LIGHTBAR DESIGN: THE EFFECT OF LIGHT COLOUR, LIGHTBAR SIZE, AND AUXILIARY INDICATORS ON TRACKING PERFORMANCE

BY

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ABSTRACT

Any useful technology that improves the steering accuracy of the agricultural machine during farm operations could be referred to as an agricultural guidance system. The global positioning system (GPS) lightbar is one such system. A lightbar consists of a set of light emitting diodes (LEDs) to the left and right of a centre position, which flash or illuminate in either of the two directions when a corrective control action is required.

A simulator study was carried out to investigate the effect of three ergonomic factors: LED colour, auxiliary indicators, and physical size in the effectiveness of the lightbar in communicating guidance information to the operator (driver) of an agricultural machine. Five lightbar displays (displays A-E) varying in size, LED (light) colour, and LED configuration were designed and evaluated. Twenty-four volunteers were used as test subjects. The experimental task consisted of a primary (steering) task and a secondary (monitoring) task. The simulator required the test subjects to control the steering component using the steering wheel and the monitoring component using a joystick located in the simulator cab. Each experimental session lasted for approximately 1h.

The results show that the effectiveness of the lightbar in transmitting guidance information can be improved by replacing the presently used red LEDs with blue LEDs and by increasing the size of the lightbar. A blue-coloured display (display B) reduced the steering error and the reaction time achieved with the use of a red-coloured display (display A) of the same size by 16% and 13%, respectively. Similarly, a large lightbar reduced the steering error and the reaction time achieved with the use of a smaller lightbar by 10% and 4%, respectively. Auxiliary indicators reduced steering error by 6%, but caused a 7% reduction in secondary task performance. Thus, an auxiliary indicator could cause an additional mental workload to the operator.

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1. INTRODUCTION

The term "guidance system" is usually associated with guiding airplanes over a large range of miles with an accuracy of a few feet or miles. There are, however, applications, which require a range of a few miles and an accuracy of inches. Farming is one of these applications (Palmer 1989). Slight deviation of an airplane from its established course is of little consequence; the duration of the flight might be extended by a few seconds, wasting a relatively insignificant amount of fuel and time (Palmer 1989). Deviation of a farm implement from its desired course is much more serious, resulting in skipping (i.e., zero application) and overlapping (i.e., double application) (Bottoms 1989). Skipping and overlapping during farm operations has been a great challenge to farmers in particular and agriculture in general. Skips (Fig. 1.1) and overlaps result in significant yield losses, excessive cost of crop inputs, environmental pollution, groundwater contamination, and reduced crop growth among other vices. Davis (1977) estimated the crop losses during sugar beet harvesting due to skips and overlaps to be about 13% of the total input. This loss ranked second highest out of ten factors and represents about 400kg of beets per hectare (Davis 1977). Palmer and Fischer (1985) reported a lateral overlap of about 10%. Similarly, Hanson (1998) estimated the loss due to skipping and overlapping to be about 7% of the total input. The truth remains that input costs are high in farming, and that farmers work on a very narrow profit margin. As such, a 7% overlap is a significant economic loss to the farmer. Therefore, further reduction of skips and overlaps will increase the profit of the farmer dramatically. This can only be achieved through precision farming.

Fig. 1.1 A picture showing the effects of skips on crop yield

Precision farming is a well-established concept whose major objective is to maximize the efficiency of the agricultural production system. It involves both good farm management skills and the use of technological devices (McKay and Pringle 1998). Precision farming is geared towards creating a technology revolution in production agriculture (Reid 1998). In practice, any technology or management decision that improves the efficiency of an agricultural operation can be considered as an aspect of precision farming. Agricultural guidance systems are one such tool.

Agricultural guidance systems are devices that provide guidance information to the driver of an agricultural machine during field operations. By so doing, they help to reduce guidance error (skipping and overlapping of implements within the field) and permit more efficient application of agricultural materials. In addition to improving tracking performance, guidance systems are intended to reduce the mental workload of the operator. Often, however, the introduction of a guidance device to the cab of an agricultural machine increases the supervisory and monitoring tasks of the operator (Gopher and Donchin 1986). The operator must monitor the guidance device continuously while performing other tasks: a phenomenon that increases his or her mental workload. O'Donnell and Eggemeier (1986) defined mental workload as the portion of the operator's limited mental capacity required to perform a given task. Excessively high levels of mental workload lead to guidance error and performance degradation (Braby et al. 1993). Thus, the less the mental workload an operator experiences in trying to obtain information from a guidance device, the better the tracking performance and hence, the guidance efficiency. Therefore, it is critical to consider ergonomic issues when designing new agricultural guidance systems, upgrading existing systems, or simply locating a system in the cab of an agricultural machine. Without considering human physiological limitations in the design, it is unlikely that the efficiency of the man-machine system can be optimized. This thesis work evaluates different designs of the GPS lightbar on ergonomic grounds using mental workload as the index of assessment.

2. LITERATURE REVIEW

2.1 Agricultural Guidance Systems

2.1.1 Definitions

An agricultural guidance system can be defined as any useful technology that improves the tracking efficiency of the agricultural machine thereby reducing guidance error (skipping and overlapping). Guidance systems for agricultural production can be classified as one of two types: autonomous systems or guidance aids. An autonomous guidance system (for example, a "driverless tractor") has sensors that determine the current posture of the vehicle, compare it to a desired posture, and make appropriate steering adjustments to direct the vehicle toward the desired posture (Reid 1998). Kanayama and Hartman (1989) defined posture of a vehicle as the position and orientation of the vehicle relative to some reference frame. Autonomous systems were developed based on the assumption that such systems could free the operator of the guidance task completely and improve significantly the operating efficiency of the agricultural machine (Tillet 1991). (Richey 1959) outlined the desired functional features of an autonomous system: (a) compatibility with regular steering; (b) no reduction in field speeds compared to manual steering; (c) adaptable to the majority of field operations; (d) simplicity and ruggedness; (e) reduced labour cost; and (f) reduced overlap (see also Schoenfish and Billingsley 1998).

However, there are a number of problems associated with the use of autonomous guidance systems in agricultural applications. For instance, the vehicle usually must be transported to the field on a public road for which a driver will be required and once in the field, the vehicle may require servicing at intervals (Tillet 1991). Secondly, the control of implements, engine, and transmission presents a number of problems to the designer of a fully autonomous system. For instance, operations like ploughing involve a complex interaction of implement depth, gear ratio, and engine speed with a soil whose properties may vary across the field. Thus, although work has been conducted on automatic engine and transmission control (see Ryan 1972; Chancellor and Thai 1983), a fully integrated system incorporating implement control is not yet commercially available (Tillet 1991). Another major disadvantage of an autonomous guidance system is the initial cost of the equipment. The system is very costly and cannot be afforded by many farmers (Grovum and Zoerb 1970). Furthermore, Automated Guided Vehicles in general require reliable fail-safe devices to prevent collisions with people and objects (Tracey 1987). It is difficult to achieve an adequate level of reliability and safety in this aspect when talking about a complex environment like the farm field where the guiding feature may be, for instance, a row of plants, which are subject to natural variation. All these shortcomings indicate that autonomous systems are not yet perfected and may not be accepted by the current generation of farmers.

Guidance aids, on the other hand, are systems or devices that provide guidance information to the driver, but do not attempt to replace the driver. In addition, they ease auxiliary control, reduce safety costs, and allow the driver to do his task better. The use of guidance aids involves manual operator steering control. The desired path is determined by the operator, usually from visual cues like stationary objects at the edge of the field, previous swaths, or some kind of deliberately placed guidance marks (Reid 1998). The operator observes the current posture of the vehicle and makes accurate steering adjustments through the steering wheel (Reid 1998). Over the years, different types of guidance aids such as flags, stakes, field markers, and fence posts have been used by farmers to reduce guidance error. These systems were very primitive and had several limitations such as low efficiency, large guidance error, and limited scope (Tang 2000). Recently, several types of guidance aids have been developed by industries to match the requirements of modern agricultural machines. Such systems include mechanical disk markers on air-seeders, foam markers on sprayers, tramlines, GPS lightbars and camera-based guidance devices. Using different techniques, these guidance systems attempt to present useful information to the driver. In this thesis, attention will be focused on the GPS-based guidance aid.

2.1.2 GPS-based guidance aid

The GPS-based guidance aids are systems that use orbiting satellites to determine the position, velocity, and bearing of an object relative to some reference frame. Satellites orbiting the earth transmit a complex signal. When the signal reaches a receiver on the earth's surface, the receiver's position is calculated. By comparing the current position to a map of the field, the receiver can determine the lateral error of the implement. The required correction is then displayed as guidance information on a monitor (which is often referred to as a "lightbar") located in the tractor's cab from where the operator reads the signal and directs his tractor accordingly.

A lightbar consists of a set of light emitting diodes (LEDs) to the left and right of a centre position, which flash or illuminate in either of the two directions when a corrective control action is required (Figs. 2.1 and 2.2). Lightbar displays are becoming more important as the use of agricultural guidance systems is becoming more widespread (Brown 2002). Markowitz (1971) outlined two major motivations behind the increasing use of such a system in precision guidance. First, it provides the most discriminable stimulus in situations with a great deal of temporal and spatial uncertainty. Secondly, there is a potential increase in the information content of the system.

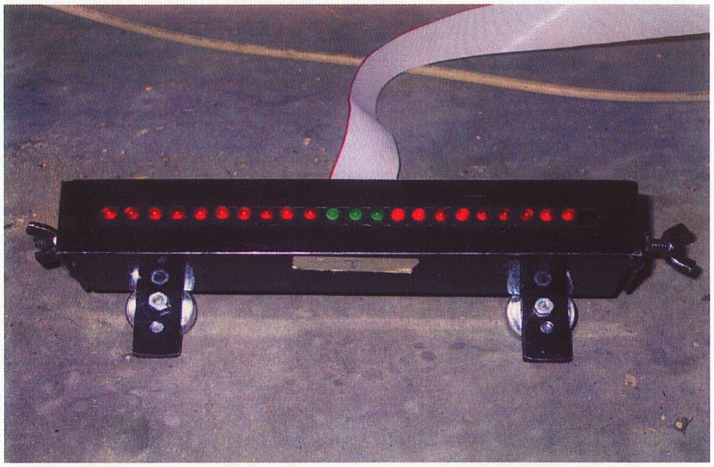

Fig. 2.1 A lightbar with no light turned on

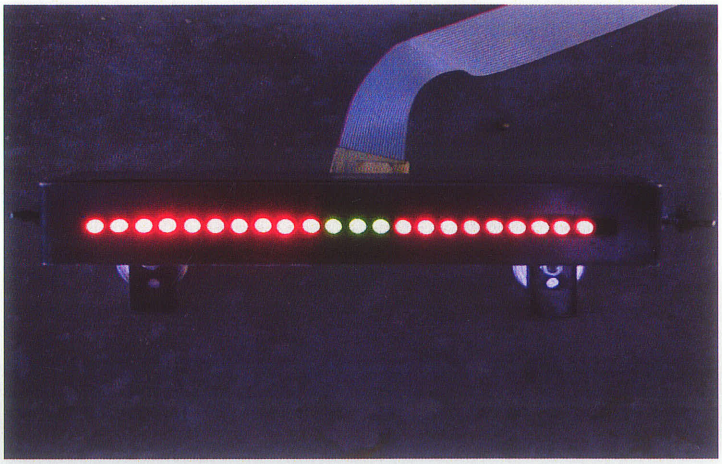

Fig. 2.2 A lightbar with all the lights turned on

Another major advantage of using the GPS lightbar as a guidance aid is its ability to work under any condition - day or night, dust or fog, wind or rain - allowing farmers to extend hours for agricultural field applications (Anonymous 1998).

To design an efficient lightbar display, the designer should consider some critical ergonomic factors such as visual demand, light colour, and flash rate. On the other hand, introducing a lightbar or other visual targets into the cab of an agricultural machine could increase rather than reduce workload if care is not taken. To avoid this situation, it is necessary, therefore, to consider factors like vertical height of placement and viewing distance from the driver when locating a lightbar or other visual targets in the cab. Each of these factors mentioned would significantly influence the level of mental workload the driver experiences while using the lightbar as a source of guidance information. Generally, a lightbar that is specially designed to cause less mental workload would be especially valuable because it would increase the quality of the operator's performance as well as decrease the level of fatigue and stress felt by the operator (Brown 2002).

2.2 Ergonomic Factors Associated with Guidance Displays

2.2.1 Visual demand

The increasing technological complexity found in the modern agricultural tractor cab has significantly increased the amount of information presented to the operator, which must be mentally processed. Often, these technologies are visually demanding and rely on the use of central (foveal) vision for feedback. To complicate matters, the operator must use his central vision to both guide and monitor the tractor and implement. Given that two competing visual channels cannot be watched simultaneously (de Waard 1996) and that visual switching between multiple information sources inhibits the rate of information acquisition (Wulfeck et al. 1958), this phenomenon often causes visual overload, which leads to decision errors, increased mental workload, decreased guidance performance, and increased potential for accidents. As such, it seems advisable to both reduce the number of displays presented to the central vision and to increase the ease with which information that must remain in the operators central visual field can be extracted from the displays (Weinstein and Wickens 1992).

To address this problem, new forms of visual feedback are needed which will enable the automation system to play a more active role in human-machine communication (Nikolic and Sarter 2001). In addition, the multiple resource theory proposed by Wickens (1992) suggests that the distribution of tasks and information across various processing channels and sensory modalities represents separate attentional resources. Therefore, one possible solution to central vision overload that has received little attention relies upon the under-utilized resource of peripheral vision (Christensen et al. 1985; Stokes et al. 1990). Trevarthen (1968) explained that peripheral vision is very sensitive in detecting position and relative motion. Leibowitz et al. (1983) further explained that peripheral vision, in contrast to central vision, is relatively insensitive to refractive error or luminance degradation, though it has poor resolution for seeing fine details. Malcolm (1984) claimed that approximately 90% of visual stimulation is obtained without conscious effort from the peripheral visual field.

Empirical evidence exists which supports the use of peripheral vision to free up central vision for concentration on other tasks related to the direct operation and monitoring of other machine systems and to support continuous tasks such as the steering task. Vallerie (1968) reported that the use of peripheral displays resulted in a significant increase in tracking performance and a decrease in visual scanning between elements of a central display. Nikolic and Sarter (2001) conducted a simulator study to compare two differential implementations of peripheral visual feedback with current foveal visual cues (flight mode annunciations) in terms of their ability to support the monitoring of changes in the status of an automated flight deck system. They found that both peripheral visual displays resulted in higher detection rates and faster response times without interfering with performance of concurrent visual tasks any more than does the currently available automation feedback. Miura (1990) examined peripheral vision performance with free eye movements in a realistic setting and reported that, with more demands, more information is acquired from the peripheral visual field (see also Moriarity et al. 1976). Jonides (1981) reported that peripheral visual cues are highly effective in capturing and guiding attention. All these empirical results suggest that the use of effective peripheral visual cues is a feasible and effective way of reducing central visual overload and of enhancing human-machine communication. Young and Mann (2001) reported that a peripheral display for agricultural guidance systems is being designed and evaluated.

Another important factor that affects detection rate or visibility of a visual stimulus is the display size. Virsu and Rovamo (1979) reported that increasing stimulus size improved visual function and contrast sensitivity in the peripheral retina. Ogle (1961) concluded that the threshold of visibility is lower for a large stimulus object than for a smaller stimulus object. Thus, increasing the display size increases the ease with which the visual stimulus is detected.

2.2.2 Light colour

Colour is that aspect of visual perception by which an observer may distinguish differences between two structure-free fields of view of the same size and shape, such as may be caused by differences in the spectral composition of the radiant energy concerned in the observation (Wyszecki and Stiles 1967). The perception of colour is due to variations in wavelength within the visible spectrum of light. Colour perception is an important tool that determines the effectiveness of lightbar displays and other visual signaling devices. While many colours of light signals are currently available, it is apparent that, under specific viewing conditions, some colours are better than others. This could be explained by the fact that the eye is not equally sensitive to all wavelengths of light, just as the ear is not equally sensitive to all frequencies of sound (Sanders and McCormick 1993). Therefore, to choose the most effective signal colour in a specific situation, stimulus colour, background colour, and ambient illumination must all be considered (Reynolds et al. 1972). In general, Sanders and McCormick (1993) noted that if a light signal has good brightness contrast against a dark background and a high absolute level of brightness, then the colour of the signal is of minimal importance in attracting attention.

Presently, red and green are the most frequently used colours for the design of lightbars and other light signals. This is possibly because these colours have been used primarily for the purpose of giving dichotomous information; red for warning and green for safety (Dudek and Colton 1970). In addition, experiments conducted by Reynolds et al. (1972) on the ease of detection and recognition of coloured signal lights show that, while using the central vision and in a low signal-to-background brightness, a red signal is the most preferable, followed by green, yellow, and white in that order. However, the colour of a fovea-centered object may appear different if seen peripherally (Ancman 1991; Dudek and Colton 1970; Marks 1971). Recent research suggests that the use of colours other than red and green will improve colour perception in the peripheral vision field. For instance, Dudek and Colton (1970) investigated the effects of lighting and background with common signal lights on human peripheral colour vision using red, green, yellow, and blue test lights. They found that for any given condition of background, or environmental light level, the blue test lights gave the best results for the greatest recognition of distance of colour and the number of errors made. Using the three primary colours (red, green, blue), Ancman (1991) studied color perception limitations in peripherally located CRTs and reported that blue is the most easily detectable and the most reliable in the periphery. He further stated that blue could be seen up to 83.1° off the fovea (along the x-axis), while red and green could be seen up to about 76.3 and 74.3°, respectively. This exceptional quality was attributed to the higher brightness differential of blue compared with any of the other colours. Another important observation from this experiment is that red was confused with green 50% of the time in the periphery. Therefore, when relying upon colour-coding as a cue, designers should realize that some colours are perceived more easily than other colours. In addition, the required visual field (central or peripheral), background colour, and ambient illumination should be considered.

2.2.3 Flash rate

Flash rate is an important consideration when dealing with flashing lights. This is primarily because a very high flash rate may exceed the flicker-fusion frequency (approximately 30 flashes per second), which is the flash rate at which a flashing light appears as a steady light (Sanders and McCormick 1993). Continuous flashing lights have been reported to be distracting to the operator; a situation that reduces his capability to carry out the guidance task effectively (Leung 2002; Heglin 1973). In this respect, Woodson and Conover (1964) recommended flash rates of about 3 to10 per second with a duration of at least 0.05 s. Markowitz (1971) investigated the optimal flash rate and the duty cycle for visual flashing indicators and reported that a range of 1 to 2 flashes per second, which is presently used on highways and in the flyways, is compatible with human discrimination capabilities. Heglin (1973) stated that a flash rate of 4 per second, with equal intervals of light and dark, is the best. In situations demanding the use of more than one flash rate to signify different variables (for example, in automobile tail lights where different flash rates represent different deceleration rates), Mortimer and Kupec (1983) reported that a maximum of three flash rates should be used (see also Tolin 1984). Otherwise, the operator may get confused by the multiple flash rates. As a final word of advice, Sanders and McCormick (1993) recommended that a flashing light should be reserved for new conditions or emergencies.

Results from several experiments have shown that different flash rates have significant effects in the quality of the information they provide. For example, Katchmar and Azrin (1956) studied the effectiveness of warning lights as a function of flash rate and reported that flashing lights get the most attention at about 10 Hz. Post (1976) investigated the performance requirements for turn and hazard warning signals and found that signal lights get the most attention when the frequency is between 2 and 3 Hz. If flashing lights are to be used in central vision, intensity is important. Because peripheral vision tends to be insensitive to luminance degradation, light intensity is of little importance if the flashing light is to be located in the periphery (Leibowitz et al. 1983). Based on the published literature, flashing lights may be useful in the design of a lightbar for a GPS-based guidance aid. It should be noted, however, that the frequency of flashing should be selected carefully and the occurrence of flashing should be reserved for short durations corresponding to new conditions.

2.2.4 Height of placement of the monitor

Height of placement refers to the vertical location of a lightbar or other visual target with respect to the horizontal eye level of the operator. Placement of a visual target in the cab of a tractor (or other vehicle) affects the orientation of the eyes and, hence, determines the body posture of the operator. Consequently, it is necessary to determine the optimum location of such targets to minimize the level of visual and musculoskeletal discomfort experienced by the operator. The preferred eye gaze direction and visual convergence have been shown to be important considerations in location of visual targets (Bergqvist and Knave 1994; Heuer and Owens 1989; Hsiao and Keyserling 1991). Hill and Kroemer (1986) reported that subjects preferred looking downwards below the ear-eye line in all experimental postures and conditions when given the opportunity to place a visual target anywhere in the vertical plane. They attributed this observation to the fact that the eyes rotate downwards relative to the head, rather than upwards (see also Heuer et al. 1991; Hering 1977; Hemholtz 1962). According to Turville et al. (1998), natural near-distance convergence occurs when the gaze angle is below the horizontal eye level, while divergence occurs when the gaze angle is above the horizontal eye level. Sotoyama et al. (1996) reported a decrease in the surface area of the eye exposed to the atmosphere when the gaze angle was downwards. This result implies a reduction in visual discomfort due to eye dryness, which usually occurs when using visual displays (Mon-Williams et al. 1999). Similarly, Ankrum and Nemeth (1995) suggested that placing the visual display downwards, below the horizontal eye level, will increase the range of comfortable neuromuscular postures that could be adopted by an operator while allowing comfortable gaze angles for the visual system.

The conventional recommendation suggests that a visual display should be placed at or just below the horizontal eye level (National Occupational Health and Safety Commission 1989; Woodson 1981). This strategy positions the center of the visual display approximately 15° below horizontal eye level and has been recommended because the normal line of sight is 15° below the eye level (Sanders and McCormick 1993; Morgan et al. 1963). Similarly, Burgess-Limerick et al. (1998) established that both gaze angle and head orientation are altered by changes in the vertical location of visual targets. In addition, they observed that subjects adopted gaze angles that were higher than preferred when the visual target was placed higher than 15° below the horizontal eye level. Based on their data, they argued that visual targets should be located at 15° below horizontal eye level (see also Mon-Williams et al. 1999; Burgess-Limerick et al. 2000).

These recommendations have been challenged recently by several researchers, all of whom argue that the visual display should be positioned more than 15° below the horizontal eye level so that the center of the monitor is well below the work surface. For example, Kroemer et al. (1994) suggested that visual displays be placed 30° below the eye level. Hill and Kroemer (1986) reported that subjects working on a visual display preferred an overall mean gaze angle of 34° below the horizontal eye level. Ankrum and Nemeth (1995) postulated that static loading of the musculoskeletal system (neck, shoulder, and back muscles) could be reduced and that the operator would be able to adopt a wider range of head inclinations while viewing the visual targets at 40° below the horizontal eye level. Turville et al. (1998) conducted an experiment to investigate the physiological and visual effects of visual target height on the operator using gaze angles of 15 and 40° below the eye level. They found no evidence indicating that switching the monitor placement from 15 to 40° below horizontal as suggested by Ankrum and Nemeth (1995) would improve the health and safety of the operator.

Hill and Kroemer (1986) observed that the preferred gaze angle is significantly affected by the target distance. They reported an average preferred angle of 38° below eye level for visual targets at 0.5m and -30° when the visual target is placed at 1m from the operator. Mon-Williams et al. (1999) reported preferred gaze angles between 19 to 36° below the eye level for a target at 0.65m.

Based on literature, locating lightbars and other visual targets at the conventionally recommended position (National Occupational Health and Safety Commission 1989) requires the operators to either compromise their preferred gaze angle, or to adopt postures in which one or more of the cervical joints are relatively extended (Ankrum and Nemeth 1995). Adopting postures requiring relative extension of the neuromuscular system for a long period of time would lead to physical discomfort and fatigue.

2.2.5 Viewing distance

The quality of the image formed on the retina while using a monitor to obtain guidance information depends, to a great extent, on the accuracy of visual accommodation (Raymond 1986). This implies that visual detection and discrimination could be influenced by any factor determining the accuracy of accommodation. Viewing distance, the distance of the visual display from the eyes, has been described as the most important stimulus parameter determining the effectiveness of accommodative response (Raymond 1986). Thus, varying the observation distance could cause significant changes in accommodative accuracy as long as parameters such as the size, intensity, and contrast of the visual display are held constant (Johnson 1976).

The majority of the standards and guidelines for work at visual display units (VDUs) recommend that the visual target be kept at a distance of about 50 cm from the operator (Helander and Rupp 1984). However, there is no evidence of physiological consideration in these recommendations (Jaschinski-Kruza 1988, Jaschinski-Kruza 1987). Consequently, recent research has tried to determine an alternative concept, on physiological grounds, for favorable viewing distance based on accommodative function. Johnson (1976) stated that the relationship between the viewing distance and accommodative accuracy is not simply a function of the optical distance between the operator and the visual target, but rather depends on the relative distance between the position of the visual target and the operator's resting state of accommodation called 'dark focus' or 'tonic accommodation'. Reviews of the dark focus are given by Owens (1984) and Gilmartin (1986). The observation by Johnson (1976) implies that the dark focus varies among individuals. The 'dark focus' has been further described as the viewing distance that results in the lowest static load on the ciliary muscles, with only small fluctuations of accommodation (Kruger 1980; Fisher 1977). Jaschinski-Kruza (1988) conducted an experiment to verify the effect of viewing distance and dark focus on visual strain during VDU work. It was found that no accommodative error occurred when the viewing distance agreed with the dark focus, and that errors in accommodation increased as the distance of the visual target relative to the dark focus of the individual operator increased (Toates 1972). Jaschinski-Kruza (1988), therefore, concluded that visual strain is directly related to how closely the visual target is located relative to the operator's dark focus. Similarly, Johnson (1976) reported that accommodation was most accurate when the visual target was located at a distance corresponding to the subject's dark focus.

Based on these results, it can be concluded that visual performance is maximized when the visual display is located at the dark focus distance where no accommodative effort is required. As such, placing the visual display at the conventionally recommended viewing distance of 50 cm will cause much eyestrain to operators whose dark focus distance is beyond 50 cm. As a design engineer, it is necessary to know how to determine the dark focus for a population of people. Jaschinski-Kruza (1988), Leibowitz and Owens (1978), and Johnson et al. (1984) described how dark focus could be measured.

2.3 Mental Workload: A Tool for Ergonomic Evaluation of Guidance Aids

2.3.1 Definition

Mental workload refers to that portion of the operator's limited mental capacity that is actually required to perform a particular task (O'Donnell and Eggemeier 1986). It is a term used to describe aspects of the interaction between an operator and an assigned task. Tasks are specified in terms of their structural properties. In addition, there are expectations regarding the quality of the performance, which derive from knowledge of the relation between the structure of the task and the nature of human capabilities and skills (Derrick 1988). Expectations may also be based on the individual operator's past performance or on knowledge of the way other people perform similar tasks (Leplat and Welford 1978). Frequently, these expectations are not met even though the operator is motivated to accept the assignment and intends to perform according to expectations. Such failures in performance are attributed to increased difficulty of the task (O'Donnell and Eggemeier 1986). It is in the attempt to explain and cope with these interactions that the concept of mental workload finds its primary use (Gopher and Donchin 1986).

2.3.2 Workload measures

2.3.2.1 Categories of workload measures

The several methods used in assessing mental workload are classified into four broad categories based on the method used in data collection. These categories include subjective measures, primary task measures, secondary task measures, and physiological measures (Wickens 1992). Modern systems are quite complex and no one measure can be expected to index all of the relevant aspects that bear upon the mental workload of the operator (Salvendy 1997). In most situations, carefully selected multiple measures will produce a more accurate evaluation of the mental workload associated with a given task (Wierwille and Eggemeier 1983).

2.3.2.2 Subjective measures

Subjective measures of mental workload refer to those measures or techniques in which the subjects (operators) are asked to judge the level of interactions between them and the system by giving a direct estimate of the workload they experience during the performance of a task (Wickens 1992). The use of subjective measures in assessing mental workload has always been very appealing to many researchers. No one is able to provide a more accurate judgment with respect to experienced mental load than the person concerned (de Ward 1996). Subjective assessment of workload reflects the direct opinion of the operator about the level of mental effort (resources) required in the context of the task environment (Wickens 1992).

Structured rating scales are frequently used to collect subjective data. In these scales, the operator is asked to rank the demand associated with a task performance along a wide variety of dimensions. For instance, he may be asked to indicate the level of physical demand, mental demand, effort, time pressure, and frustration, which he experienced in performing a task. Such rating scales can be unidimensional (e.g. Bedford scale) or multidimensional (e.g. NASA-TXL) (Tsang and Vidulich 1994). Other techniques such as the use of questionnaires, open-ended questions, and direct interviews with the operator can also provide useful information about a system (Gopher and Donchin 1986).

Subjective measures have several advantages. They do not disrupt the performance of the primary task since the operator is asked to do the rating when he has finished performing the task. In addition, subjective data are easy to collect and use (Derrick 1988). However, subjective measures can potentially be susceptible to memory loss problem if the ratings are made much later after the performance of the task (Raby and Wickens 1994). The result estimates may also be affected by operator bias, his past experience, and degree of familiarity with the task or the system being evaluated.

2.3.2.3 Primary task measures

Primary task measures refer to those measures that have to do with the overall effectiveness of the man-machine interaction. In this case, assessment of mental workload is based upon performance on the task or system of interest. Usually, there is no one prevalent primary-task measure, although all primary task measures are speed or accuracy measures (Gopher and Donchin 1986). Measures such as steering deviation from the normal course, speed of performance, or the number of errors made are frequently used as primary task measures (Wickens 1992). With the primary task method, the actual performance of the operator and system is monitored and changes are noted as the demand of the tasks varies. For example, flight path deviation may increase in conditions of strong cross winds and may further increase if emergency conditions require close monitoring of engine state indicators (Tsang and Vidulich 1994).

Primary task measures are very objective in nature. They give a very high confidence especially when they are part of the actual system performance. Except for extremely low workload conditions, primary task measures in general are sensitive to a variety of task demand manipulations (O'Donnell and Eggemeier 1986). However, primary task measures do not reflect variation in resource investment due to changes in difficulty (Gopher and Donchin 1986). In addition, they do not make possible a systematic conversion of performance units into measures of relative demands or load on the processing system, thereby posing a scaling problem when comparisons or an aggregate of different primary task workload measures are needed (Wickens and Liu 1988).

2.3.2.4 Secondary task measures

In secondary task measures, the operator is required to perform a second task concurrently with the primary task of interest. Before starting the work, it is usually explained to the operator that the primary task is more important than the secondary task and that the primary task must be performed to the best of his ability, whether or not it is performed with the secondary task (Braune and Wickens 1986). He is required to use only his spare capacity (not needed by the primary task) to perform the secondary task (Wickens and Hollands 2000). Since the primary and secondary tasks would compete for limited processing resources, changes in the primary task demand should result in changes in the secondary task performance as more or less resources become available for the secondary task (Eggemeier and Wilson 1991).

A secondary task performance will only be a sensitive workload measure of the primary task demand if the secondary task competes with the primary task for the same processing resources

(Schneider and Detweiler 1988). In other words, it is the degree of interference between the primary and the secondary task that is used for inferring the level of workload. This interference will normally produce one out of two possible results: (1) a situation where performance on primary task remains fairly constant while performance on secondary task fluctuates or (2) a situation where performance on secondary task remains fairly constant while performance on primary task fluctuates. Whichever situation occurs depends on how the test subjects perceive the relative importance of the tasks. Therefore, care must be taken to ensure that the selected secondary task demands resources similar to that of the primary task. Most frequently used secondary tasks include reaction-time tasks, time estimation tasks, time-interval production tasks, memory-search tasks and other tasks involving mental arithmetic (Wierwille and Eggemeier 1983).

The addition of a secondary task to the primary task can circumvent the problem of insensitivity to extremely low workload conditions, which is usually a major problem with primary task measures (Ogden et al. 1979). In addition, secondary tasks are selectively sensitive (Tsang and Wilson 1997). However, additional instrumentation and intensive training are required to properly conduct a secondary task evaluation and to interpret the results (Damos 1978; Damos 1991). Also, the addition of an extraneous task to the operational environment may not only add to the mental workload of the operator, but may fundamentally cause primary task intrusion (Damos 1978).

2.3.2.5 Physiological measures

As the demand for mental effort increases during the performance of a task, various bodily systems of the operator are activated or aroused in the process of marshaling resources in the service of this increased effort (Gopher and Donchin 1986). This activation or arousal causes some changes in the operator's physiological systems. Physiological measures of mental workload refer to those assessment techniques which measure changes in the operators physiology that are associated with cognitive task demands (Tsang and Wilson 1997).

The several physiological measures are either classified under the control of the Central Nervous System (CNS), which is composed of the brain, brain stem and spinal cord cells, or the Autonomic Nervous System (ANS), which is a subdivision of the Peripheral Nervous System (de Waard 1996). Measures such as changes in pupil diameter, heart rate variability, electrodermal, and hormonal levels are controlled by the ANS, whereas electrical, magnetic, metabolic, and elctrooculographic measures are controlled by the CNS (de Waard 1996). Other physiological measures are peripheral responses involving spontaneous muscle activity and eye movements (O'Donnell and Eggemeier 1986).

Physiological measures do not interfere with the performance of the primary task. Data are obtained by attaching small electrodes to the operator's body. The electrodes amplify, record, and transmit the detected potentials to special computer software, which processes the signals and produces the data in appropriate units of measurement (Tattersal and Hockey 1995). Also, small operator-worn multichannel physiological recorders are available which permit the operator to go about his normal job without interference while the recorders take readings of physiological changes in his body (Humphrey and Kramer 1994). This allows moment-to-moment monitoring of the changes in an operator's response to task demands. However, physiological measures often require specialized equipment and technical expertise (Kramer et al. 1987). This may cause a set back when the equipment and required training are not affordable (Kramer et al. 1987).

2.4 Objectives

Preliminary studies have been done by undergraduate students in the Department of Biosystems Engineering to investigate the effect of auxiliary indicators and colour coding on guidance performance, but the results were not conclusive. As such, there is a need to further study these parameters. Therefore, the objectives of this thesis include:

1. to determine the effect of light colour and colour coding on guidance performance
2. to determine the effect of lightbar size on guidance performance
3. to determine the effect of auxiliary indicators on guidance performance.

As mentioned earlier, all evaluations will be done using the concept of mental workload described in section 2.3.

The factor of lightbar size was also included based on positive results from a study conducted by Young (2003). Specifically, there was an interest in determining which factor (i.e., colour, size, or presence of an auxiliary indicator) would contribute the most to guidance performance.

Ultimately, the knowledge developed from this study will be used to produce more efficient agricultural guidance systems, which will reduce the amount of stress the operator experiences in trying to acquire information from the systems and also improve the precision of agricultural operations.

3. MATERIALS AND METHODS

3.1 Subjects

Twenty-four volunteers (20 male and 4 female) drawn mostly from the population of students and staff in the Department of Biosystems Engineering at the University of Manitoba were recruited as test subjects. The subjects were between 18 and 50 years of age and ranged in height from 1.52 to 1.93m. The subjects were predominantly right –handed, eleven had normal vision, ten were far-sighted, and three were near-sighted. The near- and far-sighted subjects wore spectacles during the experiment. All but one subject had car-driving experience, twelve had previous tractor driving experience, while only six had prior experience in experiments involving tractor driving simulator and guidance systems. Participation was voluntary, but all subjects received a $25 honorarium.

3.2 Test Site

All tests were conducted in a site located at the east end of the Grain Storage Research Laboratory at the University of Manitoba, Fort Garry campus. The site was rectangular in shape and had dimensions, 11.80 x 7.75m. Because several other works and experiments were occurring in the laboratory at the time of this experiment, sack cloth material was used to create a demarcation between the test layout and the remaining part of the laboratory to prevent the subjects from being distracted during the testing by the frequent pedestrian traffic. A glass window, 2.4 x 0.8m, located at the south end of the test chamber was completely covered with a thick black cardboard material to avoid possible glare and reflection, which could adversely affect the vision of the subjects.

3.3 Tractor Simulator

A tractor-driving simulator previously developed by Young (2003) was used for running the tests (Fig. 3.1). The interior of the simulator is similar to that of a commercial agricultural sprayer (Fig. 3.2). This is because, at the moment, agricultural guidance systems are mostly used in spraying operations. The simulator requires the operator to control a steering component using the steering wheel and primary displays (lightbars) and a monitoring component using a joystick located in the simulator cab and secondary displays. Both the steering and the monitoring components are controlled by a computer program (see Appendix D).

Fig. 3.1 Tractor simulator (Young 2003)

It was necessary to do a simulation rather than actual field-testing for some obvious reasons.

First, the climatic conditions in Winnipeg prevent fieldwork during the winter period. Second, the use of a simulator ensured that each test subject was exposed to identical sensory input with no interference from uncontrollable external factors. This allowed the different lightbar designs to be compared on an equal basis. Furthermore, the simulator ensured the safety of the test subjects.

Fig. 3.2 Interior part of the simulator (Young 2003)

3.4 Secondary Displays

The visual monitoring task is a major task in the operation of agricultural machinery. This task is demanding and requires the operator to simultaneously monitor an operation to the rear of the tractor while tracking some predefined path in front of the tractor. For example, during a spraying operation, the tractor must be driven in a straight line parallel to the previously sprayed areas. In addition, the sprayer must be monitored to ensure that a proper boom height is maintained (Kaminaka et al. 1981). To simulate this field situation, three secondary displays were connected to the simulator (Fig. 3.3). Each of these displays was located at a distance of 6m from the operator's position. One display (centre display) was placed directly in front of the operator and at eye level (Fig.3.4). Monitoring this display represents the condition where the operator is required to look forward from time to time during field operations to ensure the tractor is moving along the predefined path.

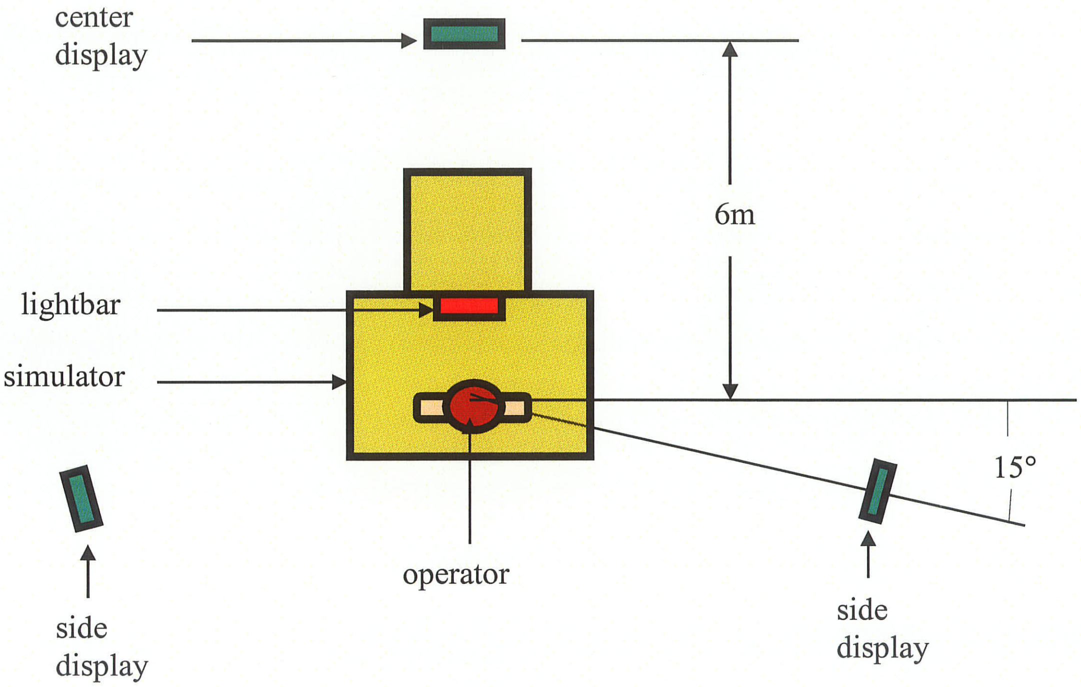

Fig 3.3. Experimental set-up

The other two displays (side displays) were placed rearward on either side, 15° behind a line directly to the side of the operator, and below eye level (Fig. 3. 5). Monitoring these two displays represents the rear-monitoring task of the operator during actual field operation. An angle of 15° was chosen because this is the direction in which an operator would have to look to see the edge of a 30m wide spray boom (Young and Mann 2002).

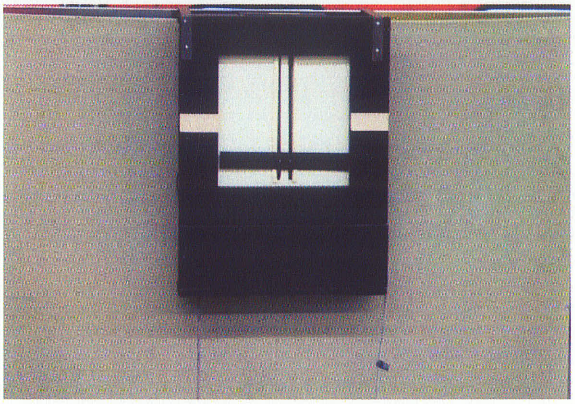

Fig. 3.4 Center secondary display

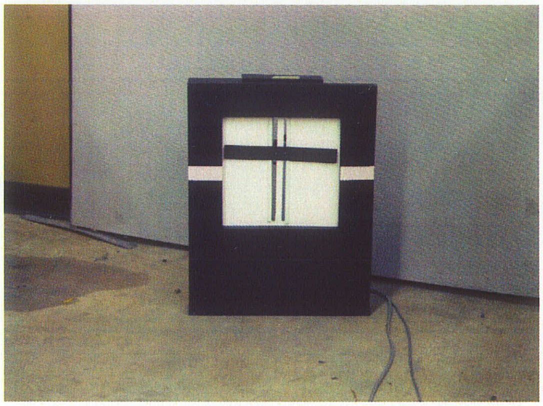

Fig. 3.5 A side secondary display

Each secondary display was 480mm wide, 640mm high, and 170mm deep, and consisted of a level bar, which moved vertically inside a frame (Figures 3.4 and 3.5). The dimensions of the level bar were 300mm wide by 50mm high.

3.5 Lightbar Displays

Five lightbar displays labeled A-E were evaluated in this experiment. During the experiment, each of the displays was placed vertically at the same spot corresponding to an angle of approximately 15° below the eye level. This position corresponds with the recommendation for vertical location of visual targets given by the National Occupational Health and Safety Commission (1989). Also, the viewing distance (i.e., the lateral distance between a subject and each of the displays) was kept constant at 880mm all through the experiment. This viewing distance was not selected based on any recommendation, but simply because this was the distance between the driver's sitting position and the front windshield of the simulator. However, this viewing distance is similar to that recommended by Jaschinski-Krutza (1988).

Display A was 210mm wide, 34mm high, and 52mm deep, and consisted of 23, 5mm diameter Lumex Poly light-emitting diodes (LEDs) spaced at equal intervals; 3 green LEDs at the center of the unit and 10 red LEDs on either side of the centre (Fig. 3.6). Display A is referred to as a conventional lightbar display because most commercially available lightbars (for example, Starlink LB-5 Smartbar) consist of red and green LEDs. As mentioned previously, this could be possibly because red and green colors are primarily used for the purpose of giving dichotomous information; red for warning and green for safety.

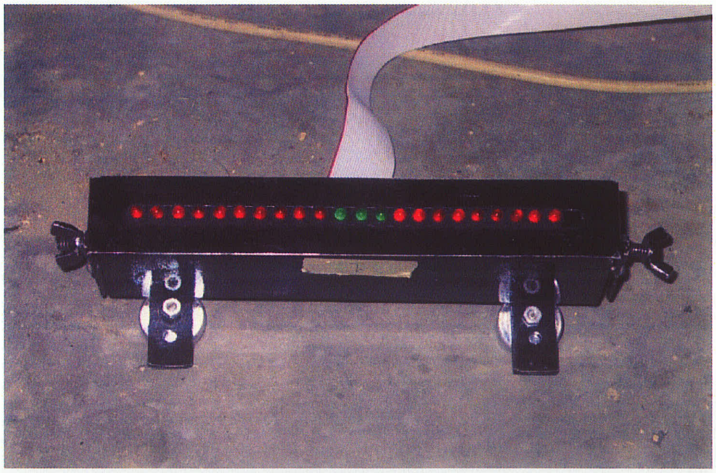

Fig. 3.6 Display A

Each of displays B and C had the same dimensions as display A and also contained the same type and number of LEDs as display A. The only difference between the three displays was in colour and arrangement. Display B consisted of 10 blue LEDs on either side of the 3 green LEDs at the centre (Fig. 3.7) while display C consisted of three different colours of LEDs; 10 blue LEDs on the left hand side and 10 yellow LEDs on the right hand side of the 3 green LEDs at the centre of the unit (Fig. 3.8).

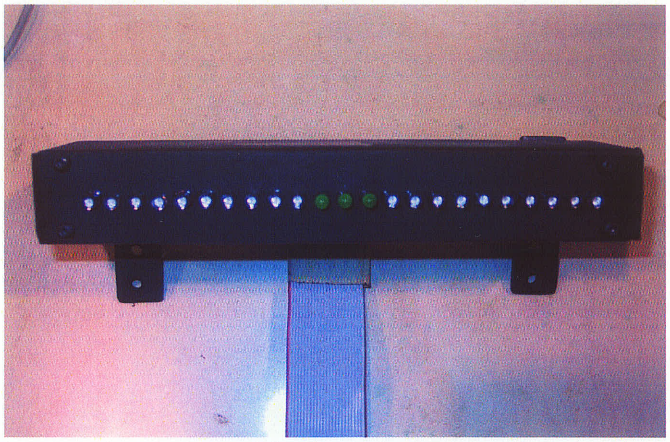

Fig. 3.7 Display B

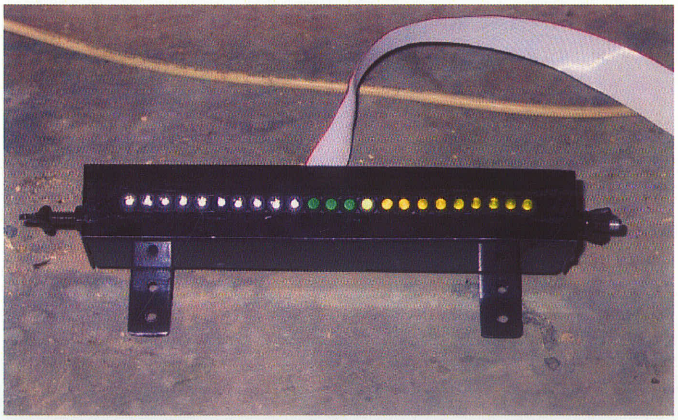

Fig.3.8 Display C

Display D consisted of display C (as the regular lightbar display component) and two auxiliary indicators (Fig. 3.9) mounted on the left and right posts of the simulator cab during the testing at a distance of 1.20m from the operator's position and a visual angle of 36.9°. Each auxiliary indicator was 41mm in diameter and consisted of circular clusters of 24, 5mm diameter Lumex Poly LEDs.

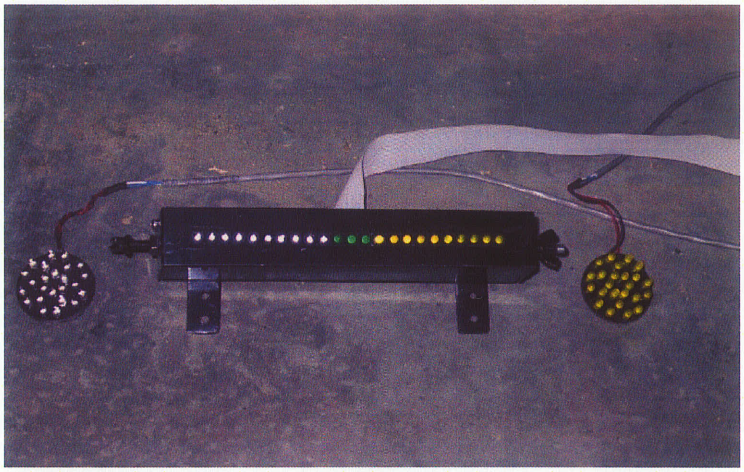

Fig. 3.9 Display D

The auxiliary indicator on the left post of the simulator contained only blue LEDs to match with the blue-coloured LEDs on the left hand side of display C while the auxiliary indicator on the right post contained only yellow LEDs, which matched with the yellow-coloured LEDs on the right side of display C. The auxiliary indicators served as a source of additional guidance information to the operator, which should be detectable using peripheral vision.

Display E was basically the same as display C in terms of LED colour and arrangement, but twice the lenght of display C (Fig. 3.10). In other words, it was simply an enlarged version of display C. It consisted of 9 circular clusters of LEDs; 4 blue clusters on the left, 4 yellow clusters on the right, and 1 green cluster at the centre of the unit. Each of the LED clusters was identical to the auxiliary indicators used in display D. Consequently, the length of light source was approximately doubled and the height was increased by a factor of approximately 8.

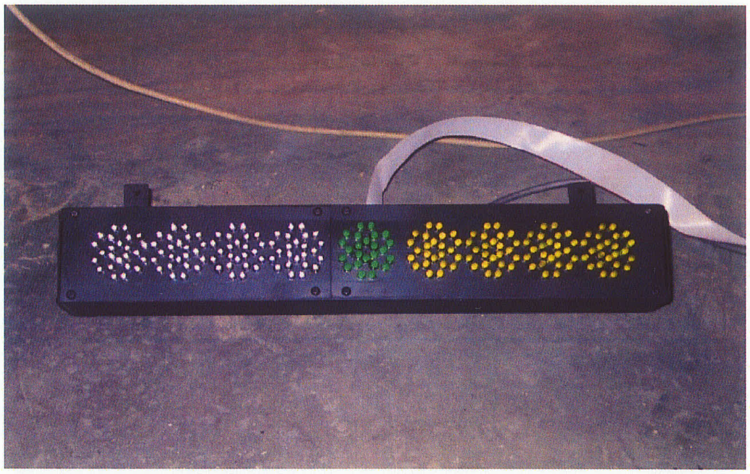

Fig. 3.10 Display E

Generally, all the lightbar displays had the same principle of operation. When the simulator was on track, the green LEDs at the centre illuminated indicating that no steering correction was needed. On the other hand, when the simulator was off the track in either the right or left direction, a maximum of 3 LEDs illuminated laterally across the lightbar in the corresponding direction showing that a steering correction was needed in that direction. However, display D had an additional response to the one described because of its auxiliary indicators. When a steering correction was needed in any particular direction, the auxiliary indicator located in that direction came on in addition to the illumination of the corresponding LEDs in its regular lightbar display component (display C). The auxiliary indicator remained on until the simulator was back on track.

In order to ascertain the effect of light colour on guidance performance, displays B and C were each compared with display A (objective 1). Also, the guidance performance of displays D and E were each compared with that of display C to determine the effect of auxiliary indicators and display size respectively (objectives 3 and 2).

3.6 Light Intensity

In order to obtain a fair comparison of the displays, the light intensity of the LEDs was measured using an L1-21O SA photometric sensor and an L1-1000 Data Logger. The light intensity of any three LEDs on displays A-C was found to be between 0.183 and 0.214lx while the intensity of any three clusters of LEDs on display E was found to be between 0.381 and 0.419lx. Using a variable resistor, the light intensity of each of the auxiliary indicators in display D was adjusted to match the intensity of any three LEDs in its regular lightbar component (display C). Leibowitz et al. (1983) stated that peripheral vision operates over a large area of visual field. This implies that there could be situations where the operator could only be able to detect one auxiliary indicator. Therefore, matching the light intensity of each auxiliary indicator in display D to that of any three LEDs on display C would ensure that the operator would have the same amount of sensation when either one auxiliary indicator or three LEDs were detected (Leung 2002). It is also necessary to mention that three LEDs were used in determining the baseline light intensity because there were always three LEDs illuminated during driving simulations at any instance.

3.7 Primary Task

The primary task of a tractor operator is a steering or tracking task. In this experiment, subjects were required to follow as accurately as possible a programmed pseudo-random forcing function of the steering wheel movement generated by a sum of six sinusoids (sine waves). The frequency and the half-amplitude of the sinusoids were kept constant at 5 and 8, respectively, all through the tests. Achieving accuracy in this task demanded that the lightbar display be maintained in a centred position at all times (i.e., making sure the green LEDs at the centre of a display were illuminated at all times). Since it is not possible to maintain the display at a centred position at all times, steering deviations occurred from time to time, which is simply calculated as the difference between the programmed steering function movement and the current steering movement achieved by a subject (Fig. 3.11).

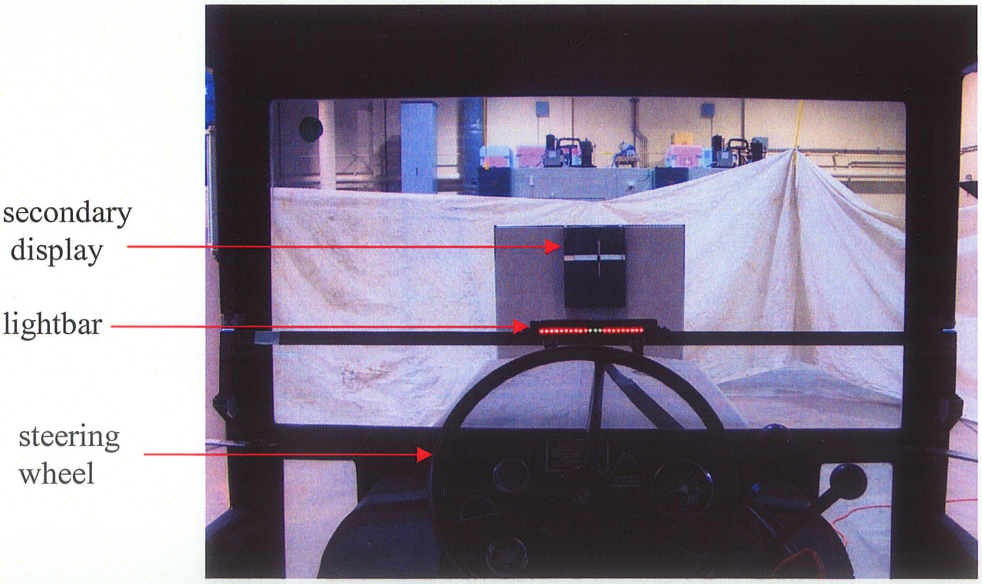

Fig. 3.11 A simulator set-up with all the lights of the lightbar turned on

At time intervals of 0.22s, a computer recorded the required function movement, subject's steering movement, the steering wheel deviation, and the index indicating which LEDs were illuminated. The computer also recorded the root mean square error (RMSE) in tracking at the end of each driving session using the values obtained for the steering deviations. The RMSE values were used to calculate the relative root mean square error (RRMSE) values, which is the primary performance measure used in this experiment. RRMSE is simply a ratio of the RMSE achieved by a subject to the RMSE obtained assuming no steering correction.

3.8 Secondary Task

The secondary task used in this experiment was a visual-monitoring task. Subjects were required to monitor three secondary displays located to the left, right, and directly in front of the operator while performing the primary guidance task (see Fig. 3.3). The secondary displays consisted of level bars, which moved vertically away from a centre (ideal) position at random and on a delay sequence (Fig. 3.12). A computer program controlled the movement of the level bars. The front (centre) display had a delay time ranging between 0-3s while the delay time for the side displays ranged between 6-10s. This implies that the centre display level bar moved vertically off the centred position within 0-3s of bringing it back to the centre while the side display bars moved within 6-10s.

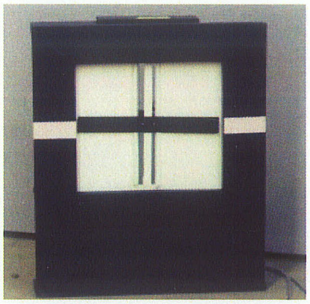

Fig. 3.12a A secondary display with the level bar at the centre (ideal) position.

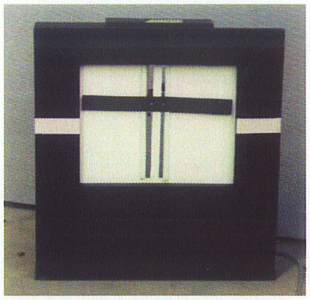

Fig. 3.12b A secondary display with the level bar above the centre position.

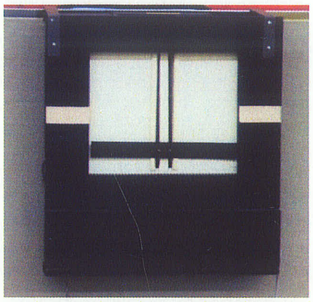

Fig. 3.12c A secondary display with the level bar below the centre position.

The task of the subject was to move the display bars back to their original (centred) position as soon as possible using a joystick (Fig. 3.13) located in the simulator cab. The time each level bar moved out of its position, the time the subject pressed the appropriate button on the joystick, and the time difference between the two times (reaction time) were recorded by the computer.

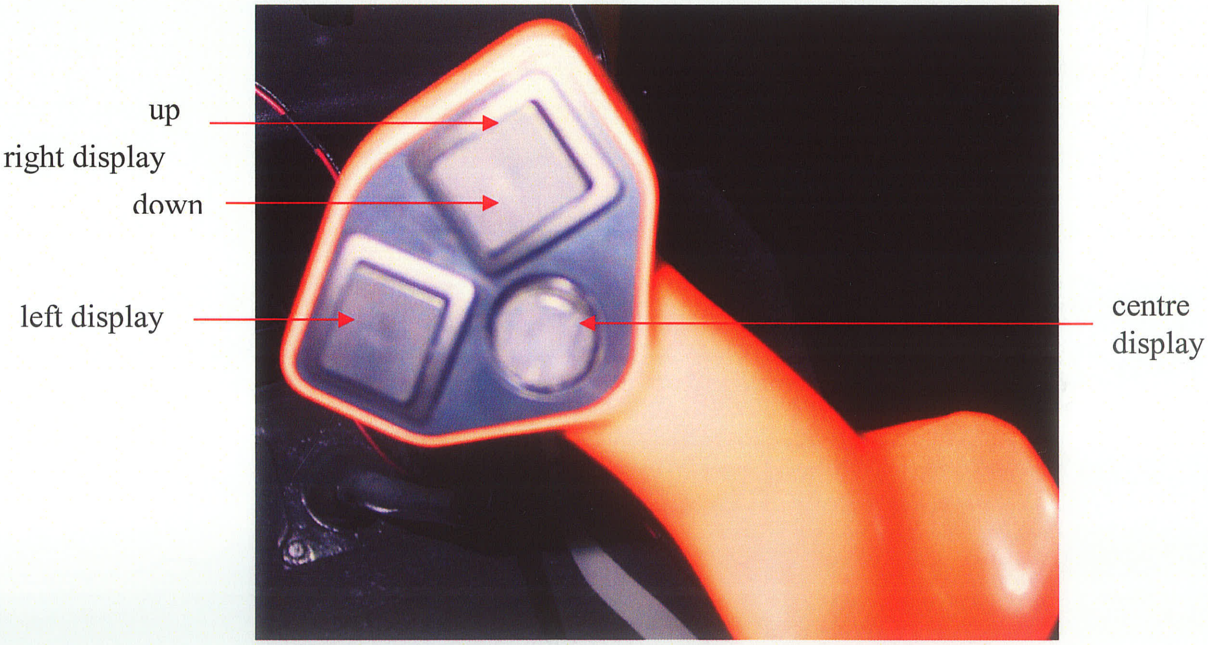

Fig. 3.13 Joystick controls for secondary displays

At the end of each driving session, the computer also recorded the average reaction time, which was used as the secondary-task measure in this experiment. A lower reaction time indicates a better secondary-task performance.

3.9 Subjective Measurement

Subjective measures have been very appealing to many researchers. No one is able to provide a more accurate judgment with respect to experienced mental load than the person concerned (de Waard 1996).

The NASA Task Load Index (TLX) was the recording sheet used to collect subjective data. As mentioned previously, the TLX is a multidimensional scale having six subscales, which include mental demand, physical demand, temporal demand, effort, frustration, and performance. The TLX recording sheet consists of two components: a rating scale sheet and a weighting scale sheet. The rating scale has two endpoint descriptors that describe each subscale. The two endpoint descriptors were connected by a straight line; 0 being the most extreme case of the left end point descriptor and 120 being the most extreme case of the right endpoint descriptor. Subjects were required to evaluate each task by placing a mark across each subscale at the point that matched their experience of workload while performing each task.

On the other hand, the weighting scale consists of a pair-wise comparison of the six subscales necessitating a total of fifteen comparisons for each task completed. For each pair, the subjects were required to identify or circle the subscale that contributed the most to their experience of workload while performing the task. In the end, the information provided by a subject on both the rating and weighting scales was used to obtain an overall workload assessment. A copy of the TLX recording sheet and the definition of the subscales are found in Appendix A.

3.10 Physiological Measurement

Heart rate was the physiological measure used in this experiment. The heart inter-beat-intervals (IBI) of each subject were measured by a heart rate monitor, which was wrapped around the subject's chest region just below the breast. Each subject wore the heart rate monitor throughout the testing period. The monitor transmitted the data obtained at any instance to a receiver located at the simulator cab beside the operator's position and connected to a computer. From the receiver, the data was sent to the computer. The inter-beat-intervals recorded were used to calculate the average heart rate of each subject for each task.

3.11 Experimental Procedure

Upon arrival to the testing site, test subjects received a brief orientation explaining and demonstrating the basic functions and operation of the simulator, the controls, the displays, and the overall testing procedure to be followed. At the end of the orientation, each subject signed a consent form and filled out a subject data sheet. A copy of the orientation package, the consent form, and the subject data sheet are found in Appendix A.

Prior to testing, subjects were asked to put on a heart rate monitor and to sit down quietly on the operator's seat in the simulator cab for about 5 min. Within this time, the baseline heart rate data was obtained. Subjects were then administered a 3 to 5-min learning session. This allowed them to gain experience with the operation of the simulator, the controls and the displays as well as their tasks before starting the driving sessions. Then a standard set of final instructions was given to the subjects. For instance, subjects were instructed: (1) to do as good a job of steering and monitoring as they possibly could; (2) that the steering task and the monitoring tasks were equally important.

The driving sessions consisted of two test sessions. The second test session was simply a replicate of the first test session and took place within 48h (but not less than 24h) of the first test session. Each test session consisted of five driving sessions of 5-min duration each (i.e., one driving session for each of the 5 lightbar displays being tested). As stated previously, the root mean square error (RMSE), the average reaction time, and the heart inter-beat-intervals, were recorded during each driving session. After each driving session, the subjects were required to fill out a TLX subjective rating form, which indicated their experience of workload in that session. The subjects were also encouraged to record any other information or comments, which could be relevant in explaining the experimental results. Each test session lasted for approximately 1h for each test subject. It is also necessary to mention that the lightbar displays were randomly assigned to the subjects within each test session to avoid any kind of bias or favoritism.

3.12 Data Analysis

All data were analyzed using the analysis of variance (ANOVA) subprogram of the Statistical

Analysis System (SAS 8.2) computer package. A further analysis of the results was performed using Duncan's multiple-range test for mean comparison. The Duncan's test was necessary to determine how significantly different one display was from the other in any of the four measures used for assessment. Error rate (α) was kept constant at 5% (0.05) all through the analysis.

4. RESULTS

The raw data obtained from the primary (steering) task, secondary (monitoring) task, physiological measure, and the subjective ratings are shown in Appendix C.

4.1 Primary (Steering) Task Performance

The mean relative root mean square error (RRMSE) values for all the lightbar displays are summarized in Table 4.1. Analysis of variance performed on the primary task data (Table 4.2) showed a significant main display effect ($p < 0.0001$). Duncan's multiple-range test for means comparison revealed significant differences between some of the lightbars (Table 4.1).

Table 4.1 Mean relative root mean square errors (RRMSE) and Duncan's grouping results for the displays

Display	Mean RRMSE	Reduction in steering error (%)
A	0.70a	0*
B	0.59c	16
C	0.68a	3
D	0.64b	9
E	0.61bc	13

N/B: - small letters represent Duncan's multiple-means grouping result
- * indicates that % reduction in steering error was calculated taking the mean RRMSE of display A as the reference point.

Table 4.2 ANOVA table for primary (steering) task performance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Display	4	0.20	0.05	10.43	< .0001
Subjects	23	4.56	0.20	42.88	< .0001

4.2 Secondary (Monitoring) Task Performance

The values of the mean reaction time for all the displays are summarized in Table 4.3. Analysis of variance (Table 4.4) showed no significant main display effect for the monitoring task (P = 0.1021). However, Duncan's multiple-range test for mean comparison (Table 4.3) revealed a significantly lower mean reaction time for displays B and E than for display A.

Table 4.3 Mean reaction times and Duncan's grouping results for the displays

Display	Mean reaction time (s)	Reduction in reaction time (%)
A	3.01a	0*
B	2.62b	13
C	2.71ab	10
D	2.89ab	4
E	2.60b	14

N/B: - small letters represent Duncan's multiple-means grouping result
- * indicates that % reduction in reaction time was calculated taking the mean reaction time of display A as the reference point.

Table 4.4 ANOVA table for secondary (monitoring) task performance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Display	4	3.03	0.77	1.99	0 .1021
Subjects	23	422.18	18.36	48.81	< .0001

4.3 Subjective Workload Rating

The mean rating values for the individual subjective subscales and the overall subjective rating for the different displays are summarized in Table 4.5. Interestingly, Fig. 4.1 shows that the order of preference of the displays obtained from the results of the overall subjective rating is consistent with the results obtained from both the mental demand and performance subscales of the subjective rating scale.

Table 4.5 Mean subjective ratings and Duncan's grouping results for the displays

	Display				
	A	B	C	D	E
Ratings and Grouping					
Overall average	56.3a	50.8bc	52.1b	46.8c	47.6c
Mental demand	54.4a	47.8b	47.8b	39.2c	40.9c
Physical demand	44.2a	47.0a	43.6a	43.8a	41.8a
Temporal demand	56.8a	58.2a	57.0a	54.4a	56.0a
Performance	51.7c	62.3ab	59.2b	69.7a	67.5a
Frustration	45.3a	39.5ab	38.7ab	39.6ab	34.6ab
Effort	53.3a	49.4a	53.8a	52.1a	51.5a

N/B: The lower the rating, the better the result. This implies that a lower rating indicates less workload than a higher rating. This idea holds for the overall subjective rating and all the subscales except performance. The reverse is the case in performance rating (i.e., a higher rating indicates less workload than a lower rating).

Analysis of variance performed on the subjective results showed significant main display effects for the overall subjective rating (Table 4.6), mental demand rating, and performance rating ($P < 0.0001$ in each case). Duncan's multiple-range test for mean comparison (Table 4.5) revealed significant differences between some of the lightbars in these scales (i.e., overall subjective rating, mental demand rating, and performance rating).

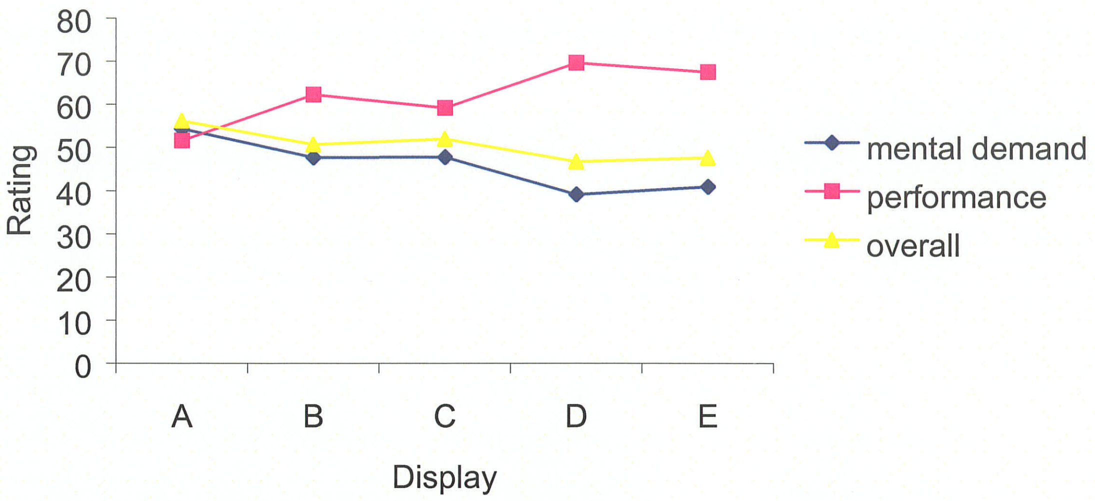

Fig. 4.1 A graph showing the relationship between mental demand subscale, performance subscale, and the overall subjective rating for the individual displays.

Table 4.6 ANOVA table for the overall subjective rating

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Display	4	1384.61	346.15	7.72	< .0001
Subjects	23	4.56	1443.79	92.22	< .0001

Analysis of variance showed no significant main display effect for any of the other four subjective subscales used: physical demand (Table 4.7), temporal demand, frustration, and effort

(P > 0.5 in each case). Further analysis (Duncan's test) revealed that no two displays were significantly different in any of these subscales (Table 4.5).

Table 4.7 ANOVA table for physical demand rating

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Display	4	337.24	84.31	0.64	0 .6369
Subjects	23	61938.30	2688.62	20.35	< .0001

Thus, the subjective results seem to indicate that only two (i.e., performance and mental demand) out of the six subscales used have a significant effect on guidance tasks involving agricultural guidance systems, especially the lightbar. The four other subscales (physical demand, temporal demand, frustration, and effort) seem to have little or no effect on such tasks.

4.4 Physiological Results

The average heart rate (HR) values for all the lightbar displays are summarized in Table 4.8. The average HR was lowest for the heart rate session (HRS) when the baseline HR of each subject was taken. This result was expected because during the HRS each subject was seated quietly in the cab and carried out no steering or monitoring task.

Table 4.8 Average heart rates and Duncan's grouping results for the displays

Display	Mean HR (beats/sec)
HRS	76.6b
LS	79.0a
A	79.1a
B	79.5a
C	78.9a
D	78.0ab
E	79.3a

Analysis of variance (Table 4.9) showed no significant main effect for display type (P = 0.1001). Similarly, Duncan's multiple-range test for mean comparison showed that all the displays belong to the same class. In other words, there was no significant difference between any two of the displays. However, Duncan's test revealed that average heart rate was significantly lower during the heart rate session (HRS) when compared to the learning session (LS) and the other five driving sessions (i.e., one driving session for each of the five displays).

Table 4.9 ANOVA table for heart rate data

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Display	4	26.27	6.57	2.02	0.1001
Subjects	23	15722.87	786.14	241.24	< .0001

The heart rate result seems to indicate that heart rate was not affected by display type. It could also be that the length of time for each driving session (i.e., 5 min) was not long enough to have caused a significant impact on heart rate.

5. DISCUSSION

The results obtained from this experiment suggest that the three factors investigated: LED (light) colour, physical size, and auxiliary indicators, all affect guidance performance. Each of these factors is discussed based on the findings from this experiment.

5.1 Light Colour

The primary (steering) task results (Table 4.1) showed that display B (blue colour) had a significantly lower steering error than display A (red colour), indicating a much better steering performance when display B was used as opposed to display A. Results obtained from both the secondary task performance (Table 4.3) and subjective workload rating (Table 4.5) showed that display B also had a significantly better reaction time and rating respectively than display A.

It had been hypothesized that display C (blue-yellow colour combination) would be significantly better than display A in both the primary and the secondary task performance. Contrary to this expectation, both the primary and secondary task results showed no significant difference between the two displays. However, the mean values shown in Table 4.1 indicates that display C caused about 3% reduction in the steering error of display A. Similarly, Table 4.3 indicates that display C caused approximately 10% reduction in the reaction time of display A. In addition, subjective scores (Table 4.5) showed that display C had a significantly lower overall subjective workload rating and mental demand than display A.

It is interesting to note that display B is also significantly better than display C. The results in Table 4.1 show that display B reduced the steering error of display C by about 13%, indicating that blue colour is much better in tracking tasks than the blue-yellow colour combination. In the secondary (monitoring) task performance, Table 4.3 shows that display B caused about 3% reduction in the reaction time of display C even though the difference between them is not significant. Similarly, display B had a lower workload rating than display C (Table 4.5), indicating that subjects felt it was less difficult to get guidance information from display B than from display C.

Subjective comments and opinions on lightbar colour (Appendix B) showed that the test subjects preferred display B followed by display C and lastly display A. Eight subjects commented that the blue colour of display B attracted their attention much more easily than did the other lightbars. Two subjects commented that they liked display C because of its colour coding system (i.e., blue colour indicating error to the left and yellow colour indicating error to the right). However, eight subjects commented that it was difficult for them to distinguish the yellow LEDs of display C from the middle green LEDs most of the time. No subject mentioned that he or she liked display A for any reason. Rather, six subjects commented that they hated display A because the red colour was very annoying to them and because they found it difficult to distinguish the red light from the middle green light most of the time.

The results on light colour obtained in this experiment are evidence that blue colour is the best colour in attracting the attention of subjects, and would, therefore, be better in the design of lightbars. These results support Dudek and Colton (1970) who concluded that for any given condition for background or environmental light level, blue test lights gave the best results for the greatest recognition of distance of colour. The results also support Ancman (1991) who reported that blue colour is the most easily detectable and the most reliable colour in the periphery.

These results are explicable in terms of differences between rod and cone mediation of brightness (Mark 1971). There are more rods in the peripheral visual field than there are cones (duplicity theory of vision) (Goldstein 1999). Rods, which are responsible for peripheral vision, are more sensitive to short wavelength lights while cones, which are responsible for foveal vision, are more sensitive to long wavelength lights (Wooten et al. 1975). The visible spectrum of light shows that a blue light reflects short wavelength while a red light reflects long wavelength. As such, a blue light is perceived more easily in the periphery than a red light (Moreland and Cruz 1959; Weale 1953). This could be the reason why the blue-coloured display (display B) was significantly better than the red-coloured display (display A) in the steering task, monitoring task, and subjective results. On the other hand, a yellow light transmits both medium and long wavelengths. Thus, a yellow light is perceived more easily in the periphery than a red light because of its medium wavelength component. However, there is still a possibility that a yellow light could be confused with a green light in the periphery since a green light reflects medium wavelength. As mentioned before, eight test subjects commented that it was difficult for them to distinguish between the green and yellow lights. This could explain why there was no significant difference between the blue-yellow coloured display (display C) and display A in both the primary and secondary task performance.

5.2 Physical Size of the Lightbar

Results of the primary (steering) task performance (Table 4.1) showed a significantly lower steering error for display E when compared with display C, indicating better steering performance with display E than display C. Also, the significantly lower overall subjective workload rating of display E as opposed to display C (Table 4.5) shows that test subjects preferred display E to display C. Although the monitoring task performance results showed no significant difference in reaction time between the two displays, the results shown in Table 4.3 indicate that display E caused about 4% reduction in the reaction time of display C. Furthermore, Table 4.5 shows that display E had a significantly lower workload rating in both Mental demand and Effort scales than display C, indicating that subjects felt more comfortable with display E than display C.

Apart from the analytical results, ten of the test subjects commented that they liked the large display (display E) because it was much easier to obtain guidance information from it than all the smaller displays. This seems to imply that light stimulus from display E produced much more stimulation of the retina (visual receptors) across a wider range of the visual field, thereby making information acquisition less difficult.

In general, the results discussed here indicate that increasing the physical size of a lightbar improves guidance performance. These results agree with Virsu and Rovamo (1979) who reported that increasing stimulus size improved visual function and contrast sensitivity in the peripheral retina (see also Kuyk 1982). The results also agree with Ogle (1961) who concluded that the threshold of visibility is lower for a large stimulus object than for a smaller stimulus object. In other words, it takes less visual energy and effort to detect light stimulus from a large object than from a smaller object 50% of the time. Moreso, Young (2003) had conducted a research on agricultural guidance displays and reported that a larger display caused 11% reduction in the steering error achieved with the use of a smaller display. The result on physical size discussed here supports his conclusion too.

5.3 Auxiliary Indicators

The primary (steering) task results (Table 4.1) showed a significantly lower steering error for display D than for display C. This result indicates that subjects performed better on the tracking task with display D than with display C. Unlike in the primary task results where there was a clear distinction (significant difference) between display D and C, secondary (monitoring) task results showed no significant difference between the two displays. Table 4.3 shows that the mean reaction time of display D to the secondary displays is about 7% greater than that of display C. However, subjective results (Table 4.5) showed a significant difference in the preference of the displays by the subjects. Subjects preferred display D to display C.

It seems that the use of display D caused additional mental processing and more competition in the use of resources between the primary and secondary tasks, perhaps because of the auxiliary indicators. This assumption was confirmed by comments made by two of the subjects who stated that they focused more of their attention on the steering task than the monitoring task while using display D when compared to all the other displays. But the result of the mental demand rating proves otherwise. Display D had a significantly lower mental demand rating than display C (Table 4.5), indicating that subjects focused more attention on the steering task than monitoring task while using display D not necessarily because they experienced more mental demand with display D but because they needed less effort (see Effort rating in Table 4.5) to obtain guidance information from the secondary displays in the case of display D and therefore took the secondary task for granted.

The result on monitoring task performance between displays C and D is quite contrary to that expected and is similar to the result obtained by Leung (2002). It was expected that using display D would result in a significantly lower reaction time and workload. Nevertheless, the result on steering task performance had been expected due to previous studies by Sarter (2000) who concluded that the introduction of effective peripheral visual cues is a feasible and effective way of reducing central visual overload and of enhancing both human-machine communication and coordination. The results also support Vallerie (1968) who reported that the use of peripheral displays resulted in a significant increase in tracking performance.

6. DESIGN IMPLICATIONS

The results from this study indicate that the effectiveness of a lightbar can be improved by:

1. replacing red LEDs with blue LEDs
2. increasing the size of the lightbar
3. introducing an auxiliary indicator

Introducing colour-coding to the lightbar design did not improve guidance performance. Therefore, further research is needed in this respect before such an idea can be implemented in the design of lightbar.

Judging from both the analytical results and subjective comments, it could be concluded that lightbar size and LED (light) colour are more important factors to consider in the design of lightbar than auxiliary indication. Even though auxiliary indicators improved steering performance, they increased reaction time considerably indicating that they could increase rather than decrease the level of workload experienced by operators if incorporated in the design of a lightbar.

Tables 4.1 and 4.3 show that there is no significant difference between the small blue lightbar (display B) and the large blue-yellow lightbar (display E), indicating that colour and size are equally important in the design of a lightbar. However, display B had a slightly lower steering error than display E. This seems to imply that guidance performance would have been much better with display E than with display B if the colour of display E were blue only. In other words, a large lightbar with blue coloured LEDs (light) might have communicated the maximum guidance information to the test subjects.

Replacing the presently used red LEDs with blue LEDs has a major financial implication. Red LEDs are less expensive than blue LEDs. For example, one piece of 5mm diameter red Lumex Poly LED currently costs $0.47 whereas one piece of the same size and type of blue LED costs $3.77. The difference in price between the two types of LEDs may look quite small when considering a single LED, but becomes quite huge when talking about a large number of LEDs.

7. RECOMMENDATIONS

Based on the observations made from this experiment, the following recommendations would be useful for further work:

1. A lot of other experiments and activities were going on in the Grain Storage Research Laboratory at the time of this experiment. As a result, there was much noise and frequent traffic, which could have distracted some of the test subjects. This type of experiment requires absolute concentration and, therefore, should be carried out in a calm environment.

2. Viewing distance and height of placement of visual targets are among the ergonomic factors discussed in the literature review (section 2.2). It might be necessary to conduct a research to investigate the optimum viewing distance and height of placement of the lightbar display in the cab.

3. Two of the subjects commented that they liked the colour coding system of displays C and E. However eight subjects commented that it was difficult for them to distinguish between the green and yellow lights. This is possibly because green and yellow lights are very close in wavelength reflection. Therefore, in further experiments, it will be nice to replace the yellow LEDs with another colour that will not conflict with the green LEDs. This may improve the effectiveness of the lightbars.

4. In experiments involving colour, there is a possibility that some of the subjects might be colour deficient. Therefore, depending on the availability of the necessary equipment, it may be necessary to examine the test subjects for colour deficiency before recruitment. In this way, hidden visual anomalies ("lucking variables") that could affect the result of the experiment would be eliminated.

5. Some of the statistical differences obtained in this simulation study between the lightbars are very small even though they are significant. It may be necessary to validate these results by running a similar experiment in actual field conditions.

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APPENDIX A

Orientation Materials

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 orientation packet contains useful information required for your participation in this study. The information has been arranged in different sections (i.e., sections A1-A4).

A1. 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.

A2. TLX Workload Scale Information
  - To be explained to you by experimenter during this meeting. Please also review this section before your testing session.

A3. Subject Data Sheet
  - To be filled out by you and given to experimenter before leaving this meeting

A4. 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 50-60 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.

Section A1: Experimental Apparatus and Tasks for Subjects in Lightbar Tests

This package 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, known as lightbar, to indicate lateral error to the operator. This experiment is intended to evaluate the performance of five different designs of the lightbar. This will be done by having subjects' use each of the lightbars 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

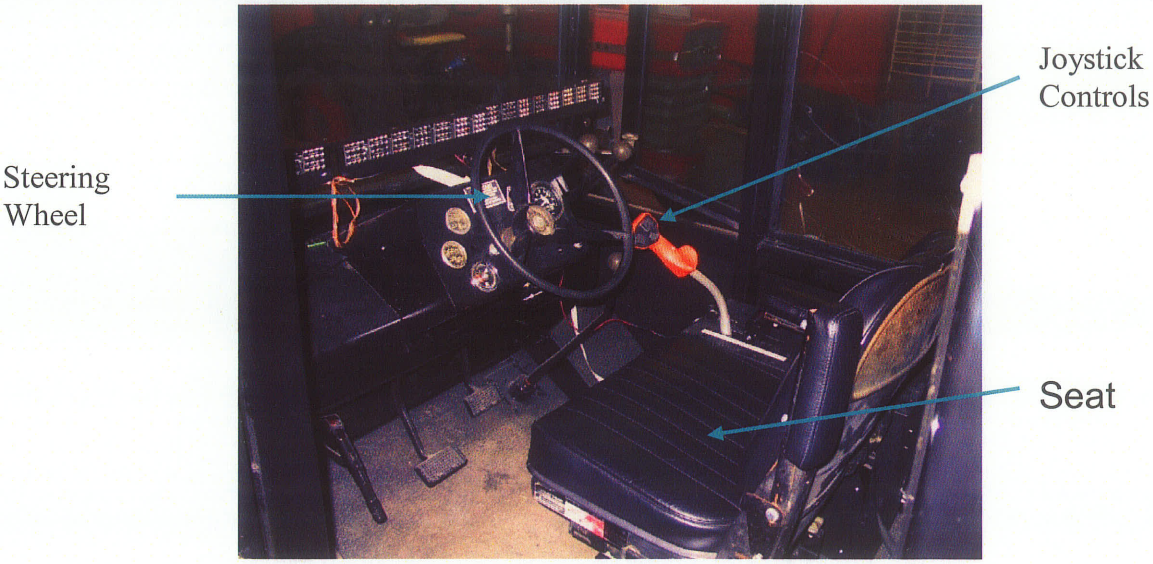

Fig. 2. Interior of Operator Station

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. Fig. 3 shows a lightbar with the center lights illuminated.

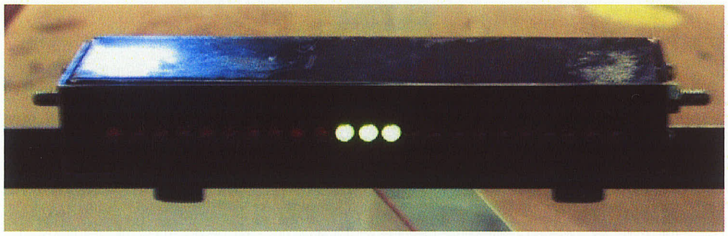

Fig. 3. A lightbar with centre lights illuminated.

When your steering wheel is left of the correct position, the 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. Fig. 4 shows a lightbar with lights to the left of the centre illuminated.

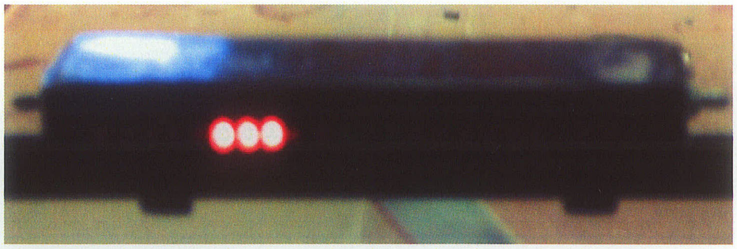

Fig. 4. A lightbar with lights on left illuminated

Similarly, when your steering wheel is right of the correct position, the 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. Fig. 5 shows a lightbar with lights to the right of the centre illuminated.

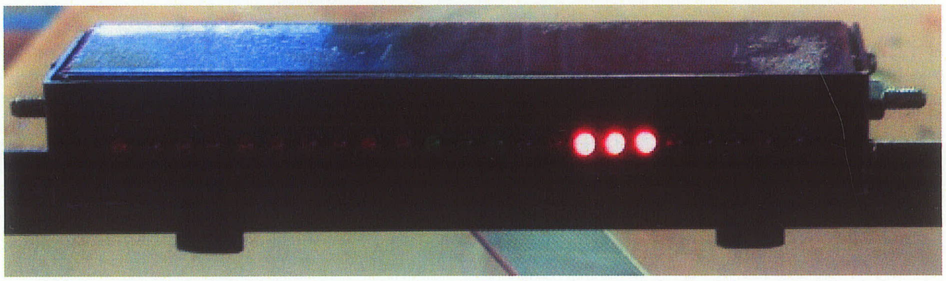

Fig. 5. A lightbar with lights on right illuminated

Monitoring Task

Concurrently with steering, you must continually monitor three secondary (bar) displays located in front of you and to your sides (Fig. 6).

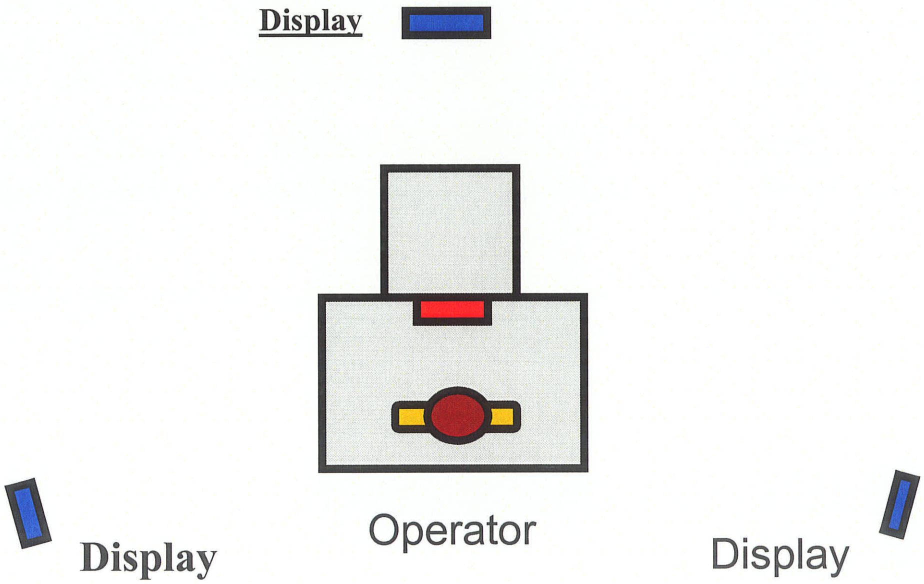

Fig. 6. Bar display locations

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. 7.

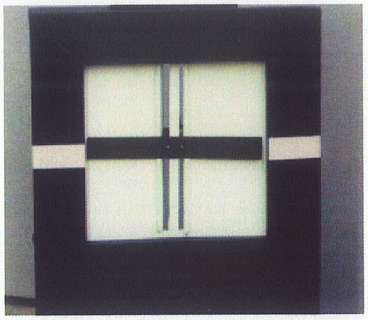

Fig. 7. Bar display in correct centred position.

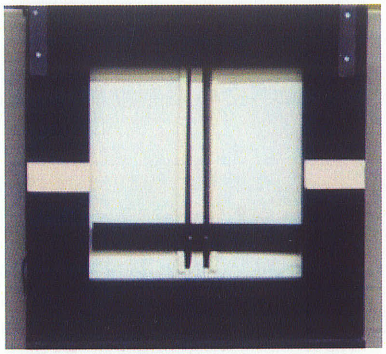

Fig. 8. Bar display below centre

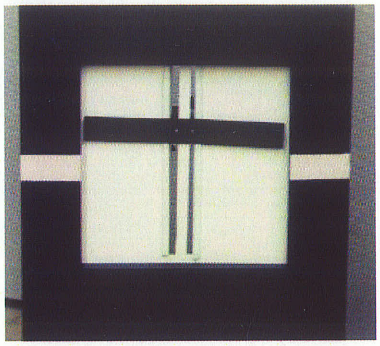

Fig. 9. Bar display above centre

The bars will move at random times below or above centre (Figs. 8 and 9). You can move it back to centre by using a switch on the joystick (Fig. 10). 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.

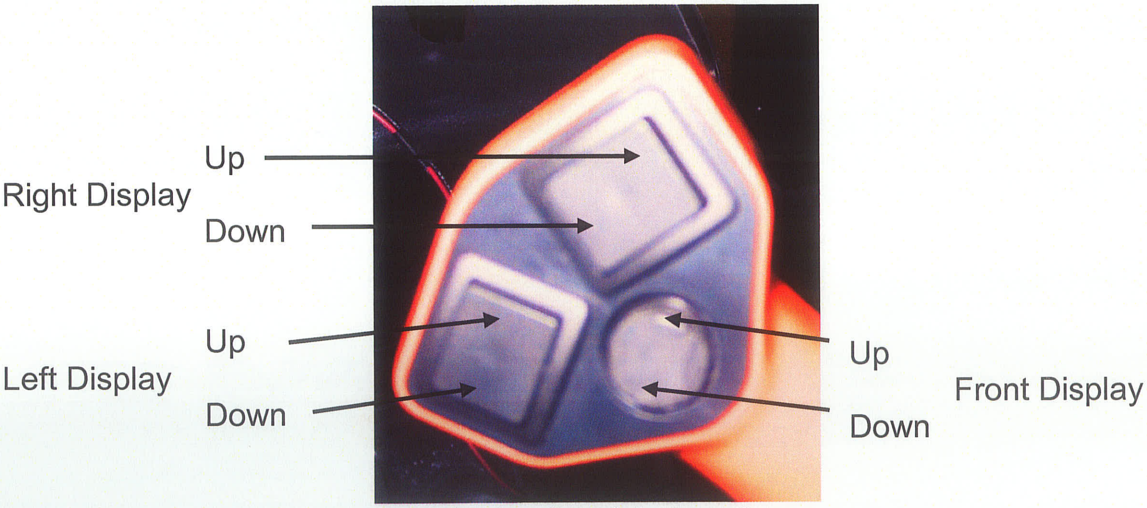

Fig. 10. Joystick controls.

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 heart region (below your chest). 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.

Section A2: 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. The instructions have been organized into the subsections below:

A2-1 Instructions for filling out the Weighting Section

A2-2 Instructions for filling out the Rating Section

A2-3 Definitions of the Rating Scales

A2-4 Sample Weighting page

A2-5 Sample Rating page

A2-6 Comments Sheet

Please follow along while I explain each page.

A2-1: 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.

A2-2: 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.

A2-3: 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?

A2-4: 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**

A2-5: 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

A2-6: Comments Sheet

Please write down your opinions or views about the:

- displays
- experimental set up

Section A3: Subject Data Sheet

Name: ____

Age: <20_____ 20-25______ 26-30_______ 31-35_______ >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:

____

____

____

Appendix A4: Consent Form

Ergonomic Concerns with Agricultural Guidance Systems

Research Objective
A guidance aid can be defined as a device that provides guidance information to the driver rather than replacing the driver. One type of agricultural guidance aid currently available on the market is the lightbar mounted in the tractor cab. The conventional lightbar uses red and green light colors. The purpose of this research project is to compare the conventional lightbar with three new designs (using colors more likely to be visible in the peripheral field of view) in terms of the ease with which guidance information can be obtained by the operator. The more information a lightbar provides, the higher the tracking efficiency and the precision of the farming process. Therefore, the ultimate aim of this research project is to develop knowledge necessary for the design of more efficient guidance aids.

Research Procedure
You will be required to drive a stationary driving simulator. While driving the simulator, you will be required to control the steering wheel in response to the information displayed on the lightbar and to respond to secondary displays situated outside the simulator using a joystick located in the cab. You will be required to complete two test sessions. The first test session will be used as a learning session. The second test session will be used as an experimental session and must take place within 48 h (but not less than 24 h) of the first test session. Each test session will consist of four driving sessions of 5 min duration each (i.e., one driving session for each of the 4 lightbar designs to be tested). After each driving session, you will be required to fill out a subject rating form indicating your opinion about the session. You will also be encouraged to record any other relevant information that may be used to explain the experimental results. Each test session is expected to last for approximately 1 h for each test subject.

Risk
During this study, you will be asked to drive a tractor simulator. The simulator is not mobile and the experiment will be carried out in a controlled environment. Therefore, there is very little or no risk involved in this experiment.

Recording Devices
During this study, you will NOT be directly observed or recorded. A computer software will be used to record your performance in different aspects of the tests.

Assurance of Confidentiality
Your name will never be used with reference to this research.

Availability of Research Results
Feedback will not be provided immediately upon participation. However, the research results will be available to you following defense of my graduate thesis.

Remuneration
You will receive a $25 honorarium for participating in this study.

Assurance of Voluntary Participation
Your participation in this research is voluntary. If at any time you wish to withdraw from the project, you may do so without consequence.

Human Subject Research Ethics Approval
This research has received approval by the Education/Nursing Research Ethics Board (ENREB). Any complaint regarding a procedure may be reported to either the Human Ethics Secretariat (474-7122) or the Head of Biosystems Engineering (474-9819).

If you have any questions or concerns, please contact the primary investigator (Dr. Danny Mann, P.Eng.):

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 understand the above conditions. I hereby give my consent for, and agree to participate in, this research project.

Name: ______________________________ Date: __________

Witnessed by: __________________________ Date: __________

Appendix B

Subjective Comments

The subjective comments obtained from this experiment are summarized in Table B below. The comments shown in Table B are not the exact words used by the subjects. Rather, they represent the meaning of the written subjective comments. The number of times each comment was made is also indicated.

Table B A summary of the subjective comments

Comments	Number of times made
I like display E because it is easier to obtain information from it than the smaller displays.	10
I found it difficult to distinguish between the yellow and green lights of display C.	8
Display B attracted my attention more easily than the other lightbars.	8
I hate display A because the red colour is very annoying to me.	6
I found it difficult to distinguish between the red and green lights of display A.	6
Monitoring the secondary displays requires more mental effort than monitoring the lightbar displays. It's like I paid more attention to the secondary displays than the lightbars.	6
This experiment is frustrating. The mental demand is very high.	5
I am impressed by the experimental set-up.	4
Display D caused me to become confused. The auxiliary indicators did not help as I thought they would.	3
I like the colour coding system of display C. It helped me to know which direction to steer when I go off the track.	2
I focused more attention on the steering task than the monitoring task while using display D when compared to all the other displays.	2
I like the auxiliary indicators in display D.	2

Comments cont'd	Number of times made
The strain on the neck will be greatly reduced if side mirrors are installed to monitor the secondary displays.	2
Sometimes I pressed the wrong button on the joystick.	2
Temporal demand is high in this experiment.	2
Performance on this experiment depends to an extent on the mood of the test subject.	1
All the lightbars are the same to me.	1
It would be nice to use this type of test in drivers' licensing.	1

APPENDIX C

Experimental Data

Appendix C contains the raw data obtained from the different workload measures used. The data are arranged as follows:

C1: Primary (Steering) Task Data

C2: Secondary (Monitoring) Task Data

C3: Subjective Data

C4: Physiological Data

C1: Primary (Steering) Task Data

Table C1 Relative root mean square error (RRMSE) values

Subject	Display				
	A	B	C	D	E
a	0.615	0.403	0.727	0.662	0.519
b	0.754	0.697	0.801	0.751	0.801
c	0.599	0.561	0.473	0.572	0.501
d	0.411	0.342	0.512	0.411	0.334
e	0.552	0.390	0.470	0.451	0.475
f	1.033	0.879	0.893	0.972	0.944
g	1.069	1.128	1.030	0.998	1.037
h	0.822	0.660	0.748	0.725	0.581
I	1.228	0.793	0.823	0.804	0.752
j	0.235	0.269	0.370	0.285	0.304
k	0.374	0.360	0.436	0.402	0.421
l	0.770	0.661	0.679	0.570	0.597
m	0.923	0.822	1.019	0.820	0.895
n	0.804	0.448	0.588	0.590	0.508
o	0.337	0.313	0.390	0.382	0.379
p	0.677	0.626	0.644	0.623	0.598
q	0.867	0.756	0.857	0.834	0.749
r	0.581	0.449	0.660	0.529	0.564
s	0.728	0.684	0.776	0.634	0.672
t	0.542	0.439	0.598	0.503	0.482
u	0.518	0.376	0.462	0.595	0.457
v	0.952	0.698	0.887	0.844	0.805
w	0.596	0.508	0.610	0.574	0.530
x	0.738	0.866	0.789	0.777	0.762

C2: Secondary (Monitoring) Task Data

Table C2 Reaction time values for the displays

Subject	Display				
	A	B	C	D	E
a	3.314	3.529	2.571	2.203	2.522
b	2.480	2.358	2.369	3.434	2.846
c	4.561	3.066	4.114	4.210	3.605
d	2.712	2.461	3.025	2.606	2.794
e	1.707	1.365	1.525	1.527	1.499
f	3.780	2.924	2.981	3.959	3.250
g	2.409	1.999	2.037	1.474	1.499
h	13.718	8.754	9.256	12.500	7.652
I	7.380	5.660	5.085	5.657	5.424
j	0.958	1.079	1.355	1.200	0.986
k	2.071	1.968	2.193	2.394	2.092
l	1.966	2.261	2.073	2.519	2.457
m	3.670	3.826	3.206	3.404	3.540
n	1.541	1.858	1.588	1.656	1.659
o	1.336	1.286	1.248	1.249	1.208
p	2.410	2.091	2.589	2.435	2.220
q	1.147	1.448	1.606	1.707	1.741
r	1.681	1.582	1.597	1.797	1.563
s	2.753	2.351	2.420	2.414	2.133
t	1.751	2.145	2.014	1.907	1.656
u	2.473	2.693	2.867	2.495	3.139
v	1.595	1.690	1.621	1.724	1.560
w	2.083	1.835	2.062	2.133	2.281
x	2.625	2.654	3.618	2.819	3.003

C3: Subjective Data

Subjective data comprises:

C3-1: Overall Subjective Rating

C3-2: Mental Demand Rating

C3-3: Physical Demand Rating

C3-4: Temporal Demand Rating

C3-5: Performance Rating

C3-6: Frustration Rating

C3-7: Effort Rating

C3-1: Overall Subjective Rating

Table C3-1 Overall subjective rating

Subject	Display				
	A	B	C	D	E
a	37.03	32.83	34.92	34.22	41.44
b	86.56	83.08	81.49	67.69	71.41
c	51.97	56.03	54.61	39.69	61.56
d	50.75	33.03	34.28	40.75	39.03
e	74.89	47.89	51.32	35.62	49.97
f	68.97	69.50	71.53	72.22	44.39
g	47.33	35.00	45.62	32.39	30.46
h	36.44	60.68	35.44	36.15	26.11
I	70.26	62.53	67.89	63.22	66.25
j	30.28	28.78	29.94	28.01	19.87
k	81.61	79.75	81.06	74.56	79.75
l	32.50	24.17	23.50	23.14	15.39
m	84.11	78.22	70.47	72.87	67.57
n	45.83	35.01	41.67	43.22	35.53
o	76.28	60.33	64.33	59.40	68.47
p	70.58	54.01	71.94	59.10	53.66
q	34.78	32.05	22.82	29.68	31.53
r	48.90	33.88	41.06	29.89	37.66
s	69.53	61.56	74.61	44.92	61.30
t	19.06	25.61	29.06	29.94	12.28
u	58.28	64.22	69.72	58.33	71.83
v	60.33	53.67	51.45	52.00	58.44
w	54.17	54.33	47.00	50.50	48.11
x	59.61	52.04	53.72	44.62	51.00

C3-2: Mental Demand Rating

Table C3-2 Mental demand rating

Subject	Display				
	A	B	C	D	E
a	45.60	22.08	19.17	26.67	25.83
b	80.00	87.92	70.83	55.00	36.67
c	57.08	52.50	56.67	39.17	30.83
d	60.00	26.67	26.67	48.33	38.75
e	68.33	70.83	48.60	33.33	67.75
f	39.06	26.67	74.58	26.67	33.33
g	38.33	33.33	50.83	19.17	29.17
h	56.67	73.00	36.67	26.67	32.06
I	48.00	18.33	36.67	32.50	34.17
j	30.00	19.17	28.75	20.00	24.00
k	95.83	60.83	66.67	56.67	60.83
l	25.83	30.83	13.33	18.33	9.17
m	81.67	78.33	76.67	58.33	49.60
n	48.33	45.83	55.83	39.17	42.50
o	76.67	63.33	58.33	52.04	72.50
p	69.83	68.33	75.83	60.00	42.50
q	23.33	18.33	13.67	20.83	28.33
r	42.00	25.83	40.00	32.50	43.33
s	70.83	70.00	80.00	52.50	54.17
t	19.17	14.17	15.83	20.00	15.00
u	33.33	51.67	62.50	39.17	42.50
v	53.33	50.83	37.50	47.50	52.50
w	71.17	70.00	40.00	60.83	53.75
x	70.83	67.33	61.67	54.17	63.33

C3-3: Physical Demand Rating

Table C3-3 Physical demand rating

Subject	Display				
	A	B	C	D	E
a	15.83	24.58	21.67	30.83	30.83
b	87.50	81.67	88.33	79.17	80.00
c	68.33	58.75	70.00	54.17	65.83
d	31.67	31.25	26.67	52.20	23.33
e	61.67	51.67	61.25	28.33	28.33
f	82.08	72.50	22.92	77.50	30.83
g	41.67	39.17	48.33	25.00	33.33
h	13.33	87.50	49.17	36.25	37.50
I	80.83	80.00	76.67	80.83	80.83
j	14.17	22.50	20.83	21.67	12.50
k	90.00	87.50	83.33	85.83	87.50
l	45.83	35.83	32.50	31.67	25.83
m	80.83	77.50	75.83	81.67	75.83
n	23.33	20.83	14.17	9.58	24.17
o	28.33	25.83	25.00	19.17	22.92
p	43.33	37.50	42.50	50.83	37.50
q	18.33	22.50	15.00	19.42	27.50
r	30.83	25.83	51.67	48.75	54.17
s	75.00	60.83	87.50	52.50	62.50
t	5.83	15.00	10.00	18.33	9.17
u	42.50	55.00	62.50	56.67	71.67
v	27.50	40.00	32.50	50.00	50.00
w	35.83	53.33	22.50	39.17	28.33
x	15.50	21.25	5.00	1.25	3.33

C3-4: Temporal Demand Rating

Table C3-4 Temporal demand rating

Subject	Display				
	A	B	C	D	E
a	21.67	36.67	29.58	34.17	30.83
b	93.33	87.50	97.50	90.00	87.50
c	40.83	40.83	69.17	60.00	70.83
d	41.67	40.00	33.75	32.92	40.00
e	84.17	51.67	59.58	53.33	65.83
f	73.33	71.67	74.58	76.25	82.50
g	42.50	35.00	32.50	30.00	33.33
h	27.50	87.50	63.33	18.33	55.00
I	79.17	81.67	75.42	72.92	75.82
j	25.00	30.00	32.50	35.83	17.50
k	87.50	88.33	87.50	80.00	84.17
l	32.50	27.50	25.83	22.50	20.00
m	79.17	75.83	64.16	81.25	75.00
n	49.17	30.00	28.33	54.58	39.58
o	69.17	72.50	63.33	67.50	69.58
p	83.33	92.50	90.83	90.00	89.17
q	30.83	31.67	30.00	28.33	38.33
r	48.33	66.17	57.50	35.83	43.33
s	84.17	72.50	76.67	45.83	75.83
t	17.50	20.00	29.17	48.33	2.50
u	67.50	66.67	65.83	65.83	70.83
v	60.83	51.67	50.00	50.00	53.83
w	50.83	60.83	57.50	63.33	52.92
x	73.33	77.50	72.50	68.33	70.00

C3-5: Performance Rating

Table C3-5 Performance rating

Subject	Display				
	A	B	C	D	E
a	20.83	47.92	35.83	70.42	66.67
b	41.67	58.33	92.67	72.40	66.40
c	55.42	68.33	68.33	58.33	65.00
d	32.08	59.58	57.08	65.00	56.67
e	37.50	66.67	41.67	82.67	81.67
f	56.67	60.83	57.08	65.00	47.50
g	40.83	82.50	48.83	51.67	69.17
h	79.17	91.67	97.50	96.33	97.50
I	81.67	76.67	72.50	69.17	92.50
j	70.00	61.67	55.00	93.24	78.50
k	41.67	56.67	29.17	45.83	59.17
l	76.67	86.67	85.00	83.33	92.50
m	67.50	59.17	75.83	73.33	62.50
n	50.00	76.20	46.25	85.00	68.33
o	25.00	40.00	36.67	43.33	43.33
p	43.33	98.64	41.67	96.50	86.50
q	35.83	31.67	77.50	32.50	30.83
r	50.00	55.83	77.50	69.17	57.50
s	47.92	43.17	40.83	69.67	65.42
t	76.67	52.50	40.83	64.17	81.67
u	27.50	36.67	46.67	70.00	39.17
v	69.17	46.67	65.83	58.33	71.67
w	58.75	61.67	57.50	69.17	58.33
x	54.17	75.83	73.33	87.17	81.67

C3-6: Frustration Rating

Table C3-6 Frustration rating

Subject	Display				
	A	B	C	D	E
a	21.67	20.83	23.33	27.50	20.83
b	91.67	87.50	80.83	52.50	81.67
c	35.00	33.33	36.67	45.83	78.33
d	33.33	29.17	40.00	46.25	34.17
e	83.33	27.50	22.92	20.00	9.17
f	67.50	72.50	76.67	78.33	49.58
g	35.00	41.67	45.83	42.50	25.00
h	43.33	63.33	1.67	49.17	17.50
I	31.67	26.67	20.83	41.25	35.83
j	40.83	36.83	26.67	42.50	16.67
k	75.00	84.17	84.17	78.33	86.67
l	28.33	15.42	17.50	22.08	12.08
m	91.67	87.50	92.50	77.50	75.00
n	11.67	9.17	5.00	6.67	8.33
o	66.67	64.17	53.33	50.83	34.17
p	64.17	37.50	54.17	72.50	50.83
q	13.33	15.00	12.50	14.17	21.25
r	31.25	8.33	7.50	15.00	22.50
s	64.17	38.33	83.33	60.83	54.00
t	21.67	33.33	32.50	10.83	0.83
u	29.17	45.00	34.17	35.83	38.33
v	31.67	41.67	35.83	40.00	27.50
w	70.83	20.83	40.00	20.00	30.83
x	5.00	7.92	0.83	0.83	0.00

C3-7: Effort Rating

Table C3-7 Effort rating

Subject	Display				
	A	B	C	D	E
a	35.00	35.83	46.67	54.17	61.67
b	71.67	85.83	88.33	72.50	85.00
c	27.50	40.83	45.83	22.08	57.92
d	24.17	42.50	30.83	44.58	43.75
e	80.83	40.00	40.42	45.00	42.65
f	57.92	73.33	81.67	79.17	48.33
g	51.67	46.67	42.50	34.17	31.67
h	46.67	82.50	47.50	70.83	30.00
I	81.67	84.58	78.75	70.83	78.75
j	10.83	15.00	13.33	13.33	15.83
k	42.50	59.17	77.50	76.67	70.83
l	30.83	20.42	16.67	18.33	10.00
m	78.33	56.67	59.58	68.33	61.67
n	49.17	55.83	47.50	75.83	39.17
o	84.17	56.67	78.33	67.50	77.08
p	70.83	49.83	55.00	76.67	63.33
q	26.50	23.33	30.00	27.50	20.00
r	57.50	19.17	56.67	27.83	48.33
s	80.83	60.00	90.00	44.17	61.67
t	20.83	23.33	8.33	30.83	15.83
u	67.50	76.67	83.33	70.00	86.67
v	82.50	62.50	71.67	60.83	85.83
w	48.33	52.50	43.33	63.33	47.50
x	50.83	21.67	57.92	35.83	53.33

C4: Physiological Data

Table C4 Heart rate values for the different sessions

Subject			Display				
	HRS	LS	A	B	C	D	E
a	58.18	63.46	69.15	73.11	68.17	72.69	69.79
b	92.37	94.30	93.34	92.35	96.89	96.23	99.63
c	95.59	94.71	93.04	95.26	95.03	89.90	94.42
d	57.44	57.57	59.27	58.06	56.29	50.21	26.21
e	69.78	68.71	73.42	71.50	72.83	71.55	72.11
f	73.53	74.96	76.68	73.69	73.87	74.13	73.76
g	75.71	78.67	80.72	79.86	82.53	81.81	83.28
h	56.30	72.23	58.59	58.85	59.71	58.62	60.18
I	53.57	58.85	55.88	56.39	56.05	56.47	56.25
j	84.08	90.52	92.75	93.58	93.73	94.47	93.34
k	104.69	98.98	97.75	95.43	94.29	93.87	92.91
l	71.30	75.68	78.19	81.51	88.62	85.22	90.93
m	70.14	69.07	69.30	70.76	52.13	6.00	27.13
n	63.44	62.78	67.29	62.39	67.40	68.76	71.30
o	61.17	62.67	61.25	60.31	60.55	60.58	61.18
p	61.50	63.45	62.92	61.74	63.64	65.02	65.58
q	82.75	86.69	81.31	81.99	86.03	83.28	83.13
r	83.57	84.02	85.55	84.84	82.23	81.95	79.54
s	61.56	76.56	69.60	72.27	74.70	71.05	76.99
t	77.13	78.73	79.40	80.11	80.40	83.60	82.89
u	93.81	91.39	90.36	87.84	87.27	83.61	90.16
v	78.68	79.63	87.38	85.97	87.86	86.58	85.82
w	89.47	86.33	87.95	87.07	89.82	88.37	87.86
x	91.74	90.49	91.61	89.69	90.30	92.53	90.31

N/B: HRS = Heart Rate Session; LS = Learning Session

APPENDIX D

Computer Program Code

Appendix D contains the computer program that controls the simulator. The program is written in Quick Basic computer language.

```
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 CountRxnTime%, TotalRxnTime!
COMMON SHARED SQTOTAL#, COUNTLOOPS!, RMSE#
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

SUB Autocenter

CLS

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

StartMove = TIMER

Optical% = INP(&H326)

DO UNTIL ((Optical% > 247) AND (Optical% < 252)) OR INKEY$ = "q"   'Center display is
```

```
centered
  LOCATE 10, 20: PRINT "optical1 = ";
  PRINT USING "###"; Optical%
  IF TIMER - StartMove < 4 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% =
254)) OR INKEY$ = "q"  'Left display is centered
  LOCATE 10, 20: PRINT "optical2 = ";
  PRINT USING "###"; Optical%
  IF TIMER - StartMove < 4 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% =
253)) OR INKEY$ = "q" 'Right display is centered
  LOCATE 10, 20: PRINT "optical3 = ";
  PRINT USING "###"; Optical%
  IF TIMER - StartMove < 4 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!
      CountRxnTime% = CountRxnTime% + 1
      TotalRxnTime! = TotalRxnTime! + RxnTime!
      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%; "  "; RightControl%; "  ";
CenterControl%

END SUB

SUB DriveInitialize

DriveIndex% = DriveIndex% + 1

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

```
SteerFile$ = "c:\qb\sam\" + Initials$ + SesNum$ + DriveIndex$ + "pr.dat"
SecFile$ = "c:\qb\sam\" + 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): "; ForwardBias%
  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

 CountRxnTime% = 0
 TotalRxnTime! = 0

 SQTOTAL# = 0
 COUNTLOOPS! = 0!
 RMSE# = 0

 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!

RMSE# = SQR(SQTOTAL# / COUNTLOOPS!)
LOCATE 16, 18: PRINT " SQTOTAL =", SQTOTAL#
LOCATE 18, 16: PRINT "COUNTLOOPS =", COUNTLOOPS!
LOCATE 20, 18: PRINT "RMSE = ", RMSE#
LOCATE 22, 12: PRINT "TotalRxnTime =", TotalRxnTime!; "CountRxnTime =",
CountRxnTime%

DO: LOOP UNTIL INKEY$ <> ""

WRITE #1, "Driving Session", DriveIndex%
WRITE #1, "Start of Driving", StartofDriving!
WRITE #1, "End of Driving", EndofDriving!
WRITE #1, "SQTOTAL", SQTOTAL#, "COUNTLOOPS", COUNTLOOPS!
WRITE #1, "RMSE", RMSE#
WRITE #1, "TotalRxnTime", TotalRxnTime!, "CountRxnTime", CountRxnTime%

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 = &H8E
dsp(0).midbyte = &HFF
dsp(0).highbyte = &HFF
dsp(1).lowbyte = &H8E
dsp(1).midbyte = &HFF
dsp(1).highbyte = &HFF
dsp(2).lowbyte = &H8E
dsp(2).midbyte = &HFF
dsp(2).highbyte = &HFF
dsp(3).lowbyte = &H8E
dsp(3).midbyte = &HFF
dsp(3).highbyte = &HFF
dsp(4).lowbyte = &H8E
dsp(4).midbyte = &HFF
dsp(4).highbyte = &HFF
dsp(5).lowbyte = &H1E
dsp(5).midbyte = &HFF
dsp(5).highbyte = &HFF
dsp(6).lowbyte = &H3E
dsp(6).midbyte = &HFE
dsp(6).highbyte = &HFF
dsp(7).lowbyte = &H7E
dsp(7).midbyte = &HFC
dsp(7).highbyte = &HFF
dsp(8).lowbyte = &HFE
dsp(8).midbyte = &HF8
dsp(8).highbyte = &HFF
dsp(9).lowbyte = &HFE
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 = &HBF
dsp(12).lowbyte = &HFF
dsp(12).midbyte = &H8F
dsp(12).highbyte = &HBF
dsp(13).lowbyte = &HFF
dsp(13).midbyte = &H1F
dsp(13).highbyte = &HBF
dsp(14).lowbyte = &HFF
dsp(14).midbyte = &H3F
dsp(14).highbyte = &HBE
dsp(15).lowbyte = &HFF
dsp(15).midbyte = &H7F
dsp(15).highbyte = &HBC
dsp(16).lowbyte = &HFF
dsp(16).midbyte = &HFF
dsp(16).highbyte = &HB8
dsp(17).lowbyte = &HFF
dsp(17).midbyte = &HFF
dsp(17).highbyte = &HB8
dsp(18).lowbyte = &HFF
dsp(18).midbyte = &HFF
dsp(18).highbyte = &HB8
dsp(19).lowbyte = &HFF
dsp(19).midbyte = &HFF
dsp(19).highbyte = &HB8
dsp(20).lowbyte = &HFF
dsp(20).midbyte = &HFF
dsp(20).highbyte = &HB8
dsp(21).lowbyte = &HFF
dsp(21).midbyte = &HFF
dsp(21).highbyte = &HB8
dsp(22).lowbyte = &HFF
dsp(22).midbyte = &HFF
dsp(22).highbyte = &HB8

END SUB

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

'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

 LOCATE 20, 10: PRINT "Steering Value: ", a%

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) THEN
'Left display is centered
 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 (Optical%
<> 254) THEN  'Display not centered
 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!
    CountRxnTime% = CountRxnTime% + 1
    TotalRxnTime! = TotalRxnTime! + RxnTime!
    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) THEN
'Right display is centered
 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 (Optical%
<> 253) THEN  'Display not centered
 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!
   CountRxnTime% = CountRxnTime% + 1
   TotalRxnTime! = TotalRxnTime! + RxnTime!
   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
Controls% = SecSignal%)) THEN
      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!; "  f: "; F!
'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 = "; 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%).midbyte;
"  "; dsp(Index%).highbyte

 IF dsp(Index%).lowbyte = 0 AND dsp(Index%).midbyte = 0 AND dsp(Index%).highbyte = 0
THEN
   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

 SQTOTAL# = SQTOTAL# + (Diff# * Diff#)
 COUNTLOOPS! = COUNTLOOPS! + 1!
 'LOCATE 22, 22: PRINT "sqtotal   count    ", SQTOTAL!, COUNTLOOPS!

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$ = "c:\qb\sam\" + 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
Controls% = SecSignal%)) THEN
      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
```