most popular brand at the time. All operators liked the GPS guidance aid. Of the six who had used foam markers before, all preferred the GPS system to foam. Five operators fastened their lightbar to the windshield, either above or below their sightline to the horizon. One operator had installed his lightbar above the windshield, and one operator had a lightbar that mounted on the end of the hood.

2. 3 Structure of Task

Operators have two major goals while spraying—cover the field in a parallel pattern, and apply chemical. The operator initially planned a parallel pattern through the field based on the patterns offered by the guidance aid. Additional planning was required for refilling the sprayer and spraying around obstacles. At the control level, the operator controlled speed and steered the sprayer along the parallel pattern.

Chemical application involved setting the correct rate of application, turning the application system on and off, and checking boom height and flow. When the boom is too low it does not cover all the plants, and when it is too high there is danger of spray drift. As well, the operator checks periodically for plugged nozzles.

2. 4 Steering and Lightbar Usage

Operators used the lightbar to determine the correct lateral location when coming out of a turn and during a parallel pass. Five of seven operators also used an aiming point while driving down the field. They looked for an object on the horizon or in the field toward which they could drive. Some said that using only the lightbar caused them to oscillate about the correct line, creating an unsteady pass and requiring more steering input. Operators scanned between the two locations when driving, shifting focus between the aiming point and the lightbar. When asked, some operators said they glanced between the aiming point and the lightbar consciously, and some said they noticed the lightbar move in the periphery of their vision. In video footage, one operator scanned the lightbar every 3 s.

The lightbar indicated lateral errors every 2-5 s, depending upon field terrain. More lateral correction was required on wet, rolling, or rough ground. The operator almost always corrected the lateral error before the lightbar showed more than two error lights. Often the errors oscillated about the centre, indicating some oscillation about the correct heading.

On the small number of curved passes observed, operators did not use the lightbar as much. They used an aerial field view if their system had that option, or they used foam markers. Operators said the lightbar was not useful in curves because it did not give enough information about the rate of turn.

2. 5 Other Control Tasks

Operators said they allocated anywhere from 10-50% of their time and energy to controlling the booms, and this agreed with observations. The rate at which operators scanned the booms depended on how likely they were to need height adjustment, and how worried the operator was about plugged nozzles. Booms must be adjusted more often in rolling terrain. One operator in rolling terrain scanned the booms every 8 s. Because each boom was 105° away from the aiming point and lightbar, operators lost sight of their steering cues whenever they scanned the booms (Fig. 7).

Operators also scanned the field, controlled speed, and scanned other displays in the cab. None of these received as much attention as the steering or booms. One thing that should be noted, however, was that it was difficult to determine how much time an operator spent scanning the field because there was no specific visual fixation point at which to look.

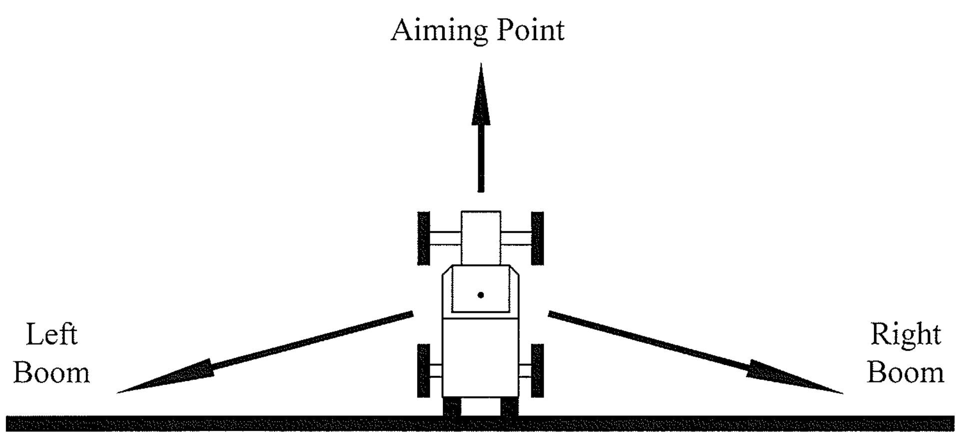


Fig. 7. Sightlines to aiming point and booms.

2. 6 Similar Findings

General tracking research helps explain why operators use both the lightbar and heading. During any tracking tasks, such as driving, flying a plane, or drawing a line, knowledge of current and future error is important in maximizing performance (Poulton 1974; Wickens & Hollands 2000). In straight passes, the lightbar indicates current error and the heading indicates future error, so the operator scans between them to get complete information on control decisions. In curves, however, this does not work. The lightbar gives the current error in curves, but the heading does not give a preview of future error. Therefore, the operator looks to another source, such as a foam line or aerial view of the field.

Additionally, similar behaviour has been found for operators in similar situations. Palmer (1989) reported on experience with a similar guidance aid for field spraying. The operator could operate the system well during the day. At night, however, he oscillated about the correct heading because he could not see any external cues from which to acquire heading information. In conversation, Palmer (2002) stated that a good guidance display should allow synthesis of both lateral deviation and heading information.

Fitts et al. (1950) analyzed the eye movements of pilots making instrument-landing approaches. The pilots were flying real planes on approach to a landing. Their view outside the cockpit was blocked, and they relied on instruments only. He found that pilots scanned their lateral deviation instrument 41% of the time and heading instrument 25% of the time. Other instruments were scanned much less frequently. Of all eye movements, 29% were between the lateral deviation and heading instruments.

2. 7 *Task Analysis Conclusions*

Two major conclusions resulted from the task analysis. First, the two major actions performed by a spraying operator are steering and controlling the booms. Operators scan these two tasks while also scanning the field and some other displays. Second, operators used two sources of guidance information—the lightbar for lateral position, and an aiming point for heading.

3 LIGHTBAR DESIGN

3. 1 Display Principles

3. 1. 1 Supervisory Control

Sprayer operators are similar to aircraft pilots and plant controllers in that they all perform a supervisory control task. The operator scans each display for information about the process(es) under control. Based on information from the display, (s)he performs control actions. Because almost all information comes from visual controls, the structure of visual attention is important for performance (Wickens & Hollands 2000).

3. 1. 2 Visual Attention

An operator directs visual attention in a series of movements and fixations (Wickens & Hollands 2000). Information acquired during each fixation is dependent on the location (centre) of the fixation, visual acuity, and mental attention. Acuity depends on the acuity threshold, accommodation, and vergence of the eyes. The acuity threshold is a rating of the least salient—least visible—stimulus that can be perceived in a particular location of the visual field. The threshold is lowest in the central 2° of the visual field, and it increases as a function of eccentricity (angle away from centre) in the peripheral visual field (Fig. 8) (Goldstein 1999). The other physical factors are accommodation—adjusting the lens of the eye so the image is clear on the retina—and vergence—aligning the eyes to point at the same location in space (Goldstein 1999; Remington et al. 1992). These factors are changed to view objects at different distances from the viewer or to adjust the level of acuity. At the optimal accommodation and vergence, objects at the acuity threshold can be perceived. At less-than-optimal accommodation and vergence, only objects more salient than the acuity threshold can be perceived. In addition to physically perceiving a stimulus, mental attention must also be focused on the stimulus. Mental attention is directed either internally by an intention to view a stimulus, or externally by the detection of a conspicuous stimulus (Wickens & Hollands 2000).

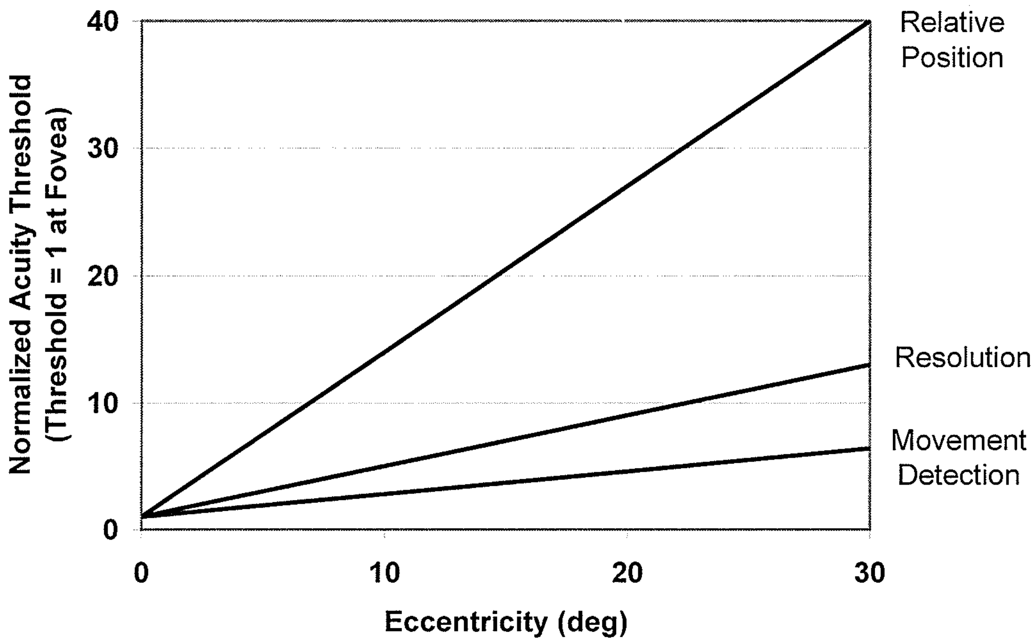


Fig. 8. Visual acuity thresholds by eccentricity. Three types of acuity are shown. (Levi 1999; Levi et al. 1984)

3. 1. 3 Display Design

The time and effort required to physically perceive a stimulus, allocate mental attention to that stimulus, and process the stimulus information is called the information access cost (Wickens & Carswell 1995). Design strategies that reduce the cost include placing frequently-used displays centrally and placing displays used sequentially close together (Wickens & Hollands 2000). Reducing information access cost is most important for displays that are used together to perform a task (Wickens & Carswell 1995). In most real-world tasks, the large eye and body movements required to view different displays and handle different controls force humans to perform in a sequential manner, processing and acting on only one piece of information at a time (Liao & Moray 1993). Reducing access cost makes sequential use faster and promotes parallel processing, further increasing task performance (Wickens & Hollands 2000).

3. 2 Peripheral Displays

3. 2. 1 Scanning

Peripheral displays were first suggested in aviation as a way to reduce scanning among cockpit displays or between cockpit displays and the runway during approach (Brown et al. 1961; Christensen et al. 1986; Fenwick 1963; Stokes et al. 1990). These displays indicated flight control—lateral deviation, attitude, or speed—in a more salient way, allowing perception at large visual eccentricities (Wickens & Liu 1988). Methods to increase peripheral salience included apparent motion in the form of streaming lights or rotating spirals, flashing lights or enlarged, luminous displays. Despite some experimental success (Brown et al. 1961; Fenwick 1963; Stokes et al. 1990), none of these displays have been widely used commercially.

3. 2. 2 Two Modes of Vision

Peripheral displays have also been advocated as a method to reduce the processing demand of guidance information (Wickens & Hollands 2000). Leibowitz (1988), has stated that visual guidance is a separate mode of visual processing from pattern recognition. Human vision has evolved to use mostly depth and motion cues in peripheral vision to direct guidance of locomotion with little attention. Pattern recognition activities such as reading, on the other hand, use central vision and require considerably more attention. If this difference in visual processing modes is valid, peripheral vision guidance displays should require less attention and result in better performance than central vision guidance displays.

Others, however, have not seen any difference between visual processing modes (Koenderick et al. 1985). As well, in an evaluation of purely central and purely peripheral guidance displays, Weinstein & Wickens (1992) found that a peripheral guidance display resulted in poorer performance and required more resources than a central guidance display.

3. 2. 3 Attention Capture

More recently, peripheral vision displays have been advocated for notifying pilots of unexpected events. Bright flashing lights are used to indicate warnings because visual attention is drawn to conspicuous (i.e. large, colourful, bright, moving, or flashing) objects in the visual field (Folk et al. 1994; Remington et al. 1992; Yantis & Hillstrom 1994; Yantis & Jonides 1990). Most warning lights, however, are not large in size. In a busy environment like a cockpit, where visual attention is distributed widely, larger, more luminous warning indicators that can be perceived in peripheral vision result in faster and more reliable notification of unexpected events (Nikolic & Sarter 2001).

3. 2. 4 Difficulties

At least two impediments have been recognized for peripheral displays. The first is that training may be required for optimal use. Most people have a tendency to fixate central vision on a stimulus, even if they can perceive it at a higher eccentricity (Sanders 1970; Wickens & Carswell 1995). A peripheral display, however, will only reduce information access cost if people can allocate visual attention to the peripheral display while fixating on the central display. Additionally, individual differences in peripheral acuity may make peripheral displays difficult to implement on large groups of operators (Christensen et al. 1986; Stokes et al. 1990). The second problem is that people tend to focus on central vision when under stress, a phenomenon called cognitive tunnelling or attentional narrowing (Stokes et al. 1990; Wickens & Hollands 2000). As a result, peripheral displays may not be effective in stressful situations.

3. 3 Other Non-Conventional Displays

3. 3. 1 Heads-up Displays

Heads-up displays (HUDs) have also been used to reduce scanning. HUDs are popular in both military and civil aviation, and they have been used in production automobiles (Tufano 1997). With a HUD, light is projected onto the windshield, superimposing an image on the exterior scene. Eye movement is reduced because the display is located directly around the exterior scene. As well, accommodation and vergence are reduced because the scene is focused at an optical distance similar to the exterior scene. Due to the reduced information access cost, HUDs may promote parallel processing (Wickens & Hollands 2000). Additionally, HUDs can reduce reaction times to exterior events (Sojourner & Antin 1990; Tufano 1997). Palmer (1989) found a crude HUD beneficial for sprayer guidance, although he provided no details.

3. 3. 2 Ecological Displays

The search for a better method for presenting guidance information in aviation has led to the development of perspective, or ecological, displays (Weinstein & Wickens 1992; Wickens et al. 1989; Wickens & Hollands 2000). An ecological display provides a pictorially realistic (Roscoe 1968) view of the plane and outside world, allowing pilots to determine flight information from characteristics of the scene. It is very similar to the view seen in computer games. Perspective displays are considered an improvement because information from several displays can be integrated into a single intuitive display, and the information is presented redundantly to a large portion of the visual field (Weinstein & Wickens 1992; Wickens & Hollands 2000). There is evidence that ecological displays can provide more efficient control and better time-sharing than conventional displays (Weinstein & Wickens 1992; Wickens & Carswell 1995).

3. 4 Peripheral Lightbar Design

3. 4. 1 Proposed Benefits

Two potential benefits of a peripheral lightbar were identified. First, a peripheral display could reduce the scanning required between the lightbar and aiming point. By allowing the operator to see lateral deviation in their peripheral vision while fixating on the aiming point, a peripheral lightbar could reduce the information access cost and may allow parallel processing of the two pieces of guidance information. Additionally, a peripheral lightbar mounted in the lower field of view may be more similar to direction information acquired during human locomotion, perhaps resulting in much faster processing of guidance information. Some operators stated they were already using their peripheral vision, so a display more noticeable in the periphery may allow the lightbar to be used more easily in this way. Second, a peripheral lightbar may better capture attention when operators scan the booms and other displays. Because more error occurs when operators look away from the steering indicators (Kaminaka 1981), earlier alerts for steering corrections could improve steering performance.

3. 4. 2 Design Principles

The lightbar design was the next thing to be decided. This was the first attempt at modifying a lightbar and testing the results, so a simple and predictable modification was desired. First, it was decided that the modified lightbar should provide the same information as a regular lightbar—single-dimension lateral error. Second, modifications to increase salience were determined. Several peripheral display designs had used flashing lights or apparent motion (Brown et al. 1961; Fenwick 1963; Stokes et al. 1990), because acuity for these characteristics do not degrade as quickly in the peripheral vision (Fig. 2). Past results with these displays, however, were inconsistent, and operators reported the displays to be distracting or obtrusive (Stokes et al. 1990). Colour was also investigated as a method of increasing salience, but peripheral detection of colour can be unreliable (Ancman 1991). Changes in stimulus size and luminance in the periphery were found to be very reliable (Anstis 1974; Johnson 1986). Therefore, these factors were modified to create the peripheral lightbar.

The peripheral lightbar design was a simple scaling in size of the original lightbar. A single light emitting diode (LED) was used for each lighted element of the regular lightbar, while an array of 16 lighted elements was used for each lighted element of the peripheral lightbar. Colours were the same—red and green. The peripheral lightbar was 5-8 times more luminous than the regular lightbar.

4 TESTING APPARATUS

4. 1 Simulator Background

4. 1. 1 Field vs. Laboratory

One of the first decisions to be made for evaluating the new lightbar was whether field or laboratory tests would be used. Poor weather, short summer testing seasons, and availability of land for testing had frustrated previous field tests in similar experiments. As well, there were several questions about the large number of variables involved in field tests. As a result, a laboratory simulation was investigated as a way to control many variables and test year-round, creating more consistent results.

4. 1. 2 Role

Simulators occupy a middle position on the continuum between pure laboratory tests and pure field tests. For human factors testing, field studies are invaluable because they provide directly valid data, and they allow the experimenter to determine the most important variables affecting performance. Due to variability of field conditions, weather, and other factors, however, field studies are often expensive and ineffective for determining functional relationships among different factors of interest (Duncan & Wegscheid 1982). Laboratory experiments are the opposite. They are very good for determining functional relationships, but the results are often relevant only to a laboratory situation that is much different than field conditions. Simulators lie somewhere in the middle. A simulator provides field-like tasks within a laboratory setting. As a result, functional relationships for field situations can be tested without the problems of field testing.

4. 1. 3 *Fidelity*

Distinctions between different simulators are often based on fidelity—how well a simulator mimics field conditions. People often rely on fidelity as an indication of validity, assuming that people will perform more like a real situation the more lifelike the simulator. The problem is that high-fidelity simulators are very expensive, making them impractical for many applications. Low-fidelity PC-based simulators, on the other hand, are much less expensive and are suitable for many research applications (Gruening et al. 1998). For most applications, in fact, there is no consensus on how much fidelity is required in a simulation (Noy 2001; Van Cott & Kinkade 1972). The best approach may be to use the least expensive simulator that suits the needs of the test, based on a task analysis (Engel 2001; Noy 2001).

4. 1. 4 *Results*

Because a simulator is not the real field situation, results must be used cautiously. Simulators tend to invite overgeneralization, as people assume most results can be applied directly to the real world (Van Cott & Kinkade 1972). It is important, however, to remember that the simulation is still a laboratory test, so its results cannot be completely generalized to the real world situation. This is especially true for results from a low-fidelity simulator (Duncan 2000).

Because of this, care must be taken in several areas. First, the tasks that are performed in a simulator must be designed carefully, with reference to a task analysis (Duncan & Wegscheid 1982). Second, the relevance of results to the real world must not be overstated. Third, all results should be validated against real-world data to establish how well the simulation reflects field situations (Easterlund 2000).

4. 2 Simulator Design

4. 2. 1 Specifications

The simulator for this study was to simulate the spraying task outlined in the task analysis. Steering and monitoring were the main subtasks involved, and the scanning involved was determined to be the most important factor for evaluating the lightbar. Therefore, the simulator would be designed to require subjects to scan the same locations and perform similar control actions as a high-clearance sprayer operator. A secondary goal was that the simulator should be flexible enough to be used for testing other interface components and instruction on operator environment design.

4. 2. 2 Options

Due to budget constraints, a low-fidelity simulation was the only option. Although several companies sold PC-based driving simulators, these packages did not fit our requirements for the spraying task (Aponso 2000). Instead, a low-fidelity simulator was created by combining a simplified steering task with monitoring tasks, as in other laboratory interface studies (Brown et al. 1961; Weinstein & Wickens 1992).

4. 2. 3 Operator Station

To ensure subjects had an environment and controls similar to that of a sprayer operator (Van Cott & Kinkade 1972), an operator station was required. The Prairie Agricultural Machinery Institute salvaged an operator station and hood from a four-wheel-drive tractor, cleaned it, painted it black, and mounted it on casters for use in the laboratory (Fig. 9). The interior was modified to be similar to the interior of a high-clearance sprayer (Fig. 10), including a new console and joystick. In further work at the University of Manitoba, several controls were instrumented to allow interfacing with a control system.

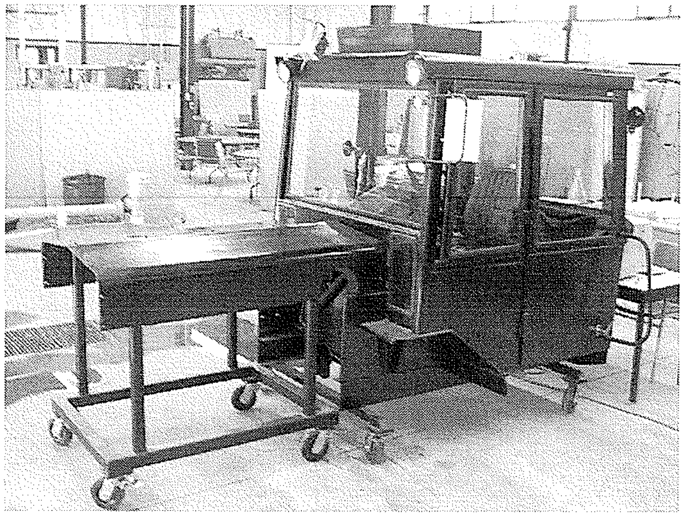


Fig. 9. Operator station and hood exterior.

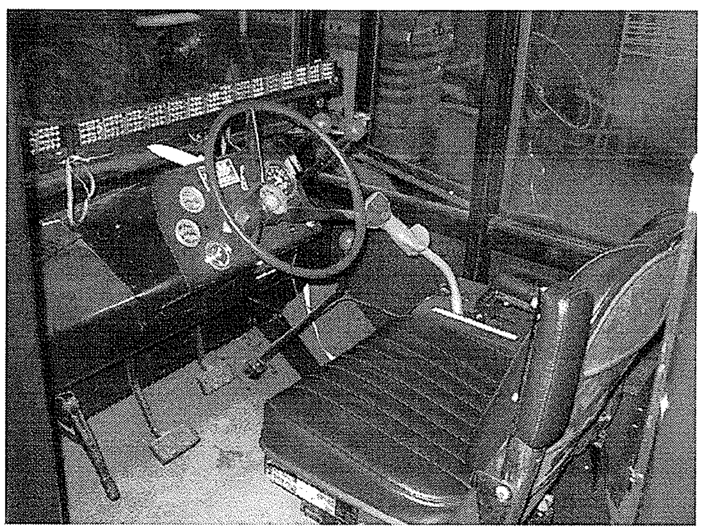


Fig. 10. Operator station interior.

4. 2. 4 Steering Task

The most important part of the simulation was creating a task to test how well a subject can use information from the lightbar to steer. In the field, lightbar information resulted from unpredictable disturbances and oscillation about the correct heading. This resulted in an oscillatory steering motion. To simulate this, a series of random steering disturbances was considered. Many similar experiments, however, required the subject to track a predetermined function (Engel 2001). This method provided several advantages, including more recorded examples and several methods for evaluating performance (Poulton 1974).

A function created by summing six sinusoids, similar to that used by Weinstein (Weinstein & Wickens 1992), was chosen for the tracking task (Fig. 11). Because the function was based on sinusoidal components, it resulted in a control motion similar to that observed in the field. The function was pseudo-random, reducing the likelihood that subjects could predict and track the function without observing the lightbar (Poulton 1974). As well, the frequency could be adjusted to achieve the range of steering oscillation seen in the field and to adjust the difficulty of the tracking task.

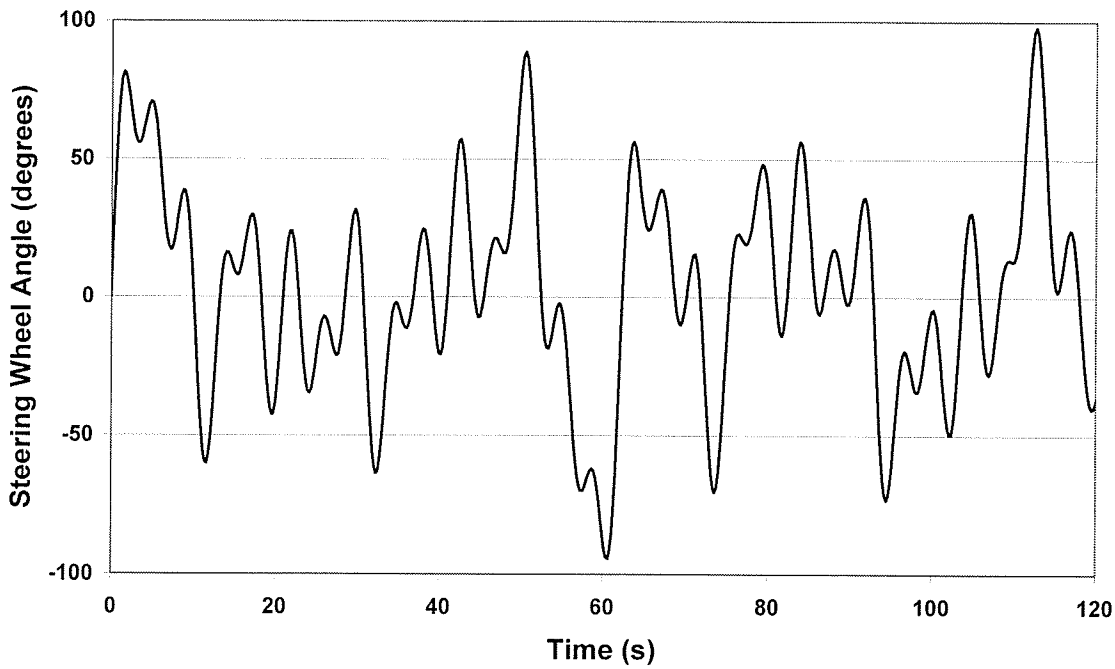


Fig. 11. Sample of tracking function. For steering wheel angle, 0 is centred.

Initially, a second-order control scheme was considered, similar to the relation between steering wheel angle and lateral error for a vehicle. However, there was concern that subjects may be unable to control this adequately (Wickens & Hollands 2000). Therefore, zero-order control was chosen, in which the steering wheel angle tracked the function value.

4. 2. 5 Monitoring Task

An active monitoring task was required for two reasons. First, the main goal for the simulator was to mimic the scanning behaviour seen in the field. Therefore, in addition to the lightbar, subjects were to scan the aiming point and the booms. Second, the monitoring task was intended to tax subject tracking performance, as boom control affects the steering of sprayer operators. Tracking performance is affected by both the scanning between tasks (Poulton 1974) and control actions performed by the non-tracking hand (Wickens & Liu 1988). Therefore, control actions based on the monitoring were also required.

A task similar to boom height control was created for the boom locations. A display containing a moving bar was located in the line of sight for an operator looking to the end of a 30 m boom (Fig. 12). When the bar was centred, no control was required. If the bar was above or below centre, the operator used a control on the joystick to move the bar back to centre (Fig. 13). Only one press of the correct direction was required. To make the task consistent, the same task was chosen for the aiming point location.

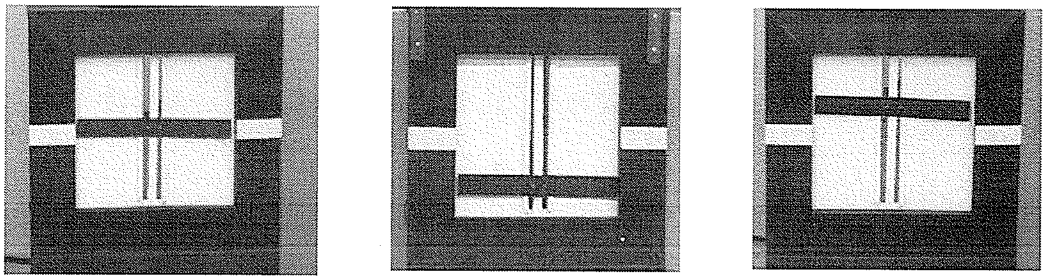


Fig. 12. Monitoring display. Bar is shown in centred position (left), down position (middle), and up position (right).

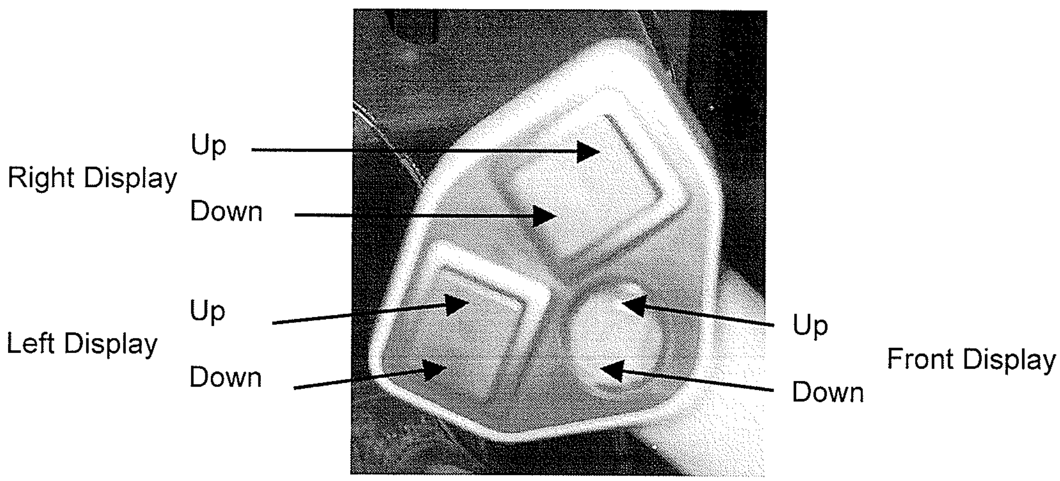


Fig. 13. Joystick with monitoring controls labelled.

In each display, the bar moved from centre independently and was returned to centre by the operator. Time between the last return and the next movement was chosen randomly within a specified range, and each display operated independently of the others. The timing for the boom displays was chosen to match observations of boom monitoring from a rolling field. Each boom display moved from centre between 6 and 10 s after it last returned to centre.

Because operators scanned the aiming point much more frequently, the bar moved away from centre at a random time between 0 and 3 s after it last returned to centre. As well, the size of the moving bar was reduced so that subjects had to use central vision to observe its location. In this way, subjects were forced to fixate on the aiming point display often and view the lightbar in peripheral vision.

Subjects were not told how often the displays moved from centre, only that the aiming point display moved more often than the boom displays. It was felt that subjects would adapt with practice (Donk 1994; Moray & Rotenburg 1989), eventually scanning the aiming point display and lightbar more frequently than the boom displays.

4. 2. 6 Control System

The simulator was controlled with a generic PC with an Intel 80486 DX-66 processor. Technical staff at the University of Manitoba constructed a control system, allowing all simulator operations to be controlled by software. A control program was created using Quick Basic. Details and program code are included in Appendix 2.

5 TESTING METHODOLOGY

5. 1 Approach

In concert with development of a testing apparatus, a methodology for evaluating lightbars had to be created. The methodology was to specify what things to measure, how to measure them, and how to analyze and interpret the results. As well, it was hoped that the methodology could be used when evaluating other interface components in the future.

Because a lightbar is part of a human-machine system, two approaches could be taken—overall system performance and the impact on the operator. Although many interface studies have measured only system performance (Fenwick 1963; Moss 1964b; Sojourner & Antin 1990), more recent studies incorporate both approaches (Hendy et al. 1993; Nikolic & Sarter 2001; Roscoe 1992; Weinstein & Wickens 1992; Wickens et al. 1989).

Integrated measurement of system performance and operator impact is outlined in the field of mental workload research. Mental workload theories are used often for comparing operator interfaces for drivers, pilots, plant controllers, and equipment operators (De Waard 1996; Wickens & Hollands 2000). In fact, Hendy et al. (1993) and Stokes et al. (1990) mention mental workload studies for a peripheral vision aviation display.

5. 2 Mental Workload

5. 2. 1 Definition

Mental workload is a measure of the resources demanded by a task as a proportion of the operator's resource capacity. Every task requires the operator to acquire information, process it, and perform actions based on the processing. The assumption made is that each person has only a limited capacity to perform these processes (labelled as maximum in Fig. 14). This capacity is set by the person's abilities, strategies, motivation, and mental state. The relation between these two amounts is mental workload.

Performance and workload are not always related (Fig. 14). In the underload region, where supply easily matches demand, performance is optimal and does not change. Performance starts to suffer only when approaching maximum workload. In the overload region, performance suffers but workload is a constant maximum (Wickens & Hollands 2000).

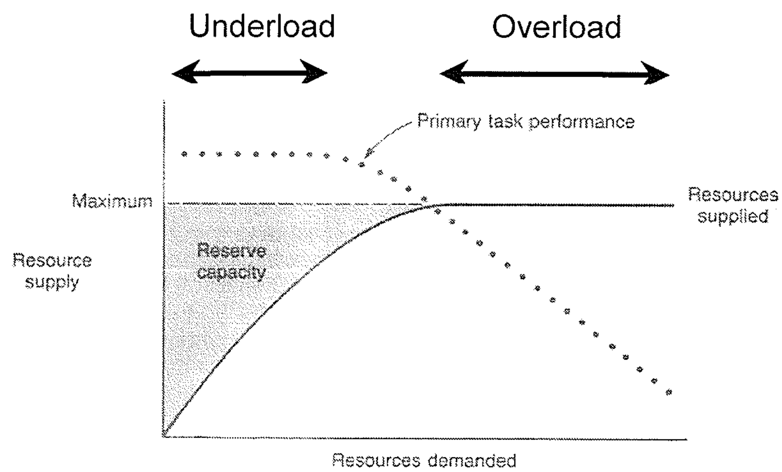


Fig. 14. Relation among resources demanded, resources supplied, and task performance. From Wickens & Hollands (2000).

5. 2. 2 Performance-Resource Function

A second major factor in mental workload is how performance is related to resources supplied for different tasks. We all know that some tasks are done almost automatically, requiring very little resources to achieve acceptable performance. For other tasks, however, performance varies greatly with resources. Difficulty and practice are often the reasons for these differences (Fig. 15) (Wickens & Hollands 2000). When performing a more difficult, or unpractised task (1), achieving the same level of performance requires more resources than when performing an easier, or practiced task (2). In a data-limited task (3), such as trying to read a language you know only partially, performance above a given level is impossible regardless of resources supplied.

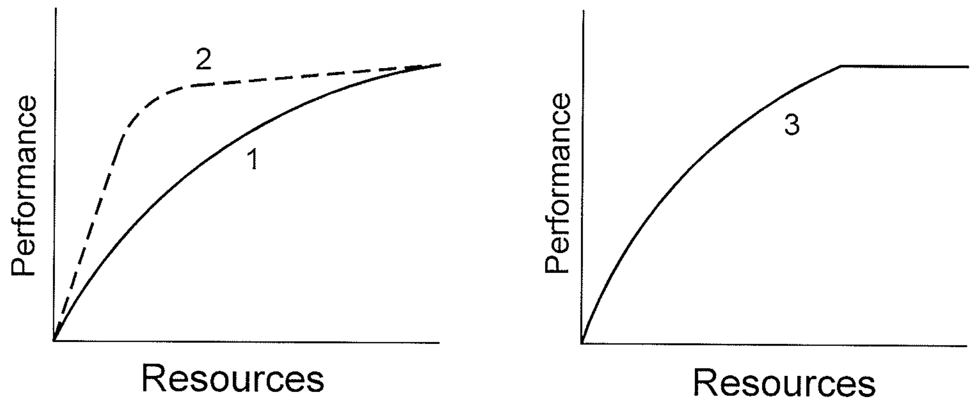


Fig. 15. Performance resource function. Task 1 is difficult or unpractised, task 2 is easy or practiced, and task 3 is data-limited.

5. 2. 3 Multiple Tasks

There are two ways of considering the workload due to performance of multiple tasks. With the single-resource model, all mental resources are the same and can be allocated to any task (Fig. 16) (Wickens & Hollands 2000). Resources allocated to one task are unavailable to all other tasks. This single-resource model works well in most cases, especially in areas where operators are scanning large distances and moving their hands between controls (Liao & Moray 1993).

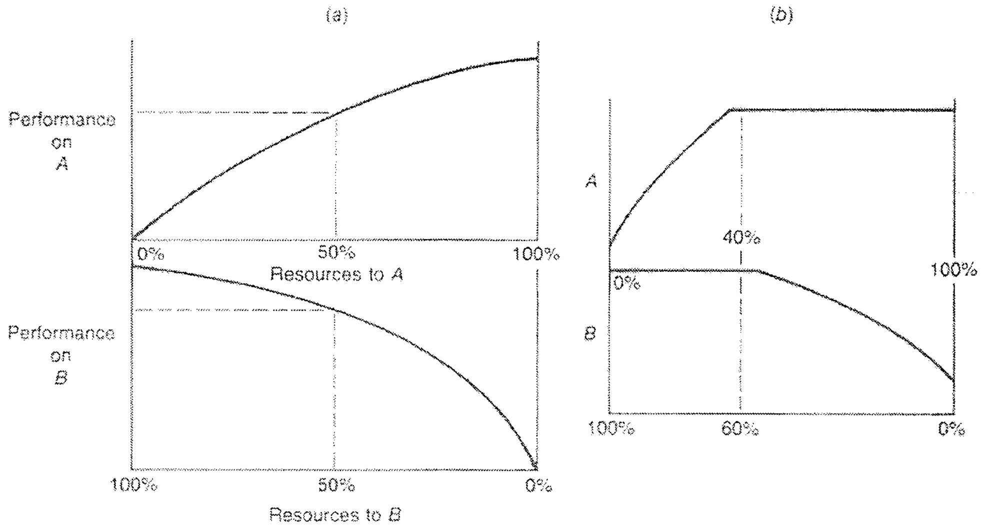


Fig. 16. Two time-shared tasks in a single-resource model. In (a) any change in resource allocation affects performance of task A and B. In (b) performance on A or B can remain constant, depending upon resource allocation (Wickens & Hollands 2000).

In some cases, however, a model with multiple pools of resources best describes mental workload. According to multiple-resource models, tasks that draw on different resources are more easily shared than tasks that draw on the same resource (Fig. 17). For example, people often share a combination of visual and aural tasks better than a combination of exclusively visual or exclusively aural tasks (Wickens & Liu 1988). As well, focal and peripheral vision may draw on separate pools of resources, allowing easier sharing (Leibowitz 1988; Wickens & Hollands 2000).

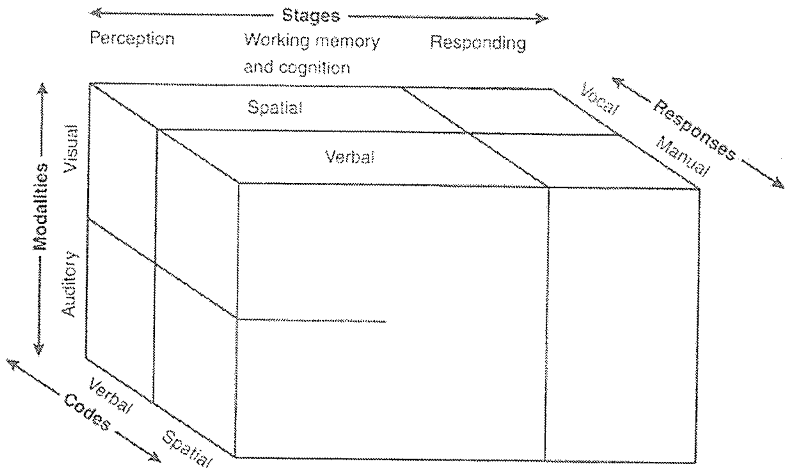


Fig. 17. Multiple resource model delineation of processing resources. Operations separated by a solid line use different resources (Wickens & Hollands 2000).

5. 3 Measurement

5. 3. 1 Overview

Four types of tests are used to measure performance and mental workload (Salvendy 1997): primary-task measures, secondary-task measures, subjective measures, and physiological measures. Several authors provide reviews of these techniques (De Waard 1996; O'Donnell & Eggemeier 1986; Salvendy 1997; Wickens & Hollands 2000). For this experiment, a method from each group was chosen based on the information desired, the simulator, and the experiment's budget.

5. 3. 2 Primary-Task Performance

Performance on the task under investigation—the primary task—should always be the first thing tested. There are several situations, however, when primary task performance does not accurately reflect workload (Wickens & Hollands 2000). First, when tasks lay in the underload section of the performance-demand curve (Fig. 14), variations in workload do not affect performance. Second, when two tasks are measured on different scales or are performed differently, performance comparison may not be feasible. Third, when the outcome of a task does not reflect the mental workload involved, a valid measure may not be possible. Fourth, differences in task performance may be caused by data limits, not workload. In these cases, other techniques must be used.

For this experiment, guidance was the task under investigation; so steering was chosen to be the primary task. Root Mean Square Error (RMSE) (1) is the most common method of measuring error for tracking tasks (Engel 2000; Poulton 1974).

To make the measure more comparable to other tasks, a normalized RMSE was used (Poulton 1974). The normalized value is the subject's RMSE divided by the RMSE that would have resulted had the subject not turned the wheel.

$$RMSE = \sqrt{\frac{\sum_{i}^{N}\left(SteeringAngle_i - FunctionAngle_i\right)^2}{N}} \qquad (1)$$

5. 3. 3 Secondary-Task Performance

Performance on a secondary task—an additional task performed concurrently with the primary task—indicates the residual capacity not allocated to the primary task (Fig. 16) (Wickens & Hollands 2000). An unrelated task, such as performing arithmetic, may be added, or investigators may measure performance on an embedded task—a less important task that the operator performs already.

Secondary tasks may be used in two ways (Fig. 18). In the secondary task case (Fig. 18a), the operator places priority on the primary task, and performs the secondary task with spare resources. Investigators measure performance on the secondary. The secondary task may also be used to load the operator (Fig. 18b). In this case, the operator places priority on the secondary task, and performs the primary task with additional resources. Investigators then measure primary task performance.

Secondary tasks are especially valuable when predicting behaviour during a crisis, when extra resources will be needed. Additionally, secondary tasks can be used to compare spare resources from two unrelated primary tasks. Care, however, must be taken when choosing a secondary task. As dictated by the multiple-resource model, the secondary task should demand the same resources as the primary task. Also, unobtrusive tasks must be chosen.

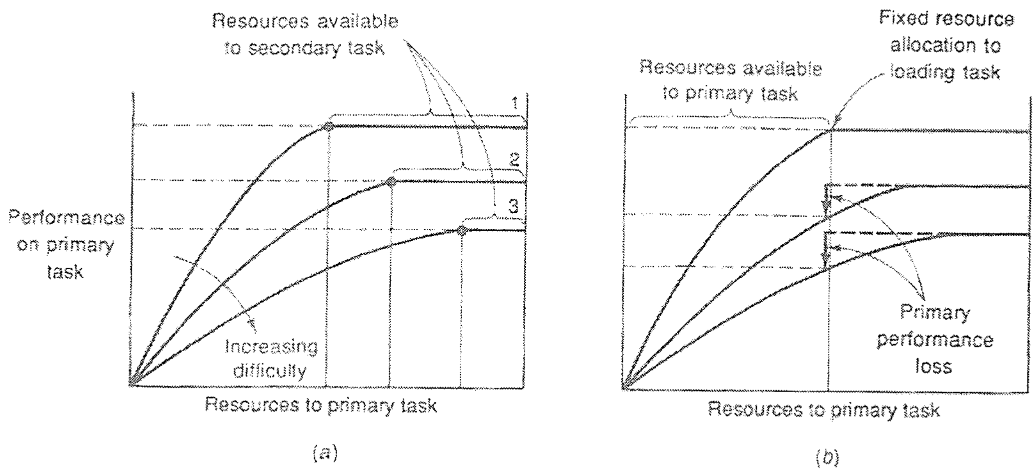


Fig. 18. Secondary task implementations. Primary task has priority in (a). Secondary task has priority in (b) (Wickens & Hollands 2000).

For this experiment, the simulated monitoring task was chosen as an embedded second task. Because the monitoring required discrete responses, the average response time was chosen to quantify monitoring performance. To recognize the difference between the monitoring locations, different average response times were calculated for the boom displays and the aiming point display.

5. 3. 4 Subjective Measures

Subjective measures assess the operator's opinion of the workload (s)he experienced. The operator fills out a scale, usually after the task is completed, rating his/her level of workload. This is the most popular, and perhaps the best, way to measure workload (De Waard 1996). Subjective scales can be divided into two groups—one-dimensional methods that measure overall workload, and multidimensional methods that analyze what type of workload the operator experienced.

Subjective measures are valued for several reasons. For one, a scale can easily be tailored for any task and diagnostic level. As well, they are filled out after the task, so there is no conflict with the primary task. The main problem with subjective measures is that they rely on human judgement. Subjects may not accurately assess their workload due to poor memory, individual preferences, or their unease with the measure (Wickens & Hollands 2000).

The NASA-Task Load Index (TLX) (Hart & Staveland 1988) was chosen for this experiment after considering several subjective scales. The largest decision was to choose between a one-dimensional or multi-dimensional scale. Literature provided no consensus on what type of scale should be used for this situation. Although several multidimensional scales were popular, some researchers felt that one-dimensional scales were more sensitive and easier to use (Hendy et al. 1993; Hill et al. 1992; Vidulich 1986). Based on this, a one-dimensional scale with specific diagnostic scales was considered. Further research, however, revealed that the TLX incorporated all diagnostic scales required, and it was one of the most popular scales currently in use (Noy 2001). As a result, the TLX was chosen.

5. 3. 5 Physiological Measures

To offset the drawbacks of subjective measures, physiological functions of the body are used as objective measures of workload (Wickens & Hollands 2000). Physiological measures are useful because they can give continuous information during the performance of a task. This allows the researcher to observe any peaks or changes in mental workload. Also, once set up, most techniques are not obtrusive. Physiological measures, however, may not correlate reliably with workload. As well, some of the techniques are very expensive and difficult to employ. Finally, many of the measures, such as heart rate variability, are sensitive to other factors such as physical workload. Measures of the heart, brain, and eye have all been correlated to mental workload (De Waard 1996).

Measures of the heart—heart rate (HR) and heart rate variability (HRV)—were chosen for this experiment due to available equipment, resources, and expertise. Heart rate measures have been used for a long time (Roscoe 1992), and they are popular for measuring workload with vehicle drivers (De Waard 1996). HR is a more established measure, and there is a consensus that it increases with increases in physical workload (Lee & Park 1990). HRV however is not as well established. The consensus appears to be that HRV decreases with increases in both physical and mental workload (Lee & Park 1990). Beyond that, there is little consensus on sensitivity or how it should be used. First, some sources state that HRV is sensitive to overall mental demand (Wickens & Hollands 2000), while other sources say that it is only affected by changes in working memory usage (Jorna 1992). Secondly, it is variably described as being useful for a) measuring task workload (De Waard 1996); b) distinguishing between rest and work (Jorna 1992); c) measuring workload difference in a regression of several work tasks

(Mulder 1992); or d) only to back up a solid subjective scale (Roscoe 1992). Additionally, there is evidence that HRV is much more useful in real-world situations than it is in simulators (Roscoe 1992).

There was also little consensus on how to best gather, calculate, and analyze the data. HR is standard—the number of beats were counted and divided by total time to give beats per minute. Several methods have been used for quantifying HRV (Mulder 1992). The two most popular methods appear to be the standard deviation or variance, and the spectral distribution. Although some sources stated that the spectral distribution was the best way to measure HRV (Jorna 1992; Kantowitz 1992a), the standard deviation was chosen due to time restraints and expertise. Additionally, on the recommendation of Dr. Dean Kriellaars (2001), the investigators also found the mean absolute derivative of heart rate. This number was calculated by averaging the absolute rate of change of heart rate during all inter-beat intervals.

5. 3. 6 Combining Measures

For evaluating workload, multiple measures are recommended, with at least one from each group (De Waard 1996). Although measures tend to agree when comparing similar tasks over a wide range of levels (Wickens & Hollands 2000), dissociation has been reported often (De Waard 1996; Hicks & Wierwille 1979). In these cases, one measure may indicate an increase in workload while another indicates no change or a decrease (Yeh & Wickens 1988). By using several measures, there is better chance of some agreement, allowing a conclusion to be made.

The reasons that measures dissociate are not well known, but at least one study has developed some guidelines for dissociation between performance and subjective measures (Yeh & Wickens 1988). First, measures will dissociate when the task is in either the overload or underload region of the resource curve (Fig. 14). Performance is unaffected in the underload region, while subjective ratings are static in the overload region. Second, performance measures are more sensitive to competition for the same resources (e.g. two visual tasks), whereas subjective measures are more sensitive to the use of separate resources (e.g. one visual task and one auditory task). Third, subjective measures are more sensitive to shared tasks than to single tasks. Finally, subjective measures are much more sensitive to changes in invested effort of subjects.

Based on the basic principles of each measure and the known dissociations, the purpose of each measure was determined. Steering, the primary measure, was intended to measure how well a subject can focus on steering with each of the displays. The monitoring task, a secondary task, was intended to both load the subject, ensuring primary performance suffers, and also to see how well the subject can share the two tasks (Kantowitz 1992b). The subjects were to give each task the same priority, so the secondary task would be considered as a combination of loading and secondary task. The TLX subjective scale was to diagnostically measure the different aspects of workload, determine differences in invested effort, and provide a measure even in the underload region. Finally, heart rate and heart rate variability were to be used as an objective reinforcement for the TLX. There were more doubts about its reliability, but the experiment would evaluate its potential for future use.

6 LIGHTBAR TEST

6. 1 Abstract

Agricultural machinery operators guide machinery across the field while monitoring the machine's operation. As a result, operators monitor a large visual area that extends from the front to the rear of the machine. Guidance aids provide lateral error information through a display called a 'lightbar'. Availability of that information, however, is limited by how well the operator can share the lightbar and other scanning requirements. Aviation researchers have previously investigated more salient 'peripheral' displays to solve similar problems. This paper presents the comparison of a regularly sized lightbar with a larger and more luminous lightbar in a simulated agricultural machinery operator task. The more salient lightbar reduced tracking error by 11% without affecting monitoring performance or increasing operator workload. As well, subjects preferred the more salient lightbar. The results suggest that designers may increase guidance aid effectiveness by making displays more salient.

6. 2 *Introduction*

6. 2. 1 *Agricultural Machinery Operator*

Although little research has been published on the agricultural machinery operator (referred to as 'operator' for rest of paper), the task is similar to many tasks discussed more widely in literature. Like an automobile driver or a pilot, the operator manually guides a machine, as well as monitoring and controlling its operation. Unlike many of those tasks, however, the operator must monitor a very large visual area including area to the rear of the machine (Kaminaka 1981).

In large prairie grain farms, the aim is to perform an operation to a large area in a short period of time. As a result, all operations are performed by wide (8-30 m) machines driven in a series of parallel passes (Fig. 19) across the field. In addition to guiding the machine, the operator must monitor and control other parts of the machine on a regular basis. Because the areas requiring monitoring are often mounted behind the operator, rear monitoring is part of the operator's task. Rear monitoring can increase guidance errors because guidance information comes from the front of the machine (Kaminaka 1981).

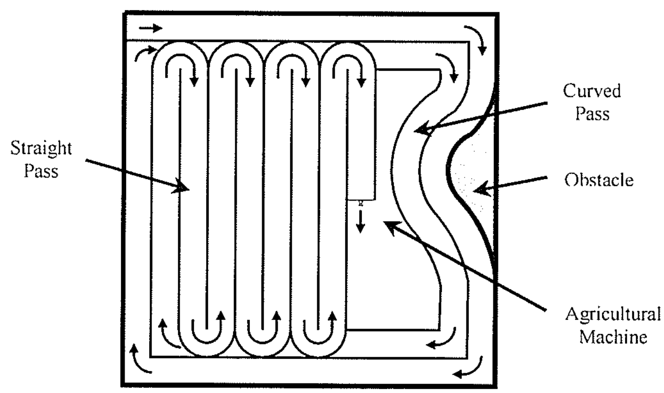


Fig. 19. Field coverage pattern. Machine entered field from upper left corner; arrows indicate direction of travel.

6. 2. 2 Agricultural Guidance Aids

Global positioning system (GPS) guidance aids are one of the latest innovations aimed at reducing lateral error in agricultural operations. Due to the inability of operators to guide machinery accurately along the edge of the previous pass, average lateral overlap is 10% of implement width (Palmer & Matheson 1988). The added costs in seed, fertilizer, herbicide, and other inputs can be significant. A GPS guidance aid provides the operator with an indication of lateral error via a display mounted in the operator station, similar to a flight director in aircraft. The operator uses the lateral position information to help make better steering decisions, thereby guiding machinery more efficiently.

Guidance aids are used in conjunction with guidance cues in the field (Young 2003). Most guidance aids use a single-dimension, compensatory display to indicate lateral error. The display is called a 'lightbar' because it uses an array of light-emitting diodes (LEDs) as display elements. The lightbar is placed in the cab or on the hood of the machine. When driving over the field, the operator uses information from both the lightbar and from an aiming point to guide the machine. The aiming point is a location in the field or on the horizon from which the operator acquires a heading reference. This reliance on both heading and lateral position information has been identified previously with agricultural guidance systems (Palmer 1989), and with pilots on straight runway approaches (Fitts et al. 1950).

The attention required for the lightbar, aiming point, and machine monitoring causes a large amount of visual scanning. Lightbars available commercially are not salient enough to be interpreted outside central vision. Because the aiming point also requires central vision, operators scan between these locations frequently while driving through the field. To make this easier, many operators place the lightbar near the sightline to the aiming point. Additionally, the operator must monitor the equipment periodically. This can happen as frequently as once every 8 s (Appendix 1), and requires further eye movement and change in focal distance.

6. 2. 3 Increasing Salience

Changes to the lightbar design could reduce the scanning required when using the guidance aid. Discussions with dealers of this equipment revealed that the design of the lightbar was a large factor in how well operators adapted to the system. In particular, there was a demand for larger lightbars. Because visual acuity degrades with eccentricity (Anstis 1974), a larger or more salient lightbar could allow lightbar information to be acquired further into the visual periphery. This could reduce scanning between the lightbar and aiming point, and allow information from the lightbar to be acquired more easily after scanning the machine. Possible ways of increasing salience include increasing size, increasing luminance, using flashing lights on the lightbar, or optimizing colors for peripheral vision (Ancman 1991; Christensen et al. 1986).

Similar display designs, termed peripheral displays, have also been investigated in aviation. Initial designs were intended to reduce scanning between the runway scene and navigation displays during runway approaches (Brown et al. 1961; Fenwick 1963). Other peripheral displays have been designed to increase pilot awareness of control instruments or automation changes while scanning other cockpit displays (Nikolic & Sarter 2001; Stokes et al. 1990). Although peripheral displays have not been used widely in commercial applications, research has shown them to be useful in drawing operator attention and sharing with other displays (Brown et al. 1961; Nikolic & Sarter 2001; Stokes et al. 1990).

Because of the benefits found in aviation, the authors believe that a peripheral lightbar may improve the use of agricultural guidance aids. The agricultural equipment operator's task is similar to both situations in which peripheral displays have been investigated in aviation. The operator scans between the cab instruments and the exterior for guidance information. As well, the operator scans a wide field of view while also using guidance information.

The objective of this study was to determine whether a lightbar designed for higher salience in peripheral vision could improve tracking in agricultural machinery operation. Evaluation was based on subject performance and workload in a simple laboratory simulation of agricultural machinery operation.

6. 3 Method

6. 3. 1 Participants

Twenty-two students from the University of Manitoba participated in the study. All participants volunteered, but received an honorarium for their time. Eighteen were male, and ages ranged from 18 to 45 years. All participants were right-handed. Eleven participants had normal vision, and 11 wore corrective lenses for myopia. All participants had driven automobiles, 11 had driven farm equipment, but no participants had used a guidance aid or lightbar.

6. 3. 2 Simulator

A simple simulation of a spraying task was used to test the lightbars. A desktop PC with an Intel 80486DX-66 processor controlled the simulation (Young 2003). Participants sat in an operator station similar to that of an agricultural sprayer (Fig. 20). The operator station was a refurbished tractor cab containing a steering wheel and joystick for controlling the simulator. The subjects responded to lightbars mounted inside and displays that could be seen through the windows of the operator station. A fan in the operator station provided ventilation and white noise for the subjects.

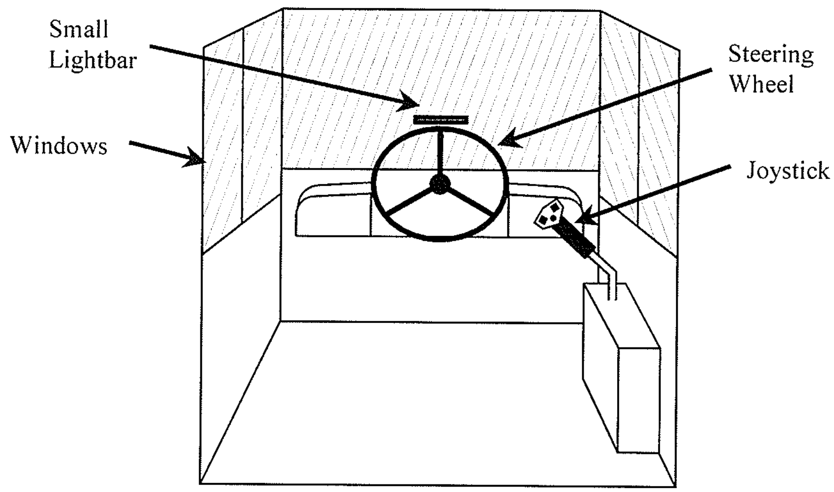


Fig. 20. Operator station (shown without seat). Participants control tracking task with the steering wheel and monitoring tasks with buttons on the joystick. Small lightbar shown; large lightbar was placed in same position as small lightbar.

6. 3. 3 Lightbars

Two lightbars–small and large–were used. The small lightbar was modeled after a popular commercial model. It used 23 light emitting diodes (LEDs), 5 mm in diameter, mounted in a single row 180 mm wide (Fig. 21). The center 3 LEDs were green, and all others were red. When in operation, 3 adjacent LEDs were always lit, creating the appearance of a section of light moving across the lightbar. Three LEDs subtended a visual angle of 1.5°, and each change of position moved the lit section 0.5°.

Colors and action of the large lightbar were identical to the small lightbar, but the large lightbar was scaled 8 to 10 times larger than the small lightbar (Fig. 22). Instead of a single LED, each lighted element was an array of 16 LEDs, 44 mm square. This lightbar was 1420 mm wide. It was made in three sections, and the outer two sections were angled to face the operator. Three lit elements subtended a visual angle of 12.0°, and each change of position moved the lit section 4.5°. The large lightbar also created approximately six times higher illuminance than the small lightbar.

6. 3. 4 Tasks

The simulation consisted of a tracking task and three choice reaction time tasks. Participants used the steering wheel with zero-order control to track a pseudo-random function composed of six sinusoids. By varying the frequency, three levels of tracking difficulty were created. Error was shown on the lightbar, with each step representing 17° of error. Relative root mean square error (RMSE) was measured. The relative RMSE is the RMSE achieved by the subject divided by the RMSE that would have resulted had the subject not moved the steering wheel at all (Poulton 1974).

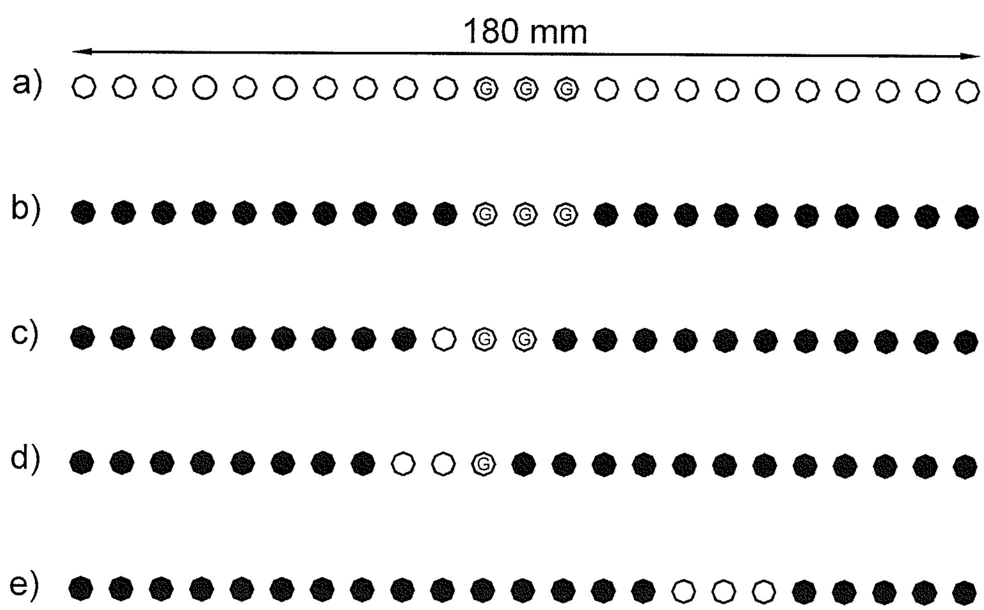


Fig. 21. Small lightbar configuration. a) LED colours: center (G) are green, all others are red, b) less than 9° of steering wheel error (black is off), c) 9 to 26° error to left, d) 26 to 42° error to left, e) 76 to 92° error to right

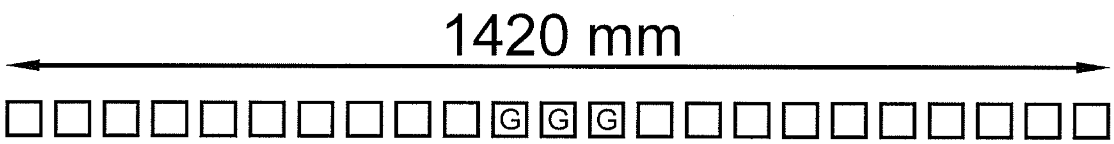


Fig. 22. Large lightbar configuration. Center (G) elements are green, and others are red.

To simulate the monitoring performed in the field, participants also performed three choice reaction time tasks. Task displays were mounted in front and to the sides of the participant (Fig. 23). All displays were 6 m from the participants to ensure a change in focal distance from the lightbar. The front display was also masked to ensure participants used foveal vision.

After semi-random delays, a bar in the task display moved from centered to a low or high position. It remained there until the participant pressed the correct joystick button, at which time it returned to center, and the delay time started again. Each reaction time task was independent of the others. The forward display had a delay of 0 to 3 s, and the side displays each had a delay of 6 to 10 s. Response time (from bar movement until the subject pressed the correct joystick button) was used to measure performance.

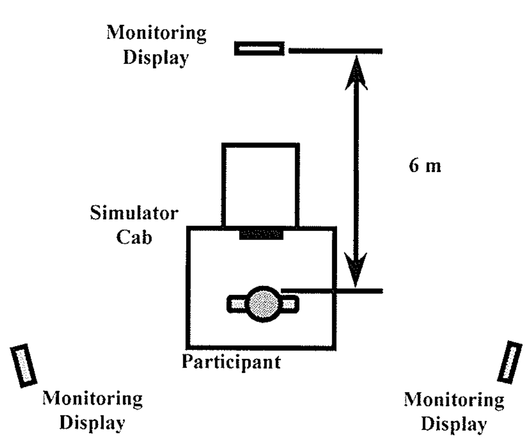


Fig. 23. Overhead view of monitoring task arrangement. Visual angle from front display to each side display is 115°.

6. 3. 5 Workload Measures

Subjective workload ratings were acquired with the paper-based NASA Task Load Index (TLX) (Hart & Staveland 1988) after each testing session. Subjects filled out both the weighting and rating sections of the TLX for the first and second testing sessions, and the rating section for the third through sixth sessions. This provided an overall workload rating and individual ratings of mental demand, physical demand, temporal demand, performance, frustration, and effort. In addition, subjects were asked to write down any comments at the end of testing.

Participants' heart rate was measured in a series of inter-beat intervals (IBIs) transmitted from a heart rate transmitter and recorded on the simulator computer. Prior to testing, baseline heart rates were acquired while the participant sat idle, and while they moved the steering wheel and controls freely. Mean and standard deviation of heart rate were calculated using IBIs from the middle 3 min of each testing session. Heart rate and heart rate standard deviation have been correlated to physical and mental workload (Lee & Park 1990).

6. 3. 6 Procedure

All subjects attended a briefing session the week before testing. The experiment was explained both orally and in a booklet distributed to each subject. The following week each participant came to the laboratory on two separate days. The first day was intended for subjects to practice the simulator task and TLX. Each participant performed both tasks in six 5-min sessions. Medium tracking difficulty was used for all sessions. Participants alternated between small and large lightbars; half started with the small lightbar, and half started with the large lightbar. Each participant returned to the laboratory approximately 24 or 48 h later. Again, participants performed both tasks for six 5-min sessions. Tracking difficulty was set at medium for the first and second sessions, low for the third and fourth sessions, and high for the fifth and sixth sessions. Lightbar order was the same as the first day. During analysis, each measure was analyzed using two-way repeated measures ANOVA.

6. 4 Results

All display means and effects are shown in Table II. Difficulty effects were found in tracking ($F(2,42) = 163.68$, $p < 0.001$, partial $\eta^2 = 0.886$) (Fig. 24), and front monitoring ($F(2,42) = 5.03$, $p = 0.011$, partial $\eta^2 = 0.193$). There were no interaction effects.

Table II. Observed display means and effects.

Parameter	Mean by Lightbar: Small	Mean by Lightbar: Large	F(1,21)	Statistical Significance: p < 0.05	Statistical Significance: Level	Effect Size partial η^2
Tracking Performance						
Relative RMSE	0.81	0.72	26.58	Yes	<0.001	0.559
Monitoring Performance						
Forward reaction time (s)	1.2	1.2	0.48	No	0.497	
Side reaction time (s)	2.9	2.9	0.22	No	0.644	
Subjective Reports (scale of 0-100)						
Combined	55	53	2.06	No	0.167	
Mental Demand	58	55	4.63	Yes	0.043	0.181
Physical Demand	40	37	5.94	Yes	0.024	0.221
Temporal Demand	65	67	1.25	No	0.276	
Performance	65	67	1.61	No	0.219	
Frustration	37	35	0.86	No	0.364	
Effort	56	53	2.12	No	0.160	
Heart Measures						
Heart Rate (beats/min)	78.3	79.0	5.61	Yes	0.029	0.237
Standard Deviation of Heart Rate (beats/min)	3.7	3.8	0.06	No	0.816	

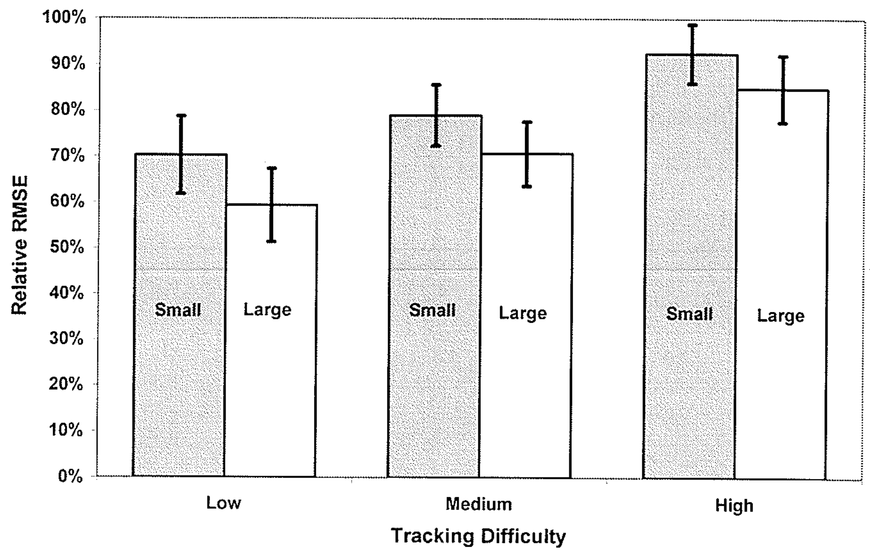


Fig. 24. Tracking error across display and tracking difficulty conditions. Error bars represent 95% confidence intervals.

The researchers concluded that the difficulty effect in front monitoring resulted from accommodation on the first trial. All medium difficulty trials were at the start of the testing session, confounding the effects. As well, the researchers decided that the display effect found for heart rate was too small to be considered meaningful in this experiment.

6. 5 Discussion and Conclusions

6. 5. 1 Simulation Interpretation

Based on the performance measures, the large lightbar reduced error by a mean of 11%, and by a similar amount at all three levels of difficulty. There was no display effect found in monitoring, showing that subjects did not sacrifice monitoring to track better.

Based on the workload measures, the large lightbar may have reduced workload slightly, if at all. Only mental demand and physical demand TLX scales showed a reduction in demand under the large lightbar. Heart rate and standard deviation of heart rate also showed little variation due to display.

Additionally, in written comments, 12 participants expressed a preference for the large lightbar. Eight participants commented they could see the large lightbar more easily in their peripheral vision. Four participants expressed a preference for the small lightbar.

6. 5. 2 Implications for Lightbar

The display effects seen in this experiment can be attributed to the size and illuminance difference between lightbars. This reduced the eye movement, accommodation, and vergence needed to acquire information from the lightbar, thereby reducing the time to acquire information while scanning (Sanders 1970; Weintraub et al. 1984, 1985). As well, the larger lightbar may have captured attention better (Nikolic & Sarter 2001; Remington et al. 1992). Comments indicated that subjects noticed the difference in salience.

Benefits of the large display are similar to those reported for similar peripheral displays in aviation. Only two other reported displays have been modified by increasing only size and illuminance. The Malcolm Display (Christensen et al. 1986; Stokes et al. 1990) was used to indicate a plane's attitude. Although it covered a larger visual area, perhaps reducing suitability for comparison, it also allowed better sharing of attention when scanning other displays. More recently, peripheral vision flight mode annunciations (FMAs) were tested in a commercial airline simulator (Nikolic & Sarter 2001). Larger size and higher luminance resulted in better knowledge of flight mode, especially during busy scanning periods.

These results may have implications for future design of guidance aid lightbars, as long as the base conditions of the experiment transfer to the field. At best, this experiment shows that a lightbar with greater salience would improve the effectiveness of guidance aids. This agrees with feedback from dealers. It must be stressed, however, that this experiment was a low-fidelity simulation that has not been validated with field data. Although it was constructed to simulate the field situation, there will undoubtedly be differences. In the field, scanning patterns and objects may vary with several factors. As well, workload levels will differ, perhaps changing the difference in performance between displays. Finally, it is unknown if benefits of this display will be as large in the field as they were in this tracking task.

A final implication of this research is that that knowledge acquired in other fields, such as aviation, has value in the design of agricultural operator interfaces. Much more work has been performed on interface design in the aviation, military, and automotive industries than in agriculture. Fortunately, much of this knowledge can be applied with careful attention to the differences between tasks. This information will be increasingly important as agricultural field operations become more automated, and operators assume a more supervisory role in machine operation. For example, automated guidance is becoming a reality for an increasing number of farmers. It is hoped that co-operation and sharing between these fields can help advance the efficiency of agricultural field operations, while also making the operator's task more fulfilling.

6. 5. 3 Acknowledgements

This research was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Agri-Food Research and Development Initiative of Manitoba (ARDI). The authors would like to thank the Prairie Agricultural Machinery Institute (PAMI) for constructing the simulator; and Matt McDonald, Layne Maciura, Dale Bourns, and Gerry Woods for technical assistance.

7 CONCLUSIONS AND RECOMMENDATIONS

7. 1 Introduction

As stated in the background section, this project was an initial step towards testing the hypothesis that a peripheral vision guidance lightbar could improve guidance aid use. The conclusions about alternate display are reviewed in the manuscript. Another large part of this project, however, was developing the methodology and apparatus for performing a laboratory simulation and test of different lightbar designs. The experiment outlined in the manuscript served as the first test of this system. This section contains a discussion and conclusions about how successful the system was. Lessons learned and observations of the laboratory test, the experimental design, and all tasks and measurements are included. Recommendations on changes for the future are included as well as recommended directions for future research.

7. 2 Laboratory Testing

The researchers believe that the testing apparatus and methodology worked well in this instance. The results were believable and agreed with theory and previous experiments on peripheral displays. As well, this testing scenario allowed easier and more consistent testing than was anticipated from field tests. Lessons were learned, however, on the limitations, proper place, and execution of laboratory tests in the future.

The limitations of laboratory testing became increasingly evident throughout the project. The results from any laboratory experiment are directly relevant only to the apparatus and methodology; relevance to real-world tasks is limited by the assumptions made when creating the laboratory task. In the case of this project, one may question how well guidance and monitoring goals, scanning patterns, and task demand related to the real agricultural spraying task.

Due to this, care should be taken in how laboratory tests are both used and designed. The author feels that, for human factors testing, laboratory tests should be part of an overall strategy that also incorporates field observation and field testing where they can be most effective (Kantowitz 1992a). Field observation (or task analyses) should be used for identifying the structure of the task, the most important variables, and defining questions to be tested. Laboratory tests should then be used to evaluate hypotheses developed through field observation. Finally, field-testing should be used to verify and refine the laboratory results. As well, field tests can serve as part of the initial field observation step.

This project also helped illustrate some of the precautions and objectives that should be maintained in both field observation and laboratory studies. The field observation stage should involve sufficient data and analysis to a) understand the physical and cognitive processes involved, and b) prove the existence of problems investigated at later stages. The author believes that the field observation performed in the future should satisfy these goals more fully than the field observation performed as part of this experiment. As well, during future laboratory tests, researchers should use more pilot studies and observation to ensure the laboratory tasks create the desired subject behaviour.

Theory should also be used through all steps of testing and observation (Kantowitz 1992a). Models and theory provide a basis for analyzing results, simplifying hypotheses and tests, and building on the work of others. While mental workload theory was valuable in this experiment, control theory, signal detection theory, and other human operator models may prove useful in future research.

7. 3 *Experimental Design*

Several lessons were learned about components of experimental design, including sample size, accommodation effects, and proper arrangement of treatments. First, knowledge of the typical sample variance and treatment means gained through this experiment could allow future sample sizes to be tailored to the testing needs. This experiment used a conservatively large sample size because knowledge of expected results was limited. Some of the significance levels, such as those found for heart rate and tracking, suggest this test was overly powerful. As well, other similar studies in this area use smaller sample sizes (Nikolic & Sarter 2001; Weinstein & Wickens 1992; Wickens et al. 1989). In the future, smaller sample sizes could allow faster and more flexible testing.

Lessons on practice effects and treatment placement occurred together. As explained briefly in the manuscript, accommodation effects in the first testing session became confounded with the difficulty effects because a) accommodation at the start of the test day occurred during testing, and b) the difficulty effects were not randomized or counterbalanced. Future tests should avoid accommodation effects by giving subjects an accommodation trial (no data used) before testing. As well, all effects should be randomized or counterbalanced.

7. 4 *Tracking Performance*

The sensitivity, comments, and scores in tracking indicate that subjects were likely overloaded when performing this task. In the experiment, each change in difficulty or display resulted in a consistent change in tracking performance. According to mental workload theory, this occurs when the operator is overloaded (Fig. 14). This possibility was also reflected in the comments and tracking scores. Six comments indicated that the task was tiring, difficult, or monotonous, while only one comment indicated that more demand was needed. As well, the relative root mean square error (RMSE) treatment means ranged from 59% to 93%. Although there is no particular 'point' of poor performance (Poulton 1974), no steering at all results in a relative RMSE of 100%. As a result, the author considers this range to be a high level of error, indicating a high load and possibly overload.

Future tracking functions should be set at a single level that will conserve operator motivation. In this experiment, three levels of tracking difficulty were used to see how demand affected tracking performance and lightbar effects. Although difficulty affected performance, there was no interaction with the display effect. Therefore, a test with a single difficulty level should provide the same result. For future tests, this level should be set so that it does not reduce participant motivation. Tasks with too little and too much demand can reduce participant motivation, resulting in reduced performance (De Waard 1996; Yeh & Wickens 1988). This level can be set through pilot tests.

Although relative RMSE worked well as a single measure of performance, control measures may provide more information on operator behaviour. This experiment showed that tracking performance can be a sensitive measure of how effectively operators use information from a lightbar. For more knowledge of operator behaviour, control measures such as movement velocity, holds, gain, and lag may provide a better picture of the mental processes occurring during tracking and sharing tasks (Wickens & Gopher 1977).

7. 5 Monitoring Performance

The monitoring task appeared to work as a loading task (Fig. 18b) in this experiment. Because subjects were told to give equal priority to both tracking and monitoring tasks, the researchers were unsure of how subjects would perform. It appears that the monitoring task forced subjects to follow a prescribed scanning pattern, making tracking more difficult. Meanwhile participants performed similarly on monitoring at all treatment levels. The researchers are unsure of whether subjects consciously gave priority to monitoring, or if the scanning required for monitoring forced a level of priority.

In the future, more steps should be taken to ensure that the scanning pattern is realistic. The subjects were expected to adapt to the rate at which the boom displays needed observation, eventually scanning each boom display only every 6-10 s. Adaptation to event rate, however, is often sluggish (Wickens & Hollands 2000), and subjects may not have adapted to this rate. Although this cannot be verified through observation, five comments indicate that subjects found observing side displays or performing all tasks difficult. To ensure that a scanning pattern is followed, participants should be observed during pilot testing or real testing. As well, more predictable patterns or better instructions may allow subjects to behave as expected.

An analysis that accounts for missed signals may be useful in future tests. Response time data from the boom locations included a range of short reaction times and a few very long reaction times. The initial analysis was performed using these reaction times. Based on pilot inspections of the distribution, and examples set by several other studies (Nikolic & Sarter 2001; Sojourner & Antin 1990; Srinivasan 1997), an additional analysis was performed in which reaction times over 5 s were counted as missed signals. There was no difference in results, so the initial reaction time analysis was used. In the future, however, criteria for missed signals should be created while designing response time tasks.

7. 6 Subjective Measures

Although the task load index (TLX) results did exhibit a display effect, they did not fully agree with the tracking performance results. Tracking exhibited strong display and difficulty effects. TLX, on the other hand, exhibited display effects for only two subscales, and no difficulty effects. Because improved performance is usually associated with lower workload, the author believes that the small effects may be considered as a dissociation between measures. Two possible reasons for this dissociation can be identified. According to workload theory (Fig. 14), subjective measures work poorly when subjects are overloaded (Yeh & Wickens 1988). As already discussed, the sensitivity of the primary task performance suggests that this may be true. Additionally, subjective measures are sensitive to the motivation and resources invested by subjects (Yeh & Wickens 1988). In this case, subjects performed the same task 12 times over two days, with little change, no results, and no incentives (money, etc.). Under these conditions, subjects will reduce their resource investment to reach a more comfortable level of loading, resulting in little variation in workload (Yeh & Wickens 1988). The author believes that some combination of these factors contributed to the small subjective workload effects.

Future tests can account for dissociations in several ways. First, the task could be intentionally designed for the underload or overload section of the demand curve (Fig. 14). In this case only differences in subjective measures or performance measures, respectively, would be expected. Second, the task could be designed for the middle part of the curve, in which both subjective and performance measures should work. Finally, the task difficulty and incentives should be designed to ensure that subjects do not lose motivation during the testing.

The method of collecting subjective measures should be considered carefully in the future. A uni-dimensional scale should be used for repeated tests where the nature of the task did not change much, while a multi-dimensional scale should be used to diagnose workload and when testing tasks that differ in demands. The author makes this recommendation because the individual mental demand and physical demand scales appeared to be more sensitive than the combined workload rating based on the TLX protocol (Hart & Staveland 1988); and because the relative ratings on each individual scale did not change in this experiment, making most of the information superfluous.

One final thing learned about subjective measures is the value of participants' comments. Though comments are difficult to quantify, they provide great insight into what was actually happening in the test. The experience from this test can help future researchers determine particular comments to look for or solicit. Additionally, a debriefing session for each subject may be helpful in soliciting more in-depth opinions on the task.

7. 7 Heart Rate Measures

Heart rate measures appear to have served their purpose as an objective validation of the subjective reports. The lack of meaningful effects seen in heart rate agree with the lack of effect seen in the combined workload rating, although they are different than the small effect seen on the mental demand and physical demand subscales. Heart rate measures are known to vary with motivation and expectations (Jorna 1992), similar to subjective reports. Therefore, the discussion on these effects is likely applicable to heart rate measures as well. Normalizing heart data did not produce meaningfully different results. The author evaluated normalization relative to a) the 'resting' baseline, b) the 'moving' baseline, c) the first driving session, and d) the first small lightbar session.

To adequately assess the usefulness of heart rate measures, it is necessary to observe their values over a larger range of mental and physical workload than was seen in the testing sessions. To do this, an additional analysis was performed on the effect of order, including the 'resting' baseline and 'moving' baseline sessions (Table III). In the baseline sessions the subjects should have experienced less mental workload, less physical workload, and less motivation, all things that affect the heart rate measures.

Table III. Significance tests for order.

Measure	F	P	Sig.	Partial η^2
Heart Rate	.856	0.451	No	0.045
Standard Deviation of Heart Rate	8.248	< 0.001	Yes	0.314
Mean Absolute Derivative of Heart Rate	3.256	0.037	Yes	0.153

Based on the results of heart rate in both analyses, the author believes that heart rate is not a good measure for the testing to be performed on agricultural operator interfaces. The display effect was not meaningful, there was no difficulty effect, and there was no order effect. Heart rate varies with changes in physical workload only (Lee & Park 1990), and the differences in physical workload encountered in this testing are too small to use for future testing.

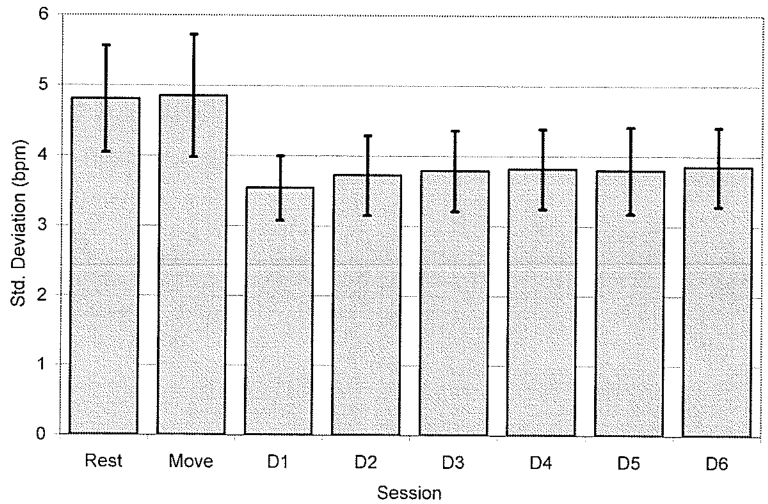


Fig. 25. Standard deviation of heart rate by session order. 'Rest' and 'Move' refer to the two baseline sessions. Error bars represent 95% confidence intervals.

With further investigation, heart rate variation may be a valuable method. Both standard deviation of heart rate (SDHR) and mean absolute derivative of heart rate (DHR) showed no effects in the testing sessions. The order analysis, however, illustrated that they were significantly different in the baseline sessions (Table III and Fig. 25). This agrees with the opinion offered by Jorna (1992), that heart rate variability is good at determining between rest and work conditions. Future testing of a variety of tasks in the laboratory and the field should further define the sensitivity of HRV measures. Future work could also look at finding the best method of measuring HRV. In this experiment, SDHR and DHR had similar trends, but SDHR appeared to be more sensitive. As explained earlier, some researchers believe spectral analysis is the best measure of HRV. Future tests should also evaluate this method.

7. 8 Future Research

This project attempted to use methods developed in other areas to evaluate problems with the agricultural operator interface. This has created experience, better abilities in this area, and questions about future challenges. To proceed, three main areas must be pursued—definition of the operator's task and problems; development of the operator's optimum role; and exchange of information with other research fields.

First, a better understanding of the operator's task must be developed. This requires observation, both quantitative and qualitative, of the entire system and the operator's role in it. Qualitative observation will provide information on the structure of the task. This can be performed in person and through videotape. Quantitative methods can provide bases for testing in the future. The utility of various performance methods, such as control measures and Global Positioning System measurement of guidance error, must be evaluated. As well, the usefulness of the workload measures used in this project must be considered. There are indications from aviation that many workload measures are more effective in the field than in a simulator (Roscoe 1992). By doing this, the operator's task and problems can be better defined, creating future work in obviating those problems.

Second, the operator's future role in agricultural equipment operation must be considered. The operator is quickly moving from a manual control role to a supervisory control role, similar to a pilot in commercial aviation or a process controller in a plant. New demands, problems, and abilities presented by this change must be identified and analyzed. This will require integration of knowledge about the operator, the field tasks to be performed, and the future machinery development.

Finally, an exchange of ideas from other fields must be maintained. Theories, models, and research from many different fields of psychology, aviation, and process control are applicable to the operator's task. As well, other methods of evaluation, including computer models and high-fidelity simulations, may be very useful for future testing and observation. In addition to texts and journals, personal contact with many researchers in these areas can provide a better perspective of the research relevance.

8 REFERENCES

Ancman, E. 1991. Peripherally located CRTs: color perception limitations. Pages 960-965. IEEE National Aerospace and Electronics Conference. Institute of Electrical and Electronics Engineers, New York.

Anstis, S. M. 1974. A chart demonstrating variations in acuity with retinal position. Vision Research **14**:589-592.

Aponso, B. L. 2000. Simulator information from Systemstech. Personal communication with S. Young.

Brown, I. D., S. D. Holmqvist, and M. C. Woodhouse. 1961. A laboratory comparison of tracking with four flight-director displays. Ergonomics **4**:229-251.

Statistics Canada. 2002. 1996 Agricultural Operations National and Provincial Highlights Tables: Manitoba, Saskatchewan, and Alberta. Statistics Canada.

Christensen, J. M., R. D. O'Donnell, C. A. Shingledecker, C. L. Kraft, and G. Williamson. 1986. Optimization of Peripheral vision. Page 65. USAF School of Aerospace Medicine, Brooks Air Force Base, TX.

De Waard, D. 1996. The Measurement of Drivers' Mental Workload. Traffic Research Centre. University of Groningen, Haren. Netherlands.

Donk, M. 1994. Human monitoring behavior in a multiple-instrument setting: Independent sampling, sequential sampling or arrangement-dependent sampling. Acta Psychologica **86**:31-55.

Duncan, J. R. 2000. Email communication with S. Young.

Duncan, J. R., and E. L. Wegscheid. 1982. Off-road vehicle simulation for human factors research. ASAE Paper 82-1610. ASAE.

Easterlund, P. 2000. Email communication with S. Young.

Engel, R. 2000. Email communication with D. D. Mann.

Engel, R. 2001. Email communication with S. Young.

Fenwick, C. A. 1963. Development of a Peripheral Vision Command Indicator for Instrumented Flight. Human Factors **5**:117-127.

Fitts, P. M., R. E. Jones, and J. L. Milton. 1950. Eye movements of aircraft pilots during instrument landing approaches. Aeronautical Engineering Review **9**:1-5.

Folk, C. L., R. W. Remington, and J. H. Wright. 1994. The structure of attentional control: contingent attentional capture by apparent motion, abrupt onset, and color. Journal of Experimental Psychology: Human Perception and Performance **20**:317-329.

Goldstein, E. B. 1999. Sensation and Perception. Brooks/Cole, Pacific Grove, CA.

Gruening, J., J. Bernard, C. Clover, and K. Hoffmeister. 1998. Driving Simulation. 1998 SAE International Congress & Exposition. SAE, Detroit, MI.

Hart, S. G., and L. E. Staveland. 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. Pages 139-183 in P. A. Hancock, and N. Meshkati, editors. Human Mental Workload. Elsevier, Amsterdam.

Hendy, K. C., K. M. Hamilton, and L. N. Landry. 1993. Measuring subjective workload: when is one scale better than many? Human Factors **35**:579-601.

Hicks, T. G., and W. W. Wierwille. 1979. Comparison of five mental workload assessment procedures in a moving-base driving simulator. Human Factors **21**:129-143.

Hill, S. G., H. P. Iavecchia, J. Alvah C. Bittner, A. L. Zaklad, and R. E. Christ. 1992. Comparison of four subjective workload rating scales. Human Factors **34**:429-439.

Johnson, M. A. 1986. Color vision in the peripheral retina. American Journal of Optometry & Physiological Optics **63**:97-103.

Jorna, P. G. A. M. 1992. Spectral analysis of heart rate and psychological state: a review of its validity as a workload index. Biological Psychology **34**:237-257.

Kaminaka, M. S. 1981. Visual Monitoring in a Simulated agricultural machinery operation. Human Factors **23**:165-173.

Kantowitz, B. H. 1992a. Selecting factors for human factors research. Human Factors **34**:387-398.

Kantowitz, B. W. 1992b. Heavy vehicle driver workload assessment: lessons from aviation. Human Factors Society 36th Annual Meeting. Human Factors and Ergonomics Society.

Koenderick, J. J., A. J. v. Doorn, and W. A. v. d. Grind. 1985. Spatial and temporal parameters of motion detection in the peripheral visual field. Journal of the Optical Society of America A **2**:252-259.

Krielaars, D. 2001. Personal communication with S. Young.

Lee, D. H., and K. S. Park. 1990. Multivariate analysis of mental and physical load components in sinus arrhythmia scores. Ergonomics **33**:35-47.

Leibowitz, H. W. 1988. The Human Senses in Flight. Pages 83-110 in Human Factors in Aviation. Academic Press.

Levi, D. M. 1999. Progress and paradigm shifts in spatial vision over the 20 years of ECVP. Perception **28**:1443-1459.

Levi, D. M., S. A. Klein, and A. P. Aitsebaomo. 1984. Detection and discrimination of the direction of motion in central and peripheral vision of normal and amblyopic observers. Vision Research **24**:789-800.

Liao, J., and N. Moray. 1993. A simulation study of human performance deterioration and mental workload. Le Travail humain **56**:321-344.

Moray, N., and I. Rotenburg. 1989. Fault management in process control: eye movements and action. Ergonomics **32**:1316-1342.

Moss, S. M. 1964. Tracking with a differential brightness display: II. peripheral tracking. Journal of Applied Psychology **48**:249-254.

Mulder, L. J. M. 1992. Measurement and analysis methods of heart rate and respiration for use in applied environments. Biological Psychology **34**:205-236.

Nikolic, M. I., and N. B. Sarter. 2001. Peripheral visual feedback: a powerful means of supporting effective attention allocation in event-driven, data-rich environments. Human Factors **43**:30-38.

Noy, I. 2001. Telephone communication with S. Young.

O'Donnell, R. D., and F. T. Eggemeier. 1986. Workload Assessment Methodology. In K. R. Boff, L. Kaufman, and J. P. Thomas, editors. Handbook of Perception and Human Performance. John Wiley & Sons, New York.

Palmer, R. 2002. Telephone communication with S. Young.

Palmer, R. J. 1989. Techniques of navigating in a farm field. Navigation: Journal of The Institute of Navigation **36**:337-344.

Palmer, R. J., and S. K. Matheson. 1988. Impact of navigation on agriculture. ASAE, St. Joseph, MI.

Poulton, E. C. 1974. Tracking Skill and Manual Control. Academic Press, New York.

Remington, R. W., J. C. Johnston, and S. Yantis. 1992. Involutary attentional capture by abrupt onsets. Perception & Psychophysics **51**:279-290.

Riemersma, J. B. J. 1981. Visual control during straight road driving. Acta Psychologica **48**:215-225.

Roscoe, A. H. 1992. Assessing pilot workload. Why measure heart rate, HRV, and respiration? Biological Psychology **34**:259-287.

Roscoe, S. N. 1968. Airborne displays for flight and navigation. Human Factors **10**:321-332.

Salvendy, G. 1997. Handbook of Human Factors and Ergonomics. John Wiley & Sons, New York.

Sanders, A. F. 1970. Some aspects of the selective process in functional visual field. Ergonomics **13**:101-117.

Sinden, J. V., W. J. Becker, and W. D. Shoup. 1985. The effects of psychological load and speed on tractor operator error. Applied Ergonomics **16**:183-185.

Sojourner, R. J., and J. F. Antin. 1990. The effects of a simulated head-up display speedometer on perceptual task performance. Human Factors **32**:329-339.

Srinivasan, R. 1997. Effect of selected in-vehicle route guidance systems on driver reaction times. Human Factors **39**:200-215.

Stokes, A., C. D. Wickens, and K. Kite 1990. Display technology: human factors concepts. Society of Automotive Engineers, Warrendale, PA.

Tang, P. 2000. Ergonomic evaluation of visual guidance aids for agricultural machines. M.Sc. Thesis. Department of Biosystems Engineering. University of Manitoba, Winnipeg, MB.

Tufano, D. R. 1997. Automotive HUDs: the overlooked safety issues. Human Factors **39**:303-311.

Van Cott, H. P., and R. G. Kinkade 1972. Human Engineering Guide to Equipment Design. US Government Printing Office, Washington, DC.

Vidulich, M. A. 1986. Techniques of subjective workload assessment: a comparison of SWAT and the NASA-Bipolar methods. Ergonomics **29**:1385-1398.

Weinstein, L. F., and C. D. Wickens. 1992. Use of nontraditional flight displays for the reduction of central vision overload in the cockpit. International Journal of Aviation Psychology **2**:121-142.

Weintraub, D. J., R. F. Haines, and R. J. Randle. 1984. The utility of head-up displays: eye-focus vs. decision times. Pages 529-533. Proceedings of the Human Factors Society 28th Annual Meeting. Human Factors and Ergonomics Society.

Weintraub, D. J., R. F. Haines, and R. J. Randle. 1985. Head-up display (HUD) utility, II: runway to HUD transitions monitoring eye focus and decision times. Pages 615-619. Proceedings of the Human Factors Society 29th Annual Meeting. Human Factors and Ergonomics Society.

Wickens, C. D., and C. M. Carswell. 1995. The proximity compatibility principle: its psychological foundation and relevance to display design. Human Factors **37**:473-494.

Wickens, C. D., and D. Gopher. 1977. Control theory measures of tracking as indices of attention allocation strategies. Human Factors **19**:249-366.

Wickens, C. D., I. Haskell, and K. Harte. 1989. Ergonomic design for perspective flight-path displays. IEEE Control Systems Magazine **1989**:3-8.

Wickens, C. D., and J. G. Hollands 2000. Engineering Psychology and Human Performance. Prentice-Hall, Upper Saddle River, NJ.

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

Yantis, S., and A. P. Hillstrom. 1994. Stimulus-driven attentional capture: evidence from equiluminant visual objects. Journal of Experimental Psychology: Human Perception and Performance **20**:95-107.

Yantis, S., and J. Jonides. 1990. Abrupt visual onsets and selective attention: voluntary versus automatic allocation. Journal of Experimental Psychology: Human Perception and Performance **16**:121-134.

Yeh, Y.-Y., and C. D. Wickens. 1988. The dissociation of subjective measures of mental workload and performance. Human Factors **30**:111-120.

Young, S. 2003. Design of an agricultural driving simulator for ergonomic evaluation of guidance displays. M.Sc. Thesis. Department of Biosystems Engineering. University of Manitoba, Winnipeg, MB.

9 APPENDIX 1: TASK ANALYSIS

9. 1 Interview Questions

General Information
Name, Operation Type:
System:
Machinery:
Acres done(all machinery):
Terrain(Square/Broken, Flat/Rolling, Smooth):
Parallel swath or contours?

Field operation
Start:
Turn:
Back on line:
Aim(do you?):
    Other cues?
    Look at display? Screen?
    Going around curves?
What are you looking at when driving down field?
    Ahead? Booms? Screen? Horizon? Last tracks?
Do you look back at booms often?
How do you make boom adjustments? Feel? Look? Do you have to adjust often?
What else do you do(Monitor/Controller, etc.)?

Thinking/Concentration
What are you thinking about while spraying?
    Steering? Booms? Other things?
Time spent(Steering/Booms/Others):
What are your goals while spraying? How important are they?
    What makes a bad operator? Practice? Effort? Lack of talent?
How automatic does it become?
    Lose track of what has been done? Surprised how far you get?
    Any particular task become automatic?
Anything you have to plan for?
    Straightening out? Refilling? Finishing portions of field?
    Booms(ahead of time)? Speed?
Do you get bored/Are you working hard?
    How long before break?
    Most challenging: Speed? Steering? Booms?
Extra tasks: Cell phone? Radio(s)? Conversation?
    What is limit? Hands? Thinking?
What would you compare this operation to? Fieldwork? Driving?
    Do you slow down for anything? Stop?
How long does it take to get back in swing of things?

Comparison with other systems, no system?
How does this system compare to foam? Markers? Other ways?

Particular time when better? Weather? Day/Night?

Where do you look to stay on track with other systems? Ahead/ Booms?

More/less accurate?

Do you rely on this system solely? What if it stopped working? For days?
Less tired, more tired?
Longer hours?

Suggestions

9. 2 Subject A—Interview

Name, Operation Type: A, Grain Farm
System: Trimble lightbar and receiver with control pad. Has used foam for a long time; this was first year with guidance system.
Machinery: 75 ft. Willmar sprayer; 9200 JD Tractor; 40 ft. Morris Maxim Air Drill
Acres done(all machinery): 8000 – 10000 acres done with sprayer
Terrain(Square/Broken, Flat/Rolling, Smooth): Combination
Parallel swath or contours? Parallel Swath

Field operation:
Does headland on one end, AB line, second end, continues on parallel swaths. Doesn't use system to judge end—use foam and wheel tracks.
On turn, does large loop, comes back, recognize pattern of lights(on lightbar) on way back—can tell where to aim with lights
Uses Lightbar to get back on line. Drives straight with lightbar—uses this primarily for information
Doesn't aim at end or anything
Doesn't look right at lightbar, but just below. Notices when lightbar changes away from ctr., then adjusts steering
Looks ahead, not looking at anything in particular, but not looking at lightbar. Likely looking at field, thinking.
Has to adjust booms often because he tries to keep them low. Does a quick shoulder-check at boom unless he his approaching a drainage ditch.
Adjusts radio, thinks about amount of product, looks at sprayer controller, does not use cell phone.

Thinking/Concentration
Thinking about what to do with field. Still thinking about steering, etc., but that does not occupy all of mind.
Steering—75% of time, Booms—25%
Goals: Keep booms down, don't shake machine up, don't miss.
Operation becomes somewhat automatic, but not too much. Doesn't lose track or forget.
Has to practice going around sloughs and getting to end with an empty tank.
Thinks about boom height for ditches.
Not as much extra time as when doing fieldwork.
Also controls radio
Not sure whether hands or mind is limit
Compares spraying to fieldwork, but with more things to do.

Comparison with other systems, no system?
A lot less stressful than foam. Easy to see mark, so no searching. Doesn't he overlaps any less now, just easier. This is particularly easier at night. He stops working when it stops working. He feels a lot less tired when using this system. He can work longer hours, but will only spray at night when just finishing off a field.

Suggestions: Adjustable brightness control, Automatic steering

9. 3 Subject B—Interview

Name, Operation Type: B, Grain farm and custom application
System: Trimble 114 AgGPS with control pad
Machinery: RoGator 200 hp model, 1997 model
Acres done(all machinery): 12,000 acres sprayed in 2000
Terrain(Square/Broken, Flat/Rolling, Smooth): Flat, smooth, square
Parallel swath or contours? Parallel

Field operation:
Resets at corner of field, sets A pt. Drives down edge, sets B pt. Does 2 headlands.
When coming back on line, lines up with lightbar, gets a point at end of field or a seed row to follow. Hard to line up when a discer was seeding method.
Looks for something at the end like a bump, etc.
Does not pay attn. to numbers on lightbar.
Rarely has curves, so not applicable.
Doesn't pay attn. to lightbar all the time because it is "wobbly"—oscillates.
Looks ahead at aiming point. Lightbar is above sightline in periphery of vision. Notices when it is off-line. He's not sure how he notices, but just does.
Does not look at booms often because flat ground. Only has to look at them for ditches.
Does check them periodically for plugged nozzles.
Also checks rate monitor, amount in tank, other gauges. Does not check these often.

Thinking/Concentration
Mostly just thinking about steering b/c booms are not a big deal. Must keep himself thinking.
80-90% steering, 10-20% Booms
His main goal is not missing any area
Somewhat automatic, but still must think.
Must make sure not done at far end of field. Look out for ditches. Set speed by how smooth field is.
Speed control is most challenging. Can carry on extra tasks, except when turning.
Neither hands nor mind is limit usually. Similar to fieldwork, but more demanding.
Don't stop often, except to fill.
Takes about a field or 2 to get back in the swing of things

Comparison with other systems, no system?
A lot more relaxing than foam because you are not looking out front and to sides for foam. When using foam look forward and to side. Feels this is more accurate than foam. He stops when it shuts down—happens every once in a while. Less tired, and not on edge. Definitely longer hours.

Suggestions
Automatic steering

9. 4 Subject C—Interview

Name, Operation Type: C, Operator for Dealer in St. Claude
- 2000 was first year driving sprayer—has only driven with a guidance system. Puts bar right in view on window, just above straight-ahead sightline.

System: Trimble with control pad
Machinery: RoGator
Acres done(all machinery): 16,000 in 2000
Terrain(Square/Broken, Flat/Rolling, Smooth): Mostly flat and square. 1000-1200 rolling
Parallel swath or contours? Parallel Swath

Field operation:
Does C-clamp type. I think that is where you do two ends while also doing first two passes on one end. Continues parallel for rest of field. Uses foam on ends.
Uses foam to tell where he has started turn, where to come back on. Looks at lightbar to figure out how to line up.
Looks at lightbar while driving
Doesn't look at marks at end of field—too hard to find correct point.
Uses foam on curves
Just looks at lightbar. Doesn't feel that it is too wobbly (oscillating). Tracks are a bit wobbly, but overall straight.
Looks at booms to adjust (mostly at ditches). Keeps eye on boom for dipping into ground while driving. Looks at boom often to make sure no nozzles are broken,etc.

Thinking/Concentration
Is thinking both about steering and booms. Always thinking of spraying, a bit of planning for end.
70-80% steering, 10-15% booms, 10-15% checking flow monitor
Goals are (in order) no misses, don't burn crop(overlapping), go fast
Expectation is a big part of good/bad performance. Practice is a factor, but not emphasized.
Becomes somewhat automatic, but still thinking about spraying.
Doesn't lose track of field, etc.
Plans some for refilling, finishing parts of field, booms hitting ground. Usually drives flat out in field, if possible—15-16 mph
½ - 1 hr Between breaks
Doing all tasks together is challenging part
Can talk to someone no problem. \
Cord from radio is a problem.
Hands are limit, not thinking.
Spraying can be compared to a mix of fieldwork and driving
Slows down for ditches, stops only rarely.
Not sure how long to get back in swing of things because only one year experience, but thinks only 1-2 fields.

Comparison with other systems, no system?
Not sure how this system compares to foam because has never used anything else.

Suggestions
Automatic boom ht.
Doesn't see benefit of automatic steering.
Not sure about peripheral display—would have to be easy to see

9. 5 Subject D—Interview and Ride-Along

<u>Interview</u>

Process in field

Doesn't look at guidance system on first pass—just edge of boom with edge of field
Looks at it for second headland, if doing one
On turns, turns around boom—tries to keep end of boom stationary while turning. When end of turn, watches system to line up correctly for next pass. Aims for something up ahead, and starts driving.
While driving, looks up ahead at aiming spot(if straight rows, follows rows, if not, looks for place up ahead in field or tree, etc.). Can see light bar just below field of view. If light bar goes off centre, he can notice it and correct. He doesn't look right at it, he just sees it below his field of view.
He does not look at the mapping screen. He only looks at it to check that he hasn't missed spraying anything, or to plan how to spray, or if going around corners. Lightbar doesn't work well going around curves—not enough information, it oscillates too much to follow well around corner. He says his dad looks at the screen a lot, but his dad doesn't drive the sprayer as much.
He keeps system set on contour. This setting does not place down parallel swaths according to an AB line, it just marks where you have been, and sets the light bar according to the previous pass.
While driving, only looks ahead. Does not look around at booms unless something big like a ditch. He adjusts booms by feel. When front wheel goes down, knows to adjust boom switch, etc. Does not look back to see if good(will clarify).

Concentration Distribution

He says half machine operation is steering and half is booms. The odd time he must adjust rate monitor, but not very often.
The machine operation only takes up (his estimate) 10-20% of thinking. He says it gets pretty automatic, and he is usually thinking about something else, such as what is going on with harvest, etc.
He says it is similar to driving—you do what you are doing, but only think of it minimally. You can get lost in your own thoughts and end up spraying a big part of the field without thinking about it. You sort of "wake up" and say,"How did that get done?"
He says thought goes into steering and straightening rows(Note: this may be because he uses contour all the time). This would be primary concentration area. Booms don't take much thought-they are pretty automatic.
He says he doesn't get bored
Max. time you are out is ½ to 1 ½ hours between fills
Things are pretty intense while out there, but not mentally overwhelming
He says he always goes as fast as he can, unless he has to stop for a ditch, or large undulation
He says spraying is different than field operations—you don't have the time to look around, and there is more to do in constant monitoring
While driving, cannot do more things due to lack of hands to operate
If phone rings, must stop
Can have a conversation with someone in cab without a problem

He said expectation was a big part of being a good operator(he thought). He figured that a poor operator must be someone who did not care about the job and got sloppy.
He said if there was a problem, he would stop

Comparing this system to foam
This system easier to use, especially in dusk or night or where foam is blown around or hard to see.
You just have to look ahead with this system
When using foam, easy to not be correctly on line. You may think you are on, but would be overlapping a lot. Figured he was always overlapping 10% with foam system.
When using foam, look ahead and to side to judge correct line. Would not often be looking out to side.

Ride-Along

Date: May 30, 2001

Rode while spraying 95 acres on rolling ground near Rapid City. Crop was ryegrass.
Recorded time per pass, rate of looking at boom, rate of changing signals on lightbar
Both watched lightbar and looked forward. He said he watched lightbar mostly and looked up after that (as opposed to looking at spot at end of field and paying attention to lightbar secondary)
Steering movements tended to follow lightbar display
He also looked at booms
Lightbar was mounted on end of hood.
Satloc lightbar has a look-ahead indication and an immediate indication. Both indicators usually moved in same direction, and Adam said he didn't pay attention to one any more than the other.
On curves, he looked at screen more than lightbar
Screen gave very good aerial view, showing applied areas and unapplied areas
Avg. measurements:
Time for a pass: 90 s
Times looking at booms: 12 times (not divided into L/R)
Times display indicated a deviation from path: L: 13, R: 13
Tf 1 every ~3.5 s
Pattern usually went L-R-L-R
He had lightbar set so lightbar lit up on right indicated need to steer to right
I did not observe steering wheel movement, but assume it to be the same as Subject F

9. 6 Subject E—Ride-Along

Name, Operation Type: D, Mixed farm and custom application business
System: Trimble Lightbar with Field Computer
Machinery: JD 4700 Sprayer
Acres done(all machinery): 20,000 last year with Spra-Coupe(spring and summer) and JD 4700(fall)
Terrain(Square/Broken, Flat/Rolling, Smooth): Rolling and Cut up
Parallel swath or contours? Parallel swath

Field operation:
Starts with 2 rounds
During turns, looks at lightbar and at computer screen. Screen gives good indication of where you are and what has been done.
Uses horizon and crop rows to aim
Looks at screen more if cut up, looks at bar more of straight and open
Screen and bar for curves. Bar if curve is large enough.
Looking mostly ahead, sometimes at boom, but not often. Looking at horizon often; not looking at last tracks.
Looked at boom once every 10-20 s in this field, but he had booms really high here.
Looked at monitor some, but not a lot.

Thinking/Concentration
Did not ask these questions*

Comparison with other systems, no system?
Less tired than with foam
Can spray longer hours. When behind, leave good fields to do at night.
Much better than foam, especially in preharvest.

Notes from Reviewing Tape
Videotape of lightbar display
75 s long
5 times when centred, total time of 20 s. Therefore avg. 4 s per centred time.
4 times when left, total time of 37 s. One really long left deviation. Therefore avg. 9 s per left deviation.
2 times when right, total time of 14 s. On long right deviation. Therefore avg. 7 s per right deviation.
Most deviations are 1-3 lights

Not sure what settings are for system. I think he has it set for maximum look-ahead and maximum sensitivity

9. 7 Subject F—Ride-Along

Name, Operation Type: F, Custom Applicator
System: Trimble with Control Pad
Machinery: Miller Nitro with 100 ft. front-mounted boom
Acres done(all machinery): Did not ask
Terrain(Square/Broken, Flat/Rolling, Smooth): Field I was in: flat with some sloughs, wet at the time.
Parallel swath or contours? Parallel all the time.

Field operation:
Does two rounds at start, strikes AB line, goes from there.
Turns at end, comes around to green lights on bar. Hunted some when I was with him, but says he can do it well when ground is dry.
Looks at end of field / horizon to stay lined up. Has bar just below line of sight, watches it while driving.
Looks ahead, some booms (booms in front here), lightbar, horizon. Does not look at last tracks.
Didn't look at anything else regularly

Thinking/Concentration
Will talk on cell phone, have conversation.

Comparison with other systems, no system?
System is easier than foam, especially when travelling across rows or when no rows. With foam, looked ahead and to sides. Feels that this is more accurate than foam. With foam, you overlap more after about 10 passes(I think this means you get a bit tired and pass mark doesn't stay as straight, so there is more overlap).

Notes from video footage taken
Steering wheel movement was mostly between centred position and left-right about 45°. Repeated centre-left-centre-right-centre-left....

One pass
Watching wheel movement
42 steering corrections in 87 seconds. Therefore 1 per ~2 s

Next pass
Watching lightbar
40 s total
5 times centred, 20 s. Therefore ~ 4s each centred time.
6 times away from centre (3 each way)
18 s. Tf ~ 3 s each deviation.

Next pass 40 s
Watching lightbar
8 ctred times, 18 s. Tf ~ 2.25 s each time.
7 times away from centre, 4 L, 3R, 14 s. Tf ~ 2s each time.

Next pass 64 s
Watching lightbar
12 times ctred, 34 s. Tf ~ 3 s each time.
7 times L, 20 s. ~ 3 s each.
4 times R, 8 s. ~ 2 s each.
All deviations were 1-2 lights, sometimes 3, but never any more.

9. 8 Subject G—Ride-Along

Name, Operation Type: G, Mixed farm
System: Trimble with control pad. Lightbar was mounted above centre of windshield
Machinery: RoGator with 100' boom
Acres done(all machinery): Did not ask
Terrain(Square/Broken, Flat/Rolling, Smooth): Mostly flat; some fields broken up. This field was flat and open
Parallel swath or contours? Parallel swath

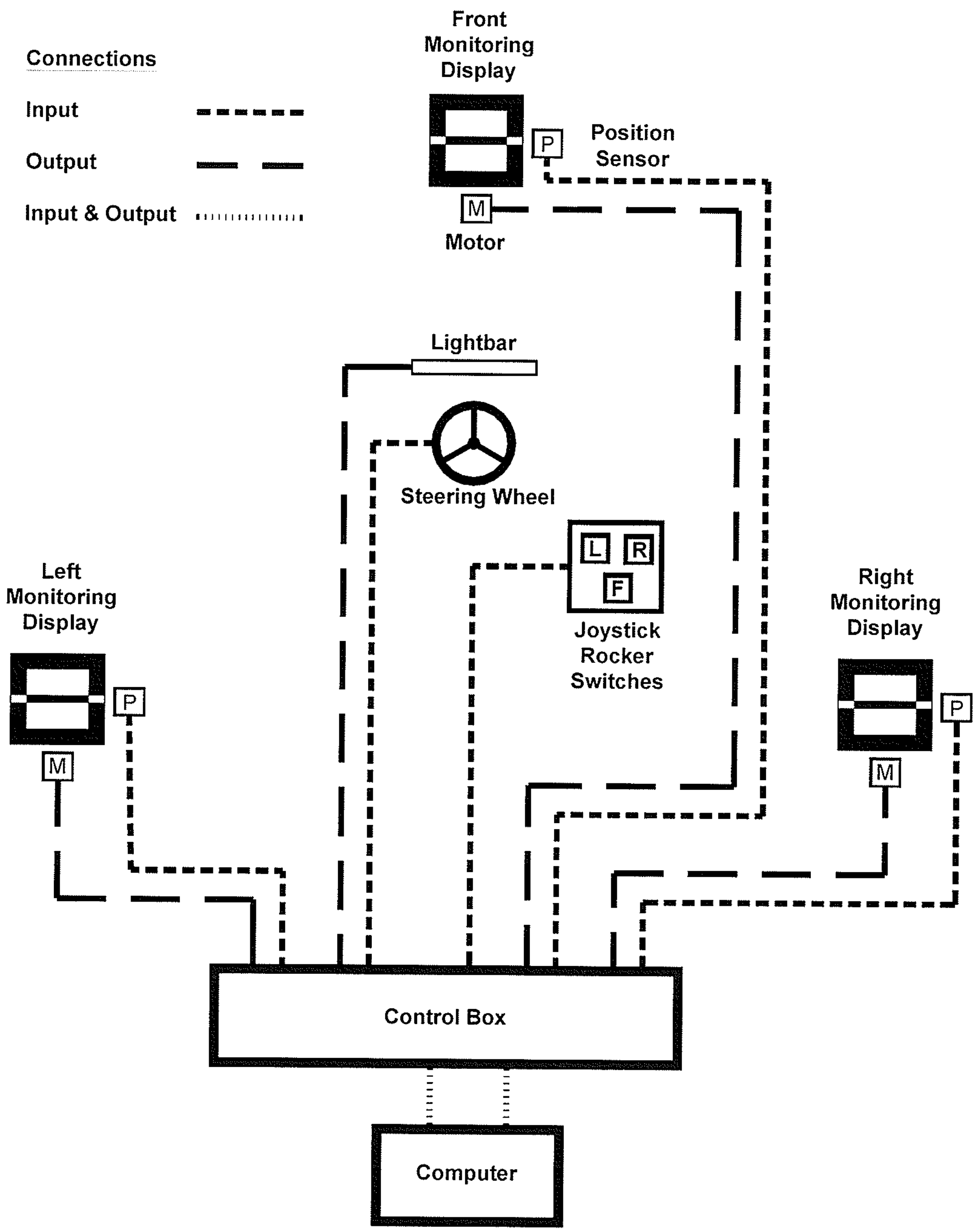
Field operation:
Aimed at something at end of field and scanned between that point and the lightbar.
Used lightbar to line up after a turn
Video taped his monitoring behaviour—lightbar glance information below
Also tried activating two flashing lights to indicate direction information
I ran them by hand while watching lightbar
They were mounted on windshield below and to side of straight ahead sightline
G said they worked okay, and allowed him to steer without having to look up at lightbar

Lightbar Glance Interval for G					
July, 2001					
Trial	Time (s)	Count 1	Count 2	Avg. Count	Avg. Interval
1	59	10	15	12.5	4.7
2	60	13	15	14	4.3
3	60	30	19	24.5	2.4
4	60	21	19	20	3.0
5	30	10	11	10.5	2.9
6	60	12	12	12	5.0
7	60	19	23	21	2.9
8	60	17	24	20.5	2.9
9	60	21	NC	21	2.9
10	60	26	26	26	2.3
		Average Interval (s)			3.3
G looked at lightbar once every 3.3 s, on average.					

10 APPENDIX 2: SIMULATOR

10. 1 Hardware

10. 1. 1 Schematic Diagram



10. 1. 2 Function of Components

Computer

- Contains all software for operating simulator
- Contains Omega CIO-DAS08 data acquisition card
- Contains Omega CIO-DIO48H digital input/output card

Control Box

- Contains all relays for operating motors
- Contains power supply
- Contains all other electronic circuitry for operating simulator

Monitoring Displays (Front, Left, Right)

- Provides information to operator for monitoring task
- Contains a position sensor to indicate when display is centred
- Contains a motor to move the bar in the display

Lightbar

- Provides information to operator for tracking task
- Contains 23 lighted elements
    - For small lightbar, each element is single LED
    - For large lightbar, each element is a square array of 16 LEDs

Steering Wheel

- Receives input from operator for tracking task
- Contains a potentiometer that indicates steering wheel position

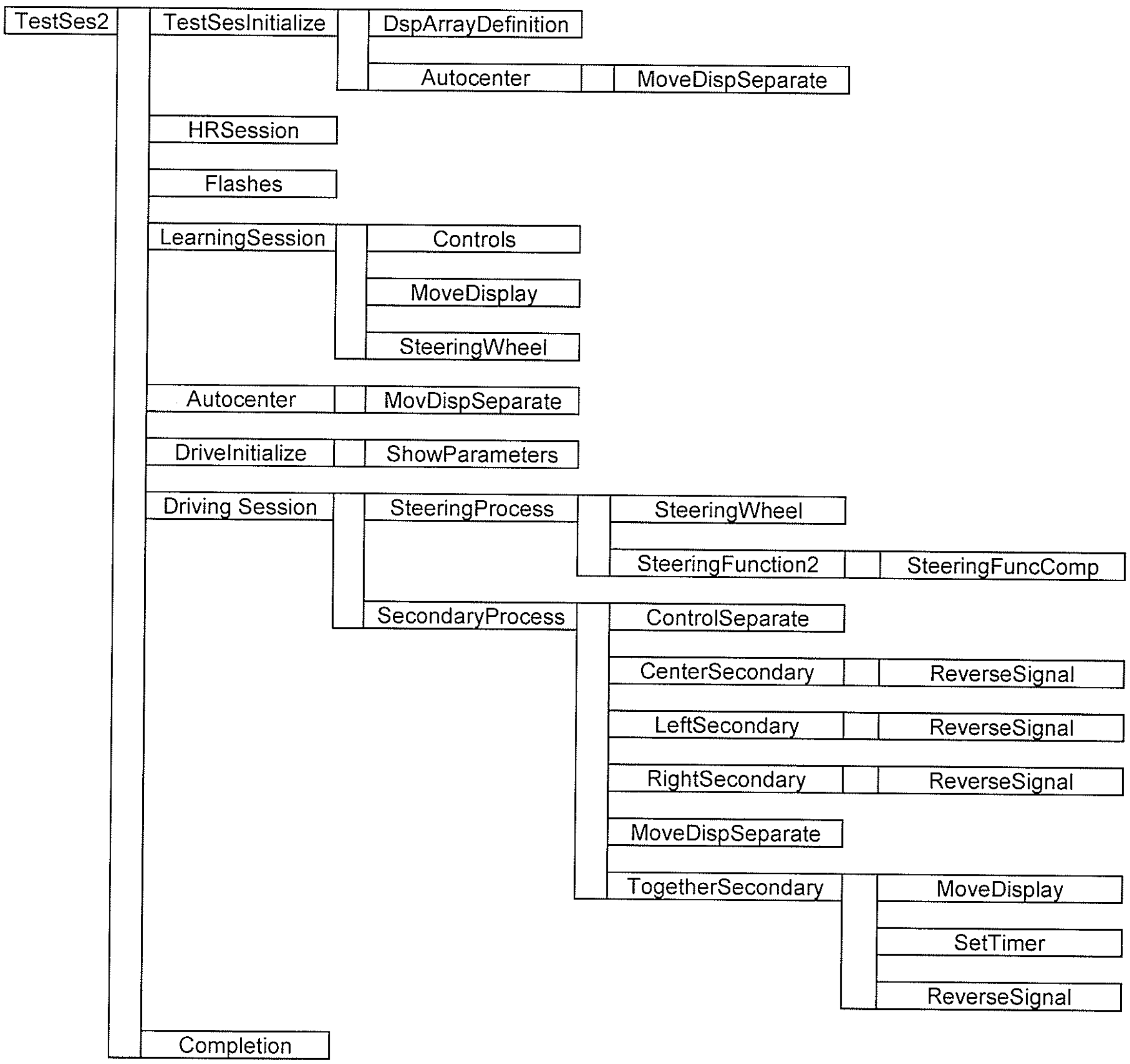
Joystick Rocker Switches (Front, Left, Right)

- Receive information from operator for monitoring task
- Each rocker switch has rests at a centred position unless it is pressed in the up or down position

10. 2 Software

10. 2. 1 Program Hierarchy

The names of all sections (functions or subroutines) of the program are shown below, each in a block. During program execution, each section calls all the sections connected to its right side.



10. 2. 2 Explanation of Program Sections

Unfortunately, I did not comment any of the code while creating it. I hope these explanations will suffice for someone who is trying to understand what the program does.

Testses2

- Main program section
- Declares all subroutines, functions, variables, and constants
- Initializes all ports to 'null' values
- Calls TestSesInitialize
- Runs loop containing main menu and all main subroutines for each menu choice
- Calls Completion

Autocenter

- Re-centres each display after each session
- Tests for centred while
  - Moving display up for 6 seconds
  - Moving display down for 6 seconds

CenterSecondary (see next page)

Completion

- This is called at the end of the program
- Closes all files
- Resets all port values to 'null' positions

Controls

- Gets information from rocker switches
- Will only respond correctly if no more than one switch is depressed

ControlSeparate

- Sets direction variables from rocker switch inputs
- Acquires information from rocker switches
- Sets direction variables for each of left, right, and front(center) switches

CenterSecondary

- Controls forward (center) monitoring task
- Defines variables for this subroutine
- Runs task. Logical outline is contained below, but I will outline the basic operation first. The display moves in a random (up/down) direction away from centre after a set delay time. If the correct rocker switch is depressed, the display returns to centre and the delay starts again.
- Logical outline:
  - If display is centred
    - If signal flag is false
      - If timer hasn't started (time flag false)
        - Stops moving display
        - Starts delay
        - Sets delay time and next movement direction
        - Sets the time flag to true
      - Else, if timer has started
        - If delay time has elapsed, sets signal flag true and sets time flag false
    - Else, if signal flag is true
      - Set centre movement variable to correct direction
      - Set start of move variable
  - Else, if display is not centered
    - If signal flag is false
      - If 0.25 s has elapsed since the correct rocker switch was depressed (rocker switch detected in next conditional section)
        - Sets the value of the movement variable to the return direction
    - Else, if signal flag is true
      - If the rocker switch is depressed in the return direction
        - Sets signal flag to false
        - Sets variable to time that rocker switch was depressed
        - Calculates reaction time
        - Writes movement direction, movement start time, time of rocker switch depression, and reaction time to file
        - Sets movement flag to false
      - Else, if display has been moving longer than delay time, sets movement flag to false

DriveInitialize

- Initializes driving session
- Sets the driving session number
- Opens files for output
- Sets the default parameter input file
- Gets parameters from parameter input file
- Calls ShowParameters
- Prompts for changes
- Explanation of all parameters
  - Session length: max length of driving session
  - Function step value: step value of steering function. Larger value means function changes at a faster rate, so this has the effect of changing the frequency of the steering function.
  - Function half-amplitude: maximum deviation from centre that steering function can reach. This is specified in index values, so anything at or above 10 means the function may reach the maximum deviation.
  - Separate….signals: Y or N, meaning the monitoring tasks operate separately or together
  - Forward min. delay: Minimum forward delay time
  - Forward max. delay: Maximum forward delay time
  - Side min. delay: same as for forward
  - Sid max. delay: same as for forward
- Loops until no changes
- Writes all parameters to file

DrivingSession

- Runs driving session
- Indicates testing session in progress and elapsed time
- Indicates driving session in progress and elapsed time
- Calls SteeringProcess
- Calls SecondaryProcess
- Stops session when 'q' is entered, or at specified session time
- Records start and end of driving time in info file
- Closes primary, secondary, and ______ files
- Sets all output ports to 'null' values

DspArrayDefinition

- Defines the display format for each index (error) value
- To define 23 LEDs, uses three 8-bit records: dsp(index).lowbyte, dsp(index).midbyte, dsp(index).highbyte

Flashes

- Flashes display at format for index = 10
- Flashes on and off at 0.2 s intervals for 5 seconds total

HRSession

- Runs heart rate session
- Specifies 'HR Session in Progress'
- Records the time elapsed during this session

LearningSession

- Runs learning session
- Indicates testing session in progress and elapsed time
- Indicates learning session in progress and elapsed time
- Gets information from rocker switches from Controls
- Calls MoveDisplay to move displays according to information from rocker switches
- Gets information from steering wheel from SteeringWheel
- Outputs information from steering wheel to lightbar
- Records total learning time
- Resets output ports

LeftSecondary

- Controls left monitoring task
- Same structure as CenterSecondary

MoveDisplay

- Will move one monitoring display at a time according to direction variable

MoveDispSeparate

- Moves monitoring displays (will move more than one at a time)
- Receives values for left, right, centre movement variables
- Specify port values for each variable
- Combines port values and outputs them

ReverseSignal

- Reverses the signal that was passed to it (if LeftUp passed, returns LeftDown, etc.)

RightSecondary

- Controls right monitoring task
- Same structure as CenterSecondary

SecondaryProcess

- Runs the monitoring (secondary) task
- If left, right, and front are set to run separate, calls the correct subroutines
- If they are set to run together, calls TogetherSecondary SteeringProcess
- Runs tracking (steering) task
- Gets steering wheel information from SteeringWheel
- Gets tracking function information from SteeringFunction2
- Finds difference between steering wheel and tracking function
- Sets index value

- Outputs index display values to lightbar
- Writes steering wheel position, function value, difference, and index to file at specified times

SetTimer
- Starts delay timer, sets delay time, sets next signal when all monitoring tasks operating together
- Sets random signal using bias value (biases for % total signals which are forward signals)
- Sets delay time

ShowParameters
- Prints all driving session parameters

SteeringFuncComp
- Calculates a sinusoidal value based on a base value passed from SteeringFunction2
- Increments base by increment passed from SteeringFunction2
- If base is greater than 3600 resets it to 0

SteeringFunction
- Calculates a single-sinusoid steering function
- Not used in this program

SteeringFunction2
- Creates a tracking function equal to the sum of six sinusoidal waves
- Acquires value of each sinusoid from SteeringFuncComp
- Adds all functions and divides by 6 (calls this Sum)
- Multiplies Sum by FunctionHAmp (half of max amplitude) and adds 10; this value is set as SteeringFunction2

SteeringWheel
- Gets potentiometer information from input/output board
- Converts reading to voltage
- Sets voltage to 0 if voltage is greater than 5 or less than 0
- Sets SteeringWheel value to 4*voltage

TestSesInitialize
- This initializes test session
- Calls DspArrayDefinition to define display array
- Sets flags to false
- Sets other values to initial values
- Gets initials and test session number from keyboard
- Opens TestSesInfo file
- Calls AutoCenter to centre all monitoring displays

TogetherSecondary

- Controls monitoring (secondary) tasks if left, right, centre operating together
- Was not used in the experiment
- Similar operation to CenterSecondary

10. 2. 3 Computer Code

Code was created and run in Microsoft QuickBasic, Version 4.5. All code is printed by program section, in alphabetical order. This is similar to the order presented in Section 10.2.2. For future use, the author recommends using the code in the included computer file, Simulator.bas. Some long lines of code are cut off in the printed copy.

```
DECLARE SUB DriveInitialize ()
DECLARE SUB ShowParameters ()
DECLARE SUB ChoosePar ()
DECLARE SUB Flashes ()
DECLARE SUB TestSesInitialize ()
DECLARE SUB HRSession ()
DECLARE SUB DrivingSession ()
DECLARE SUB LearningSession ()
DECLARE SUB SessionInitialize ()
DECLARE SUB Autocenter ()
DECLARE FUNCTION SteeringFunction2! ()
DECLARE FUNCTION SteeringFuncComp! (FBase!, Increment!)
DECLARE SUB RightSecondary ()
DECLARE SUB LeftSecondary ()
DECLARE SUB ControlSeparate ()
DECLARE SUB MoveDispSeparate ()
DECLARE SUB CenterSecondary ()
DECLARE SUB ControlReturn ()
DECLARE SUB TogetherSecondary ()
DECLARE SUB SideSecondary ()
DECLARE FUNCTION KeyControls% ()
DECLARE SUB StatusIndicator ()
DECLARE FUNCTION SteeringWheel! ()
DECLARE FUNCTION SteeringFunction! ()
DECLARE SUB DspArrayDefinition ()
DECLARE SUB Completion ()
DECLARE SUB SteeringProcess ()
DECLARE SUB SecondaryProcess ()
DECLARE SUB Initialization ()
DECLARE FUNCTION ReverseSignal% (ToBeReversed%)
DECLARE SUB SetTimer ()
DECLARE FUNCTION Controls% ()
DECLARE SUB MoveDisplay (Direction%)

'$INCLUDE: 'cb.bi'

TYPE pdsp
 lowbyte AS INTEGER
 midbyte AS INTEGER
 highbyte AS INTEGER
END TYPE

COMMON SHARED SecSignal%, FunctionBase!, ParaFile$, Initials$, SesNum$
COMMON SHARED LastWritten!, StartofTestSes!
COMMON SHARED StartofSession!, SessionLength%
COMMON SHARED FBaseMult!, FunctionHAmp!, DriveIndex%
COMMON SHARED Separate$, Separate%, FMinDelay!, FMaxDelay!
COMMON SHARED SMinDelay!, SMaxDelay!, ForwardBias%, Optical%
COMMON SHARED WheelHold!, FuncHold!, SwitchMode$, ButtonPress!
COMMON SHARED LeftControl%, RightControl%, CenterControl%
COMMON SHARED LeftMove%, RightMove%, CenterMove%

CONST OptCentered = 248, MoveTime = 1
CONST False = 0, True = NOT False
CONST LeftUp = 1, LeftDown = 2, CenterUp = 5, CenterDown = 6
CONST RightUp = 3, RightDown = 4
DIM SHARED dsp(23) AS pdsp

OUT &H320, &HFF
OUT &H321, &HFF
```

```
OUT &H322, &HFF
OUT &H323, &H80
OUT &H324, &HFF
OUT &H325, &HFF
OUT &H326, &HFF
OUT &H327, &H99

CALL TestSesInitialize

CLS

DO
  LOCATE 1, 10: PRINT "Testing Session in Progress"

  TestSesElapsed! = TIMER - StartofTestSes!
  LOCATE 3, 10: PRINT "Total Time Elapsed: ";
  PRINT USING "####.##"; TestSesElapsed!

  LOCATE 7, 10: PRINT "Press: H for HR Session"
  LOCATE 8, 17: PRINT "L for Learn Session"
  LOCATE 9, 17: PRINT "D for Driving Session"
  LOCATE 10, 17: PRINT "Q for quit"
  SessionChoice$ = INKEY$

  SELECT CASE SessionChoice$
    CASE "h"
      CALL HRSession
    CASE "l"
      CALL Flashes
      CALL LearningSession
      CALL Flashes
      CALL Autocenter
    CASE "d"
      CALL DriveInitialize
      CALL Flashes
      CALL DrivingSession
      CALL Flashes
      CALL Autocenter
    CASE "q"
      EndofTestSes! = TIMER - StartofTestSes!
      LOCATE 12, 10: INPUT "Do you really want to quit"; QuitChoice$
      IF QuitChoice$ <> "y" THEN SessionChoice$ = "a"
      LOCATE 12, 10: PRINT "                                                  "
  END SELECT
LOOP UNTIL SessionChoice$ = "q"

WRITE #1, "End of Test Session", EndofTestSes!

CALL Completion

END
```

```
;UB Autocenter

:LS

,OCATE 5, 10: PRINT "******AUTOCENTER IN PROGRESS******"

'tartMove = TIMER


Optical% = INP(&H326)

DO UNTIL ((Optical% > 247) AND (Optical% < 252)) OR INKEY$ = "q"   'Center displ
  IF TIMER - StartMove < 6 THEN
    CenterMove% = CenterDown
    MoveDispSeparate
  ELSE
    CenterMove% = CenterUp
    MoveDispSeparate
  END IF
  Optical% = INP(&H326)
LOOP
CenterMove% = False
MoveDispSeparate

StartMove = TIMER

DO UNTIL ((Optical% = 248) OR (Optical% = 250) OR (Optical% = 252) OR (Optical%
  IF TIMER - StartMove < 6 THEN
    LeftMove% = LeftDown
    MoveDispSeparate
  ELSE
    LeftMove% = LeftUp
    MoveDispSeparate
  END IF
  Optical% = INP(&H326)
LOOP
LeftMove% = False
MoveDispSeparate

StartMove = TIMER

DO UNTIL ((Optical% = 248) OR (Optical% = 249) OR (Optical% = 252) OR (Optical%
  IF TIMER - StartMove < 6 THEN
    RightMove% = RightDown
    MoveDispSeparate
  ELSE
    RightMove% = RightUp
    MoveDispSeparate
  END IF
  Optical% = INP(&H326)
LOOP
RightMove% = False
MoveDispSeparate

OUT &H325, 255
CLS

END SUB
```

```
SUB CenterSecondary

STATIC SigFlag%, TimeFlag%, DelayStart!, Delay%, CSignal%
STATIC StartofMove!, ButtonPress!

IF (Optical% > 247) AND (Optical% < 252) THEN   'Center display is centered
  IF SigFlag% = False THEN
    IF TimeFlag% = False THEN
      CenterMove% = False


       DelayStart! = TIMER
       Delay% = INT((FMaxDelay! - FMinDelay! + 1) * RND + FMinDelay!)
       CSignal% = INT((CenterDown - CenterUp + 1) * RND + CenterUp)
       TimeFlag% = True
    ELSEIF TimeFlag% = True THEN
       IF (TIMER - DelayStart!) >= Delay% THEN
         SigFlag% = True
         TimeFlag% = False
       END IF
    END IF
  ELSEIF SigFlag% = True THEN
    CenterMove% = CSignal%
    StartofMove! = TIMER
  END IF
'  IF (CenterControl% <> false) THEN
'    WRITE #3, TIMER, "Center Button, Display Centered"
'  END IF

ELSEIF (Optical% < 248) OR (Optical% > 251) THEN   'Display not centered
  IF SigFlag% = False THEN
    IF (TIMER - ButtonPress! >= .25) THEN
      ReturnSignal% = ReverseSignal(CSignal%)
      CenterMove% = ReturnSignal%
'    ELSEIF (CenterControl% <> false) THEN
'      WRITE #3, TIMER, "Center Button, No Signal"
    END IF
  ELSEIF SigFlag% = True THEN
    IF CenterControl% = ReverseSignal(CSignal%) THEN
      SigFlag% = False
      ButtonPress! = TIMER
      RxnTime! = ButtonPress! - StartofMove!
      WRITE #3, CSignal%, StartofMove!, ButtonPress!, RxnTime!
      CenterMove% = False
    ELSEIF (TIMER - StartofMove!) >= MoveTime THEN
      CenterMove% = False
'    ELSEIF (CenterControl% <> false) THEN
'      WRITE #3, TIMER, "Center Button, Wrong Way"
    END IF
  END IF

END IF

'LOCATE 9, 5: PRINT "Center:  TimeFlag: "; TimeFlag%; "SignalFlag: "; SigFlag%
'LOCATE 11, 5: PRINT "CenterMove: "; CenterMove%

END SUB
```

```
SUB Completion

CLOSE #1
CLOSE #2
CLOSE #3
CLOSE #4

OUT &H320, &HFF
OUT &H321, &HFF
OUT &H322, &HFF
OUT &H323, &H80
OUT &H324, &HFF
OUT &H325, &HFF

OUT &H326, &HFF
OUT &H327, &H99

END SUB
```

```
FUNCTION Controls%
' This function returns the selection from the control stick.

Selection = INP(&H324)

  SELECT CASE Selection
    CASE &HFE
      'PRINT "Left Down"
      Controls% = LeftDown
    CASE &HFD
      'PRINT "Left Up"
      Controls% = LeftUp
    CASE &HFB
      'PRINT "Right Down"
      Controls% = RightDown
    CASE &HF7
      'PRINT "Right Up"
      Controls% = RightUp
    CASE &HEF
      'PRINT "Center Down"
      Controls% = CenterDown
    CASE &HDF
      'PRINT "Center Up"
      Controls% = CenterUp
    CASE ELSE
      'PRINT "No switch indication"
      Controls% = False
  END SELECT

END FUNCTION
```

```
SUB ControlSeparate

  Selection = INP(&H324)

  LeftTest% = 3 AND NOT (Selection)
  SELECT CASE LeftTest%
    CASE 0
      LeftControl% = False
    CASE 1
      LeftControl% = LeftDown
    CASE 2
      LeftControl% = LeftUp
    CASE 3
      PRINT "Error: Left Switch Both Directions"
    CASE ELSE
      PRINT "Error: Left Switch Test Unrecognizable"
  END SELECT

  RightTest% = 12 AND NOT (Selection)
  SELECT CASE RightTest%
    CASE 0
      RightControl% = False
    CASE 4
      RightControl% = RightDown
    CASE 8
      RightControl% = RightUp
    CASE 12
      PRINT "Error: Right Switch Both Directions"
    CASE ELSE
      PRINT "Error: Right Switch Test Unrecognizable"
  END SELECT

  CenterTest% = 48 AND NOT (Selection)
  SELECT CASE CenterTest%
    CASE 0
      CenterControl% = False
    CASE 16
      CenterControl% = CenterDown
    CASE 32
      CenterControl% = CenterUp
    CASE 48
      PRINT "Error: Center Switch Both Directions"
    CASE ELSE
      PRINT "Error: Center Switch Test Unrecognizable"
  END SELECT

LOCATE 9, 1: PRINT "***Joystick Controls***"
LOCATE 10, 1: PRINT "Selection: "; Selection; "  "; LeftControl%; "  "; RightCon
END SUB
```

```
SUB DriveInitialize

DriveIndex% = DriveIndex% + 1

DriveIndex$ = LTRIM$(STR$(DriveIndex%))

SteerFile$ = Initials$ + SesNum$ + DriveIndex$ + "pr.dat"
SecFile$ = Initials$ + SesNum$ + DriveIndex$ + "sc.dat"

OPEN SteerFile$ FOR OUTPUT AS #2
OPEN SecFile$ FOR OUTPUT AS #3

IF SesNum$ = "1" THEN
  ParaFile$ = "testpar1.dat"
ELSEIF SesNum$ <> "1" THEN
  IF DriveIndex% < 3 THEN
    ParaFile$ = "testpar1.dat"
  ELSEIF DriveIndex% = 3 OR DriveIndex% = 4 THEN
    ParaFile$ = "testpars.dat"
  ELSEIF DriveIndex% > 4 THEN
    ParaFile$ = "testparf.dat"
  END IF
END IF

LOCATE 9, 10: PRINT "sesnum:  "; SesNum$
LOCATE 10, 10: PRINT "parafile:  "; ParaFile$

OPEN ParaFile$ FOR INPUT AS #4
INPUT #4, SessionLength%, FBaseMult!, FunctionHAmp!
INPUT #4, Separate$, SwitchMode$, ForwardBias%
INPUT #4, FMinDelay!, FMaxDelay!, SMinDelay!, SMaxDelay!


CALL ShowParameters

DO
  LOCATE 18, 10: INPUT ; "Change anything? Enter number(99 for no): "; Change%

  SELECT CASE Change%
    CASE 1
      LOCATE 20, 10: INPUT ; "1. Session Length(seconds): "; SessionLength%
    CASE 2
      LOCATE 20, 10: INPUT ; "2. Function Step Value: "; FBaseMult!
    CASE 3
      LOCATE 20, 10: INPUT ; "3. Function Half-Amplitude( <10 ): "; FunctionHAmp
    CASE 4
      LOCATE 20, 10: INPUT ; "4. Separate Fore and Side 2nd Signals: "; Separate
    CASE 5
      LOCATE 20, 10: INPUT ; "5. Bias to Forward(integer, 1 to 5): "; ForwardBia
    CASE 6
      LOCATE 20, 10: INPUT ; "6. Separate Fore and Side Switches: "; SwitchMode$
    CASE 7
      LOCATE 20, 10: INPUT ; "7. Forward Min. Delay: "; FMinDelay!
    CASE 8
      LOCATE 20, 10: INPUT ; "8. Forward Max. Delay: "; FMaxDelay!
    CASE 9
      LOCATE 20, 10: INPUT ; "9. Side Min. Delay: "; SMinDelay!
    CASE 10
      LOCATE 20, 9: INPUT ; "10. Side Max. Delay: "; SMaxDelay!
    CASE 99
      LOCATE 20, 10: PRINT "Nothing Changed"
  END SELECT
```

```
  IF Change% <> 99 THEN
    CALL ShowParameters
  END IF

LOOP UNTIL Change% = 99

WRITE #1, "Driving Session", DriveIndex%

WRITE #1, SessionLength%, FBaseMult!, FunctionHAmp!
WRITE #1, Separate$, SwitchMode$, ForwardBias%
WRITE #1, FMinDelay!, FMaxDelay!, SMinDelay!, SMaxDelay!

END SUB
```

```
SUB DrivingSession

StartofDriving! = TIMER

DO
  LOCATE 1, 10: PRINT "Testing Session in Progress"

  LOCATE 3, 10: PRINT "Driving Session in Progress"

  TestSesElapsed! = TIMER - StartofTestSes!
  LOCATE 5, 10: PRINT "Total Time Elapsed: ";
  PRINT USING "####.##"; TestSesElapsed!

  DriveElapsed! = TIMER - StartofDriving!
  LOCATE 7, 10: PRINT "Driving Time Elapsed: ";
  PRINT USING "####.##"; DriveElapsed!


  OUT &H323, &H80
  OUT &H327, &H99

  CALL SteeringProcess
  CALL SecondaryProcess
'  IF (TIMER - LastIndication!) >= .2 THEN
'    CALL StatusIndicator
'    LastIndication! = TIMER
'  END IF

LOOP UNTIL INKEY$ = "q" OR (TIMER - StartofDriving!) >= SessionLength%

StartofDriving! = StartofDriving! - StartofTestSes!
EndofDriving! = TIMER - StartofTestSes!

WRITE #1, "Driving Session", DriveIndex%
WRITE #1, "Start of Driving", StartofDriving!
WRITE #1, "End of Driving", EndofDriving!

CLOSE #2
CLOSE #3
CLOSE #4

OUT &H320, &HFF
OUT &H321, &HFF
OUT &H322, &HFF
OUT &H323, &H80
OUT &H324, &HFF
OUT &H325, &HFF
OUT &H326, &HFF
OUT &H327, &H99

CLS

END SUB
```

```
SUB DspArrayDefinition

dsp(0).lowbyte = &HF8
dsp(0).midbyte = &HFF
dsp(0).highbyte = &HFF
dsp(1).lowbyte = &HF1
dsp(1).midbyte = &HFF
dsp(1).highbyte = &HFF
dsp(2).lowbyte = &HE3
dsp(2).midbyte = &HFF
dsp(2).highbyte = &HFF
dsp(3).lowbyte = &HC7
dsp(3).midbyte = &HFF
dsp(3).highbyte = &HFF
dsp(4).lowbyte = &H8F
dsp(4).midbyte = &HFF
dsp(4).highbyte = &HFF
dsp(5).lowbyte = &H1F
dsp(5).midbyte = &HFF
dsp(5).highbyte = &HFF
dsp(6).lowbyte = &H3F
dsp(6).midbyte = &HFE
dsp(6).highbyte = &HFF

dsp(7).lowbyte = &H7F
dsp(7).midbyte = &HFC
dsp(7).highbyte = &HFF
dsp(8).lowbyte = &HFF
dsp(8).midbyte = &HF8
dsp(8).highbyte = &HFF
dsp(9).lowbyte = &HFF
dsp(9).midbyte = &HF1
dsp(9).highbyte = &HFF
dsp(10).lowbyte = &HFF
dsp(10).midbyte = &HE3
dsp(10).highbyte = &HFF
dsp(11).lowbyte = &HFF
dsp(11).midbyte = &HC7
dsp(11).highbyte = &HFF
dsp(12).lowbyte = &HFF
dsp(12).midbyte = &H8F
dsp(12).highbyte = &HFF
dsp(13).lowbyte = &HFF
dsp(13).midbyte = &H1F
dsp(13).highbyte = &HFF
dsp(14).lowbyte = &HFF
dsp(14).midbyte = &H3F
dsp(14).highbyte = &HFE
dsp(15).lowbyte = &HFF
dsp(15).midbyte = &H7F
dsp(15).highbyte = &HFC
```

```
dsp(16).lowbyte = &HFF
dsp(16).midbyte = &HFF
dsp(16).highbyte = &HF8
dsp(17).lowbyte = &HFF
dsp(17).midbyte = &HFF
dsp(17).highbyte = &HF1
dsp(18).lowbyte = &HFF
dsp(18).midbyte = &HFF
dsp(18).highbyte = &HE3
dsp(19).lowbyte = &HFF
dsp(19).midbyte = &HFF
dsp(19).highbyte = &HC7
dsp(20).lowbyte = &HFF
dsp(20).midbyte = &HFF
dsp(20).highbyte = &H8F
dsp(21).lowbyte = &HFF
dsp(21).midbyte = &HFF
dsp(21).highbyte = &H1F
dsp(22).lowbyte = &HFF
dsp(22).midbyte = &HFF
dsp(22).highbyte = &H3F

END SUB
```

```
SUB ExtraStuff
LOCATE 3, 10: INPUT ; "Please enter parameters data file(99 if none): "; ParaFil

'IF ParaFile$ = "99" THEN
  LOCATE 5, 10: PRINT "Manual Parameter Setting:"

  LOCATE 6, 10: INPUT ; "1. Session Length(seconds): "; SessionLength%
  LOCATE 7, 10: INPUT ; "2. Function Step Value: "; FBaseMult!
  LOCATE 8, 10: INPUT ; "3. Function Half-Amplitude( <10 ): "; FunctionHAmp!


  LOCATE 10, 10: INPUT ; "4. Separate Fore and Side 2nd Signals: "; Separate$
  IF Separate$ <> "y" THEN
    LOCATE 11, 10: INPUT ; "5. Bias to Forward(integer, 1 to 5): "; ForwardBias%
    IF (ForwardBias% < 1) THEN ForwardBias% = 1
  END IF
  LOCATE 12, 10: INPUT ; "6. Separate Fore and Side Switches: "; SwitchMode$

  LOCATE 14, 10: INPUT ; "7. Forward Min. Delay: "; FMinDelay!
  LOCATE 15, 10: INPUT ; "8. Forward Max. Delay: "; FMaxDelay!
  LOCATE 16, 10: INPUT ; "9. Side Min. Delay: "; SMinDelay!
  LOCATE 17, 9: INPUT ; "10. Side Max. Delay: "; SMaxDelay!

'ELSE


DO
  Correction% = Controls%
  IF (Correction% = False) THEN
    Correction% = KeyControls%
  END IF
  MoveDisplay (Correction%)
  Optical% = INP(&H326)
  LOCATE 21, 10: PRINT "Optical Sensor:"; Optical%; Correction%
'  FOR j = 1 TO 15000: NEXT
LOOP UNTIL Correction% = 9  'inkey$="q" in KeyControls%

END SUB
```

```
SUB Flashes

CLS

LOCATE 5, 10: PRINT "*****FLASH NOTIFICATION IN PROGRESS*****"

a% = 10
FlashTime = .2
TotalTime = 5

TotalStart = TIMER
Start = TIMER
Flag = False

DO

IF TIMER - Start >= FlashTime THEN
  IF Flag = False THEN
    Flag = True
  ELSEIF Flag = True THEN
    Flag = False
  END IF
  Start = TIMER
END IF

IF Flag = True THEN
  OUT &H320, dsp(a%).lowbyte
  OUT &H321, dsp(a%).midbyte
  OUT &H322, dsp(a%).highbyte
ELSEIF Flag = False THEN


  OUT &H320, &HFF
  OUT &H321, &HFF
  OUT &H322, &HFF
END IF

LOOP UNTIL TIMER - TotalStart >= TotalTime

OUT &H320, &HFF
OUT &H321, &HFF
OUT &H322, &HFF

CLS

END SUB
```

```
SUB HRSession

StartofHR! = TIMER

CLS

DO
  LOCATE 1, 10: PRINT "Testing Session in Progress"

  LOCATE 3, 10: PRINT "HR Session in Progress"

  TestSesElapsed! = TIMER - StartofTestSes!
  LOCATE 5, 10: PRINT "Total Time Elapsed: ";
  PRINT USING "####.##"; TestSesElapsed!

  HRElapsed! = TIMER - StartofHR!
  LOCATE 7, 10: PRINT "HR Time Elapsed: ";
  PRINT USING "####.##"; HRElapsed!
LOOP UNTIL INKEY$ = "q"

StartofHR! = StartofHR! - StartofTestSes!
EndofHR! = TIMER - StartofTestSes!

WRITE #1, "Start of HR", StartofHR!, "End of HR", EndofHR!

CLS

END SUB
```

```
FUNCTION KeyControls%


SELECT CASE INKEY$
  CASE "j"
    'PRINT "Left Down"
    KeyControls% = 1
  CASE "u"
    'PRINT "Left Up"
    KeyControls% = 2
  CASE "l"
    'PRINT "Right Down"
    KeyControls% = RightDown
  CASE "o"
    'PRINT "Right Up"


    KeyControls% = RightUp
  CASE "k"
    'PRINT "Center Down"
    KeyControls% = CenterDown
  CASE "i"
    'PRINT "Center Up"
    KeyControls% = CenterUp
  CASE "q"
    KeyControls% = 9
  CASE ""
    KeyControls% = False
  CASE ELSE
    'PRINT "No switch indication"
    KeyControls% = False
END SELECT

END FUNCTION
```

```
SUB LearningSession

CLS

StartofLearning! = TIMER

DO

  OUT &H323, &H80
  OUT &H327, &H99

  LOCATE 1, 10: PRINT "Testing Session in Progress"

  LOCATE 3, 10: PRINT "Learning Session in Progress"

  TestSesElapsed! = TIMER - StartofTestSes!
  LOCATE 5, 10: PRINT "Total Time Elapsed: ";
  PRINT USING "####.##"; TestSesElapsed!

  LearnElapsed! = TIMER - StartofLearning!
  LOCATE 7, 10: PRINT "Learning Time Elapsed: ";
  PRINT USING "####.##"; LearnElapsed!

  Correction% = Controls%
  MoveDisplay (Correction%)

  a% = SteeringWheel!
  OUT &H320, dsp(a%).lowbyte
  OUT &H321, dsp(a%).midbyte
  OUT &H322, dsp(a%).highbyte

LOOP UNTIL INKEY$ = "q"

StartofLearning! = StartofLearning! - StartofTestSes!
EndofLearning! = TIMER - StartofTestSes!

WRITE #1, "Start of Learning", StartofLearning!
WRITE #1, "End of Learning", EndofLearning!

OUT &H320, &HFF
OUT &H321, &HFF
OUT &H322, &HFF


OUT &H324, &HFF
OUT &H325, &HFF

CLS

END SUB
```

```
SUB LeftSecondary

STATIC SigFlag%, TimeFlag%, DelayStart!, Delay%, LSignal%
STATIC StartofMove!, ButtonPress!

IF (Optical% = 248) OR (Optical% = 250) OR (Optical% = 252) OR (Optical% = 254)
  IF SigFlag% = False THEN
    IF TimeFlag% = False THEN
      LeftMove% = False
      DelayStart! = TIMER
      Delay% = INT((SMaxDelay! - SMinDelay! + 1) * RND + SMinDelay!)
      LSignal% = INT((LeftDown - LeftUp + 1) * RND + LeftUp)
      TimeFlag% = True
    ELSEIF TimeFlag% = True THEN
      IF (TIMER - DelayStart!) >= Delay% THEN
        SigFlag% = True
        TimeFlag% = False
      END IF
    END IF
  ELSEIF SigFlag% = True THEN
    LeftMove% = LSignal%
    StartofMove! = TIMER
  END IF

ELSEIF (Optical% <> 248) AND (Optical% <> 250) AND (Optical% <> 252) AND (Optica
  IF SigFlag% = False THEN
    IF (TIMER - ButtonPress! >= .25) THEN
      ReturnSignal% = ReverseSignal(LSignal%)
      LeftMove% = ReturnSignal%
    END IF
  ELSEIF SigFlag% = True THEN
    IF LeftControl% = ReverseSignal(LSignal%) THEN
      SigFlag% = False
      ButtonPress! = TIMER
      RxnTime! = ButtonPress! - StartofMove!
      WRITE #3, LSignal%, StartofMove!, ButtonPress!, RxnTime!
      LeftMove% = False
    ELSEIF (TIMER - StartofMove!) >= MoveTime THEN
      LeftMove% = False
    END IF
  END IF

END IF

'LOCATE 13, 5: PRINT "TimeFlag: "; TimeFlag%; "SignalFlag: "; SigFlag%
'LOCATE 15, 5: PRINT "LeftMove: "; LeftMove%

END SUB
```

```
SUB MoveDisplay (Direction%)
'This subprogram moves the displays according to the Direction parameter
'passed from the main module.


'PRINT "Move Display: ";


  SELECT CASE Direction%
    CASE LeftDown
      'PRINT "Left Down"
      OUT &H325, &HFD
    CASE LeftUp
      'PRINT "Left Up"
      OUT &H325, &HFE
    CASE RightDown
      'PRINT "Right Down"
      OUT &H325, &HF7
    CASE RightUp
      'PRINT "Right Up"
      OUT &H325, &HFB
    CASE CenterDown
      'PRINT "Center Down"
      OUT &H325, &HDF
    CASE CenterUp
      'PRINT "Center Up"
      OUT &H325, &HEF
    CASE ELSE
      'Stop Moving
      'PRINT "No Move"
      OUT &H325, &HFF
  END SELECT

END SUB
```

```
SUB MoveDispSeparate

SELECT CASE LeftMove%
  CASE LeftDown
   'PRINT "Left Down"
    LeftPart% = 253
  CASE LeftUp
   'PRINT "Left Up"
    LeftPart% = 254
  CASE ELSE
    LeftPart% = 255
END SELECT

SELECT CASE RightMove%
  CASE RightDown
   'PRINT "Right Down"
    RightPart% = 247
  CASE RightUp
   'PRINT "Right Up"
    RightPart% = 251
  CASE ELSE
    RightPart% = 255
END SELECT

SELECT CASE CenterMove%
  CASE CenterDown
   'PRINT "Center Down"


    CenterPart% = 223
  CASE CenterUp
   'PRINT "Center Up"
    CenterPart% = 239
  CASE ELSE
    CenterPart% = 255
END SELECT

a% = NOT LeftPart%
b% = NOT RightPart%
c% = NOT CenterPart%
D% = a% OR b% OR c%
ToDisplays% = NOT D%

'LOCATE 17, 5: PRINT "to out:"; e%

OUT &H325, ToDisplays%

'LOCATE 21, 5: PRINT "Move: "; LeftMove%; "  "; RightMove%; "  "; CenterMove%
'LOCATE 23, 5: PRINT "ToDisplays: "; ToDisplays%

END SUB
```

```
FUNCTION ReverseSignal% (ToBeReversed%)
' This function reverses the ToBeReversed signal.

'PRINT "Reversing Signal..."

SELECT CASE ToBeReversed%
  CASE LeftDown
    ReverseSignal% = LeftUp
  CASE LeftUp
    ReverseSignal% = LeftDown
  CASE RightDown
    ReverseSignal% = RightUp
  CASE RightUp
    ReverseSignal% = RightDown
  CASE CenterDown
    ReverseSignal% = CenterUp
  CASE CenterUp
    ReverseSignal% = CenterDown
  CASE ELSE
    ReverseSignal% = SecSignal%
  END SELECT

END FUNCTION
```

```
SUB RightSecondary

STATIC SigFlag%, TimeFlag%, DelayStart!, Delay%, RSignal%
STATIC StartofMove!, ButtonPress!

IF (Optical% = 248) OR (Optical% = 249) OR (Optical% = 252) OR (Optical% = 253)
  IF SigFlag% = False THEN
    IF TimeFlag% = False THEN
      RightMove% = False
      DelayStart! = TIMER
      Delay% = INT((SMaxDelay! - SMinDelay! + 1) * RND + SMinDelay!)
      RSignal% = INT((RightDown - RightUp + 1) * RND + RightUp)
      TimeFlag% = True


    ELSEIF TimeFlag% = True THEN
      IF (TIMER - DelayStart!) >= Delay% THEN
        SigFlag% = True
        TimeFlag% = False
      END IF
    END IF
  ELSEIF SigFlag% = True THEN
    RightMove% = RSignal%
    StartofMove! = TIMER
  END IF

ELSEIF (Optical% <> 248) AND (Optical% <> 249) AND (Optical% <> 252) AND (Optica
  IF SigFlag% = False THEN
    IF (TIMER - ButtonPress! >= .25) THEN
      ReturnSignal% = ReverseSignal(RSignal%)
      RightMove% = ReturnSignal%
    END IF
  ELSEIF SigFlag% = True THEN
    IF RightControl% = ReverseSignal(RSignal%) THEN
      SigFlag% = False
      ButtonPress! = TIMER
      RxnTime! = ButtonPress! - StartofMove!
      WRITE #3, RSignal%, StartofMove!, ButtonPress!, RxnTime!
      RightMove% = False
    ELSEIF (TIMER - StartofMove!) >= MoveTime THEN
      RightMove% = False
    END IF
  END IF

END IF

'LOCATE 17, 5: PRINT "TimeFlag: "; TimeFlag%; "SignalFlag: "; SigFlag%
'LOCATE 19, 5: PRINT "RightMove: "; RightMove%

END SUB
```

```
SUB SecondaryProcess

Optical% = INP(&H326)

LOCATE 12, 1: PRINT "Optical: "; Optical%

IF Separate$ = "y" THEN
  CALL ControlSeparate
  CALL CenterSecondary
  CALL LeftSecondary
  CALL RightSecondary
  CALL MoveDispSeparate
ELSE
  CALL TogetherSecondary
END IF

END SUB

SUB SetTimer

'This subprogram starts the delay timer, sets the delay time, and sets
'the next signal. This uses the Forward Bias and separate delay times
'for forward and side signals.


DelayStart! = TIMER

SigRandoms% = 2 * (ForwardBias% + 2)
SubSignal% = INT((SigRandoms% - 1 + 1) * RND + 1)

IF (SubSignal% <= 4) THEN
  SecSignal% = SubSignal%
  Delay% = (SMaxDelay! - SMinDelay! + 1) * RND + SMinDelay!
ELSE
  Delay% = (FMaxDelay! - FMinDelay! + 1) * RND + FMinDelay!
  IF (SubSignal% <= (4 + ForwardBias%)) THEN
    SecSignal% = 5
  ELSE
    SecSignal% = 6
  END IF
END IF

END SUB
```

```
SUB ShowParameters

CLS

LOCATE 1, 10: PRINT "Testing Session in Progress"

LOCATE 3, 10: PRINT "Driving Session Initialization"

LOCATE 5, 10: PRINT "Current Parameters:"

LOCATE 6, 10: PRINT "1.  Session Length(seconds): "; SessionLength%
LOCATE 7, 10: PRINT "2.  Function Step Value: "; FBaseMult!
LOCATE 8, 10: PRINT "3.  Function Half-Amplitude( <10 ): "; FunctionHAmp!

LOCATE 10, 10: PRINT "4.  Separate Fore and Side 2nd Signals: "; Separate$
LOCATE 11, 10: PRINT "5.  Bias to Forward(integer, 1 to 5): "; ForwardBias%
LOCATE 12, 10: PRINT "6.  Separate Fore and Side Switches: "; SwitchMode$

LOCATE 14, 10: PRINT "7.  Forward Min. Delay: "; FMinDelay!
LOCATE 15, 10: PRINT "8.  Forward Max. Delay: "; FMaxDelay!
LOCATE 16, 10: PRINT "9.  Side Min. Delay: "; SMinDelay!
LOCATE 17, 10: PRINT "10. Side Max. Delay: "; SMaxDelay!

END SUB
```

```
SUB SideSecondary

  IF Optical% = OptCentered THEN
  'PRINT "All Centered"
    IF SigFlag% = False THEN
      IF SwitchMode$ = "n" THEN
        IF Controls% <> False THEN
          IF ErrorFlag% = False THEN
            WRITE #2, TIMER, "Error Start"
            ErrorFlag% = True
          END IF
        ELSEIF Controls% = False THEN
          IF ErrorFlag% = True THEN
            WRITE #2, TIMER, "Error End"
            ErrorFlag% = False
          END IF
        END IF
      END IF
      IF TimeFlag% = False THEN
        MoveDisplay (False)
        SetTimer
        TimeFlag% = True
      ELSEIF TimeFlag% = True% THEN
        IF (TIMER - DelayStart!) >= Delay% THEN
          SigFlag% = True
          TimeFlag% = False
        END IF
      END IF
    ELSEIF SigFlag% = True THEN
      MoveDisplay (SecSignal%)
      StartofMove! = TIMER
    END IF
  ELSEIF Optical% <> OptCentered THEN
  'PRINT "not centered"
    IF SigFlag% = False THEN
      IF (TIMER - ButtonPress! >= .25) THEN
        ReturnSignal% = ReverseSignal(SecSignal%)
        MoveDisplay (ReturnSignal%)
      END IF
    ELSEIF SigFlag% = True THEN
      IF ((SwitchMode$ = "n" AND Controls% <> False) OR (SwitchMode$ = "y" AND C
        SigFlag% = False
        ButtonPress! = TIMER
        RxnTime! = ButtonPress! - StartofMove!
        WRITE #2, StartofMove!, ButtonPress!, RxnTime!, SecSignal%
        MoveDisplay (False)
      ELSE
        IF (TIMER - StartofMove!) >= MoveTime THEN
          MoveDisplay (False)
          'PRINT "Move stopped by time: "; TIMER
        END IF
      END IF
    END IF

  END IF


END SUB
```

```
SUB StatusIndicator
CLS

LOCATE 4, 10: PRINT "******Status of Session********"

'LOCATE 3, 10: PRINT "Steering Data File: "; SteerFile$
'LOCATE 4, 10: PRINT "Secondary Data File: "; SecondFile$

LOCATE 5, 10: PRINT "Session Length(seconds): "; SessionLength%
Elapsed! = TIMER - StartofSession!
LOCATE 6, 10: PRINT "Elapsed Time: "; Elapsed!

LOCATE 9, 10: PRINT "****Steering Section****"
LOCATE 10, 10: PRINT "Function Step Value: "; FBaseMult!
LOCATE 11, 10: PRINT "Function Half-Amplitude: "; FunctionHAmp!
LOCATE 12, 10: PRINT "Function Value: "; FuncHold!
LOCATE 13, 10: PRINT "Wheel Position: "; WheelHold!

LOCATE 16, 10: PRINT "****Secondary Section****"
LOCATE 17, 10: PRINT "Separate Fore and Side 2nd Signals? "; Separate$
LOCATE 18, 10: PRINT "Forward Min. Delay: "; FMinDelay!
LOCATE 19, 10: PRINT "Forward Max. Delay: "; FMaxDelay!
LOCATE 20, 10: PRINT "Side Min. Delay: "; SMinDelay!
LOCATE 21, 10: PRINT "Side Max. Delay: "; SMaxDelay!

IF TimeFlag% = True THEN
  LOCATE 23, 10: PRINT "Time Flag True, Signal: "; SecSignal%
ELSE
  LOCATE 23, 10: PRINT "Time Flag False                    "
END IF

IF SigFlag% = True THEN
  LOCATE 24, 10: PRINT "Signal Flag True, Signal: "; SecSignal%
ELSE
  LOCATE 24, 10: PRINT "Signal Flag False                  "
END IF

END SUB
```

```
FUNCTION SteeringFuncComp! (FBase, Increment)

SteeringFuncComp! = SIN(FBase! / 573)

FBase! = FBase! + (Increment * FBaseMult!)

IF FBase! >= 3600 THEN
  FBase! = 0
END IF

END FUNCTION
```

```
FUNCTION SteeringFunction!

a! = SIN(FunctionBase! / 573)
b! = (a! * FunctionHAmp!) + 10

IF b! < 0! THEN
  b! = 0!
ELSEIF b > 20! THEN
  b! = 20!
END IF

SteeringFunction! = b!

FunctionBase! = FunctionBase! + FBaseStep!
IF FunctionBase! >= 3600 THEN FunctionBase! = 0

'LOCATE 8, 20: PRINT "Function = "; SteeringFunction!

END FUNCTION
```

```
FUNCTION SteeringFunction2!

STATIC BaseA!, BaseB!, BaseC!, BaseD!, BaseE!, BaseF!

IncrA = 1.028
IncrB = .617
IncrC = .343
IncrD = .274
IncrE = .206
IncrF = .12

a! = SteeringFuncComp!(BaseA!, IncrA)
b! = SteeringFuncComp!(BaseB!, IncrB)
c! = SteeringFuncComp!(BaseC!, IncrC)
D! = SteeringFuncComp!(BaseD!, IncrD)
e! = SteeringFuncComp!(BaseE!, IncrE)
F! = SteeringFuncComp!(BaseF!, IncrF)

Sum! = (a! + b! + c! + D! + e! + F!) / 6
ScaledSum! = (Sum! * FunctionHAmp!) + 10

IF ScaledSum! < 0! THEN
  ScaledSum! = 0!
ELSEIF ScaledSum > 20! THEN
  ScaledSum! = 20!
END IF

SteeringFunction2! = ScaledSum!

'LOCATE 2, 2: PRINT "IncrementA: "; IncrA
'LOCATE 3, 2: PRINT "BaseA: "; BaseA!; "  BaseF: "; BaseF!
'LOCATE 5, 2: PRINT "a: "; a!; "  b: "; b!; "  c: "; c!; "  d: "; D!; "  e: "; e
'LOCATE 8, 2: PRINT "Sum: "; Sum!; "  Scaled Sum: "; ScaledSum!

'LOCATE 10, 2: PRINT "Function = "; SteeringFunction!

END FUNCTION
```

```
SUB SteeringProcess

  t! = TIMER

  WheelHold! = SteeringWheel!
  FuncHold! = SteeringFunction2!

  Diff! = WheelHold! - FuncHold!
  Index% = Diff! + 10!

  IF Index% > 20 THEN Index% = 20
  IF Index% < 0 THEN Index% = 0

'  LOCATE 13, 2: PRINT "Function: "; FuncHold!; "   Diff = "; Diff!; "   Index =

  OUT &H320, dsp(Index%).lowbyte
  OUT &H321, dsp(Index%).midbyte
  OUT &H322, dsp(Index%).highbyte

  LOCATE 15, 1:  PRINT "Steering Output: "; dsp(Index%).lowbyte; "   "; dsp(Index

  IF dsp(Index%).lowbyte = 0 AND dsp(Index%).midbyte = 0 AND dsp(Index%).highbyt
    LOCATE 17, 1: PRINT "****All display bits zero at"; TIMER; " ****"
  END IF

  IF (t! - LastWritten!) >= .2 THEN
    WRITE #2, t!, WheelHold!, FuncHold!, Diff!, Index%
    LastWritten! = TIMER
  END IF

END SUB
```

```
FUNCTION SteeringWheel!

BoardNum = 0
Chan% = 0

Stat% = cbAIn%(BoardNum, Chan%, Gain%, DataValue%)
Stat% = cbToEngUnits(BoardNum, Gain%, DataValue%, Volts!)

'rdg1! = 5! - Volts!
'IF rdg1! < 0 OR rdg1! > 5! THEN rdg1! = 0!
'dgrs! = (rdg1! - 2.5) / .0139

IF (Volts! < 0) OR (Volts! > 5) THEN Volts! = 0!
SteeringWheel! = Volts! * 4

'LOCATE 3, 10: PRINT "DataValue: "; DataValue%
'LOCATE 5, 10: PRINT "Volts: "; Volts!
'LOCATE 7, 10: PRINT USING "Rdg1 = ####.##"; rdg1!
'LOCATE 9, 10: PRINT USING "Dgrs = ####.##"; dgrs!
'LOCATE 11, 10: PRINT USING "SteeringWheel  = ###.##"; SteeringWheel!
'LOCATE 15, 10: PRINT "                                "

END FUNCTION
```

```
SUB TestSesInitialize

CALL DspArrayDefinition
SigFlag% = False
TimeFlag% = False
SecSignal% = False
LastWritten! = 0!
BoardNum = 0
FunctionBase! = 0!

CLS

LOCATE 1, 10: PRINT "Steering and Secondary Simulation Preparation"

DO
  LOCATE 3, 10: INPUT ; "Subject Initials: "; Initials$
  LOCATE 5, 10: INPUT ; "Which Session is this(1 or 2)"; SesNum$

  TestSesInfo$ = Initials$ + SesNum$ + "info.dat"

  LOCATE 7, 10: PRINT "File Name: "; TestSesInfo$;
  LOCATE 9, 10: INPUT "Is this file name okay"; NameGood$
  CLS
LOOP UNTIL NameGood$ = "y"

OPEN TestSesInfo$ FOR OUTPUT AS #1

CLS

LOCATE 10, 10: PRINT "Centering Secondary Displays, Please Wait"
CALL Autocenter
LOCATE 12, 10: PRINT "Finished AutoCenter"
LOCATE 14, 10: PRINT "Perform additional Centering (Press q when done)"

OUT &H324, &HFF
OUT &H325, &HFF

CLS

LOCATE 15, 10: PRINT "*****Please press any key when ready to start Session*****
DO: LOOP UNTIL INKEY$ <> ""

StartofTestSes! = TIMER

END SUB
```

```
SUB TogetherSecondary

  IF Optical% = OptCentered THEN
  'PRINT "All Centered"
    IF SigFlag% = False THEN
      IF SwitchMode$ = "n" THEN
        IF Controls% <> False THEN
          IF ErrorFlag% = False THEN
            WRITE #2, TIMER, "Error Start"
            ErrorFlag% = True
          END IF
        ELSEIF Controls% = False THEN
          IF ErrorFlag% = True THEN
            WRITE #2, TIMER, "Error End"
            ErrorFlag% = False
          END IF
        END IF
      END IF
      IF TimeFlag% = False THEN
        MoveDisplay (False)
        SetTimer
        TimeFlag% = True
      ELSEIF TimeFlag% = True% THEN
        IF (TIMER - DelayStart!) >= Delay% THEN
          SigFlag% = True
          TimeFlag% = False
        END IF
      END IF
    ELSEIF SigFlag% = True THEN
      MoveDisplay (SecSignal%)
      StartofMove! = TIMER
    END IF
  ELSEIF Optical% <> OptCentered THEN
  'PRINT "not centered"
    IF SigFlag% = False THEN
      IF (TIMER - ButtonPress! >= .25) THEN
        ReturnSignal% = ReverseSignal(SecSignal%)
        MoveDisplay (ReturnSignal%)
      END IF
    ELSEIF SigFlag% = True THEN
      IF ((SwitchMode$ = "n" AND Controls% <> False) OR (SwitchMode$ = "y" AND C
        SigFlag% = False
        ButtonPress! = TIMER
        RxnTime! = ButtonPress! - StartofMove!
        WRITE #2, StartofMove!, ButtonPress!, RxnTime!, SecSignal%
        MoveDisplay (False)
      ELSE
        IF (TIMER - StartofMove!) >= MoveTime THEN
          MoveDisplay (False)
          'PRINT "Move stopped by time: "; TIMER
        END IF
      END IF
    END IF

  END IF

END SUB
```

11 APPENDIX 3: MATERIALS USED DURING TESTING

This section contains all the forms and information that were provided to participants or used for subjective feedback. In all cases, the heading of each section was the title given to that sheet when handed out.

11. 1 Welcome to the Orientation Session

Thank you for your interest in participating in this experiment. This meeting will tell you about the experiment and your role as a subject, if you choose to continue.

Remember that your participation is completely voluntary. If, at any time, you decide not to continue with the experiment, please advise one of the experimenters and you may leave.

This information packet contains several things required for your participation in this study:

1. Experimental Apparatus and Tasks for Subjects in Lightbar Tests
   - To be explained to you by experimenter during this meeting. Please also review this section before your testing session.

2. TLX Workload Scale Information
   - To be explained to you by experimenter during this meeting. Please also review this section before your testing session.

3. Subject Data Sheet
   - To be filled out by you and given to experimenter before leaving this meeting

4. Consent Form (2 copies)
   - To be read by you and signed before leaving this meeting. Give one copy to the experimenter and take one copy for your records.

This meeting should last for 30-45 minutes. Before leaving, please be sure you know where and when you will meet with the experimenter for your first test session.

Once again, thank you for your participation. Your payment for participating will be provided after you have completed your testing sessions.

11. 2 Experimental Apparatus and Tasks for Subjects in Lightbar Tests

This package is will introduce you, a subject, to the experiment in which you are participating. After reading this, you should know what the experiment is about and what is expected of you as a subject.

Background to the experiment

Guidance systems are currently available for use in farm equipment. Most systems use a horizontal array of lights to indicate lateral error to the operator. This experiment is intended to evaluate the performance of two of these displays. This will be done by having subjects use both displays while operating a simulated agricultural sprayer.

Experimental Apparatus

Figure 1 shows the exterior of the operator station, and Fig. 2 shows the interior. The interior is similar to a commercial agricultural sprayer. During this experiment you will sit in the operator station and perform two tasks similar to those of a sprayer operator. You will steer the sprayer using the steering wheel and lightbar. As well, you will monitor three bar displays and control them with switches on the joystick.

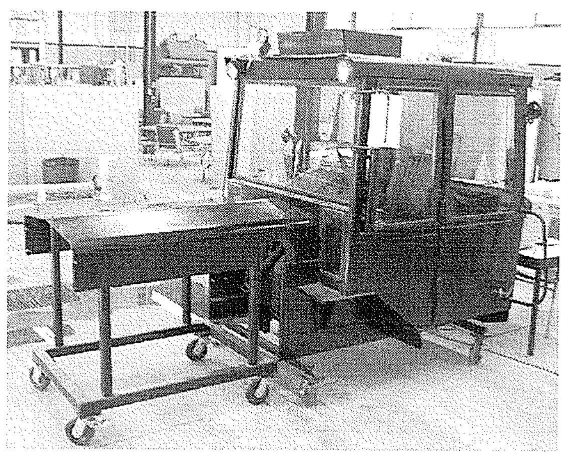


Fig. 1. Exterior of Operator Station

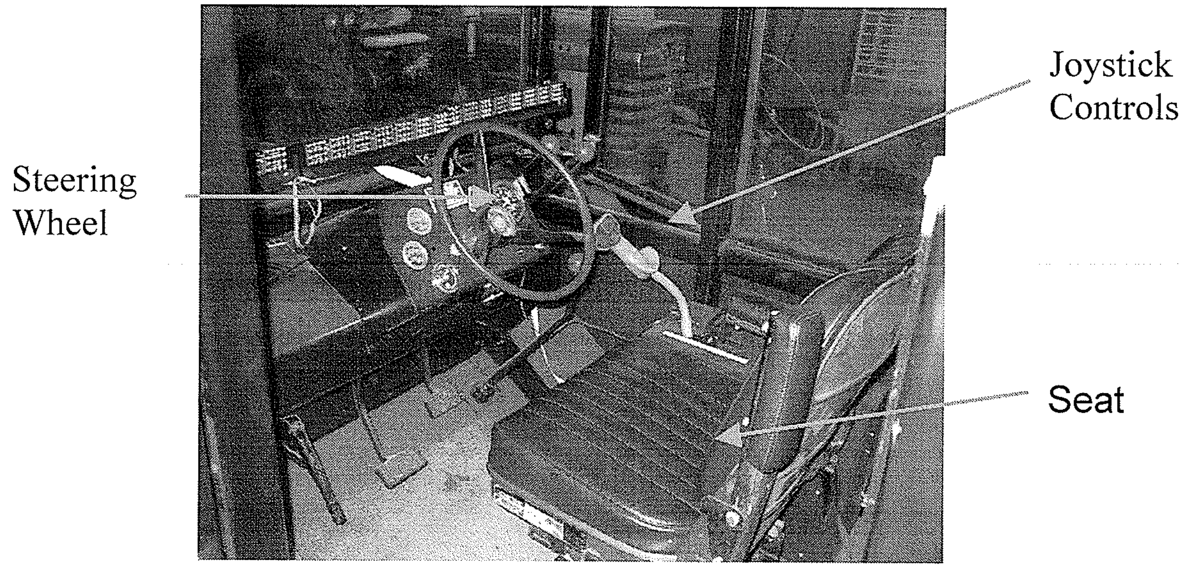


Fig. 2. Interior of Operator Station

Steering Task

A lighted display will be positioned in front of you on the windshield. The display indicates the error between your current steering wheel position and the correct steering wheel position. When the green lights in the centre are illuminated your steering wheel is in the correct position. Figs. 3 and 4 show both displays with the centre lights illuminated.

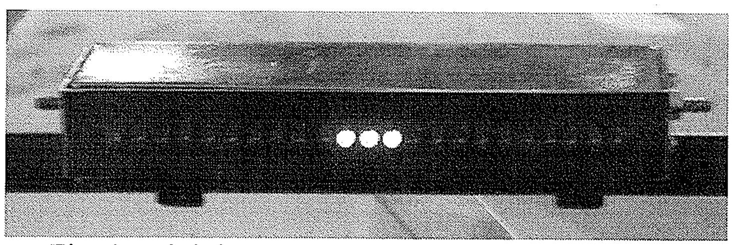


Fig. 3. Lightbar A with centre lights illuminated.

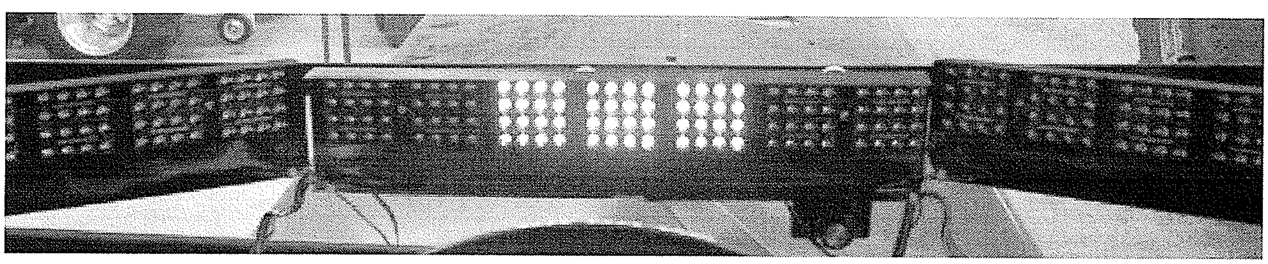


Fig. 4. Lightbar B with centre lights illuminated

When your steering wheel is left of the correct position, the red lights to the left of centre will be illuminated. You should steer to the right to bring your steering wheel back to the correct position. Figs. 5 and 6 show both lightbars with lights to the LEFT of centre illuminated.

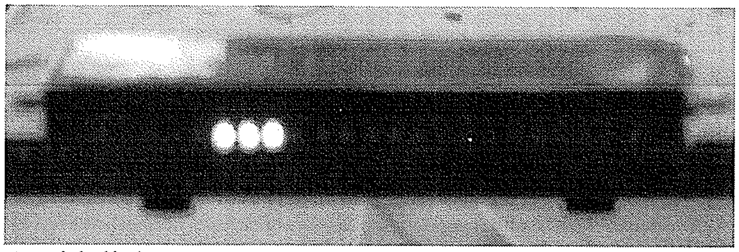


Fig. 5. Lightbar A with lights on LEFT illuminated

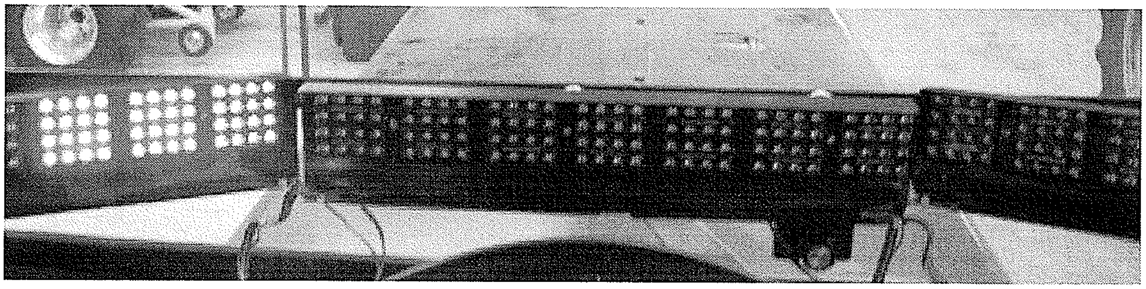


Fig. 6. Lightbar B with lights on LEFT illuminated.

Similarly, when your steering wheel is right of the correct position, the red lights to the right of centre will be illuminated. You should steer to the left to bring your steering wheel back to the correct position. Figs. 7 and 8 show both lightbars with lights to the RIGHT of centre illuminated.

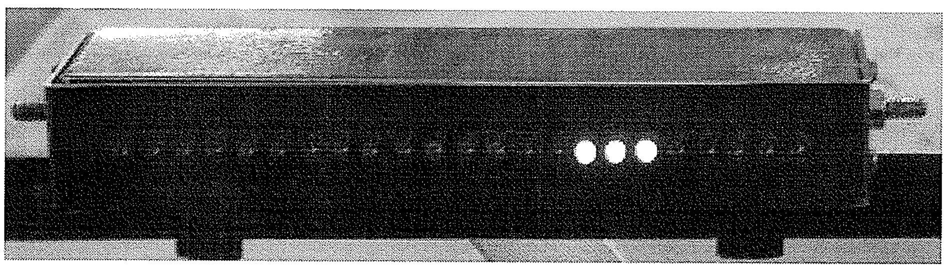


Fig. 7. Lightbar A with lights on RIGHT illuminated

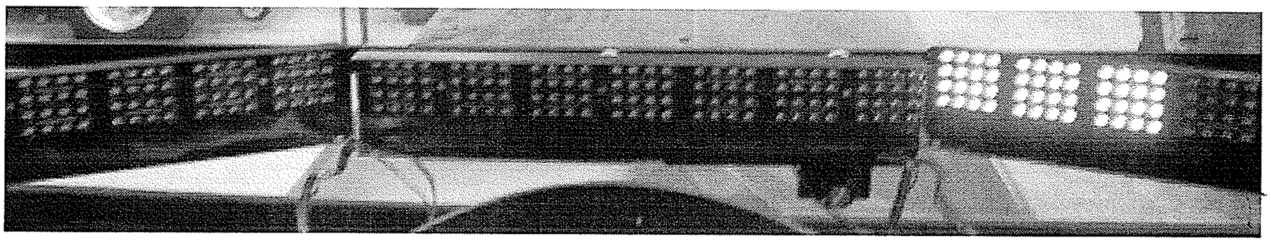


Fig. 8. Lightbar B with lights on RIGHT illuminated.

Monitoring Task

Concurrently with steering, you must continually monitor three bar displays located in front of you and to your sides (Fig. 9).

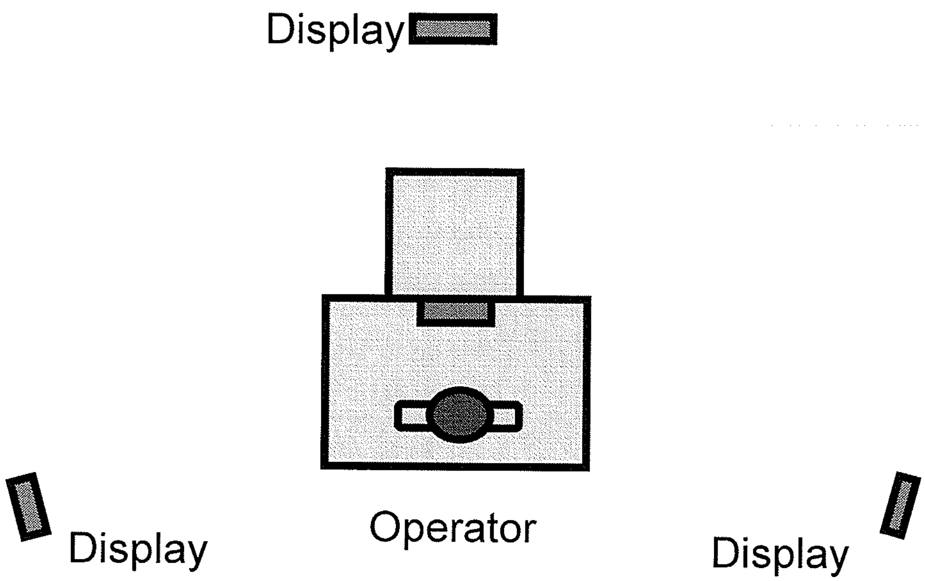


Fig. 9. Bar display locations

Each of these displays is a moving bar positioned inside a frame. The correct position for the bar is in the centre of the frame, as shown in Fig. 10.

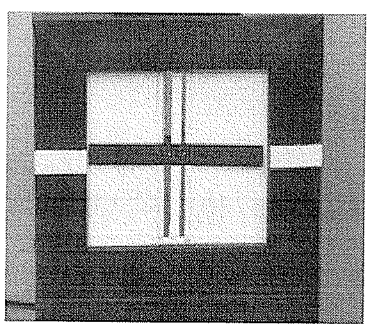


Fig. 10. Bar display in correct centred position.

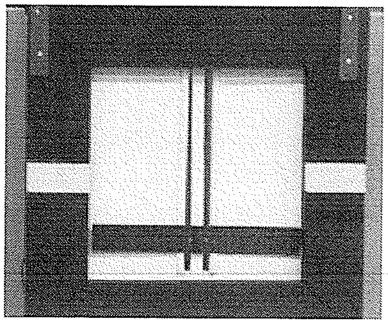


Fig. 11. Bar display below centre

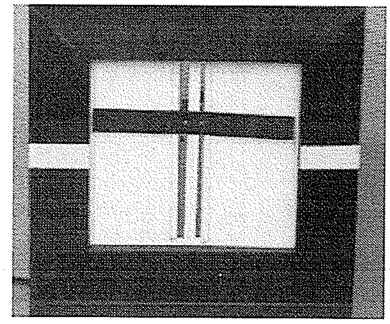


Fig. 12. Bar display above centre

The bars will move at random times below or above centre (Figs. 11 and 12). You can move it back to centre by using a switch on the joystick (Fig. 13). There is one rocker switch for each display. For example, if the right display moves below centre, you can move it back to centre by pressing up on the Right Display button. You only need to press a switch once to move the display back to centre. The display will move back to centre automatically.

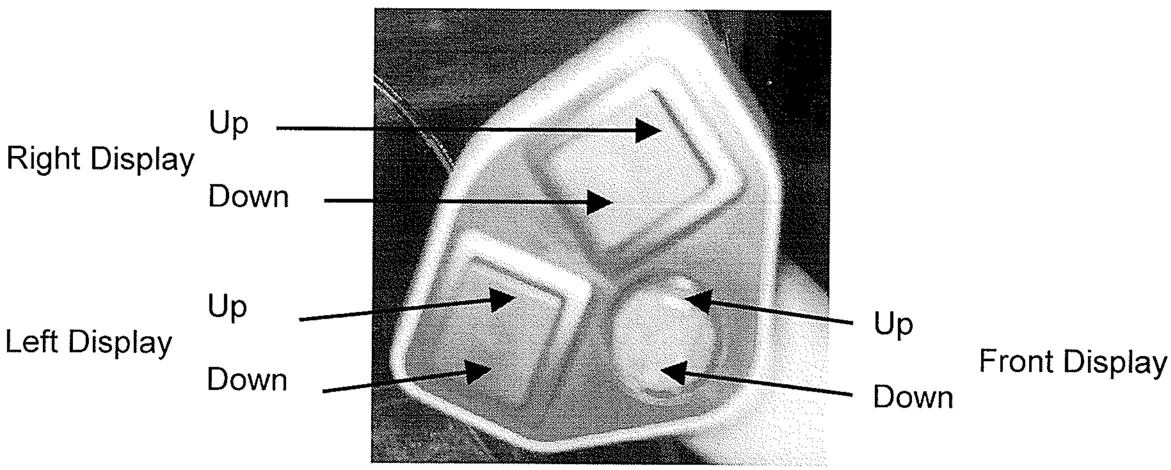


Fig. 13. Joystick controls.

You must try to keep all displays in the centred position. This will require scanning them and controlling them regularly. The display in front of you will move off centre more often than the displays to the sides, so you should monitor that one more closely.

Heart Rate Monitor

During each driving session you must wear a heart rate monitor. This consists of a band placed around your torso below your chest and a wristwatch. It will be fitted to you prior to the tests.

Evaluation of Tests

After each driving session you will fill out a workload evaluation. Please see the instructions for this evaluation.

11. 3 TLX Workload Scale Information

This section contains information on the scale used to get feedback from you on the workload you experience. The scale is called the NASA-TLX. It is a set of subscales that measure different parts of workload. These subscales are combined using weights you specify to get an overall workload rating.

This package contains an example of the test and some instructions. You will see pages:

1. Definitions of the Rating Scales

2. Instructions for filling out the Weighting Section

3. Sample Weighting page

4. Instructions for filling out the Rating Section

5. Sample Rating page

Please follow along while I explain each page.

Instructions for Weighting the Scales

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended or the performance they achieved. Others feel that if they performed well, the workload must have been low and vice versa. Yet others feel that effort or feelings of frustration are the most important factors in workload and so on. The results of previous studies have found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to your experience of workload in the task(s) that you just performed. Each pair of scale titles appears on the sheet. **Circle the Scale Title that represents the more important contributor to workload for the specific task(s) in this experiment.**

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. **Don't think that there is any *correct* pattern; we are only interested in your opinions.** If you have any questions, please ask them now. Thank you for your participation.

Instructions for Rating a Task on the Scales

We are interested not only in assessing your performance but also the experiences you had during the different task conditions. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to measure.

Since workload is something experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. This set of six rating scales was developed for you to use in evaluating your experiences during different tasks. Please read the descriptions of the scales carefully. If you have a question about any of the scales in the table, please ask me about it. It is extremely important that they be clear to you. You may keep the descriptions with you for reference during the experiment.

After performing each task, you will complete the six rating scales on the paper. You will evaluate the task by marking a line across each scale at the point that matches your experience. Each line has two endpoint descriptors that describe the scale. Please consider your responses carefully in distinguishing among the task conditions. Consider each scale individually. Your ratings will play an important role in the evaluation being conducted. Your active participation is essential to the success of this experiment, and is greatly appreciated.

Rating Scale Definitions

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?

Pair-Wise Comparisons of Factors

Instructions: Select the member of each pair that provided the most significant source of workload variation in these tasks.

Physical Demand	---	Mental Demand
Temporal Demand	---	Mental Demand
Performance	---	Mental Demand
Frustration	---	Mental Demand
Effort	---	Mental Demand
Temporal Demand	---	Physical Demand
Performance	---	Physical Demand
Frustration	---	Physical Demand
Effort	---	Physical Demand
Temporal Demand	---	Performance
Temporal Demand	---	Frustration
Temporal Demand	---	Effort
Performance	---	Frustration
Performance	---	Effort
Effort	---	Frustration

Rating Scales

Instructions: Place a mark on each scale that represents the magnitude of each factor in the task you just performed.

Mental Demand

Low ______________________________ High

Physical Demand

Low ______________________________ High

Temporal Demand

Low ______________________________ High

Performance

Poor ______________________________ Excellent

Frustration

Low ______________________________ High

Effort

Low ______________________________ High

11. 4 Consent Form

Development of a peripheral vision lightbar for GPS-based guidance systems.

Research Objective

A primary intention of a guidance system for agricultural machines is to make the task of the driver easier. Introduction of a visual display unit (VDU) into the cab of a vehicle may inadvertently make the guidance task more difficult. Anecdotal evidence suggests that GPS guidance systems which use "lightbars" are not being used to their full potential because operators find them to be "tiring and annoying to use." The objective of this research is to compare the conventional lightbar design to an alternative design (a peripheral vision lightbar) to determine which design requires less operator workload.

Research Procedure

Volunteer drivers will be asked to operate a "tractor-driving simulator" that uses either the existing lightbar design or the new, peripheral vision design. The operator must "steer" the simulator and monitor three bar displays located in front and to the sides of the operator. The lightbar will be illuminated to signify a steering error. The driver will be instructed to adjust the steering wheel to correct the error. The bar displays move from their correct location at random times. The driver will be instructed to press a button to return a bar display to its correct location.

Each volunteer driver will be expected to operate the simulator in several episodes for a total driving time of 1 to 2 h. During each driving episode volunteer's performance and workload will be determined by using several workload measures described in scientific literature. The tests to be used include:

1. **Steering performance:** The average deviation from the correct steering wheel location will be measured
2. **Monitoring performance:** The average time required to respond to a movement of the bar displays will be measured
3. **Heart rate variability**: The variability of the subjects heart rate will be measured before, during, and after the driving episode, and the results will be compared.
4. **Subjective workload reports:** The subject will be asked to rate the level of several workload factors required to perform the task.

This research project will not expose the subject to any risk because the tractor-driving simulator is stationary. The participant will be notified if his/her heart rate appears to be problematic.

Continued on Following Page

Assurance of Confidentiality

The participant is assured that his or her name will never be used with reference to this research.

Assurance of Voluntary Participation

The participant is assured that his or her participation in this research is strictly voluntary. If, at any time, the participant wishes to withdraw from the project, he or she may do so without consequence.

If you have any questions or concerns, please contact the primary investigator:

Dr. Danny Mann, P.Eng.
Department of Biosystems Engineering
University of Manitoba
Winnipeg, MB R3T 5V6
Phone: (204) 474-7149
E-mail: Danny_Mann@umanitoba.ca

My signature indicates that I have read and understood the above conditions (on pages 1 and 2). I hereby give my consent for, and agree to participate in, this research project.

Participant: Name: ______________________________ Date: __________________

Witness: Name: ______________________________ Date: __________________

11. 5 Subject Data Sheet

Name: ____

Age: <20____ 20-25____ 26-30___ 31-35____ 35-40____ >40_____

Sex: Male / Female

Height (approx): ______________

Handedness: Right / Left

Do you use corrective lenses? Yes / No

If yes, what do you use them for? Seeing Far / Seeing Near

If yes, what will you likely be wearing in the tests? Contacts / Glasses

Do you have experience driving a car? Yes / No

Do you have experience driving agricultural machinery? Yes / No

Have you ever used a guidance system in agricultural machinery? Yes / No
If yes, please explain: ______________________________________

11. 6 Comments

Please write any thoughts you have:

- about displays

- about how the experiment was set up.

11. 7 Comments—Second Day

Which lightbar did you prefer? Why?

Please write any other thoughts you have:

- about displays

- about how the experiment was set up.

12 APPENDIX 4: TESTING RESULTS

12. 1 Explanation

I have not included all raw data in this appendix, as there is more than would be reasonable. However, I have included all group means and standard deviations, profile plots, F tables, and contrasts that are important for the analyses presented in the thesis.

The labelling in the appendix is different than the labelling in the thesis. For all group means, A refers the small display and B refers to the large display. The numbers 3, 5, and 7 are used for Low, Medium, and High difficulties, respectively. If that is still confusing, the table below may clear it up.

Group Name	Display	Difficulty
A3	Small	Low
A5	Small	Medium
A7	Small	High
B3	Large	Low
B5	Large	Medium
B7	Large	High

All measurements were tested in a 2-way repeated measures for display effects and difficulty effects. In the F tables and pair-wise comparisons, display groups are labelled as **display**, with small labelled as 1, and large labelled as 2. Difficulty groups are labelled as **speed**, with low labelled as 1, medium labelled as 2, and high labelled as 3. Additional labelling changes are outlined where necessary.

12. 2 Steering Task

Descriptive Statistics

	Mean	Std. Deviation	N
A3	.702	.191	22
A5	.790	.150	22
A7	.925	.145	22
B3	.593	.180	22
B5	.706	.159	22
B7	.849	.164	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.935	1.340	2	.512	.939	1.000	.500
DISPLAY * SPEED	.955	.925	2	.630	.957	1.000	.500

Tests of Within-Subjects Effects

Measure: RMSE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	.264	1	.264	26.576	.000	.559
	Greenhouse-Geisser	.264	1.000	.264	26.576	.000	.559
	Huynh-Feldt	.264	1.000	.264	26.576	.000	.559
	Lower-bound	.264	1.000	.264	26.576	.000	.559
Error(DISPLAY)	Sphericity Assumed	.209	21	9.943E-03			
	Greenhouse-Geisser	.209	21.000	9.943E-03			
	Huynh-Feldt	.209	21.000	9.943E-03			
	Lower-bound	.209	21.000	9.943E-03			
SPEED	Sphericity Assumed	1.266	2	.633	163.679	.000	.886
	Greenhouse-Geisser	1.266	1.878	.674	163.679	.000	.886
	Huynh-Feldt	1.266	2.000	.633	163.679	.000	.886
	Lower-bound	1.266	1.000	1.266	163.679	.000	.886
Error(SPEED)	Sphericity Assumed	.162	42	3.867E-03			
	Greenhouse-Geisser	.162	39.443	4.117E-03			
	Huynh-Feldt	.162	42.000	3.867E-03			
	Lower-bound	.162	21.000	7.734E-03			
DISPLAY * SPEED	Sphericity Assumed	6.610E-03	2	3.305E-03	1.747	.187	.077
	Greenhouse-Geisser	6.610E-03	1.914	3.454E-03	1.747	.188	.077
	Huynh-Feldt	6.610E-03	2.000	3.305E-03	1.747	.187	.077
	Lower-bound	6.610E-03	1.000	6.610E-03	1.747	.201	.077
Error(DISPLAY*SPEED)	Sphericity Assumed	7.947E-02	42	1.892E-03			
	Greenhouse-Geisser	7.947E-02	40.184	1.978E-03			
	Huynh-Feldt	7.947E-02	42.000	1.892E-03			
	Lower-bound	7.947E-02	21.000	3.784E-03			

Pairwise Comparisons

Measure: MEASURE_1

(I) SPEED	(J) SPEED	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.100*	.011	.000	-.130	-7.025E-02
	3	-.239*	.014	.000	-.275	-.203
2	1	.100*	.011	.000	7.025E-02	.130
	3	-.139*	.014	.000	-.176	-.102
3	1	.239*	.014	.000	.203	.275
	2	.139*	.014	.000	.102	.176

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

12. 3 Front Monitoring

12. 3. 1 Speed-Display

Descriptive Statistics

	Mean	Std. Deviation	N
A3_FORE	1.12	.42	22
B3_FORE	1.13	.48	22
A5_FORE	1.27	.55	22
B5_FORE	1.31	.62	22
A7_FORE	1.25	.64	22
B7_FORE	1.25	.70	22

Mauchly's Test of Sphericity[b]

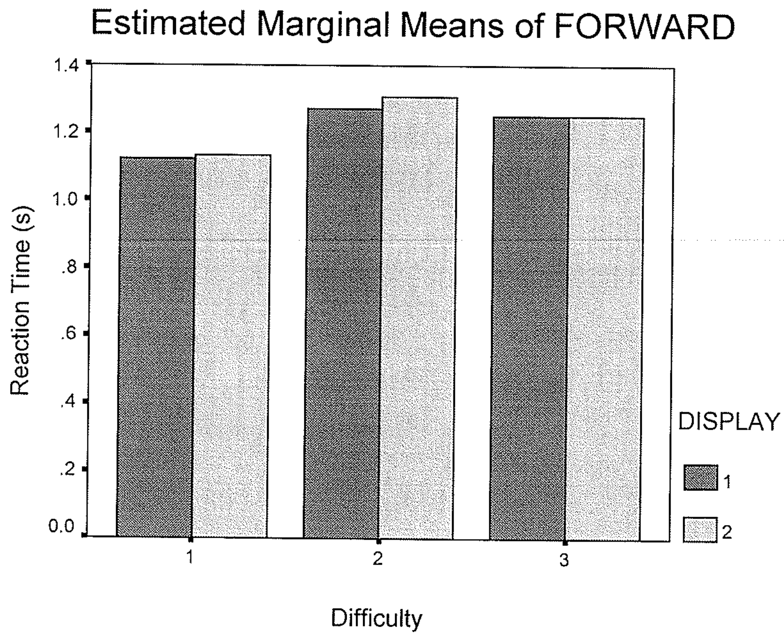
Measure: FORWARD

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
SPEED	.819	3.998	2	.135	.847	.913	.500
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED * DISPLAY	.703	7.037	2	.030	.771	.821	.500

Tests of Within-Subjects Effects

Measure: FORWARD

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SPEED	Sphericity Assumed	.638	2	.319	5.032	.011	.193
	Greenhouse-Geisser	.638	1.693	.377	5.032	.016	.193
	Huynh-Feldt	.638	1.826	.350	5.032	.013	.193
	Lower-bound	.638	1.000	.638	5.032	.036	.193
Error(SPEED)	Sphericity Assumed	2.665	42	6.344E-02			
	Greenhouse-Geisser	2.665	35.557	7.494E-02			
	Huynh-Feldt	2.665	38.342	6.950E-02			
	Lower-bound	2.665	21.000	.127			
DISPLAY	Sphericity Assumed	7.982E-03	1	7.982E-03	.220	.644	.010
	Greenhouse-Geisser	7.982E-03	1.000	7.982E-03	.220	.644	.010
	Huynh-Feldt	7.982E-03	1.000	7.982E-03	.220	.644	.010
	Lower-bound	7.982E-03	1.000	7.982E-03	.220	.644	.010
Error(DISPLAY)	Sphericity Assumed	.763	21	3.633E-02			
	Greenhouse-Geisser	.763	21.000	3.633E-02			
	Huynh-Feldt	.763	21.000	3.633E-02			
	Lower-bound	.763	21.000	3.633E-02			
SPEED * DISPLAY	Sphericity Assumed	7.845E-03	2	3.922E-03	.335	.717	.016
	Greenhouse-Geisser	7.845E-03	1.542	5.086E-03	.335	.662	.016
	Huynh-Feldt	7.845E-03	1.641	4.780E-03	.335	.675	.016
	Lower-bound	7.845E-03	1.000	7.845E-03	.335	.569	.016
Error(SPEED*DISPLAY)	Sphericity Assumed	.491	42	1.169E-02			
	Greenhouse-Geisser	.491	32.392	1.516E-02			
	Huynh-Feldt	.491	34.466	1.425E-02			
	Lower-bound	.491	21.000	2.339E-02			



Pairwise Comparisons

Measure: FORWARD

(I) SPEED	(J) SPEED	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.163*	.041	.002	-.270	-5.702E-02
	3	-.123	.058	.132	-.273	2.648E-02
2	1	.163*	.041	.002	5.702E-02	.270
	3	3.990E-02	.060	1.000	-.117	.197
3	1	.123	.058	.132	-2.648E-02	.273
	2	-3.990E-02	.060	1.000	-.197	.117

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

To investigate the difficulty (speed) effect, I performed a contrast to test the medium (2) difficulty to the mean of the low (1) and high (3) difficulty:

Contrast Results (K Matrix)

Contrast[a]			Transformed Variable T1
L1	Contrast Estimate		-.407
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		-.407
	Std. Error		.171
	Sig.		.027
	95% Confidence Interval for Difference	Lower Bound	-.763
		Upper Bound	-5.04E-02

a. Estimable Function for Intercept

12. 3. 2 Order

To further investigate speed effect, looked at the order. Groups are the trial order, with 1 being the first driving session, and 6 the last.

Descriptive Statistics

	Mean	Std. Deviation	N
FORE_1	1.33	.61	22
FORE_2	1.25	.55	22
FORE_3	1.11	.41	22
FORE_4	1.14	.48	22
FORE_5	1.23	.61	22
FORE_6	1.27	.73	22

Mauchly's Test of Sphericity[b]

Measure: FORE

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
ORDER	.113	41.623	14	.000	.542	.630	.200

Tests of Within-Subjects Effects

Measure: FORE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ORDER	Sphericity Assumed	.732	5	.146	4.002	.002	.160
	Greenhouse-Geisser	.732	2.708	.270	4.002	.014	.160
	Huynh-Feldt	.732	3.148	.233	4.002	.010	.160
	Lower-bound	.732	1.000	.732	4.002	.059	.160
Error(ORDER)	Sphericity Assumed	3.841	105	3.658E-02			
	Greenhouse-Geisser	3.841	56.872	6.754E-02			
	Huynh-Feldt	3.841	66.105	5.810E-02			
	Lower-bound	3.841	21.000	.183			

Pairwise Comparisons

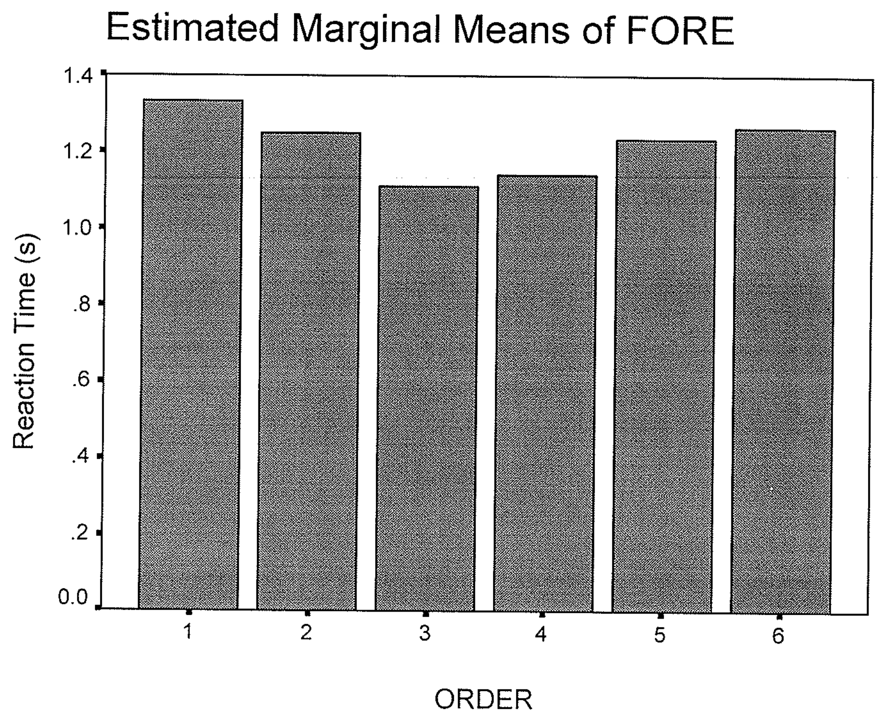
Measure: FORE

(I) ORDER	(J) ORDER	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	8.196E-02	.039	.742	-4.813E-02	.212
	3	.219*	.059	.018	2.499E-02	.413
	4	.190*	.044	.005	4.374E-02	.336
	5	9.633E-02	.060	1.000	-.103	.296
	6	6.543E-02	.070	1.000	-.167	.298
2	1	-8.196E-02	.039	.742	-.212	4.813E-02
	3	.137	.048	.142	-2.168E-02	.295
	4	.108	.040	.214	-2.580E-02	.242
	5	1.436E-02	.065	1.000	-.200	.229
	6	-1.653E-02	.077	1.000	-.270	.237
3	1	-.219*	.059	.018	-.413	-2.499E-02
	2	-.137	.048	.142	-.295	2.168E-02
	4	-2.884E-02	.033	1.000	-.137	7.970E-02
	5	-.122	.056	.608	-.308	6.319E-02
	6	-.153	.080	1.000	-.418	.112
4	1	-.190*	.044	.005	-.336	-4.374E-02
	2	-.108	.040	.214	-.242	2.580E-02
	3	2.884E-02	.033	1.000	-7.970E-02	.137
	5	-9.361E-02	.047	.867	-.248	6.076E-02
	6	-.125	.071	1.000	-.361	.112
5	1	-9.633E-02	.060	1.000	-.296	.103
	2	-1.436E-02	.065	1.000	-.229	.200
	3	.122	.056	.608	-6.319E-02	.308
	4	9.361E-02	.047	.867	-6.076E-02	.248
	6	-3.089E-02	.050	1.000	-.195	.134
6	1	-6.543E-02	.070	1.000	-.298	.167
	2	1.653E-02	.077	1.000	-.237	.270
	3	.153	.080	1.000	-.112	.418
	4	.125	.071	1.000	-.112	.361
	5	3.089E-02	.050	1.000	-.134	.195

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.



To investigate the order effect further, I performed a contrast that compared session 1 to the mean of sessions 2 through 6.

Contrast Results (K Matrix)

Contrast[a]			Transformed Variable T1
L1	Contrast Estimate		-.652
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		-.652
	Std. Error		.208
	Sig.		.005
	95% Confidence Interval for Difference	Lower Bound	-1.084
		Upper Bound	-.220

a. Estimable Function for Intercept

12. 4 Side Monitoring

Descriptive Statistics

	Mean	Std. Deviation	N
A3	2.83	.82	22
B3	2.67	.71	22
A5	2.98	.90	22
B5	3.11	1.10	22
A7	2.90	.79	22
B7	2.85	.84	22

Mauchly's Test of Sphericity[b]

Measure: RXN_TIME

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
SPEED	.489	14.311	2	.001	.662	.689	.500
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED * DISPLAY	.848	3.300	2	.192	.868	.939	.500

Tests of Within-Subjects Effects

Measure: RXN_TIME

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SPEED	Sphericity Assumed	1.924	2	.962	3.333	.045	.137
	Greenhouse-Geisser	1.924	1.324	1.454	3.333	.068	.137
	Huynh-Feldt	1.924	1.378	1.396	3.333	.066	.137
	Lower-bound	1.924	1.000	1.924	3.333	.082	.137
Error(SPEED)	Sphericity Assumed	12.124	42	.289			
	Greenhouse-Geisser	12.124	27.795	.436			
	Huynh-Feldt	12.124	28.943	.419			
	Lower-bound	12.124	21.000	.577			
DISPLAY	Sphericity Assumed	3.188E-02	1	3.188E-02	.478	.497	.022
	Greenhouse-Geisser	3.188E-02	1.000	3.188E-02	.478	.497	.022
	Huynh-Feldt	3.188E-02	1.000	3.188E-02	.478	.497	.022
	Lower-bound	3.188E-02	1.000	3.188E-02	.478	.497	.022
Error(DISPLAY)	Sphericity Assumed	1.399	21	6.663E-02			
	Greenhouse-Geisser	1.399	21.000	6.663E-02			
	Huynh-Feldt	1.399	21.000	6.663E-02			
	Lower-bound	1.399	21.000	6.663E-02			
SPEED * DISPLAY	Sphericity Assumed	.480	2	.240	1.834	.172	.080
	Greenhouse-Geisser	.480	1.736	.276	1.834	.178	.080
	Huynh-Feldt	.480	1.879	.255	1.834	.175	.080
	Lower-bound	.480	1.000	.480	1.834	.190	.080
Error(SPEED*DISPLAY)	Sphericity Assumed	5.496	42	.131			
	Greenhouse-Geisser	5.496	36.455	.151			
	Huynh-Feldt	5.496	39.453	.139			
	Lower-bound	5.496	21.000	.262			

12. 5 Combined Workload Rating

Descriptive Statistics

	Mean	Std. Deviation	N
COMA_A3	54.60	16.513	21
COMA_A5	55.48	16.852	21
COMA_A7	54.77	19.022	21
COMA_B3	51.35	17.881	21
COMA_B5	55.65	16.037	21
COMA_B7	53.34	19.805	21

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.597	9.787	2	.007	.713	.752	.500
DISPLAY * SPEED	.939	1.193	2	.551	.943	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportion:

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	71.125	1	71.125	2.055	.167	.093
	Greenhouse-Geisser	71.125	1.000	71.125	2.055	.167	.093
	Huynh-Feldt	71.125	1.000	71.125	2.055	.167	.093
	Lower-bound	71.125	1.000	71.125	2.055	.167	.093
Error(DISPLAY)	Sphericity Assumed	692.169	20	34.608			
	Greenhouse-Geisser	692.169	20.000	34.608			
	Huynh-Feldt	692.169	20.000	34.608			
	Lower-bound	692.169	20.000	34.608			
SPEED	Sphericity Assumed	142.031	2	71.016	1.290	.286	.061
	Greenhouse-Geisser	142.031	1.426	99.603	1.290	.281	.061
	Huynh-Feldt	142.031	1.505	94.402	1.290	.282	.061
	Lower-bound	142.031	1.000	142.031	1.290	.269	.061
Error(SPEED)	Sphericity Assumed	2201.419	40	55.035			
	Greenhouse-Geisser	2201.419	28.519	77.190			
	Huynh-Feldt	2201.419	30.091	73.159			
	Lower-bound	2201.419	20.000	110.071			
DISPLAY * SPEED	Sphericity Assumed	61.332	2	30.666	1.095	.344	.052
	Greenhouse-Geisser	61.332	1.885	32.532	1.095	.342	.052
	Huynh-Feldt	61.332	2.000	30.666	1.095	.344	.052
	Lower-bound	61.332	1.000	61.332	1.095	.308	.052
Error(DISPLAY*SPEED)	Sphericity Assumed	1119.913	40	27.998			
	Greenhouse-Geisser	1119.913	37.706	29.701			
	Huynh-Feldt	1119.913	40.000	27.998			
	Lower-bound	1119.913	20.000	55.996			

12. 6 Mental Demand

Descriptive Statistics

	Mean	Std. Deviation	N
MENT_A3	57.727	24.678	22
MENT_A5	56.970	25.693	22
MENT_A7	58.750	24.944	22
MENT_B3	52.955	26.423	22
MENT_B5	56.212	26.700	22
MENT_B7	55.985	27.715	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.724	6.453	2	.040	.784	.836	.500
DISPLAY * SPEED	.839	3.518	2	.172	.861	.931	.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	252.320	1	252.320	4.633	.043	.181
	Greenhouse-Geisser	252.320	1.000	252.320	4.633	.043	.181
	Huynh-Feldt	252.320	1.000	252.320	4.633	.043	.181
	Lower-bound	252.320	1.000	252.320	4.633	.043	.181
Error(DISPLAY)	Sphericity Assumed	1143.629	21	54.459			
	Greenhouse-Geisser	1143.629	21.000	54.459			
	Huynh-Feldt	1143.629	21.000	54.459			
	Lower-bound	1143.629	21.000	54.459			
SPEED	Sphericity Assumed	91.993	2	45.996	.578	.566	.027
	Greenhouse-Geisser	91.993	1.568	58.681	.578	.527	.027
	Huynh-Feldt	91.993	1.672	55.023	.578	.537	.027
	Lower-bound	91.993	1.000	91.993	.578	.456	.027
Error(SPEED)	Sphericity Assumed	3345.044	42	79.644			
	Greenhouse-Geisser	3345.044	32.921	101.608			
	Huynh-Feldt	3345.044	35.110	95.274			
	Lower-bound	3345.044	21.000	159.288			
DISPLAY * SPEED	Sphericity Assumed	88.668	2	44.334	1.497	.236	.067
	Greenhouse-Geisser	88.668	1.722	51.485	1.497	.238	.067
	Huynh-Feldt	88.668	1.862	47.629	1.497	.237	.067
	Lower-bound	88.668	1.000	88.668	1.497	.235	.067
Error(DISPLAY*SPEED)	Sphericity Assumed	1244.202	42	29.624			
	Greenhouse-Geisser	1244.202	36.166	34.402			
	Huynh-Feldt	1244.202	39.095	31.825			
	Lower-bound	1244.202	21.000	59.248			

12. 7 Physical Demand

Descriptive Statistics

	Mean	Std. Deviation	N
PHYS_A3	40.947	25.587	22
PHYS_A5	37.955	25.753	22
PHYS_A7	41.818	27.821	22
PHYS_B3	37.576	27.505	22
PHYS_B5	36.515	28.238	22
PHYS_B7	38.295	29.325	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.647	8.712	2	.013	.739	.782	.500
DISPLAY * SPEED	.744	5.902	2	.052	.796	.851	.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	254.630	1	254.630	5.943	.024	.221
	Greenhouse-Geisser	254.630	1.000	254.630	5.943	.024	.221
	Huynh-Feldt	254.630	1.000	254.630	5.943	.024	.221
	Lower-bound	254.630	1.000	254.630	5.943	.024	.221
Error(DISPLAY)	Sphericity Assumed	899.769	21	42.846			
	Greenhouse-Geisser	899.769	21.000	42.846			
	Huynh-Feldt	899.769	21.000	42.846			
	Lower-bound	899.769	21.000	42.846			
SPEED	Sphericity Assumed	186.311	2	93.156	1.172	.320	.053
	Greenhouse-Geisser	186.311	1.478	126.050	1.172	.309	.053
	Huynh-Feldt	186.311	1.563	119.182	1.172	.312	.053
	Lower-bound	186.311	1.000	186.311	1.172	.291	.053
Error(SPEED)	Sphericity Assumed	3337.995	42	79.476			
	Greenhouse-Geisser	3337.995	31.040	107.540			
	Huynh-Feldt	3337.995	32.828	101.680			
	Lower-bound	3337.995	21.000	158.952			
DISPLAY * SPEED	Sphericity Assumed	29.682	2	14.841	.481	.622	.022
	Greenhouse-Geisser	29.682	1.593	18.633	.481	.580	.022
	Huynh-Feldt	29.682	1.703	17.432	.481	.592	.022
	Lower-bound	29.682	1.000	29.682	.481	.496	.022
Error(DISPLAY*SPEED)	Sphericity Assumed	1296.475	42	30.868			
	Greenhouse-Geisser	1296.475	33.452	38.756			
	Huynh-Feldt	1296.475	35.758	36.257			
	Lower-bound	1296.475	21.000	61.737			

12. 8 Temporal Demand

Descriptive Statistics

	Mean	Std. Deviation	N
TEMP_A3	66.288	20.483	22
TEMP_A5	65.303	21.131	22
TEMP_A7	63.750	25.728	22
TEMP_B3	64.242	18.954	22
TEMP_B5	70.189	15.316	22
TEMP_B7	65.720	20.903	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.603	10.108	2	.006	.716	.754	.500
DISPLAY * SPEED	.670	8.014	2	.018	.752	.797	.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	84.854	1	84.854	1.249	.276	.056
	Greenhouse-Geisser	84.854	1.000	84.854	1.249	.276	.056
	Huynh-Feldt	84.854	1.000	84.854	1.249	.276	.056
	Lower-bound	84.854	1.000	84.854	1.249	.276	.056
Error(DISPLAY)	Sphericity Assumed	1426.142	21	67.912			
	Greenhouse-Geisser	1426.142	21.000	67.912			
	Huynh-Feldt	1426.142	21.000	67.912			
	Lower-bound	1426.142	21.000	67.912			
SPEED	Sphericity Assumed	227.410	2	113.705	.737	.485	.034
	Greenhouse-Geisser	227.410	1.432	158.815	.737	.444	.034
	Huynh-Feldt	227.410	1.508	150.836	.737	.450	.034
	Lower-bound	227.410	1.000	227.410	.737	.400	.034
Error(SPEED)	Sphericity Assumed	6479.072	42	154.264			
	Greenhouse-Geisser	6479.072	30.070	215.465			
	Huynh-Feldt	6479.072	31.661	204.640			
	Lower-bound	6479.072	21.000	308.527			
DISPLAY * SPEED	Sphericity Assumed	266.488	2	133.244	1.012	.372	.046
	Greenhouse-Geisser	266.488	1.504	177.232	1.012	.355	.046
	Huynh-Feldt	266.488	1.594	167.170	1.012	.358	.046
	Lower-bound	266.488	1.000	266.488	1.012	.326	.046
Error(DISPLAY*SPEED)	Sphericity Assumed	5531.197	42	131.695			
	Greenhouse-Geisser	5531.197	31.576	175.172			
	Huynh-Feldt	5531.197	33.476	165.227			
	Lower-bound	5531.197	21.000	263.390			

12. 9 Performance

Descriptive Statistics

	Mean	Std. Deviation	N
PERF_A3	65.795	20.684	22
PERF_A5	64.545	22.679	22
PERF_A7	64.394	20.474	22
PERF_B3	69.773	20.275	22
PERF_B5	64.962	20.037	22
PERF_B7	66.705	21.869	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.466	15.257	2	.000	.652	.678	.500
DISPLAY * SPEED	.905	1.986	2	.371	.914	.996	.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	164.820	1	164.820	1.608	.219	.071
	Greenhouse-Geisser	164.820	1.000	164.820	1.608	.219	.071
	Huynh-Feldt	164.820	1.000	164.820	1.608	.219	.071
	Lower-bound	164.820	1.000	164.820	1.608	.219	.071
Error(DISPLAY)	Sphericity Assumed	2151.962	21	102.474			
	Greenhouse-Geisser	2151.962	21.000	102.474			
	Huynh-Feldt	2151.962	21.000	102.474			
	Lower-bound	2151.962	21.000	102.474			
SPEED	Sphericity Assumed	217.214	2	108.607	.953	.394	.043
	Greenhouse-Geisser	217.214	1.304	166.565	.953	.362	.043
	Huynh-Feldt	217.214	1.355	160.295	.953	.365	.043
	Lower-bound	217.214	1.000	217.214	.953	.340	.043
Error(SPEED)	Sphericity Assumed	4788.805	42	114.019			
	Greenhouse-Geisser	4788.805	27.386	174.866			
	Huynh-Feldt	4788.805	28.457	168.284			
	Lower-bound	4788.805	21.000	228.038			
DISPLAY * SPEED	Sphericity Assumed	69.823	2	34.912	.659	.523	.030
	Greenhouse-Geisser	69.823	1.827	38.211	.659	.510	.030
	Huynh-Feldt	69.823	1.992	35.044	.659	.522	.030
	Lower-bound	69.823	1.000	69.823	.659	.426	.030
Error(DISPLAY*SPEED)	Sphericity Assumed	2224.158	42	52.956			
	Greenhouse-Geisser	2224.158	38.373	57.961			
	Huynh-Feldt	2224.158	41.841	53.157			
	Lower-bound	2224.158	21.000	105.912			

12. 10 Frustration

Descriptive Statistics

	Mean	Std. Deviation	N
FRUS_A3	36.477	18.984	22
FRUS_A5	34.735	23.745	22
FRUS_A7	40.492	23.676	22
FRUS_B3	32.841	18.889	22
FRUS_B5	34.356	22.530	22
FRUS_B7	37.121	23.577	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.637	9.005	2	.011	.734	.775	.500
DISPLAY * SPEED	.874	2.685	2	.261	.888	.965	.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	200.047	1	200.047	.861	.364	.039
	Greenhouse-Geisser	200.047	1.000	200.047	.861	.364	.039
	Huynh-Feldt	200.047	1.000	200.047	.861	.364	.039
	Lower-bound	200.047	1.000	200.047	.861	.364	.039
Error(DISPLAY)	Sphericity Assumed	4878.309	21	232.300			
	Greenhouse-Geisser	4878.309	21.000	232.300			
	Huynh-Feldt	4878.309	21.000	232.300			
	Lower-bound	4878.309	21.000	232.300			
SPEED	Sphericity Assumed	518.845	2	259.422	1.347	.271	.060
	Greenhouse-Geisser	518.845	1.468	353.471	1.347	.268	.060
	Huynh-Feldt	518.845	1.551	334.539	1.347	.269	.060
	Lower-bound	518.845	1.000	518.845	1.347	.259	.060
Error(SPEED)	Sphericity Assumed	8086.248	42	192.530			
	Greenhouse-Geisser	8086.248	30.825	262.328			
	Huynh-Feldt	8086.248	32.569	248.278			
	Lower-bound	8086.248	21.000	385.059			
DISPLAY * SPEED	Sphericity Assumed	72.001	2	36.001	.243	.785	.011
	Greenhouse-Geisser	72.001	1.777	40.523	.243	.759	.011
	Huynh-Feldt	72.001	1.929	37.317	.243	.777	.011
	Lower-bound	72.001	1.000	72.001	.243	.627	.011
Error(DISPLAY*SPEED)	Sphericity Assumed	6210.406	42	147.867			
	Greenhouse-Geisser	6210.406	37.313	166.440			
	Huynh-Feldt	6210.406	40.518	153.274			
	Lower-bound	6210.406	21.000	295.734			

12. 11 Effort

Descriptive Statistics

	Mean	Std. Deviation	N
EFFT_A3	55.682	23.324	22
EFFT_A5	57.500	23.377	22
EFFT_A7	54.583	27.160	22
EFFT_B3	50.644	27.307	22
EFFT_B5	54.053	23.586	22
EFFT_B7	55.720	27.054	22

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	1.000	.000	0	.	1.000	1.000	1.000
SPEED	.630	9.235	2	.010	.730	.771	.500
DISPLAY * SPEED	.920	1.663	2	.435	.926	1.000	.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	Sphericity Assumed	198.001	1	198.001	2.123	.160	.092
	Greenhouse-Geisser	198.001	1.000	198.001	2.123	.160	.092
	Huynh-Feldt	198.001	1.000	198.001	2.123	.160	.092
	Lower-bound	198.001	1.000	198.001	2.123	.160	.092
Error(DISPLAY)	Sphericity Assumed	1958.481	21	93.261			
	Greenhouse-Geisser	1958.481	21.000	93.261			
	Huynh-Feldt	1958.481	21.000	93.261			
	Lower-bound	1958.481	21.000	93.261			
SPEED	Sphericity Assumed	163.920	2	81.960	.583	.562	.027
	Greenhouse-Geisser	163.920	1.460	112.271	.583	.512	.027
	Huynh-Feldt	163.920	1.542	106.338	.583	.521	.027
	Lower-bound	163.920	1.000	163.920	.583	.453	.027
Error(SPEED)	Sphericity Assumed	5900.663	42	140.492			
	Greenhouse-Geisser	5900.663	30.661	192.449			
	Huynh-Feldt	5900.663	32.372	182.278			
	Lower-bound	5900.663	21.000	280.984			
DISPLAY * SPEED	Sphericity Assumed	226.084	2	113.042	1.348	.271	.060
	Greenhouse-Geisser	226.084	1.852	122.061	1.348	.270	.060
	Huynh-Feldt	226.084	2.000	113.042	1.348	.271	.060
	Lower-bound	226.084	1.000	226.084	1.348	.259	.060
Error(DISPLAY*SPEED)	Sphericity Assumed	3520.907	42	83.831			
	Greenhouse-Geisser	3520.907	38.897	90.519			
	Huynh-Feldt	3520.907	42.000	83.831			
	Lower-bound	3520.907	21.000	167.662			

12. 12 Heart Rate Measures

12. 12. 1 Speed-Display Effects

All heart rate tests were performed together, so each table contains a section for heart rate (HR), standard deviation of heart rate (SD), and mean absolute derivative of heart rate (DEL). All figures are not normalized.

Descriptive Statistics

	Mean	Std. Deviation	N
A3_HR	77.994	7.491	19
A5_HR	78.873	7.775	19
A7_HR	78.145	7.756	19
B3_HR	78.790	8.301	19
B5_HR	79.621	7.836	19
B7_HR	78.682	8.543	19
A3_SD_HR	3.827	1.140	19
A5_SD_HR	3.534	.996	19
A7_SD_HR	3.849	1.276	19
B3_SD_HR	3.794	1.250	19
B5_SD_HR	3.721	1.148	19
B7_SD_HR	3.753	1.163	19
A3 Avg dHR	2.934	.954	19
A5 Avg dHR	2.845	.702	19
A7 Avg dHR	2.872	.923	19
B3 Avg dHR	2.886	.897	19
B5 Avg dHR	2.993	1.135	19
B7 Avg dHR	2.863	.955	19

Mauchly's Test of Sphericity[b]

						Epsilon[a]		
Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
DISPLAY	HR	1.000	.000	0	.	1.000	1.000	1.000
	SD	1.000	.000	0	.	1.000	1.000	1.000
	DEL	1.000	.000	0	.	1.000	1.000	1.000
SPEED	HR	.473	12.717	2	.002	.655	.686	.500
	SD	.671	6.785	2	.034	.752	.806	.500
	DEL	.692	6.256	2	.044	.765	.821	.500
DISPLAY * SPEED	HR	.931	1.223	2	.543	.935	1.000	.500
	SD	.924	1.344	2	.511	.929	1.000	.500
	DEL	.871	2.351	2	.309	.886	.975	.500

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
DISPLAY	HR	Sphericity Assumed	13.714	1	13.714	5.606	.029	.237
		Greenhouse-Geisser	13.714	1.000	13.714	5.606	.029	.237
		Huynh-Feldt	13.714	1.000	13.714	5.606	.029	.237
		Lower-bound	13.714	1.000	13.714	5.606	.029	.237
	SD	Sphericity Assumed	1.011E-02	1	1.011E-02	.056	.816	.003
		Greenhouse-Geisser	1.011E-02	1.000	1.011E-02	.056	.816	.003
		Huynh-Feldt	1.011E-02	1.000	1.011E-02	.056	.816	.003
		Lower-bound	1.011E-02	1.000	1.011E-02	.056	.816	.003
	DEL	Sphericity Assumed	2.586E-02	1	2.586E-02	.219	.645	.012
		Greenhouse-Geisser	2.586E-02	1.000	2.586E-02	.219	.645	.012
		Huynh-Feldt	2.586E-02	1.000	2.586E-02	.219	.645	.012
		Lower-bound	2.586E-02	1.000	2.586E-02	.219	.645	.012
Error(DISPLAY)	HR	Sphericity Assumed	44.038	18	2.447			
		Greenhouse-Geisser	44.038	18.000	2.447			
		Huynh-Feldt	44.038	18.000	2.447			
		Lower-bound	44.038	18.000	2.447			
	SD	Sphericity Assumed	3.247	18	.180			
		Greenhouse-Geisser	3.247	18.000	.180			
		Huynh-Feldt	3.247	18.000	.180			
		Lower-bound	3.247	18.000	.180			
	DEL	Sphericity Assumed	2.125	18	.118			
		Greenhouse-Geisser	2.125	18.000	.118			
		Huynh-Feldt	2.125	18.000	.118			
		Lower-bound	2.125	18.000	.118			
SPEED	HR	Sphericity Assumed	18.065	2	9.033	1.388	.263	.072
		Greenhouse-Geisser	18.065	1.310	13.790	1.388	.260	.072
		Huynh-Feldt	18.065	1.371	13.172	1.388	.261	.072
		Lower-bound	18.065	1.000	18.065	1.388	.254	.072
	SD	Sphericity Assumed	.806	2	.403	1.698	.197	.086
		Greenhouse-Geisser	.806	1.505	.536	1.698	.205	.086
		Huynh-Feldt	.806	1.612	.500	1.698	.204	.086
		Lower-bound	.806	1.000	.806	1.698	.209	.086
	DEL	Sphericity Assumed	5.702E-02	2	2.851E-02	.246	.783	.013
		Greenhouse-Geisser	5.702E-02	1.529	3.729E-02	.246	.724	.013
		Huynh-Feldt	5.702E-02	1.643	3.471E-02	.246	.740	.013
		Lower-bound	5.702E-02	1.000	5.702E-02	.246	.626	.013
Error(SPEED)	HR	Sphericity Assumed	234.355	36	6.510			
		Greenhouse-Geisser	234.355	23.580	9.939			
		Huynh-Feldt	234.355	24.687	9.493			
		Lower-bound	234.355	18.000	13.020			
	SD	Sphericity Assumed	8.542	36	.237			
		Greenhouse-Geisser	8.542	27.086	.315			
		Huynh-Feldt	8.542	29.017	.294			
		Lower-bound	8.542	18.000	.475			
	DEL	Sphericity Assumed	4.169	36	.116			
		Greenhouse-Geisser	4.169	27.525	.151			
		Huynh-Feldt	4.169	29.566	.141			
		Lower-bound	4.169	18.000	.232			
DISPLAY * SPEED	HR	Sphericity Assumed	.362	2	.181	.123	.884	.007
		Greenhouse-Geisser	.362	1.870	.194	.123	.872	.007
		Huynh-Feldt	.362	2.000	.181	.123	.884	.007
		Lower-bound	.362	1.000	.362	.123	.729	.007
	SD	Sphericity Assumed	.419	2	.209	.929	.404	.049
		Greenhouse-Geisser	.419	1.859	.225	.929	.399	.049
		Huynh-Feldt	.419	2.000	.209	.929	.404	.049
		Lower-bound	.419	1.000	.419	.929	.348	.049
	DEL	Sphericity Assumed	.205	2	.103	.995	.380	.052
		Greenhouse-Geisser	.205	1.771	.116	.995	.372	.052
		Huynh-Feldt	.205	1.950	.105	.995	.378	.052
		Lower-bound	.205	1.000	.205	.995	.332	.052
Error(DISPLAY*SPEED)	HR	Sphericity Assumed	52.822	36	1.467			
		Greenhouse-Geisser	52.822	33.664	1.569			
		Huynh-Feldt	52.822	36.000	1.467			
		Lower-bound	52.822	18.000	2.935			
	SD	Sphericity Assumed	8.112	36	.225			
		Greenhouse-Geisser	8.112	33.456	.242			
		Huynh-Feldt	8.112	36.000	.225			
		Lower-bound	8.112	18.000	.451			
	DEL	Sphericity Assumed	3.716	36	.103			
		Greenhouse-Geisser	3.716	31.882	.117			
		Huynh-Feldt	3.716	35.108	.106			
		Lower-bound	3.716	18.000	.206			

12. 12. 2 *Order Effects—Heart Rate*

Unlike the Speed-Display ANOVA of heart rate measures, each Order ANOVA was performed separately. In each table there are eight order groups. The first two are the 'resting' and 'moving' baselines, respectively, and the last 6 are the driving sessions.

Descriptive Statistics

	Mean	Std. Deviation	N
HR_HS	78.12	9.13	19
HR_LS	78.90	8.73	19
HR_D1	79.75	8.04	19
HR_D2	78.85	7.60	19
HR_D3	78.08	7.58	19
HR_D4	78.62	8.19	19
HR_D5	78.21	7.90	19
HR_D6	78.60	8.41	19

Mauchly's Test of Sphericity[b]

Measure: HR

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
ORDER	.001	105.881	27	.000	.349	.408	.143

Tests of Within-Subjects Effects

Measure: HR

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ORDER	Sphericity Assumed	40.423	7	5.775	.856	.543	.045
	Greenhouse-Geisser	40.423	2.443	16.544	.856	.451	.045
	Huynh-Feldt	40.423	2.856	14.156	.856	.465	.045
	Lower-bound	40.423	1.000	40.423	.856	.367	.045
Error(ORDER)	Sphericity Assumed	849.619	126	6.743			
	Greenhouse-Geisser	849.619	43.979	19.319			
	Huynh-Feldt	849.619	51.400	16.530			
	Lower-bound	849.619	18.000	47.201			

12. 12. 3 Order Effects—Standard Deviation of Heart Rate

Descriptive Statistics

	Mean	Std. Deviation	N
SD_HR_HS	4.801	1.573	19
SD_HR_LS	4.847	1.812	19
SD_HR_D1	3.535	.955	19
SD_HR_D2	3.718	1.181	19
SD_HR_D3	3.782	1.195	19
SD_HR_D4	3.812	1.184	19
SD_HR_D5	3.791	1.284	19
SD_HR_D6	3.841	1.171	19

Mauchly's Test of Sphericity[b]

Measure: SD

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
ORDER	.009	73.637	27	.000	.412	.499	.143

Tests of Within-Subjects Effects

Measure: SD

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ORDER	Sphericity Assumed	34.297	7	4.900	8.248	.000	.314
	Greenhouse-Geisser	34.297	2.886	11.886	8.248	.000	.314
	Huynh-Feldt	34.297	3.495	9.813	8.248	.000	.314
	Lower-bound	34.297	1.000	34.297	8.248	.010	.314
Error(ORDER)	Sphericity Assumed	74.848	126	.594			
	Greenhouse-Geisser	74.848	51.939	1.441			
	Huynh-Feldt	74.848	62.909	1.190			
	Lower-bound	74.848	18.000	4.158			

Pairwise Comparisons

Measure: SD

(I) ORDER	(J) ORDER	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-4.684E-02	.468	1.000	-1.759	1.665
	3	1.265*	.276	.007	.254	2.277
	4	1.083	.302	.060	-2.414E-02	2.190
	5	1.019	.287	.064	-3.153E-02	2.069
	6	.989*	.266	.043	1.695E-02	1.961
	7	1.010	.284	.064	-3.109E-02	2.051
	8	.960	.285	.097	-8.517E-02	2.005
2	1	4.684E-02	.468	1.000	-1.665	1.759
	3	1.312*	.355	.046	1.320E-02	2.611
	4	1.130	.311	.053	-7.233E-03	2.267
	5	1.065	.348	.189	-.209	2.340
	6	1.036	.365	.307	-.302	2.374
	7	1.057	.348	.198	-.217	2.330
	8	1.007	.318	.151	-.159	2.172
3	1	-1.265*	.276	.007	-2.277	-.254
	2	-1.312*	.355	.046	-2.611	-1.320E-02
	4	-.182	.135	1.000	-.678	.313
	5	-.247	.211	1.000	-1.018	.525
	6	-.276	.185	1.000	-.955	.403
	7	-.255	.190	1.000	-.950	.439
	8	-.306	.164	1.000	-.906	.295
4	1	-1.083	.302	.060	-2.190	2.414E-02
	2	-1.130	.311	.053	-2.267	7.233E-03
	3	.182	.135	1.000	-.313	.678
	5	-6.435E-02	.151	1.000	-.619	.490
	6	-9.386E-02	.139	1.000	-.601	.413
	7	-7.301E-02	.131	1.000	-.554	.408
	8	-.123	.110	1.000	-.526	.280
5	1	-1.019	.287	.064	-2.069	3.153E-02
	2	-1.065	.348	.189	-2.340	.209
	3	.247	.211	1.000	-.525	1.018
	4	6.435E-02	.151	1.000	-.490	.619
	6	-2.952E-02	.182	1.000	-.694	.635
	7	-8.661E-03	.139	1.000	-.519	.502
	8	-5.883E-02	.127	1.000	-.522	.404
6	1	-.989*	.266	.043	-1.961	-1.695E-02
	2	-1.036	.365	.307	-2.374	.302
	3	.276	.185	1.000	-.403	.955
	4	9.386E-02	.139	1.000	-.413	.601
	5	2.952E-02	.182	1.000	-.635	.694
	7	2.085E-02	.136	1.000	-.477	.519
	8	-2.931E-02	.132	1.000	-.512	.453
7	1	-1.010	.284	.064	-2.051	3.109E-02
	2	-1.057	.348	.198	-2.330	.217
	3	.255	.190	1.000	-.439	.950
	4	7.301E-02	.131	1.000	-.408	.554
	5	8.661E-03	.139	1.000	-.502	.519
	6	-2.085E-02	.136	1.000	-.519	.477
	8	-5.017E-02	.120	1.000	-.490	.390
8	1	-.960	.285	.097	-2.005	8.517E-02
	2	-1.007	.318	.151	-2.172	.159
	3	.306	.164	1.000	-.295	.906
	4	.123	.110	1.000	-.280	.526
	5	5.883E-02	.127	1.000	-.404	.522
	6	2.931E-02	.132	1.000	-.453	.512
	7	5.017E-02	.120	1.000	-.390	.490

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

To inspect the order effect, I performed a contrast comparing the mean of the baseline sessions to the mean of the driving sessions.

Contrast Results (K Matrix)

Contrast[a]			Transformed Variable T1
L1	Contrast Estimate		6.466
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		6.466
	Std. Error		1.109
	Sig.		.000
	95% Confidence Interval for Difference	Lower Bound	4.137
		Upper Bound	8.795

a. Estimable Function for Intercept

12. 12. 4 Order Effects—Mean Absolute Derivative of Heart Rate

Descriptive Statistics

	Mean	Std. Deviation	N
DEL_HS	3.282	.932	19
DEL_LS	3.224	1.113	19
DEL_D1	2.908	1.075	19
DEL_D2	2.954	.840	19
DEL_D3	2.914	.872	19
DEL_D4	2.886	.945	19
DEL_D5	2.880	1.038	19
DEL_D6	2.851	.822	19

Mauchly's Test of Sphericity[b]

Measure: DELTA

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
ORDER	.007	75.812	27	.000	.360	.424	.143

Tests of Within-Subjects Effects

Measure: DELTA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
ORDER	Sphericity Assumed	3.716	7	.531	3.256	.003	.153
	Greenhouse-Geisser	3.716	2.522	1.473	3.256	.037	.153
	Huynh-Feldt	3.716	2.967	1.252	3.256	.029	.153
	Lower-bound	3.716	1.000	3.716	3.256	.088	.153
Error(ORDER)	Sphericity Assumed	20.540	126	.163			
	Greenhouse-Geisser	20.540	45.400	.452			
	Huynh-Feldt	20.540	53.406	.385			
	Lower-bound	20.540	18.000	1.141			

Pairwise Comparisons

Measure: DELTA

(I) ORDER	(J) ORDER	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	5.802E-02	.128	.656	-.211	.327
	3	.374*	.120	.006	.121	.627
	4	.328*	.137	.028	3.930E-02	.617
	5	.368*	.142	.019	6.929E-02	.666
	6	.396*	.171	.033	3.644E-02	.755
	7	.401*	.133	.007	.123	.680
	8	.430*	.132	.004	.153	.708
2	1	-5.802E-02	.128	.656	-.327	.211
	3	.316*	.093	.003	.120	.512
	4	.270	.167	.123	-8.008E-02	.620
	5	.309	.178	.100	-6.534E-02	.684
	6	.338	.199	.107	-8.027E-02	.755
	7	.343	.171	.059	-1.482E-02	.702
	8	.372*	.175	.047	4.752E-03	.740
3	1	-.374*	.120	.006	-.627	-.121
	2	-.316*	.093	.003	-.512	-.120
	4	-4.578E-02	.130	.729	-.319	.228
	5	-6.383E-03	.146	.966	-.313	.300
	6	2.172E-02	.172	.901	-.340	.383
	7	2.759E-02	.133	.838	-.252	.308
	8	5.654E-02	.158	.724	-.275	.388
4	1	-.328*	.137	.028	-.617	-3.930E-02
	2	-.270	.167	.123	-.620	8.008E-02
	3	4.578E-02	.130	.729	-.228	.319
	5	3.939E-02	.070	.580	-.108	.186
	6	6.749E-02	.106	.531	-.154	.289
	7	7.337E-02	.088	.416	-.112	.259
	8	.102	.078	.209	-6.260E-02	.267
5	1	-.368*	.142	.019	-.666	-6.929E-02
	2	-.309	.178	.100	-.684	6.534E-02
	3	6.383E-03	.146	.966	-.300	.313
	4	-3.939E-02	.070	.580	-.186	.108
	6	2.810E-02	.076	.716	-.132	.188
	7	3.398E-02	.080	.676	-.134	.202
	8	6.292E-02	.051	.237	-4.517E-02	.171
6	1	-.396*	.171	.033	-.755	-3.644E-02
	2	-.338	.199	.107	-.755	8.027E-02
	3	-2.172E-02	.172	.901	-.383	.340
	4	-6.749E-02	.106	.531	-.289	.154
	5	-2.810E-02	.076	.716	-.188	.132
	7	5.878E-03	.092	.950	-.188	.200
	8	3.482E-02	.088	.696	-.149	.219
7	1	-.401*	.133	.007	-.680	-.123
	2	-.343	.171	.059	-.702	1.482E-02
	3	-2.759E-02	.133	.838	-.308	.252
	4	-7.337E-02	.088	.416	-.259	.112
	5	-3.398E-02	.080	.676	-.202	.134
	6	-5.878E-03	.092	.950	-.200	.188
	8	2.894E-02	.085	.736	-.149	.207
8	1	-.430*	.132	.004	-.708	-.153
	2	-.372*	.175	.047	-.740	-4.752E-03
	3	-5.654E-02	.158	.724	-.388	.275
	4	-.102	.078	.209	-.267	6.260E-02
	5	-6.292E-02	.051	.237	-.171	4.517E-02
	6	-3.482E-02	.088	.696	-.219	.149
	7	-2.894E-02	.085	.736	-.207	.149

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

To inspect the order effect, I performed a contrast comparing the mean of the baseline sessions to the mean of the driving sessions.

Contrast Results (K Matrix)

Contrast[a]			Transformed Variable T1
L1	Contrast Estimate		2.123
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		2.123
	Std. Error		.728
	Sig.		.009
	95% Confidence Interval for Difference	Lower Bound	.594
		Upper Bound	3.652

a. Estimable Function for Intercept

12. 13 Comments

All comments are organized by their frequency. The wording shown is not the exact wording on each comment; I grouped them by their general meaning.

Comment	Number
Preference for lightbar B or felt they had more control with lightbar B.	12
Preference for lightbar A or felt they had more control with lightbar A.	4
Easier to see lightbar B in periphery while looking at secondarys, or hard to see A in periphery.	8
Easier to perform tasks on second day	4
Felt they saw a pattern	3
B could be annoying with large lights	2
Would like a way to see side displays without turning	2
Found B harder to center	2
Hit button too many times	1
Found head turning tiring	1
Found tasks monotonous	1
Performing many tasks was difficult	1
Would like tasks organized so they are easier to do.	1
Liked large lights of lightbar B	1
Spent most time looking at side displays	1
Order of subjective scales could be changed to avoid people following a pattern	1
Found B more precise than A	1
A was too small	1
Need more demand	1
B is too big	1

13 APPENDIX 5: COMPUTER FILES

13. 1 Overview

In addition to the written copy, computer files are included on a compact disc with this thesis. These files contain the raw data, the program used to control the simulator, and an electronic copy of the thesis text.

13. 2 Data

13. 2. 1 Heart Rate

Individual files in Microsoft Excel 2000 format are included for the 19 participants included in the analysis. Data files for the remaining three participants were either missing or contained too many errors. Each file contains four sheets—'HR Data', 'Info', 'Summary', 'HR Chart', and 'dHR_dt Chart'.

The 'HR Data' sheet contains all inter-beat intervals (IBIs) collected in the testing session and calculated values of elapsed time, instantaneous heart rate (HR), and instantaneous change of heart rate with respect to time (dHR/dt).

The 'Info' page contains the times used to synchronize the heart rate data with the simulator program. This includes the start and end of each driving session and heart rate analysis section.

The 'Summary' page includes the log of all heart rate processing activity and the calculated values of average HR, standard deviation of HR, and average absolute dHR/dt. The data processing log includes the start and end of all measurement sections, any detected artefacts, and the corrected values of those artefacts. Corrected values are the average of the surrounding four instantaneous HR values.

The 'HR Chart' page includes a chart of instantaneous heart rates over the entire test session, and the 'dHR_dt Chart' page includes a chart of instantaneous dHR/dt over the entire test session.

13. 2. 2 Primary

Individual files in Microsoft Excel 2000 format are included for all 22 participants. There are seven sheets in each file—one for each driving session and a summary sheet. Each session sheet contains a sequence of instantaneous values of absolute time, elapsed time, steering wheel position, error (Difference), error that would have existed had the steering wheel been centred (NS Difference), and the lightbar position (Index)

The summary sheet contains the display and speed, error values, and root mean square rate of movement for each session. The error values are root mean square error (RMSE), modulus mean error (MME), average error, standard deviation of error (Std Dev), and ratios of each error value. The ratios are the actual error value divided by the error that would have resulted had the steering wheel remained at centre for the entire session.

13. 2. 3 Secondary

Individual files in Microsoft Excel 2000 format are included for all 22 participants. There are seven sheets in each file—one for each driving session and a summary sheet. Each session sheet contains a sequence of values for all signals in that session. Values recorded are type of signal (1 through 6, representing left up and down, right up and down, and front up and down, respectively), time when the signal started, time the button was pressed, and the reaction time (difference between start and button times).

The summary sheet contains the display and speed, number of signals, and average reaction times for each session. Signals are grouped by up and down for each of the left, right, and front displays.

13. 2. 4 Subjective

There are two files for the subjective responses. The TLX Data file contains all the data from the NASA Task Load Index (TLX). The weightings page contains two sets of weightings for each subject—one taken after driving session 1, and the other taken after driving session 2. The ratings page contains six sets of ratings for each subject, one set from each driving session. In addition to a rating for each subscale, there are three combined ratings. Combined A and B combine the scores using the weights from display A or B, respectively. The Combined A-B value uses the A or B weights alternately, depending upon the display used in that session.

The comments file contains all comments written by the subjects. The first sheet—comments—contains all the raw comments. The second sheet—summary—contains groups of similar comments, and the number of comments in that group.

13. 3 Simulator Program

This folder contains the simulator program. It is a Basic file, written in Microsoft QuickBasic version 4.5. The details of the program are covered in Appendix 2.

13. 4 Written Copy

This folder contains a Microsoft Word 2000 version of this thesis. The only part of the written thesis not included in the computer file is the simulator program (See section 13.3).

M. Sc. Thesis, Scott Young: Contents of Accompanying CD-ROM

Microsoft Excel 2000 Files (in Data Folder):
Primary Folder: 22 Files (ASteering, BSteering, CSteering, through VSteering)
Heart Rate Folder: 19 Files (AAnal through MAnal, PAnal through TAnal, VAnal)
Secondary Folder: 22 Files (ASecondary, BSecondary, through VSecondary)
Subjective Folder: 2 Files (Comments, TLX Data)

Microsoft Word 2000 File:
Written Copy Folder: 1 File (Scott Young Masters Thesis)

Microsoft QuickBasic 4.5 File:
Simulator Program Folder: 1 File (Simulator)