An Advanced Driver Warning Framework Incorporating Educational Warnings

by Taly Sharon

Submitted to the Program in Media Arts and Sciences
School of Architecture and Planning

In partial fulfillment of the requirements for the degree of
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Abstract

Car accidents are a serious problem. The measures currently being taken are not very successful in preventing accidents. To reduce the number of accidents, driver support and warning systems are built. Part of their solution is the use of education, in the form of educational warning systems. However, issuing warnings might distract the driver from the driving task exactly when the stress level is high and immediate action is required. This work concentrates on educational warning systems in the framework of cars and driving. It proposes an innovative design that is demonstrated via a prototype of an educational warning system. One of the main objectives of the research presented here is to test if delaying warnings and feedback (to prevent stress and distraction) improves the learning ability and the performance of drivers using them.

Are delayed (educational) warnings superior to immediate warnings? Using the 300M IT Edition, an experiment to test the effects of delayed feedback on the learning process in two driving tasks was carried out. The findings showed significant evidence of better performance overall, while yielding marginal significant of improvement in task understanding, and some indication, although not significant, of faster and stronger improvement in task performance of the delayed feedback group. The main impact of the work is some evidence that delayed warnings in driver learning tasks are superior. More importantly, it is not evident that it is inferior, which makes it preferable to immediate feedback that may distract the driver from the driving task.

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1. Introduction

Motor vehicle crashes are the leading killer of Americans between the ages of one and 29. For example, in 1999, an average of 112 people were killed in motor vehicle crashes every day – one every 13 minutes. While the greatest cost is incalculable human suffering and loss, motor vehicle crashes also cost Americans an estimated $192.2 billion in 1999. The largest expenses in this loss were $66.4 billion in lost wages and reduced productivity, $45.8 billion in property loss, and $20.7 billion in medical expenses. Numbers this large tend to be incomprehensible. For a perspective, the total amount of money 'consumed' by motor vehicle crashes amounts to 75 cents of every dollar spent by individuals for transportation in 1999 [NSC 2000].

Moreover, the US Department of Transportation safety programs were unable to meet their own fatalities reduction targets. For example, in 2002, the target rate of reduction of highway fatalities was 1.4 fatalities per 100 million vehicle-miles traveled. However, this target was not met, and the actual estimated rate was 1.5 [BTS1 2002].

This is caused partially by the fact that many licensed drivers are not good drivers - some have forgotten the rules over time; others have developed bad habits along the way; and they often drive in an automatic-unconscious manner [Nardi 1997].

Therefore, to cope with this severe problem, driver support and warning systems are being built (for example, see [Michon 1993]). For example, it has been suggested that technological solutions can provide feedback on driving ability, warn about dangers, and ultimately improve driving performance [Hutton et. al. 2001].

However, even though more and more safety systems are being installed in cars, such as ABS, they may actually increase the chances of crashing rather than reducing it. This is because the drivers learn the improved braking ability of the car, and even push it to its limits [ABS 2001]. According to the Risk Homeostasis Theory (RHT) [Gibson & Crooks 1938] people keep their risk level constant - they decide what is the level of risk they want to take, and keep it the same even when systems improve the car's safety [Gibson & Crooks 1938][1]:

> *"More efficient brakes on an automobile will not in themselves make driving the automobile any safer. Better brakes will reduce the absolute size of the minimum stopping zone, it is true, but the driver soon learns this new zone and, since it is his field-zone ratio which remains constant, he allows only the same relative margin between field and zone as before."*

This suggests that in addition to safety systems, warning and education systems are required. A special type of warning is performance warnings that are meant to continuously monitor and train drivers to drive at their best. The assumption is that these systems can improve the overall skill of a driver in all cases and that by this overall improvement, they could also facilitate either a better response from the driver at the time of an emergency or reduce cognitive load during the emergency, in which case additional warnings could be useful and not taxing.

Educational warnings have been proposed as a useful and important approach [Sviden 1993, Janssen et. al. 1993, Groeger 1993]. In one such case, Groeger [1993] describes a

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[1] p.458

performance support system for drivers, which he terms "Personalized Support And Learning Module" (PSALM). Another example of a system with an educational purpose is proposed by Roadsafety [2002]. Roadsafety's system monitors the driver and provides educational feedback in the form of a beep whenever a certain G force is applied on the car. Despite their initial appeal, one of the main problems with these systems is that the complete feedback is not fully conveyed in real-time and as an outcome is presented to the user only long after the event.

Regardless of the type of system used, driving can be a stressful activity, in which the driver is exposed to distracting events such as changing surroundings, passengers, cellular phone calls, etc. There is a risk that these systems may cause more harm than good. In this case of stress, such warning systems can also present a paradoxical situation – the instant in time in which most of the warnings are needed (when the driver is in danger) can be the same exact instant in which the driver needs all his or her attentional and cognitive capacity to cope with the situation [Verwey 1993].

For illustration, imagine two cases: falling asleep on the wheel and skidding. If one falls asleep at the wheel and consequently the car drifts to the side, a warning can be very useful because it can wake up the driver and potentially prevent an accident. On the other hand, if one starts to skid, while being fully awake, additional alerts from the warning systems might load the driver, which might ultimately reduce his or her ability to safely get out of the skid. It is this type of cases in which warning systems might be less efficient and could potentially cause more harm than good.

One solution to this problem is to delay the warnings when the driver is overloaded [Verwey 1993]. There has been some evidence from the field of education that delaying feedback can even lead to better performance [Groeger 2000]. The current study proposes to examine some of the effects of warning systems in a driving situation by contrasting the effectiveness of on-time and delayed feedback in educational warning systems. The system proposed in this work will use short delays (5-10seconds) to provide feedback on deviant driving behavior. It is speculated that by using such a short delay, the system could both avoid the cognitive load problem mentioned earlier while at the same time also providing feedback that is easily associated with the events – allowing for faster learning.

The hypotheses here are that delayed (educational) warnings will be: 1) more effective in the short-run; 2) more effective in the long-run; and 3) allow faster learning.

This work is organized as follows:

- Chapter 2 establishes the basis for the research and provides a survey of the existing technologies for driving-related risk reduction.
- Chapter 3 describes the existing research platform used for the research, the 300M IT Edition. The 300M provided a basis for the development of a prototype of an educational warning system as well as a tool to carry out the experiment.
- Chapter 4 presents a design for an educational warning system and a prototype implemented to demonstrate the feasibility of this design.
- Chapter 5 describes the experiment carried out in order to learn how delayed (educational) warnings affect the learning process.
- Chapter 6 provides the results and their analysis.
- Chapter 7 discusses the results and points out future directions.

2. Technology Approaches for Risk Reduction

Driver Support and Warning systems

Driver support systems have many functions. Janssen et. al. describe nine types of basic driver support functions (examples in parenthesis) [Janssen et. al. 1993]:

- Enhancing information (increasing visibility by retroflection).
- Augmentation (special information about icy patches).
- Warning (against speeding or other violations).
- Advice (to take a less congested route).
- Explanation (reason for delay, e.g., accident ahead).
- Instruction (feedback about incorrect action).
- Intervention (speed delimiter).
- Substitute or secondary control (cooperative driving).
- Autonomous or primary control (robot driving).

One of the most beneficial driver support systems is warning systems. For example, important driver assistance and warning systems are Collision Avoidance Systems (CAS), Lane Departure Warning Systems (LDWS), Side Obstacle Warning systems (SOW) and Maneuvering Aids for Low Speed Operations (MALSO) [ISO 2001]. The purpose of CAS is to alert the driver to a hazardous situation requiring some action to avoid collision. SOW is intended to warn the driver against potential collisions with objects to the side of the vehicle, for instance in lane change maneuvers. MALSO are detection devices, which are intended to assist the driver during low speed maneuvering, such as parking.

These warning systems require an immediate reaction from the driver to prevent accident. However, there are many other types of systems to support drivers, as listed above.

Educational Warnings

As part of the overall driver support systems, an educational system to support driver improvement has been envisioned. The most comprehensive design for an educational warning system was described as part of a large scale European project for Generic Intelligent Driver Support (GIDS). It was named Personalized Support And Learning Module (PSALM) [Groeger 1993]. PSALM was never implemented, but its principles are still relevant [Groeger 2000][2]:

> *"To improve driving performance by training, by increasing the amount and breadth of practice drivers have (different times, difficulties, with and without passengers), and by making this practice more systematic (e.g. graduated reduction of feedback and instruction)."*

The design of PSALM included driver profiles and driving tuning [Verwey et. al. 1993][3]:

> *"Storing the performance profiles of individual drivers, documenting the frequency with which they have encountered particular situations and their history of 'abnormal' performance in each situation.*

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[2] p.97

[3] p.135

... For instance, abrupt hard braking, attempts to make fast and unusually large steering corrections, excessive acceleration and adoption of highly variable headway."

PSALM was planned to include after-trip statistics and comments given to the driver after the driver reached a halt [Piersma et. al. 1993]. In addition, giving the driver real-time feedback, as well as premeditated training [Verwey et. al. 1993]:

"It seems probable that in the future PSALM may, once a criterion is exceeded, inform the driver that performance is not adequate, and suggest a local route, which requires performance of the relevant 'problem' activities".

PSALM design included user preferences in the form of a menu or by having the user talk to the computer to provide feedback orally ("Undesired", "Too early", "Too late") [Piersma 1993].

Unfortunately, the only function of PSALM that was implemented, as part of the European GIDS project, provided anticipatory spoken warnings regarding the upcoming traffic situation (e.g., "Round-about ahead", "Obstacle ahead") – intended to be used by novice drivers [Piersma et. al. 1993].

A full implementation of an educational warning system could benefit the entire population, especially in the injury prone groups such as younger and older people. It is a fact that especially younger (16-24 years) and older (over 64) people have higher involvement in car accidents and higher fatalities rates than the rest of the population [USFHA 1998, USFHA 2000]. The young population requires more training, and the older population requires reminders and maintenance of their driving skills. This is true especially considering the fact that most drivers overestimate their driving abilities [Groeger 2000][4]:

> *"Our sense of self-efficacy, while neither universally positive across all tasks, nor necessarily positive with respect to driving, is probably more positive than is warranted on the basis of our actual ability."*

Stress Reduction

Driving is both a demanding and a stressful activity [Healey & Picard 2000, Groeger 2000, Michon 1993]. Driver support and warning systems help drivers but at the same time they can be distracting or irritating, especially when the stress level is high (such as in highway lane merging, etc.) [Wagner 2003].

Verwey [1993] suggested three ways of coping with stress and distraction:

1. **Dynamic Allocation** - use of dynamic allocation to remove tasks from the driver when the load is high, and return them when the load is lower.
2. **Change** - the warnings' modality, format, and content can be changed, for example by providing more information or additional details when the driver load is low.
3. **Postpone (delay) or cancel** - non-urgent warnings should be postponed or cancelled completely.

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[4] p.163

It is quite obvious that taking tasks off the driver as in dynamic allocation is desirable. Moreover, it might also be desirable to enable removing tasks from the driver upon his or her request, and not just according to the stress level. There are many tools to achieve this, some which already exist in the market, such as automatic transmission, cruise control, etc.; others, such as adaptive cruise control are currently under development. It is obvious that a lot of work is being done already in this area. Similarly, changing the modality, format and content of the messages is being extensively researched (see [ISO 2001, Tijerina et. al. 2000]). On the other hand, not much is known about delaying messages, especially in the driving environment.

Postponing (delaying) or canceling warnings

Several suggestions have been made in this direction. For instance, it has been suggested not to present messages when in curves [Piersma 1993]. PSALM was planned to provide on-line warnings, or feedback once the driver left the critical situation, or off-line messages when the driver reached a halt [Groeger 1993].

Sviden [1993] related to not overloading the driver with information. He suggested prioritizing and delaying messages according to list of priority groups he presented:

- Safety: warning, advice, system status, tutoring.
- Traffic: guidance, rules and information, tutoring.
- Navigation: calculated arrival time at destination, street names and numbers.
- Service Options: park-and-ride options, user charges, etc.
- Communication: business messages, private telephony, booking of services and commercial advertising.

However, it is not clear about the priorities in the groups listed above. Tutoring appears for example in two categories above (Safety and Traffic).

Wagner [2003] defined urgency of vehicle warnings by importing warning definitions from the aerospace industry. He defined three levels of messages: WARNING, CAUTION, and ADVISORY. About 15 warnings (mostly those presented to the driver in the instrument panel such as "low washing fluid", "low oil") were classified into these levels of warnings. He delayed CAUTION warnings when the driver is distracted (defined by the location or by some characteristics of the driving such as reverse, U turn, etc.) until not distracted, and disabled them completely from the instrument panel after the driver acknowledges them.

A more standard definition came from ANSI standards, which defined the following standard for communicating hazard in vehicles [Laux & Mayer 1993]:

1. DANGER: immediate hazard, which will result in severe injury or death.
2. WARNING: hazard or unsafe practice, which could result in severe injury or property damage.
3. CAUTION: hazard or unsafe practice, which could result in minor injury or property damage.

The problems in this definition are the following:

1. It is hard to measure the effect of each error (and hence classify a mistake to a group). A small mistake can result in death.
2. The classification does not relate to other types of messages, such as advisory educational, or navigation messages? These have no potential risk, only guidance.

Also, the ISO draft referred to this subject by suggesting to classify warnings according to a definition of the response time expected from the driver [ISOTC22 2002]: Immediate (immediate), Short term (10-20 seconds), and Long term (longer).

However, this ISO definition has its own problems:

1. Immediate is bounded by the Short term, and appears to be under 10s. In a driving situation, for immediate reaction, 0-10s is a long time frame.

2. Long term relates to everything over 20s and is unbounded. There is a significant difference between seconds, minutes, hours, day and so forth. Maybe a more detailed classification is required.

3. The classification does not relate to warnings that do not require action from the driver.

However, considering the proliferation of solutions and classification, regardless of their problems, there is still no answer here on how message delays can affect the driver.

Delaying Warnings and Learning

In the educational context it is important to know how delaying warnings and feedback to the driver can influence the learning process. There are three main timing options to when to give warnings: before, during, or after an action [Groeger 1993]. Each timing option has its benefit and drawbacks as follows:

1) **Before** – giving warning prior to an action can be very effective in preventing that action or mistake. However, forecasting actions is often impossible, thus the major risk associated with it is that it might be conceived as unrelated to current behavior, and would be irritating.

2) **During (on-line)** – giving warnings during the action is most technologically demanding, and may not be feasible except for very limited circumstances. Furthermore, it has the risk of dangerously distracting the driver.

3) **After (called feedback/Knowledge of Result (KR)) –** giving warnings after the action. This includes giving the feedback immediately after the action, or somewhat delayed.

   - Immediately after – there is a risk of distracting the driver from the driving task, and also of making the driver reliant on that warning.
   - Delayed - there is a risk that the driver will not understand the problem (especially in significant delays) especially in driving, which is a complex task where the circumstances can be different every time a specific feedback is given.

Focusing on the third and mostly feasible option, giving feedback after the action, knowledge collected about motor skills learning (not specifically driving) suggests that immediate feedback, regardless of its distracting effect, is not necessarily the most effective. Lorge & Thorndike [1935] studied motor skills of throwing balls onto a target while using delays of a few seconds (less than 10s). They found that delaying the KR, as long as not filled with similar activity, has no detrimental effect on learning.

In addition, immediate feedback may have the effect of guiding the performer, making the performer system dependent, rather than to let the performer develop an understanding of what behavior actually led to the feedback, [Groeger 1993]. Therefore, there are even recommendations for graduated reduction of feedback and instruction to prevent such a dependency [Groeger 2000][5]. The explanations for this phenomenon are:

- Extensive immediate feedback may mask/distract learner's attention away from the task-intrinsic feedback.
- Less/withdrawn feedback encourages relying more on task-intrinsic feedback.

When studying withdrawn (intermittent) feedback the conclusions reached were that general or movement learning is better with intermittent feedback, while learning timing and force is better learned with feedback after each trial (for a full survey see [Groeger 2000]).

To summarize, it appears that delayed feedback in motor learning may have some advantages. However, it is not clear how these findings would apply to driving.

[5] According to Groeger [2000], in the long run, less useful feedback or withdrawn feedback (called fading) is better.

3. Research Platform – The 300M IT Edition

Since simulators do not provide as real an experience as driving cars [Denn 1994], the research platform is a real car, the 300M IT Edition (see Figure 3.1 for a picture of the car from the outside and Figure 3.2 for the interior). The 300M is a regular model offered by Chrysler, while the additional sensors and devices have provided us with this special model called the "IT Edition". The 300M IT Edition is a highly instrumented research vehicle equipped with many sensors and devices [Pompei et. al. 2002], as presented in Figure 3.3. The platform with all the sensors was fully available for this research, and in this work, only interfacing and debugging of it was carried out.

Figure 3.1 – The 300M IT Edition

The architecture and computation center is housed in the car's trunk (see Figure 3.4). It includes an 802.11 communication network with a wireless access point (see Figure 3.5). The architecture is flexible; its core is a set of NetBurners, which are programmable boards connecting sensors and serial devices to the local Ethernet [NetBurner 2003]. They are configured here with either UDP or Telnet network protocol, as suitable for each device. At any time, one application computer can read the data from the devices by connecting to the network and setting up the boards to send UDP information to it through HTTP (see Figure 3.6 for an example setup page). Each relevant device in the car is described herein:

- Engine data: speed, throttle position, brake pressure, RPM, etc. The access protocol is based on the J1850 protocol [J1850 2001].
- A set of sensors accessible via a data acquisition board (nicknamed DataPump): steering angle, pressure sensors in the seats, cup holders, arm rests and all the car pedals, cellular phone activity (and disabling) sensor, and infrared sensors for legs position on the pedals (including the special dead-pedal to rest the left foot).

Figure 3.2 – The 300M IT Edition Interior

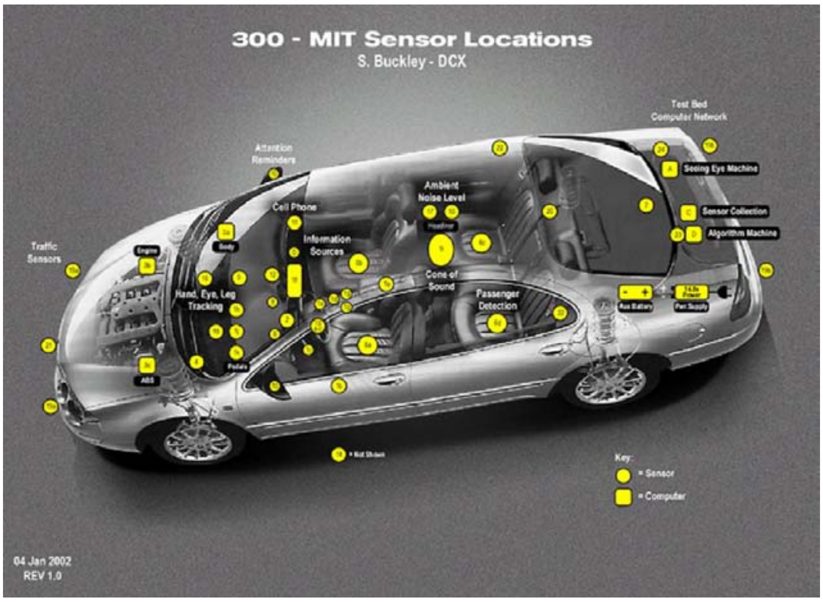

Figure 3.3 – The 300M IT Edition Sensors Location

Figure 3.4 – 300M IT Edition Trunk Computation Center

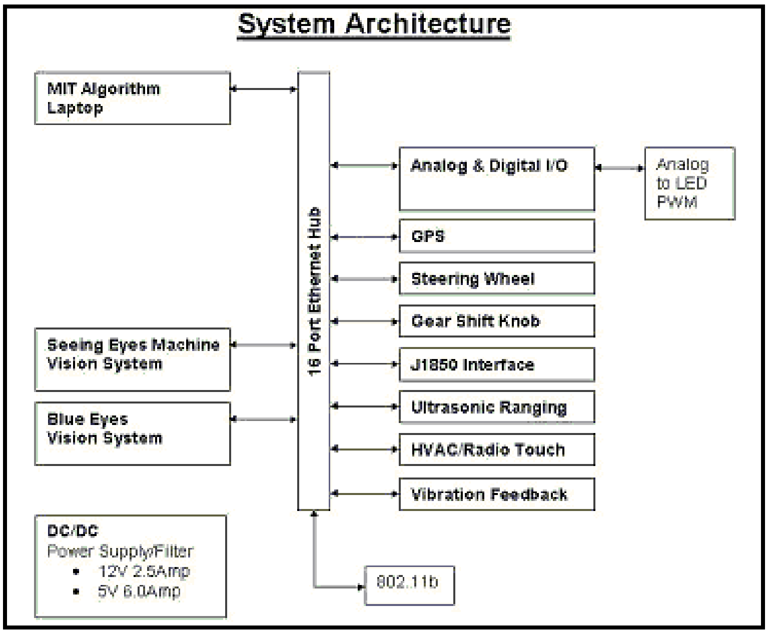

Figure 3.5 – 300M IT Edition Architecture.

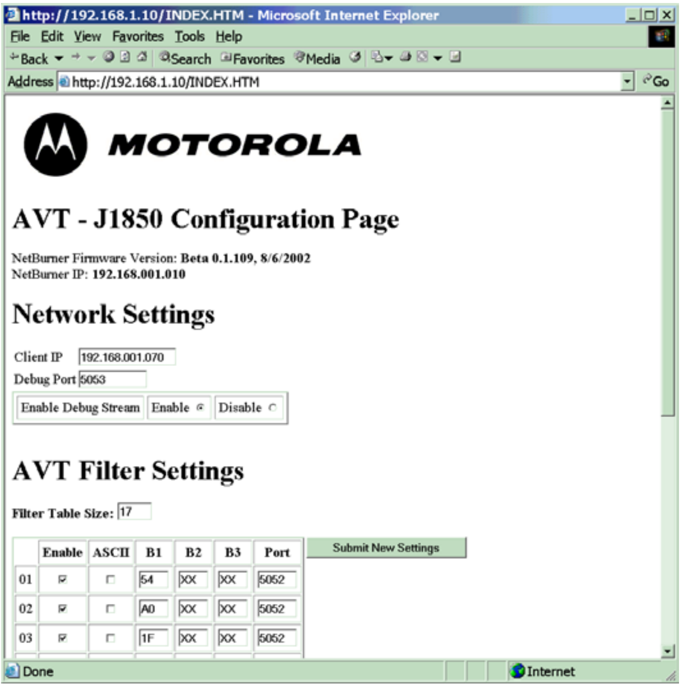

Figure 3.6 – Example HTTP Setup Page of the J1850

- Controllable lights on the mirrors and car sides (see Figures 3.7 and 3.8 respectively), accessed via the DataPump.

Figure 3.7 - Light on the Right Mirror

Figure 3.8 - Light on the Car Side

- A Busy and a Warning (two colors – yellow and red) combination of lights and buttons, all accessible via the DataPump (see Figure 3.9).

Figure 3.9 - Busy and Warning Lights/Buttons

- Vibrators in the steering wheel, driver seat, gas and brake pedals, and setup knobs, allowing affirmation and criticism intensity setup. They are built using a modified IRX [Poor 1999].
- Controllable standard lights in the instrument panel, such as signal, brake, fuel, and warnings.
- A set of cameras and FaceLab software for gaze tracking from SeeingMachines [SM 2003]. FaceLab can be interfaced via UDP and provides a full set of information items. It requires calibration for each driver using it. But first it requires a one-time construction of a world model that defines location of objects such as windshield, instrument panel, rearview mirror, side mirrors, etc., as defined by the constructor (see Figure 3.10 lower frame). Then, it provides the location and object on which the driver is looking at. In addition, it provides a general (non-accurate) drowsiness measure. Aside from the calibration needed, Facelab has latency in calculating the objects on which the driver is looking and is also sensitive to the use of glasses, especially reflecting sunglasses.
- Infrared sensor built around the Heating Ventilation and A/C (HVAC) and the radio controller (see the frame around the radio area in Figure 3.2). This sensor is capable of sensing movement and location around the HVAC.
- Pressure sensors in the steering wheel and in the gearshift. The sensors are meant to detect the location of the hands and the amount of pressure applied on the devices[6].

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[6] In the process of interfacing to the car network.

- Global Positioning System (GPS) [GPS 2003] to detect the location of the car, available via Telnet with GAR NMEA protocol [NMEA 2000].
- Other sensors in work such as BlueEyes camera [BlueEyes 2003], special bike warning lights, etc.

Figure 3.10 - Facelab Software with an Active World Model

4. Educational Warning System Design

A design for an educational warning system is outlined here using the following approach. The system outlined here is meant to improve performance - not to teach unlicensed drivers how to drive, nor to warn drivers about their driving (at least not as the main task). Its role is to provide feedback, usually **after** the driving mistake has been made and to try and educate drivers to drive at their best. An important feature of the system is the use of calculated feedback, so as to separate the input from the output and make it more versatile and human like, for instance, by giving both criticism and affirmation (positive feedback on improvements).

This design is based on previous ideas and works in the area, especially PSALM [Groeger 1993], recommendations regarding vehicle-warning systems, and it takes into account known considerations of human factors.

The design addresses three main aspects of driving: illegal, unsafe, and inefficient driving behavior, as follows:

1) Illegal driving - such as turning or changing lanes without signaling.
2) Unsafe driving - such as using excessive force on the brake that might increase the risk of being hit from behind.
3) Inefficient driving - such as using excessive force on the throttle, which reduces gas mileage as well as the engine's lifetime.

Following the identification of driver behavior, the design aim to balance between the following guidelines:

- Personalized interaction – based on learning each driver's profile, or history of behavior.
- Multimodal interaction – use different channels of feedback rather than audio, such as tactile and some visual ones.
- Humanly interaction – provide versatile feedback (not the same reaction or verbal comments on the same mistake all the time) and positive reinforcements in addition to criticism.
- Quick reaction – give the feedback as soon as possible after the mistake, to prevent confusion.
- No information overload – give the feedback when the driver is not overloaded.
- Post driving information – provide statistics and information for after drive analysis.

The following sections describe an intelligent layered architecture that can benefit application developers. Then, a high-level design of an educational warning system is described; a design that suggests factors to consider when giving feedback and a draft of an algorithm to present it. It leaves the exact thresholds for feedback to the implementation itself. Lastly, a prototype demonstrating the feasibility of such a system is presented.

Intelligent Layered Architecture

As part of the design, a higher-level architecture is proposed for the car. A more comprehensive approach than the existing one (see chapter 3), in the form of a layered architecture, can benefit researchers and application developers alike. The purpose of this architecture is to avoid the need for each researcher or developer to program the low-level sensors and to develop new models for similar things, such as stress detectors. This can be achieved by adding to the car a computer that includes support for applications using generic modules.

The architecture (see Figure 4.1) includes four layers: Car Sensors, Interfaces, Intelligent Mediators, and Applications. The Car Sensors and Interfaces layers already exist, as described in chapter 3, and the Applications layer can include any application, such as the educational warning system presented here. The new layer described herein is the Intelligent Mediators one.

Applications: warning, coaching, controlling distraction...
Intelligent Mediators: stress, distraction, behavior…
Interfaces: interface boards, DataPump, FaceLab…
Car Sensors: camera, J1850, GPS, IR/pressure sensors...

Figure 4.1 - Intelligent Layered Architecture

The Intelligent Mediators layer includes modules that serve many applications. As an example, three generic modules that serve many applications are described here: Stress, Distraction, and Driving Behavior Identification. The following points describe some examples for possible factors and sensors needed to detect these states that may be relevant to that module.

1) Stress

Previous works have attempted to identify stress in driving [Healey & Picard 2000, Wagner 2003]. Using their and others' conclusions, as well as common sense, a stress model can be developed. This model can include different stress inducers and calculate a measure of stress to be used by upper-level applications. A few examples for stress inducers are described in Table 4.2, with possible sensors to identify their existence. For instance, bad conditions of weather and environment can increase the difficulty and load on the driver: wetness, ice, fog, dark, etc. These can be detected by using telemetric sensors in the car, such as the external temperature and humidity, or even the activity of the windshield wipers, as well as by using external information such as weather forecasts and reports. A different example for stress can be based on the driving activity, such as driving in reverse, or performing maneuvers such as changing lanes, turning, etc. Another example, based on location, is stressful locations that can be identified based on a compiled database of stressful areas coordinates combined with use of a GPS. This database can include, for example, drivers' subjective reports, all ramps merging into highways, or reports from the police about risky driving areas. A different approach, based on the subjective behavior of drivers may be potentially detected by using pressure sensors on the steering wheel, with the assumption that the amount of pressure applied on the steering wheel often increases when the driver is in stress (similar to pressure applied on a computer mouse [Qi et. al. 2001]).

Factor	**Detection**
Bad conditions – wetness, icy roads, fog, darkness	Humidity, temperature, darkness sensors, wipers on, lights on, external information
Reverse	Car gear state
Changing lanes	Specific classifier
Intersections, rotaries	GPS
Merging into highway	GPS
Certain risky locations	GPS with reports from other drivers or local police (accident leading areas)
General stress (some aspects)	Grip force on the steering wheel

Table 4.2 – Example Stress Factors and Sensors

2) Distraction

To answer a different problem, of driver distraction, many factors can be taken into account, as presented in the examples of Table 4.3. Such factors can be driver in active conversation (can be detected by using a microphone, the cell phone activity), driver drinking, handling the radio, or even just not looking at the road.

Factor	Detection
Driver conversing	Microphone, cell phone in use
Driver drinking	Cup holder is active
Driver handling radio/AC	IR sensor around the HVAC
Driver does not look at the road	Cameras/Facelab

Table 4.3 – Example Distraction Factors and Sensors

3) Driving Behavior Identification

Some driving maneuvers can be identified and even predicted [Oliver & Pentland 2000, Liu & Pentland, 1997, Kuge et. al. 1998]. The Driving Behavior Identification module can identify driving maneuvers (e.g., lane keeping, lane changing, turning etc.), as well as driving mistakes (e.g., unsteady steering, lane changing or turning without signaling, etc.) to be used for a variety of applications.

Unfortunately, many of the existing classifiers are not yet mature enough to be integrated into real systems. However, considering the vast amount of resources devoted to research in this area, the assumption is that as time goes by there will be more and more classifiers robust enough for implementation.

Software Design

The proposed software design for the educational warning system is presented in Figure 4.4. It includes the Car Interface (1), States & behavior Identifier (2), Feedback Generator (3), Control Panel (4) and supporting data repositories.

The modules' functionalities are as follows:

(1) Car Interface

The Car Interface module interacts with the car and reads the sensor inputs into a representation of the car in memory. A secondary role of that interface is to activate output devices in the car. This interface could be a higher-level interface if the above-described intelligent layered architecture is implemented in the car.

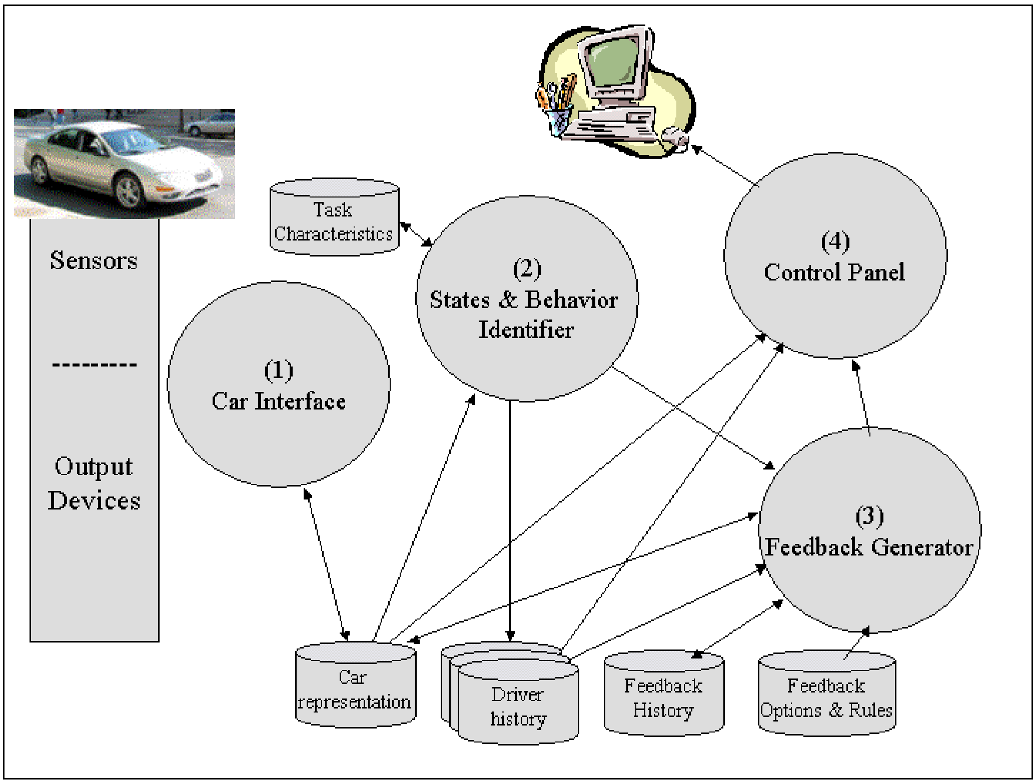

Figure 4.4 - Software design of Educational Warning System

(2) States & Behavior Identifier

The States & Behavior Identifier (SBI) module tests the state of the car and identifies states and driver behaviors (such as “did not look in the rear view mirror when pressed the brake”). It obtains extra knowledge from a task characteristics knowledge repository. As a result, SBI updates the driver history to reflect the new state.

SBI manages the driver history repository. It keeps a log of every criticism scenario as counters of successes and failures per mileage. The scenarios may be organized in groups of mistakes of the same type; for instance, all signaling mistakes (when changing lanes, when turning, when pulling over, etc.) can be grouped together.

If the intelligent layered architecture is implemented in the car, this module will receive from it the state or behavior that was already classified by the architecture, and focus on maintaining the driver history repository.

(3) Feedback Generator

The Feedback Generator (FG) module is the core of the system. FG is activated when a new state has occurred. Its task is to react to the new state. It takes into account the driver's history, the feedback history, and executes a series of rules to generate feedback. Its role is to decide when it is a good time to interrupt (e.g., not in the middle of a turn), how much feedback should the driver get (e.g., based on knobs setup), and using which modality. For example, previous results from lab environments have indicated that tactile feedback is effective in conveying messages to drivers [Enriquez et. al. 2001, Tijerina et. al. 2000] and when using several channels, effectivity increases [ISOTC22 2002]. Therefore, the design will include a combination of feedback methods, such as tactile, visual, and audio feedback channels. Tactile feedback will be provided as controlled vibrations of the steering wheel, accelerator, brake, and the seat. The guidelines followed here regarding tactile feedback are [ISOTC22 2002]:

- It should be given right after the task or it will not be understood.
- It should be given with the relevant device or it may not be understood. For example, steering vibration for steering mistakes, throttle vibration for mistakes related to throttle/speed, brake vibration for mistakes related to braking, etc.

Other relevant guidelines for audio feedback considered here are [Reeves & Nass 1996]:

- Praise should sound sincere.

- Critique should be gentle, and given sparingly.
- Novices prefer more flattery while for experts the compliments should be subtler by picking up more intricate material and by noticing detail.

FG uses the following information to make the feedback decision:

- Setup knobs (Car Representation) - depending on the switches setting, the amount of feedback will be increased or reduced. For instance, when the criticism switch is all the way down – no criticism feedback will be provided, and vice versa. Because people tend to switch off things and forget to switch them on again, the setup knobs should be digital, to be reset by the system as needed.
- Stress/distraction level (Car Representation) - stress/distraction level gauges that take into account several factors such as weather, number of passengers in the car, speed and driving patterns – they affect the feedback amount and timing decision.
- Driver history - including the repetition pattern of a mistake and a group of mistakes, enabling prioritization of feedback messages.
- Feedback history - including what feedback was already given to the driver, when, and how effective it was, enabling further provision of variable (non-repetitive), effective feedback, using the right modality.
- Priorities - are established on the driving mistakes to address. The priorities are based on the ratio of failures vs. successes for each mistake and group of mistakes, the frequency per mileage, and on the overall severity of the mistake. The focus will be given to higher priority mistakes, while lower priority mistakes will not be related to until the higher priority mistakes are overcome.

- Feedback Options and Rules - to select the feedback from. This repository stores an absolute priority of severity of driving mistakes (e.g., changing lanes without signaling is more dangerous than over-exerting the car). In addition, it stores all the feedback options for each mistake. Generally, each mistake has a few associated audio messages and often tactile or visual feedback as well. Also, it has affirmation feedback options to be used when the driver performed well and did not make the mistake. Finally, each feedback option has a rating of expertise level, from novice to expert.

The Feedback Algorithm

In the beginning, the system will collect information about the driver behavior and learn the driver's weak points without providing feedback. After adequate information has been collected, the driver has been by now evaluated as novice or expert. The more severe failures the driver has - the more novice is the driver considered. This will later on affect the type of feedback the system will generate. This process goes on all the time, also after this stage is done, when feedback is given to the driver.

After the first phase has passed, feedback messages are enabled. Whenever a mistake is being made, the following questions are being asked:

1) Is its priority high enough compared to the setup knobs configuration to pass the feedback threshold?
2) Is that a good time to react? If the stress level is lower than a certain "do not disturb threshold"? If the driver is busy or stressed from a short-term activity, to delay the message until it is over. If it is a long-term activity/stress, to cancel the message completely.

3) Check the feedback options to see what has already been given to the driver and choose the right feedback message to be issued:
    - Start with giving audio feedback + tactile/visual to bond the different types of feedback so that the driver will comprehend what is the meaning of the feedback from the audio. Later on, continue just with the tactile/visual and get back to audio sparsely, as needed.
    - The driver heard less or did not hear at all (to avoid many repetitions of the same feedback).
    - The feedback is suitable to the driver's level (novice to expert).

If a correction of a mistake is made (e.g., the driver used turn signals after forgetting it often), a similar decision process, as used in giving feedback on mistakes, is being made to acknowledge the correct behavior.

(4) Control Panel

The Control Panel module monitors the states of the car and the driver, and displays that information. It enables selecting drivers, giving setup parameters for all the driver support systems in the car, and eventually downloading information to be further analyzed and reported.

Prototype: CarCoach

To demonstrate the design, a prototype was implemented in the 300M IT Edition that includes some scenarios of user warnings and feedback, and also some stress/distraction considerations. From the design described above, the prototype implements partially the

Car Interface (1), and the States and Behavior Identifier (2) and the Feedback Generator (3) unified. It is implementing a sample of each but not the full algorithm.

The prototype uses basic car sensors, ones that exist in any standard car, or ones very cheap to install. A detailed summary of them is provided in Table 4.5. The sensors and devices have been described in detail in chapter 3.

Device	**Sensors and effectors used**
CarCoach kit	Vibrators + setup knobs.
Amplifier	
J1850 interface	RPM, turn signals, speed, gear state.
Extra sensors and devices (Datapump)	Brake pressure, steering angle, cell phone sensor, warning and busy lights and buttons.

Table 4.5 - CarCoach Sensors and Effectors

CarCoach has five scenarios implemented, which are summarized in Table 4.6:

1. Over-exerting the car
2. Strong braking
3. Low gear
4. Turn without signaling
5. Turn with signaling.

CarCoach provides both criticism (scenarios 1-4) and affirmation (scenario 5). It provides audio and tactile feedback. The tactile feedback is immediate and uses the most appropriate device: steering wheel for mistakes related to steering/turns, throttle and brake vibration for mistakes related to gas and brake. For the affirmation, it uses the seat vibration massage as a device that gives pleasure/reward for good actions.

Action	**Feedback**	**Type**
Over exerting the car (RPM>3000)	Throttle vibrates Audio: "Easy on the gas"	Criticism
Strong braking (Brake pressure>2100)	Brake vibrates Audio: "Brake gently"	Criticism
Low gear (instead of Drive)	Audio: "Gear is low"	Criticism
Turn without signaling	Steering wheel vibrates Audio: "Please signal"	Criticism
Turn with signaling	Seat vibrates Audio: "Thank you for signaling"	Affirmation

Table 4.6 - CarCoach Scenarios

In addition, the driver has full control over the feedback by using the setup knobs and may switch off the criticism and/or the affirmation at any time. In order to demonstrate the load and stress prevention, whenever the car is in reverse or there is a cell phone activity, the feedback is either switched off completely (reverse) or does not use the audio channel (cell phone activity). To demonstrate this "Busy" state, the "Busy" light is switched on as long as the system is in "Busy" mode and does not generate feedback. Due to the lack of a suitable display in the 300M, to demonstrate the informing of the drivers on the level of their driving, use is made of the warning lights. When the driver has made three mistakes, the amber warning light is turned on. After five mistakes, the amber is turned off and the red is turned on. Once the driver acknowledges getting the information, by pressing the button in the middle of the warning device, the light switches off. Note that the warning light is located on the left side of the driver (see Figure 3.9), and is rather private to the driver. Table 4.7 presents this CarCoach effectors model.

Sensor	**Effect**
Setup knobs – criticism off	Cancels all criticism feedback
Setup knobs – affirmation off	Cancels all affirmation feedback
Cell phone is in active call	Eliminates audio messages
Reverse gear	Busy light turns on, cancels all feedback
3^{rd} mistake this drive	Yellow warning turns on
5^{th} mistake this drive	Red warning turns on

Table 4.7 - CarCoach Effectors Model

The CarCoach Prototype has been shown at several forums with at least 30 people driving with it enabled over a six month trial. It has been shown at the Media Lab TTT and DL consortium meetings during fall 2002 and spring 2003. It has been shown at ACM's CHI conference and to visitors of the Media Lab in the same time frame. Most people changed their behavior based on CarCoach feedback within a few hundred feet of taking the wheel. Drivers found the feedback interesting and in most cases delightful. People expressed positive feelings about the affirmation and criticism knobs allowing them to turn off the feedback..

Our initial experience with CarCoach, mostly in demonstrations, has shown that CarCoach is appealing to drivers. Those who tried CarCoach have shown strong reaction and excitement from it, especially from the tactile feedback. We used this feedback to improve and adjust the strength of the vibrations to the adequate level. In one case, a driver used CarCoach for a period of half an hour and then switched to different software in the car. The driver and the passengers noticed that also during this period, when CarCoach was not active, he improved his driving and made fewer mistakes, especially signaling mistakes.

This has shown us that CarCoach has good potential to improve driving performance, as well as to be appealing to the drivers. The main question about CarCoach is how drivers will accept it and use it on a long-term basis. Many concepts in CarCoach could be tested. The possibility of delaying feedback when a driver is in a complex maneuver is generally important element that would pertain to other scenarios as well. We decided to start with exploring the possibility of delaying the feedback and its effects, as described in the next chapter.

5. Experiment

An experiment was conducted using the 300M IT Edition to test immediate vs. delayed feedback. Each subject was requested to perform two driving tasks several times: a turn task and an acceleration task.

The Turn Task

One task was to make a very slow turn. In order to perform the task correctly, the driver had to stop before the turn, and then to leave the brake and let the car glide during the turn. This task is very unnatural for drivers, who do not expect the car to complete the turn without the use of the accelerator. It is a task in which the correct advice looks unreasonable or even impossible, just like in learning to cope with skidding, when the driver needs to let go of the brake and turn the steering wheel in the opposite direction.

The Acceleration Task

The other task was acceleration at a certain pace – a bit stronger and faster than normal. The driver needs to tune to the correct pace, which is faster than normal, but not with full strength. These tasks were chosen because they were:

1) new to the driver
2) safe to perform on a normal city road.
3) repeatable over a short amount of time.
4) the turn task tested simple learning ability and the acceleration task tested tuning – learning the exact amount of force required to apply on the accelerator.

During the two tasks, audio feedback was given to the drivers to direct them to perform the task correctly. Half the subjects were given immediate feedback, and the other half was given delayed feedback (i.e., at the end of the task). It is important to note that the feedback that the immediate and delayed groups were given was exactly the same. This was done to keep the groups identical except for the timing of the message.

During each drive, the data of each driver in each task was logged, to enable processing and comparison of the performance of each group.

The hypotheses for these two cases were as follows:

1) The subjects in the delayed feedback group will have a better understanding of the task than those in the immediate feedback group.
2) Subjects in the delayed feedback group will perform the task better.
3) Subjects in the delayed feedback group will improve more and faster than the immediate feedback group.

The basis for these hypotheses is that the delayed feedback will be less distracting and will encourage relying more on task-intrinsic feedback, hence, promoting better and faster learning.

The Experiment Software

Special software was developed for the experiment. The software analyzes and saves the following information: throttle position, speed, RPM, steering position, and brake pressure. The software is activated with the following command:

Java CarCoach [save] [task] [options]

The parameters include whether to save a data file, which task is currently run, and an option for immediate and delay feedback (see Table 5.1).

	Save	**Task**	**Options**
Description	Save file named savefile.txt (needs renaming after task)	Type of task to run	Immediate or delayed feedback
Values	0 – no save 1 – save file	1 – Acceleration 2 – Turn	0 – immediate 1 – delay

Table 5.1 - Software Parameters

Once the software is started, using a simple user interface shown in Figure 5.2, the experimenter marks each task repetition by pressing the button "Maneuver Started" (or by pressing S on the keyboard) at the beginning of it, and "Maneuver Ended" (E) at the end. This causes the software to run the algorithm and save the data. The details of the two tasks are as follows:

Figure 5.2 – Experiment Software Interface[7]

1) Acceleration task

[7] The "bad" button was designed for a feature that was not used in the final experiment procedure.

When the speed is between 5 and 30MPH, if the throttle position is less than 2500 or the RPM is higher than 4500, audio messages "More gas" and "Less gas" are played, respectively (see Table 5.3).

Conditions	**Error message**
Throttle position<2500 & 5<Speed<=30MPH	"More gas"
RPM>4500	"Less gas"

Table 5.3 - Acceleration Task Algorithm

2) Turn task

When the turn started (steering over 2144) and the car did not reach a complete stop, or when the driver used the accelerator during the turn, audio messages "Stop before turning" and "No gas" are played, respectively (see Table 5.4).

Conditions	**Error message**
Did not stop & Steering>2144	"Stop before turning"
Throttle position>0 & steering>2144	"No gas"

Table 5.4 - Turn Task Algorithm

Note that only one audio message was played once within each task repetition.

The Subjects

The subjects were recruited using email and posters (see Figure 5.5). Most of them from the MIT community and related people (mostly research staff, UROPs, students, and their friends/families). The test group included 14 male and 16 females, ages 21-71, most of them either pursuing an academic degree or already have one. Most of them were computer literate.

Figure 5.5 – Recruiting Poster

The subjects were assigned to get immediate or delayed feedback randomly, while keeping the men to women ratio in each group similar. The order of the tasks performed was changed for each drive.

The Location/Route

The Acceleration task was done in the straight part of Binney Street, from east to west (see arrows on map in Figure 5.6). Usually, between 1-3 accelerations were carried out from 1st Street to Fulkerson Street, where the drivers were asked to circle the block and return to the start point. The reason that this specific street was chosen is because it is close to the start point (MIT Media Lab), it is a wide street with a long straight area (2 lanes in each direction) and it does not have much traffic.

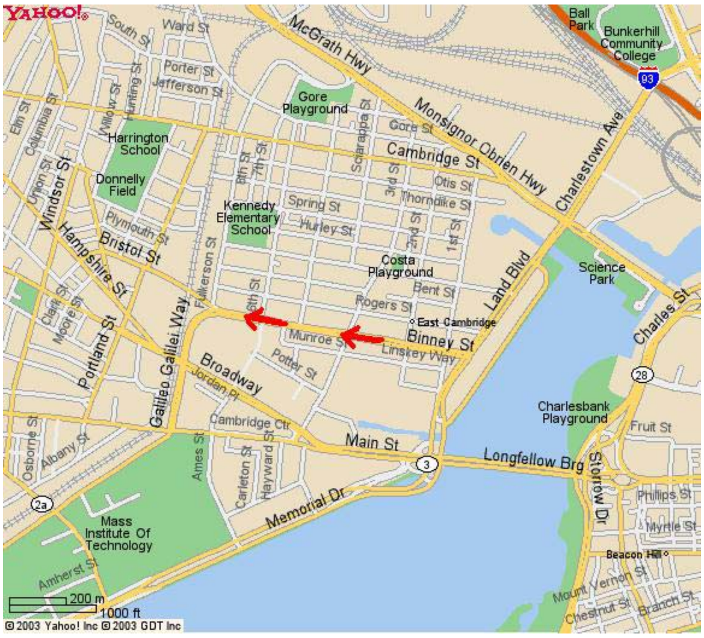

Figure 5.6 - Acceleration Task Area

The turn task was a right turn performed from 6th Street to Rogers Street (see arrow on map in Figure 5.7). The drivers then circled the block to repeat the same turn again. Because of construction work, the section of 6th Street from Binney to Rogers Street was sometimes closed to traffic. In these cases, an alternative turn was taken - a right turn from 5th Street to Rogers Street (see arrow on map in Figure 5.8). The characteristics of the two turns were similar – a right turn with no stop sign.

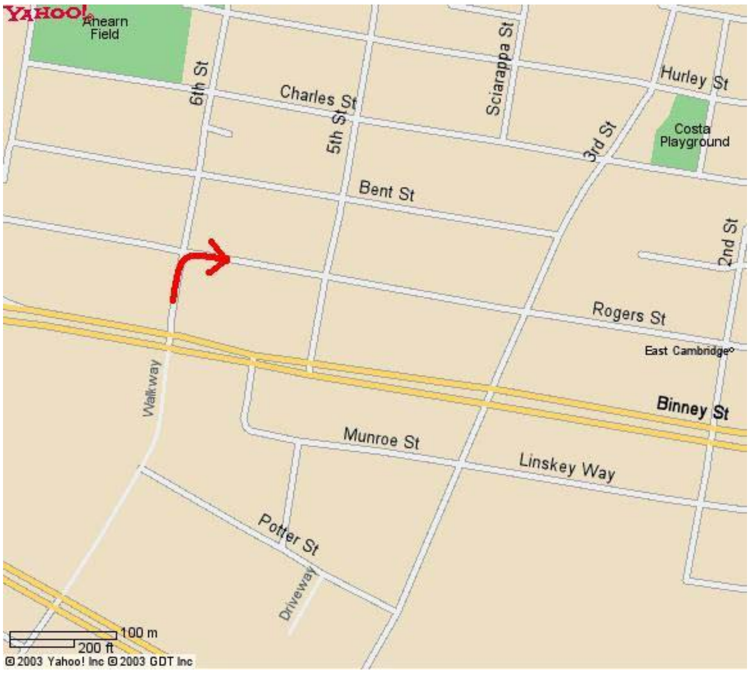

Figure 5.7 - Turn Task Area

The Procedure

The subjects got into the car in the driver seat. They got a small introduction to the car and the special devices (especially the visible ones, such as the cameras). They presented a drivers license and signed a consent form (see appendix A). They got the instructions – perform repeated fast accelerations and slow turns. For safety reasons, to prevent the surprise of hearing the audio for the first time during driving, some of the audio messages were played to the subjects during the introduction. This was also done in order to make sure that they understand the terminology and to prevent misunderstandings because of a noisy environment. The audio messages played were: “No gas”, “More gas”, “Less gas”. The subjects drove from the MIT Media Lab to East Cambridge and got used to driving the car on the way. They repeated the Acceleration task 10 times, and the Turn task until they succeeded, or maximum 5 times. After both tasks ended, they filled out a questionnaire (see appendix B), and got gift certificates (worth $10), and then they returned to the start point.

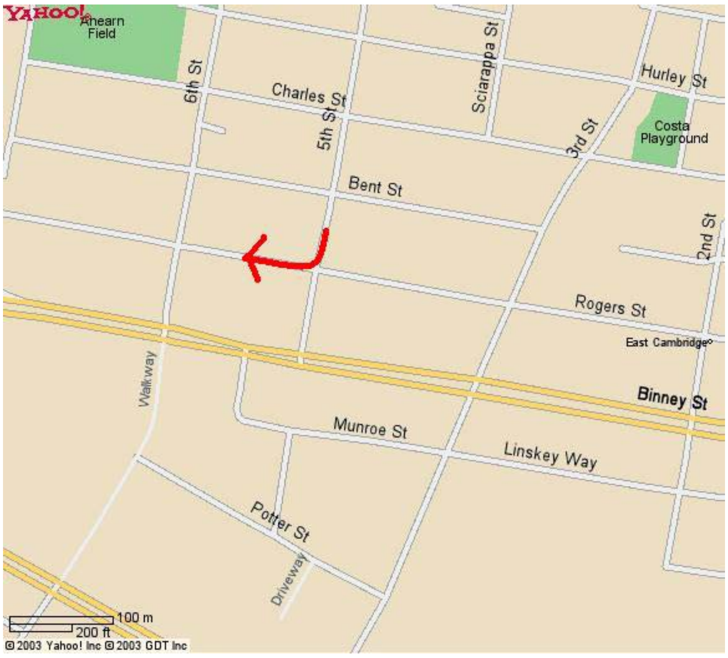

Figure 5.8 - Alternative Turn Task Area

6. Results

The results from the experiment were coded and analyzed. The following analysis uses one tail t-test. In all the charts, the immediate feedback group is on the left hand side, colored blue/dark, and the delayed feedback group is located on the right-hand side, colored white. Mi and Md stand for the Means of the immediate and delayed group, respectively. In all the figures, the error bar represents the standard error. In the t-test tables, the significant results are marked with asterisks (*) as follows:

- * marginally significant
- ** significant
- *** highly significant

The Subjects

30 subjects participated in the experiment, 15 were assigned to the immediate feedback group and 15 to the delayed feedback group. From the subjects in the immediate feedback group, one subject did not cooperate, claiming, “The computer does not know the context of the driving, therefore I will not listen to it” while disregarding the instructions. The data of this subject was disregarded, leaving this group with 14 subjects. From the subjects in the delayed feedback group, at least four subjects did not understand the instructions and the feedback properly and reported it to the experimenter. They complained about the lack of timing information in the feedback as confusing (e.g., the use of “less gas” instead of indicating **when** in the message, as in “less gas **at the**

beginning of the acceleration”). These subjects were also removed from the group, leaving the delayed feedback group with 11 subjects[8].

Task Understanding

The first hypothesis was that subjects in the delayed feedback group would have a better understanding of the task than those in the immediate feedback group. In order to test this hypothesis, the subjects' average success in the multiple-choice questions was checked. The acceleration and turn tasks descriptions were coded as 0-Incorrect, 1-Correct, and the means are presented in Figure 6.1 (see also Table 6.2). The delayed feedback group appeared to show better understanding of both tasks. However, the difference for the turn task was not significant, while the difference for the acceleration task was marginally significant (Mi=0.57, Md=0.82, t(22.996)=1.344, p=0.096) (see Table 6.3).

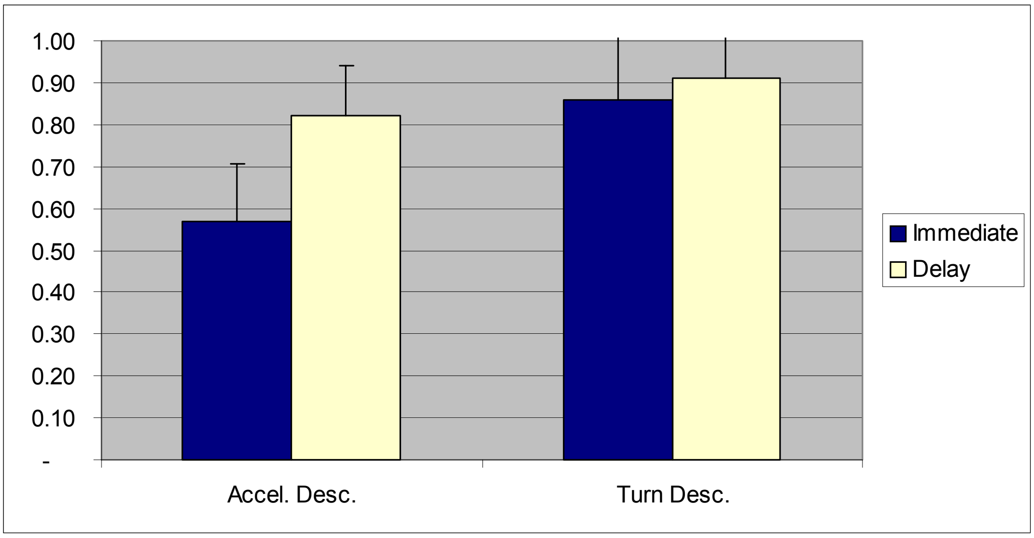

Figure 6.1 – Acceleration and Turn Task Descriptions Multiple-choice Questions Success

[8] The results prior to removing these subjects were in the same direction of the results after removing them, however, only after removing them, the results were statistically significant.

	Feedback	Mean	Std. Deviation	Std. Error Mean
Acceleration Description	Immediate	0.57	0.514	0.137
	Delay	0.82	0.405	0.122
Turn Description	Immediate	0.86	0.363	0.971
	Delay	0.91	0.302	0.909

Table 6.2 – Accel. and Turn Task Desc. Multiple-choice Questions Success Means

	Levene's Test for Eq. Of Variances			t-test for Eq. of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.
Acceleration Description	Eq. Var.	7.149	0.014	-1.305	23.000	0.205	-0.247
				-1.344	22.996	*0.192	-0.2468
Turn Description	Eq. Var.	0.605	0.444	-0.382	23.000	0.706	-0.052
				-0.391	22.901	0.700	-0.052

Table 6.3 - Accel. and Turn Task Descr.Multiple-choice Questions Success t-values

Overall Performance

The second hypothesis was that subjects in the delayed feedback group would perform the task better. In order to test this hypothesis, the subjects' success in the task descriptions was checked.

The measured results for the tasks were coded as follows: for the turn task, success was coded as 1-failed, 0-succeeded, and the acceleration task was coded in two ways, once as 0-failed, 1-succeeded, and once as a performance grade. The grade was calculated as a distance from the target range as follows:

Sum(Abs[9](throttle-target throttle))/(length of acceleration data series)

Note that for turns the count is of failures (up to 5), because once the subject succeeded the task ended, while for acceleration the count is of successes out of 10 trials.

Note also that the lower the grade for the acceleration task, the better the performance is.

On average, the delayed feedback group performed both tasks significantly better than the immediate feedback group according to all the coding methods (see Figures 6.4 and 6.5, and Tables 6.6 and 6.7 for details).

In the turn task, the delayed feedback group failed to perform only 3.36 turns vs. 4.21 turns for the immediate group, on average. This difference is marginally significant ($t(15.887)=1.723$, $p=0.052$). In the acceleration task, the delayed feedback group performed well 8.27 accelerations vs. 6.14 accelerations for the immediate group, on average. This difference is highly significant ($t(23)=2.704$, $p=0.007$). A similar result is found in the acceleration performance grades. The delayed feedback group's acceleration's grade average was better (lower), 81.88 vs. 148.43 for the immediate feedback group. This difference is significant ($t(20.287)=1.748$, $p=0.048$)[10].

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[9] ABS is Absolute Value, ABS(X) in math is often marked as |X|.

[10] There is no significant difference in tasks performance for the first trial of the turn task. See the next section for details.

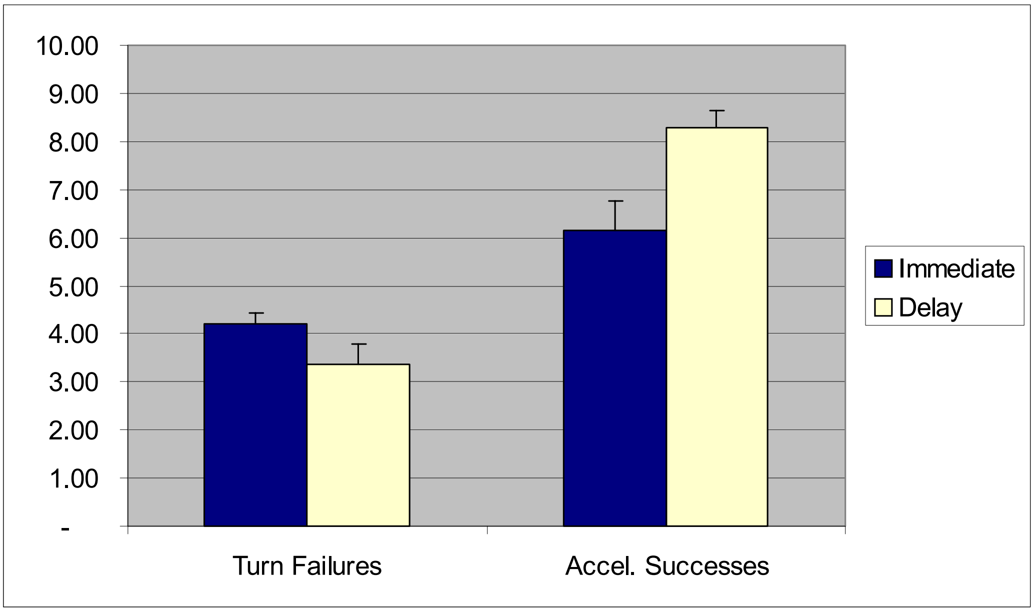

Figure 6.4 – Average Turn Failures and Acceleration Successes

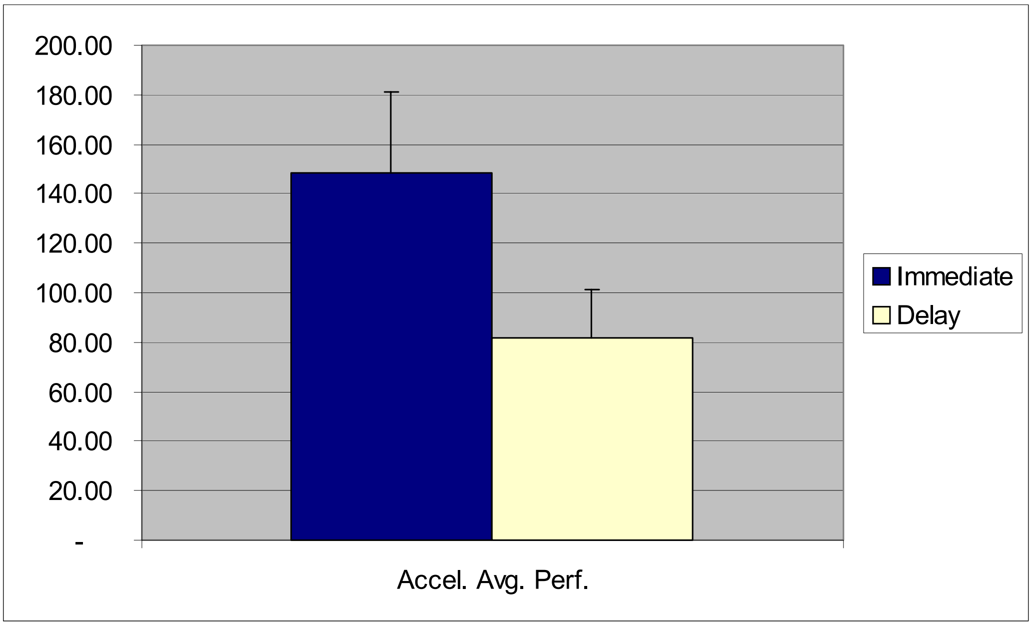

Figure 6.5 – Acceleration Average Performance

	Feedback	Mean	Std. Deviation	Std. Error Mean
Turn failures	Immediate	4.21	0.893	0.239
	Delay	3.36	0.143	0.432
Acceleration Successes	Immediate	6.14	2.349	0.628
	Delay	8.27	1.272	0.384
Acceleration Average Performance	Immediate	148.43	122.027	32.613
	Delay	81.88	62.118	19.643

Table 6.6 - Average Turn Failures, Acceleration Successes and Performance Means

	Levene's Test for Eq. Of Variances			t-test for Eq. of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.
Turn failures	Eq. Var.	5.452	0.029	1.821	23.000	0.082	0.850
				1.723	15.887	*0.104	0.850
Acceleration Successes	Eq. Var.	2.275	0.145	-2.704	23.000	**0.013	-2.130
				-2.895	20.758	0.009	-2.130
Acceleration Average Performance	Eq. Var.	6.653	0.017	1.578	22.000	0.129	66.551
				1.748	20.287	***0.096	66.551

Table 6.7 - Average Turn Failures, Acceleration Successes and Performance t-values

Improvement

The third hypothesis was that subjects in the delayed feedback group would improve more and faster than the immediate feedback group. In order to test this hypothesis, the subjects' success in each task trial was tested, as well as the relative success in the second and third acceleration try relatively to the first try.

Figure 6.8 and Tables 6.9 and 6.10 present the analysis of the average success for each consecutive turn for the two groups. In the first turn, none of the subjects succeeded. In the second turn, some of the delayed feedback group's subjects succeeded, with a gradual improvement in each turn until the fifth, and last, turn. In all the turns (except the first, in which all the subjects failed) the delayed feedback group seemed to do better. However, this difference is not significant, except in the third turn, in which the difference is marginally significant (Mi=0.07, Md=0.36, t(14.359)=1.739, p=0.052).

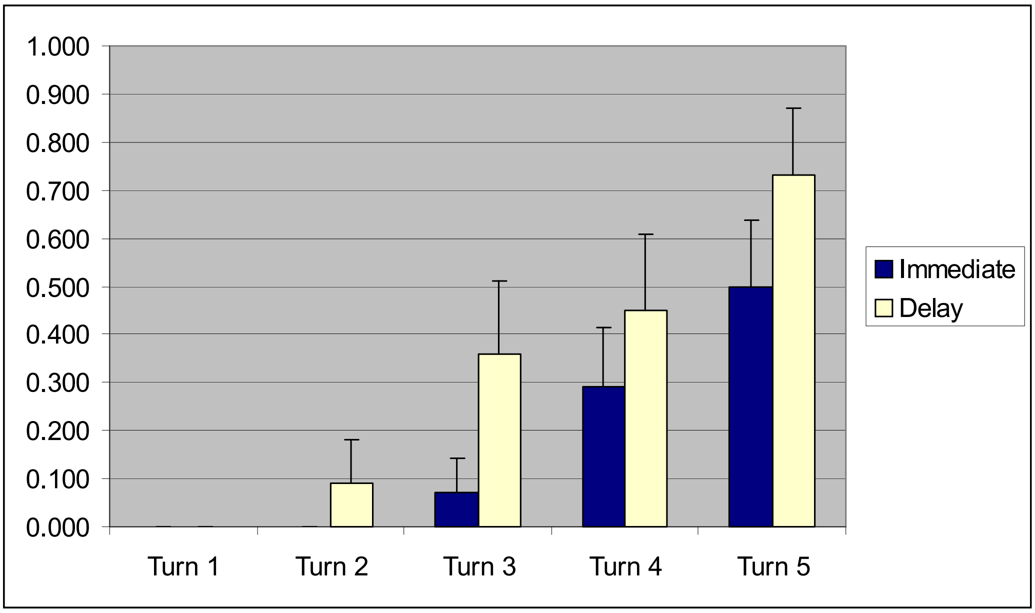

Figure 6.8 – Average Success in Each Repetition of the Turn Task

	Feedback	Mean	Std. Deviation	Std. Error Mean
Turn 1	Immediate	0.00	0.000	0.000
	Delay	0.00	0.000	0.000
Turn 2	Immediate	0.00	0.000	0.000
	Delay	0.09	0.302	0.091
Turn 3	Immediate	0.07	0.267	0.710
	Delay	0.36	0.505	0.152
Turn 4	Immediate	0.29	0.469	0.125
	Delay	0.45	0.522	0.157
Turn 5	Immediate	0.50	0.519	0.139
	Delay	0.73	0.467	0.141

Table 6.9 – Average Success in Each Repetition of the Turn Task Means

	Levene's Test for Eq. Of Variances			t-test for Eq. of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.
Turn 2	Eq. Var.	6.360	0.019	-1.135	23.000	0.268	-0.090
				-1.000	10.000	0.341	-0.090
Turn 3	Eq. Var.	17.720	0.000	-1.866	23.000	0.075	-0.290
				-1.739	14.359	*0.103	-0.290
Turn 4	Eq. Var.	1.991	0.172	-0.850	23.000	0.404	-0.170
				-0.839	20.386	0.411	-0.170
Turn 5	Eq. Var.	3.354	0.080	-1.135	23.000	0.268	-0.230
				-1.150	22.513	0.262	-0.230

Table 6.10 – Average Success in Each Repetition of the Turn Task t-values

Figure 6.11 and Tables 6.12 and 6.13 present the analysis of the average grade for each acceleration for the two groups. Both groups start with a non-significant difference in performance for the first acceleration (300.25 average grade for the delayed, and 330.36 for the immediate, with no statistical significance of difference). From there, the delayed feedback group improves fast in the 2^{nd}-4^{th} trials of the acceleration, with the immediate feedback group catching up around the 5^{th} trial of the acceleration until the 10^{th} trial. The delayed group performed better, with statistical significance for the difference in the following trials:

- Second acceleration highly significantly better (Mi=226.69, Md=54.97, t(14.39)= 2.762, p=0.008).

- Third acceleration significantly better (Mi=214.50, Md=54.97, t(15.635)= 2.514, p=0.011).
- Forth acceleration significantly better (Mi=167.56, Md=32.76, t(14.534)= 2.364, p=0.016).
- Last (tenth) acceleration marginally significantly better (Mi=65.46, Md=30.34, t(18.836)=1.347, p=0.097).

Note that there is some kind of evidence, even though marginal, that the groups did not perform differently during the first acceleration (beginning of the task), while the delayed feedback group performed marginally better in the last acceleration (the end of the task).

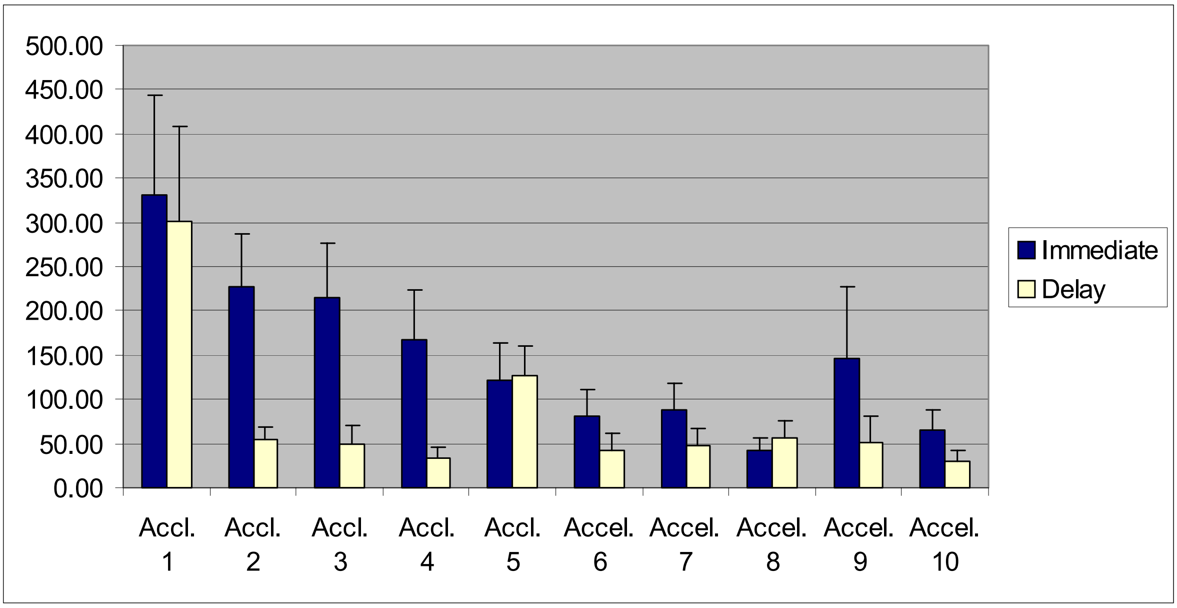

Figure 6.11 – Average Performance in Each Repetition of the Acceleration Task

	Feedback	Mean	Std. Deviation	Std. Error Mean
Acceleration 1	Immediate	330.36	424.140	113.356
	Delay	300.25	360.587	108.721
Acceleration 2	Immediate	226.69	226.532	60.543
	Delay	54.97	46.804	14.112
Acceleration 3	Immediate	214.50	233.508	62.408
	Delay	49.60	66.889	20.168
Acceleration 4	Immediate	167.56	207.240	55.387
	Delay	32.76	44.927	13.546
Acceleration 5	Immediate	121.90	158.321	42.313
	Delay	126.33	115.226	34.742
Acceleration 6	Immediate	81.36	109.146	29.170
	Delay	42.12	66.760	20.129
Acceleration 7	Immediate	88.50	110.243	29.464
	Delay	46.68	69.690	21.012
Acceleration 8	Immediate	42.56	54.153	14.473
	Delay	57.02	61.683	18.598
Acceleration 9	Immediate	145.47	305.481	81.643
	Delay	51.84	97.173	29.299
Acceleration 10	Immediate	65.46	87.144	23.290
	Delay	30.34	38.828	11.707

Table 6.12 – Average Performance in Each Repetition of the Acceleration Task Means

		Levene's Test for Eq. Of Variances		t-test for Eq. of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.
Acceleration 1	Eq. Var.	1.746	0.199	0.188	23.000	0.853	30.110
				0.192	22.817	0.850	30.110
Acceleration 2	Eq. Var.	7.924	0.010	2.462	23.000	0.022	171.710
				2.762	14.396	***0.015	171.710
Acceleration 3	Eq. Var.	8.004	0.010	2.261	23.000	0.034	164.890
				2.514	15.635	**0.023	164.890
Acceleration 4	Eq. Var.	9.452	0.005	2.110	23.000	0.046	134.800
				2.364	14.534	**0.032	134.800
Acceleration 5	Eq. Var.	1.154	0.294	-0.078	23.000	0.939	-4.420
				-0.081	22.904	0.936	-4.420
Acceleration 6	Eq. Var.	0.905	0.351	1.046	23.000	0.307	39.230
				1.107	21.879	0.280	39.230
Acceleration 7	Eq. Var.	1.621	0.216	1.095	23.000	0.285	41.820
				1.156	22.141	0.260	41.820
Acceleration 8	Eq. Var.	0.390	0.538	-0.624	23.000	0.539	-14.470
				-0.614	20.107	0.546	-14.470
Acceleration 9	Eq. Var.	1.140	0.297	0.975	23.000	0.340	93.630
				1.079	16.214	0.296	93.630

	Levene's Test for Eq. Of Variances			t-test for Eq. of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.
Acceleration 10	Eq. Var.	6.645	0.017	1.239	23.000	0.228	35.110
				1.347	18.836	*0.194	35.110

Table 6.13 – Average Performance in Each Repetition of the Acceleration Task t-values

To test the latest observation of the differences in performance in certain accelerations, the following was done:

1) A paired comparison of the first and the last acceleration to look for differences between the groups (in the overall improvement).

2) A paired comparison of the first and second accelerations to look for differences between the groups (i.e., a better improvement from the first to the second acceleration in the delayed feedback group).

Figure 6.14 and Tables 6.15 and 6.16 present this analysis. The two comparisons showed that:

1) The overall improvement was not that much different between the groups (and not significant).
2) In spite of the apparent faster improvement of the delayed feedback group, from the first to the second acceleration of 245.28 vs. a much lower improvement of 103.68 for the immediate feedback group, the difference is not statistically significantly.

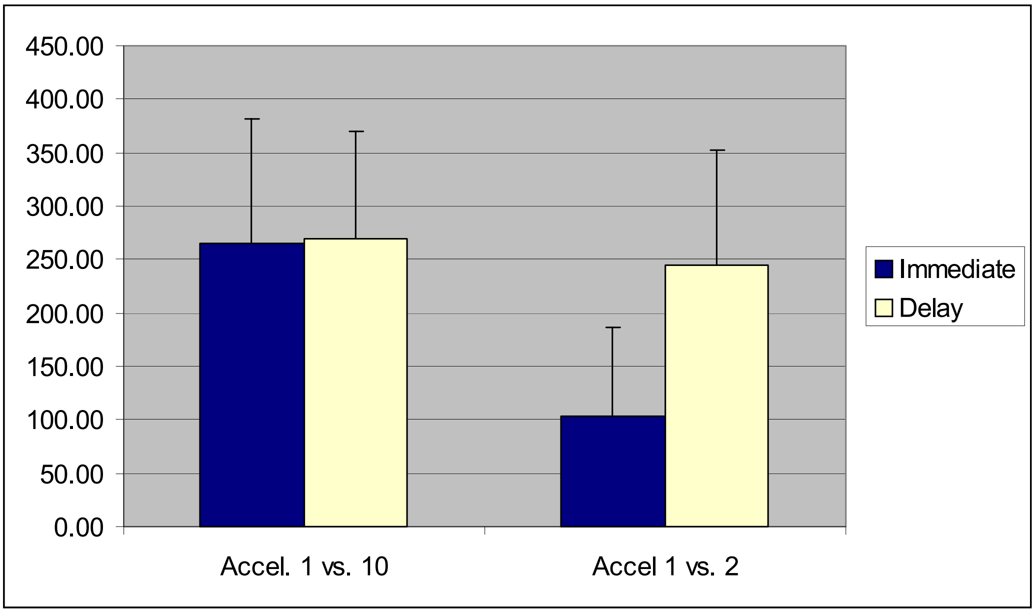

Figure 6.14 – Performance in the First vs. Second, First vs. Last Acceleration

	Feedback	Mean	Std. Deviation	Std. Error Mean
First vs. Last Acceleration	Immediate	264.91	438.015	117.064
	Delay	269.90	331.717	100.016
First vs. Second Acceleration	Immediate	103.68	309.837	82.807
	Delay	245.28	356.821	107.586

Table 6.15 – Performance in the First vs. Second, First vs. Last Acceleration Means

	Levene's Test for Eq. Of Variances			t-test for Eq. of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.
First vs. Last Acceleration	Eq. Var.	2.026	0.168	-0.031	23.000	0.975	-5.001
				-0.032	22.985	0.974	-5.001
First vs. Second Acceleration	Eq. Var.	0.128	0.724	-1.062	23.000	0.299	-141.606
				-1.043	19.967	0.309	-141.606

Table 6.16 – Performance in the First vs. Second, First vs. Last Acceleration t-values

Questionnaire

Regarding the results of the questionnaire, no hypothesis was made, but it is interesting to learn about the groups' impression about the feedback. Therefore, in this analysis, a two-tailed t-test is used.

Both groups evaluated, using a Likert scale, the pleasantness, usefulness and timing of messages about the same, with a slightly higher grading of the delayed group. The delayed feedback group evaluated the clearness somewhat better than the immediate feedback group. However, this difference is not statistically significant (see Figure 6.17 and tables 6.18 and 6.19).

The resulting average evaluation that the subjects gave the feedback (as used in the questionnaire) can be described as:

- Clearness: immediate - "Slightly clear", delayed – "Somewhat clear"
- Pleasantness: "Slightly pleasant"

- Usefulness: “Somewhat useful”
- Timing: “Slightly too late”

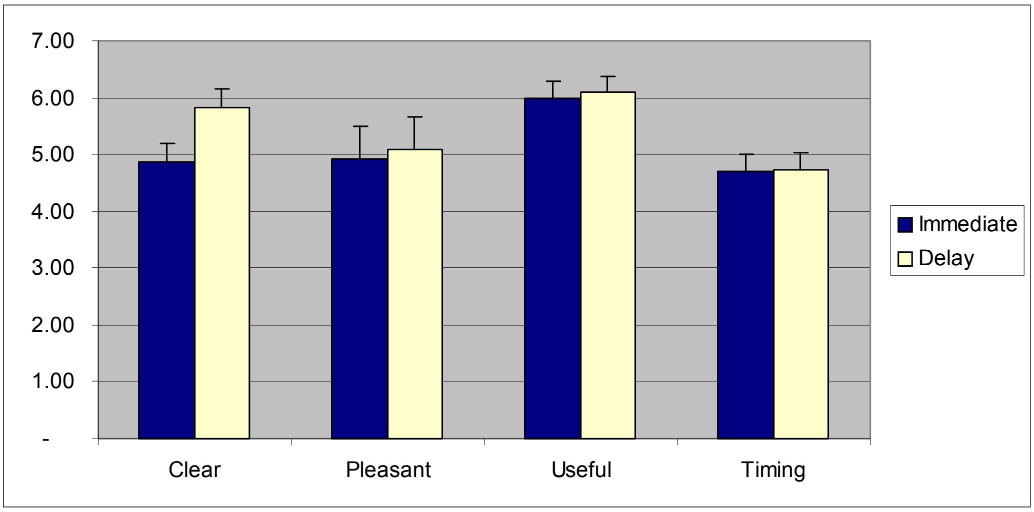

Figure 6.17 - Questionnaire (Likert Scale) Means

	Feedback	Mean	Std. Deviation	Std. Error Mean
CLEAR	Immediate	4.86	1.875	0.501
	Delay	5.82	1.079	0.325
PLEASANT	Immediate	4.93	1.492	0.399
	Delay	5.09	1.921	0.579
USEFUL	Immediate	6.00	0.784	0.210
	Delay	6.09	0.944	0.285
TIMING	Immediate	4.71	0.994	0.266
	Delay	4.73	1.009	0.304

Table 6.18 - Questionnaire (Likert Scale) Means

	Levene's Test for Eq. of Variances			t-test for Eq. of Means		
		F	Sig.	t	df	Sig. (2-tailed)
CLEAR	Eq. Var.	7.935	0.010	-1.511	23.000	0.145
				-1.609	21.336	0.122
PLEASANT	Eq. Var.	3.621	0.070	-0.238	23.000	0.814
				-0.231	18.521	0.820
USEFUL	Eq. Var.	0.804	0.379	-0.263	23.000	0.795
				-0.257	19.404	0.800
TIMING	Eq. Var.	0.026	0.874	-0.032	23.000	0.975
				-0.032	21.469	0.975

Table 6.19 - Questionnaire (Likert Scale) t-values

No significant results were found for the interaction of gender, age, and driving experience.

Observations

During the experiments, the experimenter observed some interesting behaviors and comments of the subjects, as follows:

1) Most of the subjects did not stop completely (even during the normal drive situation to and from the experiment area). Instead, they just used the brake to slow down the car and then continued. It was especially obvious in the turn task, in which they failed to stop even though they knew they had to. They expressed

their thoughts by saying, “but I did stop”…”well, maybe I didn’t stop completely”.

2) The subjects that thought that the feedback was pleasant explained it by the gender of the voice, they said, “it is a women’s voice”.
3) Some subjects thought that the voice was synthesized, even though it was human recorded voice.
4) The subjects called the feedback source “she” and not “the car” or “the software” or “the computer”. Apparently, because of the use of a human voice, they gave it a personality. This is similar to previous findings (see [Reeves & Nass 1996]).
5) When evaluating the timing of the feedback, some subjects, some from the immediate feedback group, commented that the feedback was too late and explained that it was given after the mistake was made, thus not enabling them to fully correct it (this is also reflected in the questionnaire answers regarding the timing of the feedback).
6) Almost all the subjects, once received the feedback, instead of trying to improve (e.g., by immediately pressing the accelerator more when they got the feedback “more gas”) they just treated the trial as failure and chose to improve only in the next trial.

7. Conclusions and Future Directions

The contribution of this work is a design for an educational warning system, as well as some initial evidence for the importance and the advantage of using delays in such systems. The next section summarizes the conclusions reached from the experiment, and in the following and last section, some future directions are proposed.

Conclusions

This work investigated three hypotheses and the results suggest that delayed (educational) warnings are better as follows:

1) **The subjects in the delayed feedback group would have a better understanding of the task than those in the immediate feedback group.**

   The marginal evidence for the understanding, found only in the acceleration task, suggests that in tasks such as the acceleration task, which requires tuning and not simple learning, delaying the feedback improves the understanding of the task. This could be explained by the fact that in the acceleration task, the driver tunes his or her pressure on the accelerator by “feeling” the car (e.g., the G force applied on the car, the noise of the engine) and therefore learns more clues from the task itself before even getting the actual feedback.

2) **Subjects in the delayed feedback group would perform the task better.**

   There is significant evidence in both tasks that delayed feedback contributes to the performance. In the acceleration task the difference is stronger. This suggests that delayed feedback contributes to better task performance in learning and tuning tasks. Also, in tuning tasks, the effect is stronger (with similar possible explanations to the differences found as in the previous hypothesis).

3) **Subjects in the delayed feedback group would improve more and faster than the immediate feedback group.**

   In spite of the faster improvement apparent in the performance per trial (see Figures 6.8 and 6.11) and the significance of better performance in the relatively first trials[11] and better performance in the last trial of the acceleration task, no solid evidence was found for this hypothesis.

In addition to the above, there is no evidence that the delay affects the acceptance of systems by the drivers or their concept of the clearness, pleasantness, usefulness and timing of the feedback.

This work has shown that there is some evidence that delayed messages are superior. More importantly, it is not evident that it is inferior, which makes it preferable to immediate feedback that may, as noted, distract the driver from the driving task.

Future Directions

There is still much research to be done to continue this work in the field of the car architecture and educational warning systems, as well as in the area of delays in warning systems. These include:

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[11] With a similar starting point to both groups.

1) **Improve the Educational Warning System Design.**

The design presented in this work is a high-level design. A more comprehensive and detailed design needs to be presented before the system can be fully implemented. This design should include the exact parameters and thresholds for the algorithm, more specific stress and distraction detection algorithms, etc. In addition, there are some other aspects that can be added to it such as enabling the driver to feedback the system itself on its generated output. As described in [Reeves & Nass 1996], if the system is one sided and only gives feedback to the driver, without receiving feedback from the driver on its performance, the driver may get frustrated. For example, it could enable the driver to criticize the system on its behavior (e.g., using a microphone, telling the system “I hated this”).

Another example is taking into account privacy issues – how the system should behave when there are passengers on board. For example, which feedback (e.g., negative, positive), what type of feedback (e.g., public - audio, private - tactile) and how much feedback should be given to the driver when there are passengers in the car.

2) **Implement the Intelligent Layered Architecture.**

Implement in the car, in a computer inboard, the layered architecture while providing support for all the applications running in the car, including the proposed Educational Warning System.

3) **Implement and Test the Design.**

Extend CarCoach to fully support the design, as well as the Intelligent Layered Architecture. Then CarCoach would need to be tested for its reliability, but more importantly, to test its acceptance by the drivers in a long term driving situation. For example, by letting drivers use the car during a period of weeks or months.

4) **Repeat the study with improvements.**

It can be beneficial to repeat the study done here with small changes. First, to provide timing information in the delayed feedback (e.g., "Less gas at the beginning"), to eliminate the understanding problem reported herein. Second, in the acceleration task, modeling of the RPM was done to decide when the subjects were exerting the car. RPM depends on the state of the gear and therefore is not even during the stage of the acceleration (i.e., increases or decreases depending on the gear and the speed). Therefore, it is recommended to use the throttle position for this threshold as well.

5) **Study delays more thoroughly.**

There is still much to be done to more thoroughly study delays. First, there is a need to learn more its effects on performance improvement. Second, more testing of possible effects and benefits to drivers.

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Terms and Acronyms

GIDS – Generic Intelligent Driver Support

GPS – Global Positioning System

KR – Knowledge of Result

RHT – Risk Homeostasis Theory

RTI – Road Transport Informatics

Appendix A: MIT Driving Study Consent Form

1. Participation in this test is entirely voluntary. You are free to withdraw your consent and discontinue participation in the test at any time.
2. For your participation, you will get a gift worth 10$, to be kept even if the experiment ends before completion.
3. The purpose of this study is to assess the functionality of driver feedback channels including vibrating steering wheel, pedals, and seat and audio and visual displays.
4. In the study that will take approximately 1:30 hours, from which you will spend an hour driving in the greater Boston/Cambridge area, normally within a 20-mile radius of MIT. Information about your driving will be logged into a computer. The steering wheel, pedals and seat will vibrate and audio/visual messages will be displayed occasionally. Your role is to experience that and answer the experimenter's questions. Before/After driving, you will be asked to complete a questionnaire. You may decline to answer any questions. All the data that will be collected during the experiment or answers you will provide for questionnaires will be kept separately from your personal information. Your name will be kept confidential and will not be used in any way in evaluation and publication of experimental data. If you wish your data to be ignored and destroyed you may ask for it at any time.
5. Feel free to ask any questions concerning test procedures at any time.
6. You must be a licensed driver and you must obey the motor vehicle laws of the state of Massachusetts. Because of the serious nature of driving, safety and attention to the driving task is the first priority and the experiment is secondary. As with all driving, by participating in this test you put yourself at risk of having a motor vehicle accident. You will be expected to wear a seat belt while driving. You will not drive in dangerous weather conditions. You will not be identified and any reported result so there is neither risk of invasion of privacy, embarrassment, or exposure of sensitive or confidential data nor any other personal risk. The vehicle used in this study is owned and insured by the DaimlerChrysler Corporation.
7. In the unlikely event of physical injury resulting from participation in this research, medical treatment will be available from the MIT Medical Department, including first aid emergency treatment and follow-up care as needed, and your insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. Making such medical treatment available or providing it does not imply that such injury is the Investigator's fault. By participation in this study you are not waiving any of your legal rights.
8. You may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, MIT 253-6787, if you feel you have been treated unfairly as a subject.
9. As a subject, you will get a copy of this Consent Form.
   Subject Name: ___________________________ Signature ____________

   Experimenter Signature____________________ Date___________

Appendix B: Questionnaire

Subject number: ____
Age: ___ Sex: M/F
Number of years driving: ____
Feedback: Immediate/Delay

1. The feedback was:

1	2	3	4	5	6	7
Completely unclear	Somewhat unclear	Slightly unclear	No opinion	Slightly clear	Somewhat clear	Completely clear

2. The feedback was:

1	2	3	4	5	6	7
Completely unpleasant	Somewhat unpleasant	Slightly unpleasant	No opinion	Slightly pleasant	Somewhat pleasant	Completely pleasant

3. The feedback was:

1	2	3	4	5	6	7
Completely unuseful	Somewhat unuseful	Slightly unuseful	No opinion	Slightly useful	Somewhat useful	Completely useful

4. The feedback timing was:

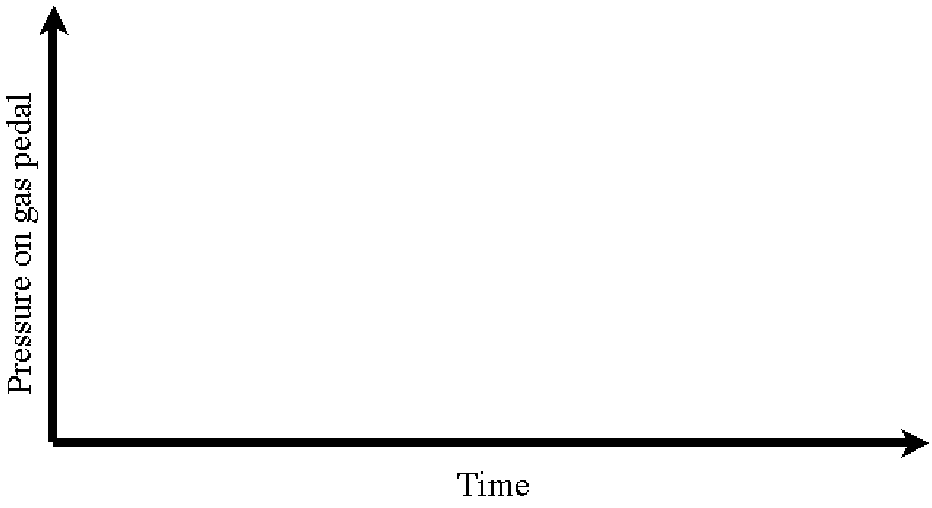
1	2	3	4	5	6	7
Completely too early	Somewhat too early	Slightly too early	On Time	Slightly too late	Somewhat too late	Completely too late

5. The acceleration task required you to:
   (Choose the sentence that describes it the best)
   a. Accelerate.
   b. Accelerate rapidly but not as fast as possible from.
   c. Accelerate rapidly.
   d. Accelerate as fast as possible.

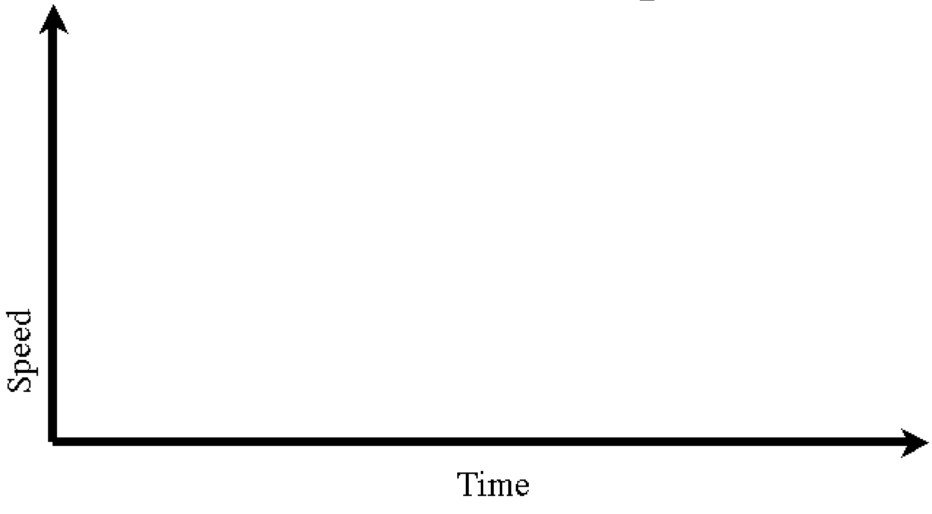
6. The turning task required you to:
   (Choose the sentence that describes it the best)
   a. Turn slowly.
   b. Turn very slowly.
   c. Stop and turn slowly without using the accelerator.
   d. Turn close to the curb.

7. Any other comments you have on the task:

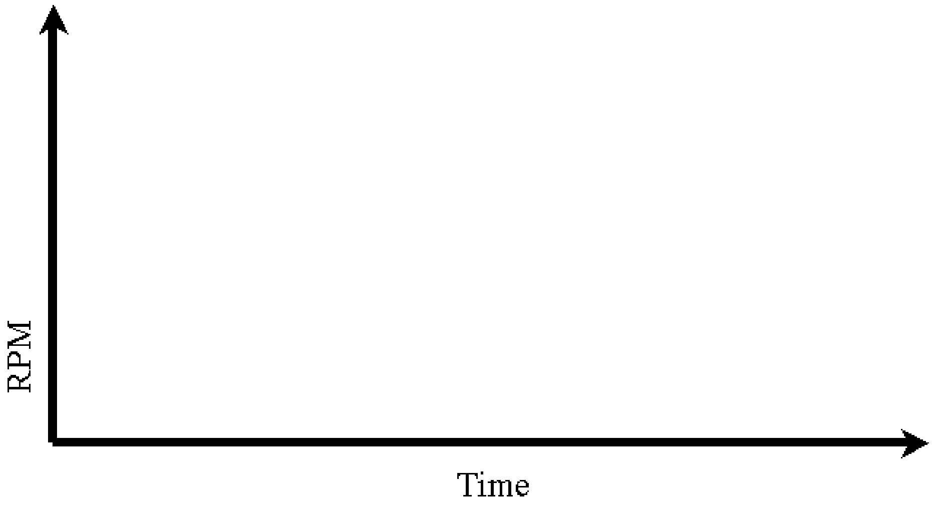
Acceleration - Gas



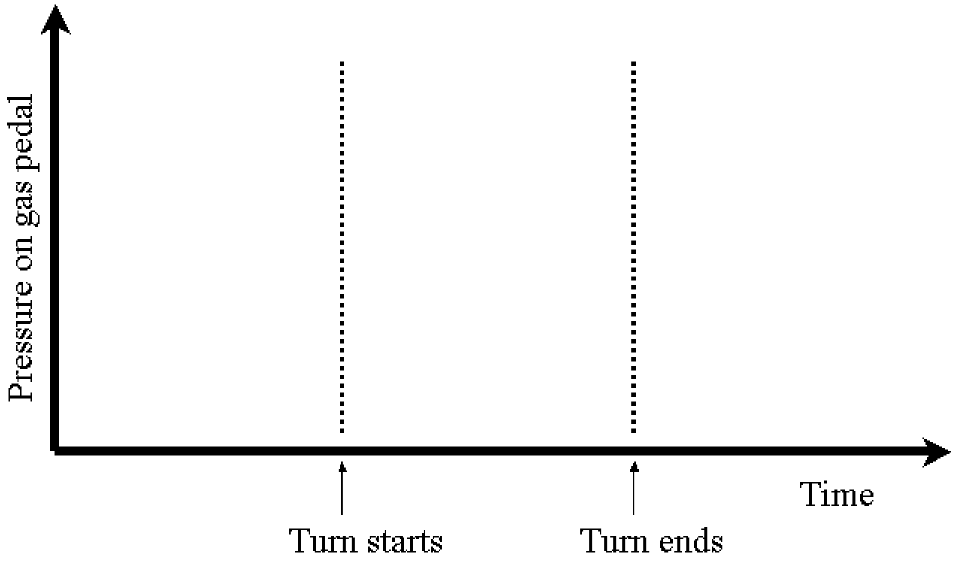
Acceleration - Speed



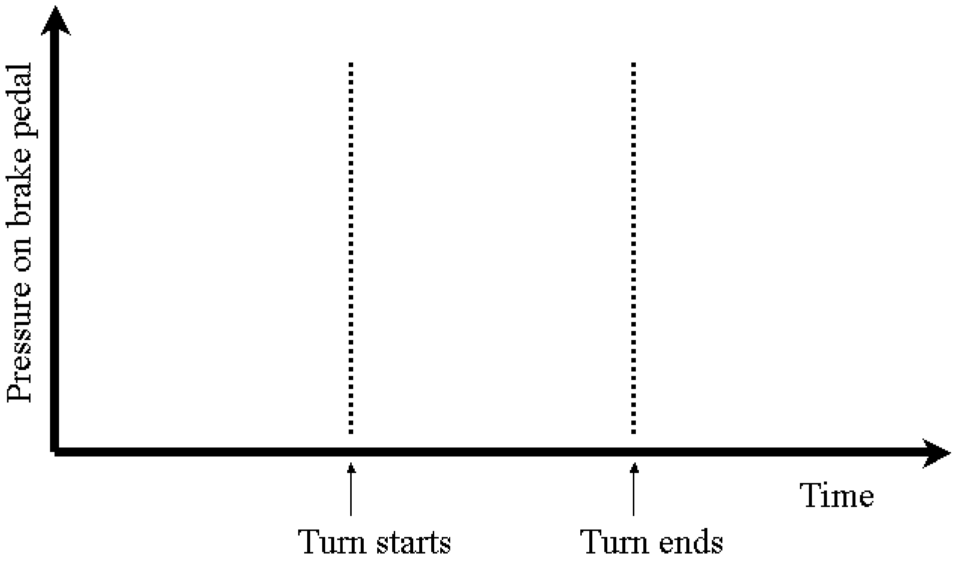
Acceleration - RPM



Turn - Gas



Turn - Brake



Appendix C: Experiment Data Summary

Demographics and Questionnaire answers.

- subject number

#	Age	Gender	Experience	Feedback	Clear	Pleasant	Useful	Timing
1	23	F	5	Immediate	2	3	6	4
2	27	M	10	Delay	5	7	7	5
3	19	F	3	Delay	3	3	4	5
4	47	F	20	Delay	7	7	7	4
5	22	F	5	Immediate	6	7	6	5
6	28	F	11	Delay	6	3	7	4
7	32	M	15	Immediate	6	5	6	5
8	27	M	12	Immediate	3	5	7	4
9	29	M	12	Delay	6	4	7	4
10	26	F	10	Immediate	3	5	6	5
11	27	M	10	Delay	6	6	6	5
12	33	F	16	Immediate	7	4	7	4
13	31	M	15	Delay	2	3	5	6
14	24	F	8	Delay	6	7	5	4
15	19	M	4	Immediate	5	2	4	4
16	24	M	8	Delay	6	3	6	7
17	23	F	7	Delay	2	3	5	4
18	71	F	58	Immediate	3	6	6	4
19	21	M	5	Immediate	5	1	1	4
20	32	M	16	Delay	2	4	6	6
21	24	M	8	Immediate	2	5	6	6
22	21	M	5	Immediate	7	6	6	5
23	32	F	1	Delay	6	7	6	6
24	30	F	12	Immediate	6	6	6	7
25	19	M	1	Delay	6	5	6	4
26	30	F	12	Immediate	7	7	7	5
27	27	M	12	Delay	7	3	6	5
28	24	M	6	Immediate	6	3	5	3
29	26	F	10	Delay	6	7	6	4
30	28	M	12	Immediate	5	5	6	5

Descriptions answers (accel/turn), and turn failures

- subject number

Acceleration task and turn answers, B and C are the correct answers, respectively.

Turn 0 – failed, 1-succeeded

#	Accel. Task	Turn Task	Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Turn failures
1	C	C	0	0	0	0	0	5
2	B	C	0	0	0	0	0	5
3	D	C	0	0	0	0	1	4
4	B	B	0	1	1	1	1	1
5	C	C	0	0	0	0	0	5
6	B	C	0	0	0	0	1	4
7	B	B	0	0	0	0	0	5
8	B	C	0	0	0	0	1	4
9	B	C	0	0	1	1	1	2
10	B	C	0	0	0	0	1	4
11	B	C	0	0	0	1	1	3
12	B	C	0	0	0	0	1	4
13	B	C	0	0	0	1	1	3
14	B	C	0	0	0	0	0	5
15	B	C	0	0	0	0	0	5
16	B	C	0	0	0	1	1	3
17	B	C	0	0	0	0	0	5
18	C	C	0	0	0	1	1	3
19	C	C	0	0	1	1	1	2
20	B	C	0	0	0	0	1	4
21	B	C	0	0	0	0	0	5
22	B	C	0	0	1	1	1	3
23	B	C	0	0	0	0	1	4
24	D	B	0	0	0	0	0	5
25	D	C	0	0	1	1	1	2
26	C	C	0	0	0	1	1	3
27	B	C	0	0	1	1	1	2
28	C	C	0	0	0	0	0	5
29	B	C	0	0	0	0	0	5
30	B	C	0	0	0	1	1	3

Acceleration Successes – for each Acceleration Trial.

- subject number

0-failed, 1-succeeded

#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Number of Accel. Successes**
1	0	0	0	0	0	1	1	1	0	1	4
2	1	1	1	1	1	1	0	1	1	1	9
3	0	0	0	1	1	0	1	1	1	1	6
4	1	1	1	1	1	1	1	1	1	1	10
5	0	0	1	0	0	0	1	1	0	0	3
6	0	1	1	1	0	1	1	1	1	1	8
7	1	1	0	1	1	1	1	1	1	1	9
8	0	0	1	1	1	1	1	1	1	1	8
9	0	1	1	1	1	1	1	1	1	1	9
10	0	0	0	1	0	1	1	0	0	1	4
11	0	0	0	0	0	0	0	0	1	1	2
12	1	1	0	1	0	1	0	0	1	1	6
13	0	0	0	0	0	0	1	0	1	0	2
14	1	1	1	1	1	1	1	0	1	1	9
15	1	0	0	0	1	1	1	1	0	1	6
16	1	0	0	1	0	1	1	1	1	1	7
17	0	0	0	0	0	0	0	0	0	0	0
18	1	0	1	1	1	0	1	1	0	1	7
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	1	1	1	1	1	5
21	1	0	0	1	1	0	1	1	1	0	6
22	0	0	1	1	0	0	1	1	1	1	6
23	0	1	0	1	1	1	1	1	1	1	8
24	1	1	1	1	1	1	1	1	1	1	10
25	1	1	1	1	1	1	1	1	1	1	10
26	0	0	1	0	1	1	1	0	1	1	6
27	0	1	1	1	1	1	1	1	0	0	7
28	0	0	0	0	0	0	0	0	1	1	2
29	0	1	1	1	1	1	0	1	1	1	8
30	1	1	1	1	1	1	1	1	1	0	9

Acceleration Performance – for each Acceleration Trial.

- subject number

The lower the number – the better the performance, "-" is 0 (perfect performance).

#	1	2	3	4	5	6	7	8	9	10
1	708	340	142	679	410	36	102	38	138	12
2	219	173	12	7	55	-	30	154	4	3
3	414	76	135	14	15	4	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-
5	462	244	438	260	146	415	241	113	84	274
6	242	-	-	-	393	-	23	-	-	-
7	12	4	52	43	27	34	18	30	20	11
8	210	38	13	64	79	16	38	3	1	3
9	258	69		-	193	-	-	2	-	-
10	184	304	240	151	89	97	100	141	161	117
11	360	703	609	686	826	902	784	854	-	-
12	661	77	628	-	333	-	340	-	91	112
13	404	439	812	666	429	79	43	30	6	106
14	28	42	22	15	109	65	133	87	29	36
15	-	208	273	82	17	53	21	11	45	101
16	99	42	183	41	204	24	-	60	145	48
17	374	148	272	234	107	121	465	186	300	370
18	-	243	123	73	-	144	-	17	175	8
19	725	732	666	624	915	757	732	883	883	801
20	422	731	548	681	234	31	32	60	190	50
21	-	333	162	10	-	148	0	0	1187.2	212
22	86	112	-	-	-	-	-	-	-	-
23	1,292	52	127	50	109	92	117	131	-	128
24	-	-	36	323	63	59	94	19	26	30
25	19	27	11	5	3	-	5	-	0	23
26	1,134	413	84	158	87	21	38	149	60	10
27	370	56	-	140	166	61	7	57	308	47
28	1,160	846	747	502	455	116	248	76	49	27
29	361	68	56	88	143	217	200	136	83	49
30	10	12	66	-	-	-	-	-	-	-