ECSE 618 Class project

Pre-study on distracted motor reaction time to haptic, visual and acoustic stimulation

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Presented to: Vincent Hayward

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Abstract:
The time from stimulation to the retreat of the right foot from a pedal is measured under distracted conditions for optic, acoustic and haptic stimulation, in order to determine which one provides the fastest feedback. The slowest average reaction time, 1969ms, is found in the optical mode with a LED lighting up. The response times for acoustic (a beep sound) and haptic (vibration of the foot pedal) stimulation are with 486 ms (acoustic) and 691 ms (haptic) much faster. As measurements were taken only from four individuals, further studies will be necessarily to verify this results.

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1. Introduction

Currently there are several driving assistance programs in development, that detect hazardous situations and alert the driver. Examples are lane departure detection [1] or collision avoidance systems [2].
For these programs, different ways of alerting the driver are imaginable: Visual signals, acoustic warnings as well as haptic stimulation. The question is, which one provides the fastest reaction time, especially if the driver is distracted, and would thus be best suited to be implemented in those driving assistance programs. As the most useful reaction in any dangerous situation probably is to reduce speed, the reaction time from alerting to the retraction of the right foot from a pedal (the gas pedal) will be considered in this pre-study.

While signal processing to translate visual and acoustical stimulation in a movement of the foot necessarily needs to pass the brain, haptic stimulation of the foot might be able to use the withdrawal reflex [3] mechanism in the vertebral cortex. This mechanism allows for example that, if a hot surface is touched, the fingers are already retracted before the brain realizes that there is a hot surface. Thus the hypothesis is made, that the foot will be retracted in orders faster when stimulated by a vibratory device at the foot itself than in any other stimulation.

Some reference reaction times of what is to be expected are given by D. Hecht et al. [4]. In their paper, a comparison of the motor reaction time to auditory, haptic and visual stimulation is done for the hands. The haptic stimulus is provided by a Phantom display and the user feedback consists of pressing a button on the pen of the Phantom. The reaction times for the dominant hand in non distracted condition are 430 milliseconds for visual, 330 milliseconds for acoustic and 318 milliseconds for haptic stimulation.
As in our case, the feedback is given by the foot, which means longer nerve connections to the brain, and as users are distracted, reaction times above this numbers have to be expected.

2. Methodology

2.1 Interface devices

2.1.1 Optical Interface

The optical interface for the experiment is a red LED that can be either activated or deactivated. The red color is chosen as it is the color most people connect with danger [5].

2.1.2 Acoustic Interface

The standard alarm of the linux operating system is used. It consists of a beep sound, that is activated when the character set "\a" is written to the standard output in a C-program. To make the alarm more pertinent and to avoid that the single instance is missed, it is repeatedly activated.
Unfortunately, there is a not insignificant delay from the sending of the alarm command to the output of it. In the system used, the average delay over 100 samples is about 508 milliseconds. The measurement was done by simply rectifying the line out signal of the computer to an ADC card and measuring the time between activation of the alarm and the first signal above noise level on the line out.

2.1.3 Haptic Interface

For the haptic interface, a foot pedal with two states, "down" or "up", is used. If the pedal is "down", a push-button is pressed what enables a contact. If the pedal is "up" the button is released, what disables the contact.
To provide haptic feedback to the user in form of vibration, a rumble motor, which was extracted from a toothbrush, is inserted inside the pedal. In order to reduce the delay of the motor upon activation due to its own back EMF, a current driver is used (see appendix).

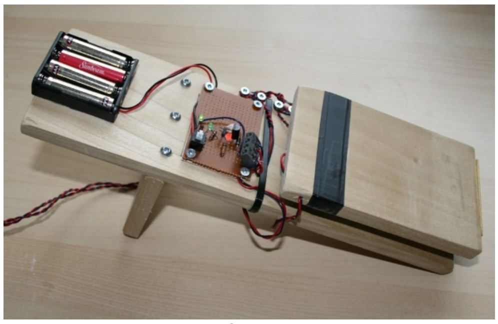


Figure 1: The foot pedal with the necessary electronics.

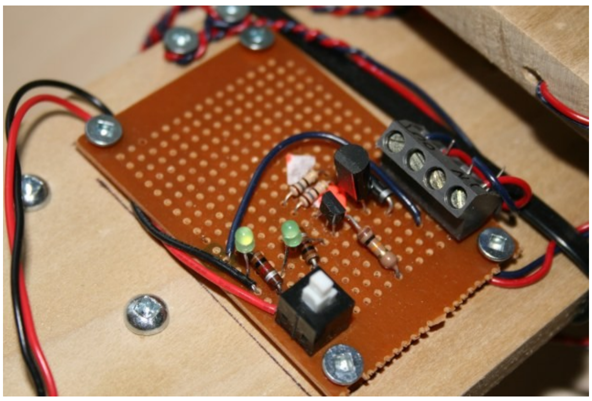


Figure 2: The current driver electronics. The schema can be found in the appendix section.

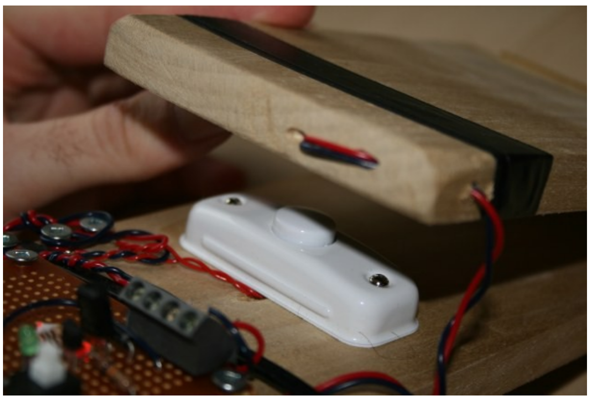


Figure 3: The push-button

2.2. Experimental setup

2.2.1 Subjects

The subjects of this pre-study, 3 males and 1 female, where recruited from friends. While having different backgrounds, all were avare of the purpose of the experiment. No compensation was given for participation. All subjects were required to sign a consent form (see appendix).

2.2.2 Setup

Figure 4: The foot-pedal imitating the gas pedal of a car.

For the experiment, the LED and the haptic interface are connected to the computer on which the experiment-program is running with a ADC-Card (Velleman K8055 USB Experiment Interface Board). To imitate a warning lamp in the armature of a car, the LED is attached right under the computer screen and to enhance its visibility, the room is darkened. The haptic interface is placed under the table at a position comparable to the gas pedal, once the subjects sit down on a chair.

2.2.3 Task

The subjects are asked to hold down the foot pedal and release it as quick as possible when either the LED is on, the vibrator is activated or a beep sound is heard.
In order to distract them, they are asked to play a simple computer game (Xtetris) during the trials, but are alerted that it is crucial to respond as quick as possible to the stimuli.

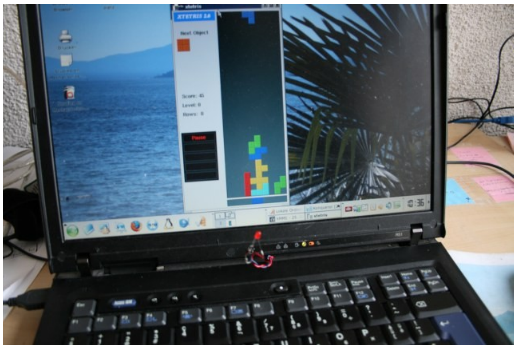


Figure 5: The computer screen with Xtetris running and the deactivated LED next to it.

2.2.4 Procedure

Three runs of about 5 minutes are done with each subject. The first one is a test run to familiarise with the devices, the stimuli and the Xtetris game. Measurements are taken only at the later two runs.
When the foot pedal is down, a computer program (see appendix) sends a stimulus in random mode (haptic, acoustic or visual) after a random time and measures the time from sending the signal to the release of the push-button. After each stimulation the experiment is interrupted and continued only once the pedal is pressed down again.

3. Results

3.1 Reaction time

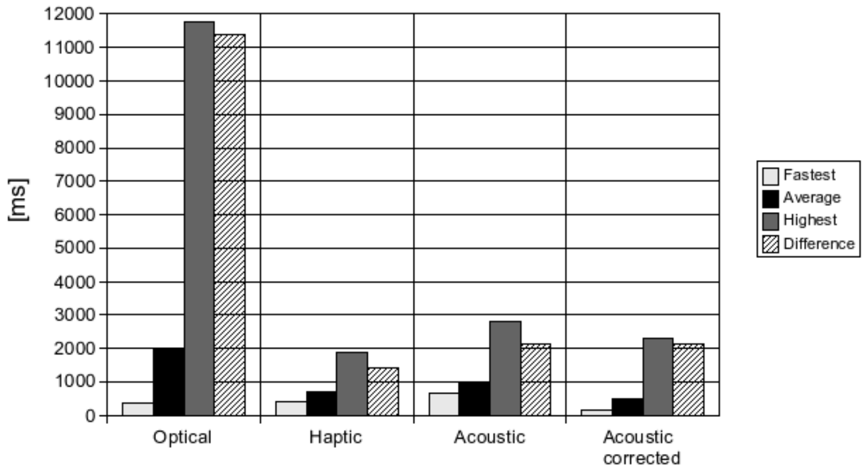


Figure 6: Fastest, average, highest and difference between the highest and the fastest reaction times for each stimulation mode

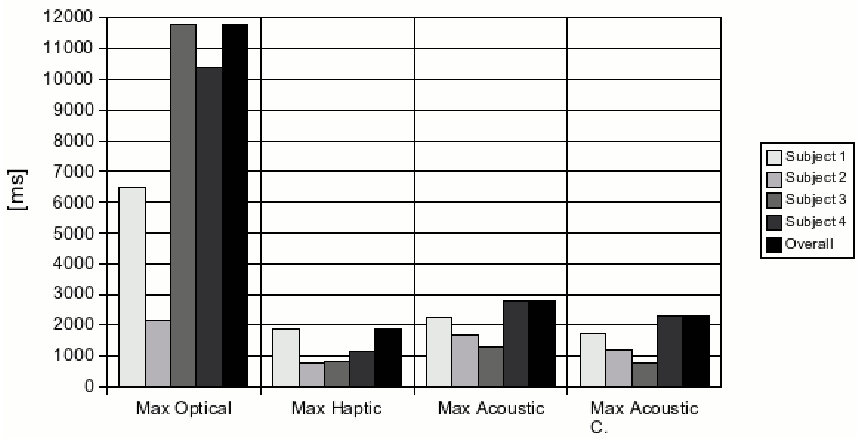


Figure 7: Maximal reaction time for each stimulation mode and each subject

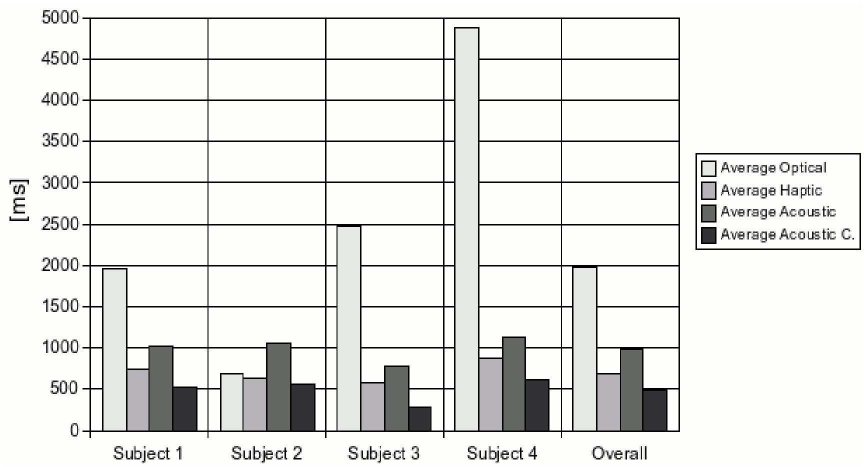


Figure 8: Reaction time by subject

The average reaction time from the raw results is, with 691 milliseconds, lowest with haptic stimulation (see figure 6). However, if the acoustic result is corrected by the delay of about 508 milliseconds caused by the output method, its average becomes slightly slower with 486 milliseconds. The worst result has clearly the optical stimulation, with an average response time of over 1.9 seconds.

The optical mode performs also bad, looking at the variations of the response time. It has a difference of 11.4 seconds between the fastest and the slowest reaction recorded and variations between candidates are big (figure 7 and 8). Haptic stimulation, while being slightly slower in average and maximal reaction times than the corrected acoustic results, but being much faster than optic stimulation, has the overall smalest difference between the fastest and the slowest reaction.

The maximal reaction time is obtained for each candidate in the optical mode while haptic and acoustic maxima are significantly better and very close one to each other.

3.2 Learning effect

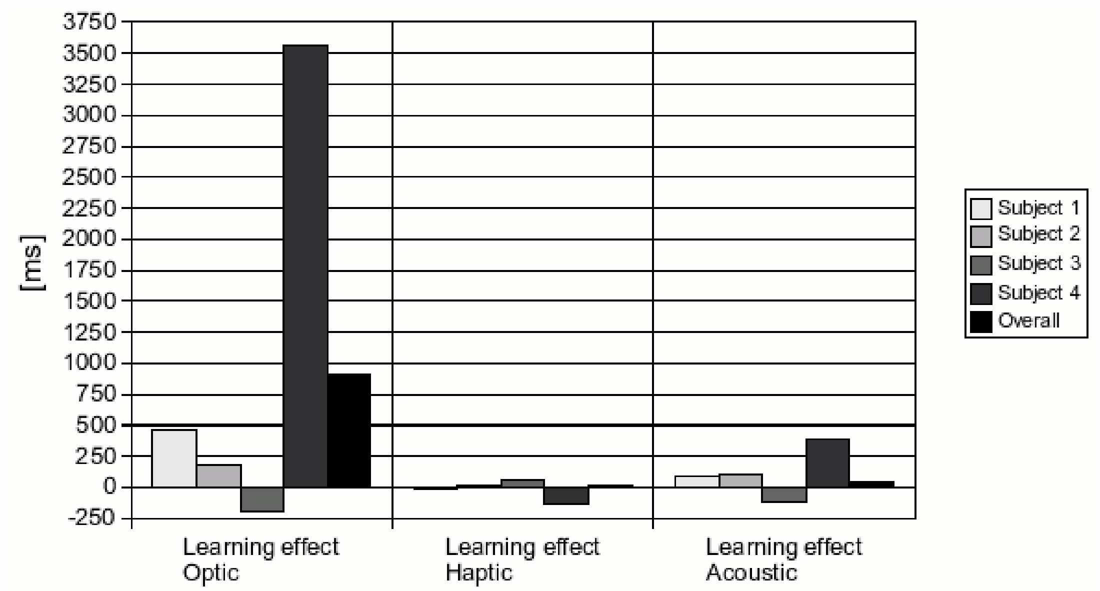


Figure 9: Learning effect: The performance difference between run 2 and run 3

As the data for run 2 and 3 of each candidate are recorded separately, it is possible to look if there is any improvement between the runs that could be associated to a learning effect. To do this, the performance between the two runs is compared (differences of the averages) for each mode. The result is that the candidates got considerably better in reaction to the optical stimulation only. No big difference can be seen in the acoustic or haptic mode.

4. Discussion

4.1 Results

The obtained results are, as expected, higher than those of Hecht et Al. [4] in the non distracted reaction task on the dominant hand. The averages are 1969 milliseconds for optical (Hecht et Al.: 430 ms), 486 milliseconds for acoustic (Hecht et Al.: 330 ms) and 691 milliseconds for haptic (Hecht et Al.: 318 ms) stimulation.

The optical stimulation in the experiment showed to be absolutely not recommendable for the application in cars. First, the average response time is clearly slowest, but more important, some signals have completely been missed. A explanation for this might be that, unlike the other two stimulation modes, the subject has to play an active role in receiving the signal by looking directly at the LED in order to detect it.
As there was some improvement during the trials one might want to verify how many test runs have to be done until the user does not get any more better.

The results for the acoustic and haptic feedback are too close to determine, based on the low number of participants in this pre-study, which one is better suited. At the time, both seem to be possible candidates for the application, as they provide low averages and no signals are missed. Further on, there is no learning curve, what means that the users perform well right from the beginning, a feature that is highly desirable in the application as a warning device in a car.

4.2 Methodology

Influence of position and stimulation type

The response times depend not only on the stimulation mode, but also on other parameters, like stimulation location, form of stimulation and intensity of stimulation. Thus in a full scale study, for the optical feedback, various LEDs with different colors and intensities might be placed at different locations. Probably as well a flashing LED will cause more attention than simply lighting it up. For the acoustic feedback, different volumes and sounds might be tried. The haptic stimulation as well could be done at different positions (seat, steering wheel, gas pedal) and in different types (pulsation, frequency).

Multi-modal stimulation

As in their paper [4] Hecht et. Al. found that the reaction times for multi-modal stimulations are always faster than the ones for single modal stimulation, multi-modal stimulation combinations (haptic-acoustic, haptic-visual and acoustic visual) should also be included in an extended study.

Noise

It was not tried what happens if there is acoustic and vibratory noise present. The vibration of the gas pedal might be effective in the test setting, but what happens in a real car that vibrates itself, is unpredictable. In the same way, acoustic signals might be missed if the driver listens to music at high volume.

Cross contamination

Usually, when doing haptic experiments, people where earmuffs or other protection in order not to confuse the haptic experience with the sound produced by the haptic device. This was not done in this experiments and might be considered later on. But the rumble motor inserted in the gas pedal does not produce any detectable noise, thus it can be assumed that there was no cross contamination of the results.

Delays

The purpose of this pre-study was not to measure the time from stimulation to reaction of the human subjects, but the over all response time, from the moment a computer program decides, that there must be a warning, to the users reaction to this warning. Thus the remaining delays due to the hardware implementation have to be included. It is clear however that they should be reduced as much as possible. While in the haptic and optic feedback, not much more reduction will be possible, some clear improvement can be expected by doing a hardware implementation of the sound ouput.

Distraction

The distraction chosen, a tetris game, is very simple and might not be comparable to the task of driving. Further on during the experiments, it was observed, that the subjects got little jolts from the very alarming sound signal. Such reactions might even cause car accidents. Thus ideally, a full scale driving simulator would be used and not only the response time, but as well the driving performance measured.

4. Conclusion

This pre-study gives some useful information about which stimulation method provides fastest feedback times on distracted users. The number of participants is clearly too low to have statistically evident data, but the tendency observable is, that optical stimulation is much worse than acoustic and haptic stimulation. The hypothesis that the motor response time to haptic stimulation is in orders smaller, because of the withdrawal reflex mechanism, could not be supported by the data, as the acoustic stimulation provided approximately the same results.
Based on the results and the improvement suggestions in the discussion section, it should be possible to do a large scale study that will produce significant results on what stimulation mode and type should be used and where the actuator has to be placed to get fastest response times as well as to ensure that no warning is missed.

5. Ethic approval

This project was reviewed and approved in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Subjects by the Research Ethics Board I of McGill on november 20, 2007. (REB File # 144-1107)

References

[1] S. Mammar, J. Saint_marie, S. Glaser, “On the use of steer-by-wire systems in lateral driving assistance applications”. 19th IEEE International Workshop on Robot and Human Communication, Bordeaux-Pars, 2001

[2] L. M. Stanley, “Haptic and auditory interfaces as a collision avoidance technique during roadway departures and driver perception of these modalities”. Unpublished D.Eng., Montana State University, Montana., 2006

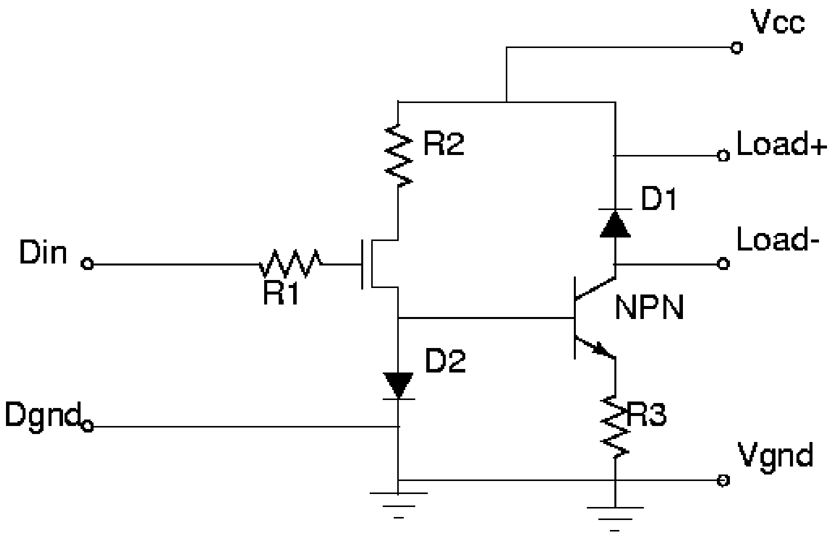
[3] M. M. Morgan, “Direct Comparison of Heat-Evoket Activity of Nociceptive Neurons in the Dorsal Horn With the Hindpaw Withdrawal Reflex in the Rat”. Journal of Neurophysiology. 1998

[4] D. Hecht, M.Reiner, G. Halevy, “Multi-Modal Stimulation, Response Time, and Presence”. Presence 2005.

[5] A. H. S. Chan, A. J. Courtney. “Color associations for Hong Kong Chinese”. International Journal of Industrial Ergonomics 28, 2001

Appendix

Current source schema



Component List	
R1	10kOhm
R2	1kOhm
R3	9Ohm
D1	Diode, max 1Amp
D2	Diode, Vd=1.94V
MFET	ZVN3320A
NPN	2SC1518, Vbe=0.60V

Ports	
Din	Digital In
Dgnd	Digital Ground
Vcc	Voltage Source + (6V)
Vgnd	Voltage Source Ground
Load+	Load connector +
Load-	Load connector -

Source Current at Load connections

$$I_{load}=\frac{(V_D-VBE)}{R_3}=149mA$$

Consent form

You are being invited to participate in class project experiment for the Haptics Class (ECSE 618) at McGill by Stefan Bracher, supervised by Vincent Hayward..
The study collects data to determine which way of stimulation causes to shortest time between stimulation and retraction of the right foot while being distracted. To do so, you will be asked to play a simple computer game while resting your right foot on a foot pedal. Different stimulations, a vibration of the foot pedal, a beep-sound by the computer and a LED that lights up are given and you are asked to retract your foot as fast as possible when you detect one of these stimulations.

The safety concerns of this study are minimal. The foot pedal will not vibrate more than a cellular phone rings in vibration mode, the speaker volume of the computer is reasonable and the LED is not bright.

The experiment will last for about 5 minutes. After each stimulation the experiment is interrupted and continued only after you put the foot back on the pedal.

No data that could be used to identify you will be recorded together with the results.

Please note that you are free to withdraw from this study at any time, and that you are entitled to have further explanation if necessary.

Finally, should you have any concerns or complaints about this study, you may contact Professor Hayward at XXXX.

I have read and understood this consent form. I have agreed to participate voluntarily in this study.

Participant's name and signature: ________________________________

Today's date: ________________

Witness: ____________________

Program C-Code

```
/*****************************************************************************
// Program:        haptics_k8055/main.c
// Description:    Makes a response time measurement for 3 different types of
//                 stimuli, using Velleman USB Experiment Interface Board K8055
// Author:         Stefan Bracher
// Using:          libk8055 Library by Pjetur G. Hjaltason to connect to the
//                 USB board
//
// Ports:          Digital Out:      1 = Optical (All digital outs for verification only)
//                                   2 = Foot
//                                   3 = Sound
//                 Digital In:       1 = Response (Cable with isolation band)
//                                   5 = Stop program
//                 Analog out:       1 = Optical
//                                   2 = Foot
// Hint:           To execute must have right to open a USB access, this is
//                 normaly not allowed for non-root users
// Compile:        qmake -project
//                 qmake
//                 Add "LIBS     = $(SUBLIBS) -lusb " to the makefile
//                 make
*****************************************************************************/
/***INCLUDES***************************************************************/
#include <string.h>
#include <stdio.h>
#include <usb.h>
#include <assert.h>
#include <sys/time.h>
#include "k8055.h"              // libk8055 Library by Pjetur G. Hjaltason
#include <time.h>

/***********************************************************************/
/***GLOBAL VARIABLES***************************************************/
int board_nr = 0;               // The assigned port number for the USB board
/***********************************************************************/
/***FUNCTION TIME_MSEC*************************************************/
// Function: time_msec()
// Description: Gives back the unix time in milliseconds
/***********************************************************************/
int time_msec()
        {
        struct timeval tv;
        gettimeofday(&tv, NULL);
        return ((1000*tv.tv_sec)+(tv.tv_usec/1000));
}
/***********************************************************************/
/***FUNCTION TEST******************************************************/
// Function: test
// Description: Performs a test on dch_out
// Input:   int dch_out: The channel on which to send a stimuli
//          int dch_in:  The channel on which to look for a response
// Output: time between sending of the stimuli and response
/***********************************************************************/
int test(int dch_out, int dch_in)
{
/*...Local variables..................................................*/
int rand_time;                  // Random time
int starttime;                  // Time at start
int in=1;                       // Variable in which the response is saved
rand_time = rand() % 10 + 1;    // Random number between 0 and 10
/*...................................................................*/
usleep(rand_time*1000000);                      // Wait for a random time
if (dch_out<3)
{
OutputAnalogChannel(dch_out, 255);
}
else
{
printf("\a");
fflush ( stdout );
```

```
}
SetDigitalChannel(dch_out);    // Send the stimuly
starttime=time_msec();         // Save the time when the stimuly was sent
while(in==1)                   // Wait until response is given
        {
        in=ReadDigitalChannel(dch_in);          //Read channel dch_in
        if (dch_out==3)
                {printf("\a");
                fflush ( stdout );
                }
        }
ClearDigitalChannel(dch_out);           // Clear all outgoing channels
OutputAnalogChannel(dch_out, 0);
return(time_msec()-starttime); // Return time interval
}
/*******************************************************************/
/***FUNCTION MAIN**************************************************/
int main ()
{
/*...Local variables.........................................*/
        int i=0;                // A Counter variable
        int ranNr;  // A random number
        int stop=0;             // Logic state variable, default state=0
        int in=0;
/*..............................................................*/

        if ( OpenDevice(board_nr)<0 ) {                         // Connect to the device
        // Not connected
                        printf("No connection to k8055\n");
                        return (-1);

                } else {
        // Connected

        srand ( time(NULL) );                           // Initiate randum number generator
        ClearAllDigital();                              // Clear all Digital outputs

        while(stop==0)                                  // While in state 0
        {
                while(in==0)                            // Wait until response is given
                {
                in=ReadDigitalChannel(1);               //Read channel dch_in
                }
                ranNr=rand() % 4 + 1;                   // Random number between 1 and 4

                if (ranNr==1)                           // Perform optical test
                printf("%d\t Optical \t %d \n", i, test(1, 1));
                fflush ( stdout );

                if (ranNr==2)                           // Perform Foot test
                printf("%d\t Foot \t %d \n", i, test(2, 1));

                if (ranNr==3)                           // Perform Sound test
                {
                printf("%d\t Sound \t %d \n", i, test(3, 1));
                fflush ( stdout );
                }

                i++;
                in=0;
                stop=ReadDigitalChannel(5); // Read Channel 5 (to stop program)
        }
                }

        /*...Clean up......*/
                ClearAllDigital();
                CloseDevice();
        return 0;
}
```

Experimental Results

	Run1				Run2				Overall			
Subject 1	**Fastest**	**Average**	**Highest**	**Difference**	**Fastest**	**Average**	**Highest**	**Difference**	**Fastest**	**Average**	**Highest**	**Difference**
Optical	376	1735,92	6471	6095	360	2194,33	4343	3983	360	1965,13	6471	6111
Haptic	448	751,14	1872	1424	432	738,25	1432	1000	432	743,56	1872	1440
Acoustic	680	967,11	1755	1075	722	1051,14	2264	1542	680	1025,93	2264	1584
Acoustic corrected	172	459,11	1247	1075	214	543,14	1756	1542	172	517,93	1756	1584
Subject 2												
Optical	464	631,27	2144	1680	471	809,17	2144	1673	464	682,1	2144	1680
Haptic	568	627,75	784	216	575	649,4	784	209	568	634,12	784	216
Acoustic	680	1022,5	1696	1016	705	1122,38	1696	991	680	1062,45	1696	1016
Acoustic corrected	172	514,5	1188	1016	197	614,38	1188	991	172	554,45	1188	1016
Subject 3												
Optical	368	2591,6	10407	10039	536	2391,8	11767	11231	368	2471,72	11767	11399
Haptic	472	550,15	680	208	512	606,4	840	328	472	574,61	840	368
Acoustic	680	843,89	1295	615	664	732,3	921	257	664	785,16	1295	631
Acoustic corrected	172	335,89	787	615	156	224,3	413	257	156	277,16	787	631
Subject 4												
Optical	752	2755,5	4759	4007	4038	6316	10366	6328	752	4891,8	10366	9614
Haptic	816	946,8	1143	327	696	811	936	240	696	878,9	1143	447
Acoustic	776	903,4	975	199	737	1295,14	2810	2073	737	1131,92	2810	2073
Acoustic corrected	268	395,4	467	199	229	787,14	2302	2073	229	623,92	2302	2073
Overall												
Optical	368	1582,74	10407	10039	360	2486,67	11767	11407	**360**	**1969,85**	**11767**	**11407**
Haptic	448	680,34	1872	1424	432	691,1	1432	1000	**432**	**691,26**	**1872**	**1440**
Acoustic	680	945,31	1755	1075	664	1031,35	2810	2146	**664**	**994,17**	**2810**	**2146**
Acoustic corrected	172	437,31	1247	1075	156	523,35	2302	2146	**156**	**486,17**	**2302**	**2146**