AALBORG UNIVERSITY COPENHAGEN

The Correlation Between Galvanic Vestibular Stimulation and Divided Attention

Master Thesis

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2. Introduction

Technological advancement quickly adopts making our daily life easier, changing our everyday habits, and thus transforming our lives. Small devices are cancelling the need of carrying around more devices. Software applications are eliminating the need of hardware pieces, thus transforming the way people spend their time. A recent technical breakthrough is Google glass, which is a lightweight device looking like a pair of sci-fi glasses that has a single see-through display and numerous on-board sensors such as gyro meters, compass, altimeter and GPS. With this small device people do not have a need of carrying a camera or a GPS device with them. It also gives an opportunity not to miss an important moment and surmise to perpetuate them. New technological devices also increase individuals' engagement in the entertainment sphere. Galvanic vestibular stimulation is rapidly gaining popularity in the entertainment area as a controller for people. This is a new concept, which is in the beginning of its investigation. The concept of this device is based on the idea to be connected to human vestibular system and control their balance, thus potentially being able to move the person. It can be used to increase engagement while playing games, for example simulating movements in racing games and in real life. Thus, such device is in progress of development and it is significant to investigate both positive and negative effects it can have in order to prevent the possible damage that can be done to people. The application of such devices will need thorough research about the relation of the vestibular stimulation and other perceptual and cognitive processes when interacting with advanced immersive media. Since our previous work (Parel, Human Standing Balance Relationship with Executive Function, 2013), (Parel, 2012) has been revolving around human balance relation to other brain functions, we found it interesting to investigate the field more. Previous works have had a wide perspective concerning the whole balance system (Parel, 2013), (Johansson, Magnusson, & Fransson, 1995), but evidently isolating them is needed to pinpoint variables (Gaerlan, Alpert, Cross, Louis, & Kowalski, 2012). One device that is capable of influencing just a subset of the balance system is galvanic vestibular stimulator. A galvanic vestibular stimulation (GVS) device is capable to give the users a sense of acceleration through only using the vestibular system (Fitzpatrick & Day, 2004), (Day & Fitzpatrick, 2005), (Curthoys & MacDougall, 2012).

Initial Problem Statement

Following what we have found interesting and integral to the problem, we came up with an initial problem statement:

Is there a correlation between human vestibular balance and attention?

3. Vestibular System and Balance

Individuals control their balance depending on their physiological state. However, modern technology, such as galvanic vestibular stimulation (GVS) has investigated the possibility to control human balance. The following paragraphs explore the vestibular system in relation to balance and technology that can make revolutionary changes in human lives.

Human balance might have a significant meaning in the improvement for different areas, such as vehicle simulation trainings, or in the rehabilitation sphere in order, for example, to prevent falling among old adults. Based on the goals of our study it is important to investigate vestibular system and the significance it might have for achieving balance.

The vestibular system or vestibular apparatus is located in each ear and provides sensory information about motion, equilibrium and spatial orientation. The study by Johansson et al. (1995) found that balance can be obtained by a sensorimotor control system that involves sensory input from visual perception (sight), proprioception (touch), and the vestibular system (motion, equilibrium, spatial orientation). Decent balance performance involves clear vision while moving, orientation recognition with respect to gravity, determination of direction and speed of movement, and automatisation of postural adjustments to maintain posture and stability in different conditions and activities. According to Gaerlan et al. (2012), the vestibular system is most distinguished from other systems as it is multisensory and multimodal. What this means, is that the balance system consists of multiple sensory inputs, making it difficult to assess as a single measure, because the performance depends on many factors.

Both visual and proprioceptive systems interact with the vestibular system. In the visual system input from the eyes is transferred through the sensory receptors in the retina, which send impulses to the brain when the light strikes them. Proprioceptive information is collected from the skin, muscles and joints involving receptors that are sensitive to stretch or pressure. All sensory receptors respond by sending impulses to the brain. Input from the vestibular system can be received when vestibular organs on both sides of the head are functioning properly, then the brain receives symmetrical impulses. The cerebellum is a coordination center of the brain. Watson et al. (2008) have found that: "*the cerebellum provides information about automatic movements that have been learned through repeated exposure to certain motions*". This explains that repeated actions on the balance system teach to optimize balance control. When the vestibular apparatus on both left and right sides of the head are well functioning, they send symmetrical impulses to the brain. Balance information is categorized and combined with previously perceived information contributed by the cerebellum, which is the brain coordination center and the cerebral cortex, which is functioning as a processing and memory center. The coordination center of the brain gives information about automatic actions that have been learned through repeated experience of certain types of movements. The brain contains previously learned information; for example, if a road is slippery, a person travelling the road is switching to a different type of movement in order to safely navigate. The study by Watson et al. (2008) emphasizes an example about an individual turn movement by explaining how brains react to that movement: "*[...] when a person is turning cartwheels in a park, impulses transmitted from the brain stem inform the cerebral cortex that this particular activity is appropriately accompanied by the sight of the park whirling in circles.*" In the realms of this context, practicing teaches the brain to perceive a rotating visual field as normal during this type of body movement. For example, dancers learn that in order to keep balance while performing they should concentrate their visual perception on one spot in the distance as long as possible. The study by Gaerlan et al. (2012) has found that the visual system is the predominant sensory system for maintaining postural balance. The vision importance was also found in the study by Reed-Jones et al. (2008), which has been investigating the relationship between postural stability and virtual environment adaptation using electrical stimulation techniques of the vestibular sensory system. Postural stability was evaluated by asking individuals to stand on one leg during two conditions: eyes opened and eyes closed. The results showed that visual information controls posture in VE. This shows that a VE environment is sufficient to alter postural control. The method for testing the postural stability is straight-forward and gives an accurate measure, together with some qualitative data. When a person is standing on one leg, but not steadily, it could be noted and used for evaluation later as a means to test the effect of the GVS device.

Understanding the mechanism which maintains balance could also be helpful for medical purposes for creating strategies that can help patients to improve their balance and prevent them from falling. Regarding Watson et al. (2008) who defined balance as: "*[…] the ability to maintain the body's center of mass over its base of support.*" The study by Johansson et al. (1995) describes human balance as follows: "*Since the human body is not statically stable, maintaining upright posture requires continuous anti gravity action by means of coordinated adjustments of the tone of the antigravity muscles, and human postural control can, at least partly, be viewed as a dynamic feedback control system*". This means that a human can be visually observed and analyzed to conclude on their sense of balance.

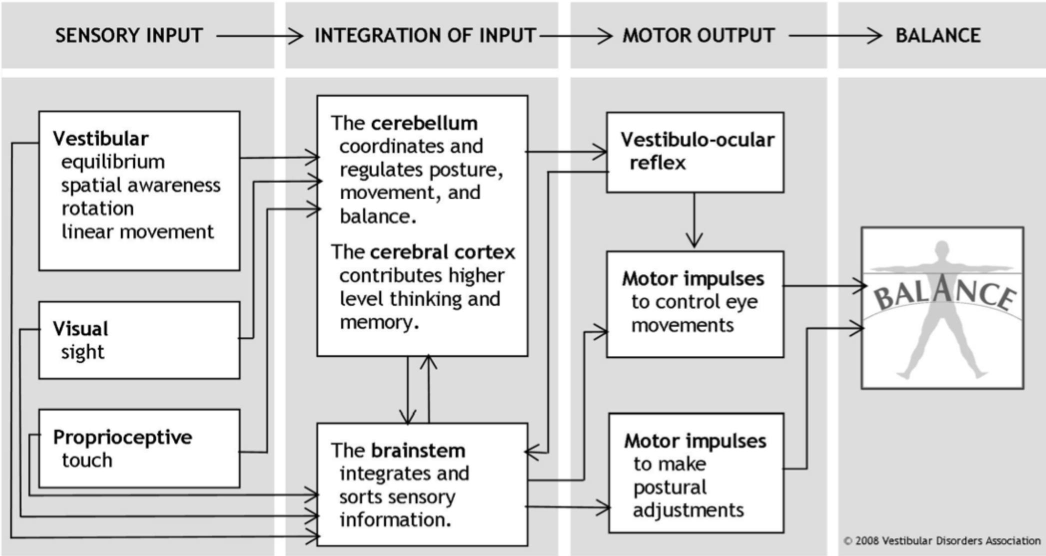

Figure 1. Representation of a complex set of sensorimotor control system, which aids to achieve balance (Watson & Black, 2008)

Balance and aging are interconnected and it is investigated that balance depends on human's age. Research by Kalisch et al. (2011) hypothesized that aging can affect almost all physiological processes, such as: reduction in postural stability, which can be explained by various causes, such as a loss of receptor cells in the vestibular organ, impaired sensory perception, a weakening in muscle strength as well as increased reaction times. Age-related changes in balance were investigated by comparing the performance of healthy young individuals and older adults observing static stance, unidirectional and rotational displacement of their center of pressure. According to Kalisch et al. (2011), Holtzher et al. (2007), Shumway et al. (1997), Buracchio et al. (2011), Verghese et al. (2002), the visible degradation in balance performance of older adults was distinguished.

As it was mentioned earlier in this paragraph, balance is very dependent on human vestibular system. Balance system cannot properly function based only on visual or proprioceptive systems. Galvanic vestibular stimulation is a new method for balance control, which is the point of interest in our work and will be described in the following paragraph.

Galvanic Vestibular Stimulation

GVS is a new research area, which is not well explored yet, but in which interest is growing rapidly as it involves application in different areas, such as entertainment, biomedical, training, and several other fields. It is also a new technique, which is widely used to investigate human balance.

Vestibular system in the ears is what gives a sense of balance, direction and acceleration. An electrical current passed through the vestibular system can alter the sense of balance of the person who has electrodes attached to their heads (Noorden, 2006). This is what is referred to as a GVS device. By sending electrical messages to the vestibular system, the remote controlling of the current can literally put users off balance, sending a person to the right, or left, or straight ahead when walking (Day & Fitzpatrick, 2005).

GVS device is based on two electrodes connected to the mastoid processes on either side of the head (which is a bone located just behind the ear) and wirelessly transmits electrical impulses to the nerves inside the ear, thus altering the sense of vestibular balance (Day & Fitzpatrick, 2005), (Fitzpatrick & Day, 2004), (Watson & Black, 2008). Electrical impulses are stimulating a viscous fluid that activates hair cells located in the inner ear, which are responsible for vertical orientation and linear movement. Rotational movement is detected by the semicircular canals, which are filled with a fluid called endolymph. It is important to avoid connecting the electrodes to hair, because they are an insulator for electrical impulses that are sent to the nerve in the vestibular system.

A GVS device could potentially be used as an extra dimension of realism in a virtual reality application, making sure that the pilot or driver of the simulation is paying attention to the significant changes, which in real world situation would be triggered by the vestibular system.

Types of Stimulation

Before analyzing types of stimulation it is significant to determine the orientation classifications that the galvanic vestibular system is generating. The terms roll, yaw and pitch are used to describe the three planes of rotation around axes (Coulter & Vogt, 2008), (Wardman & Fitzpatrick, 2002). Pitch is determinant for nodding head up and down or more generally the rotation around the x-axis. The roll explains the heads movement from the left to the right shoulder, or panning, or rotation around the z-axis. The yaw explains lateral movement left and right, meaning rotation around the y-axis.

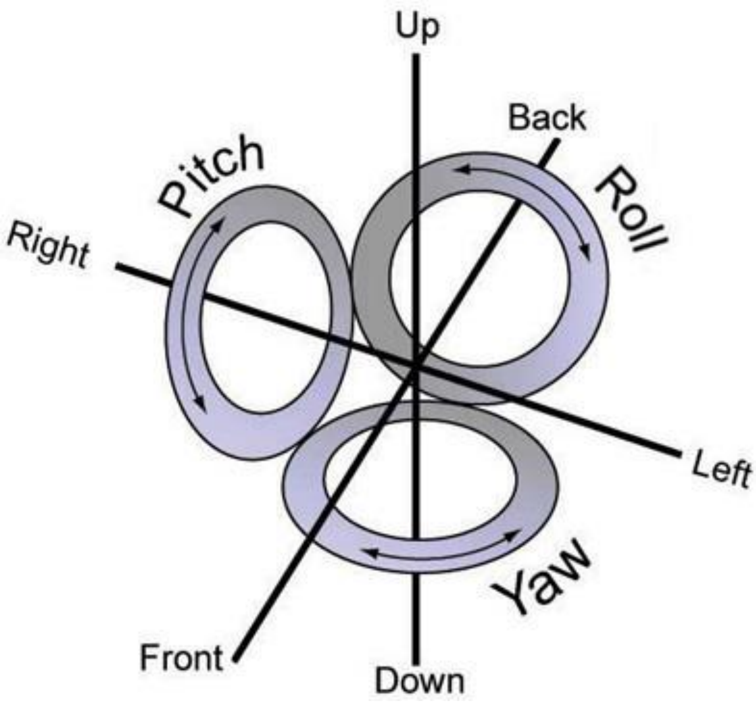

Figure 2. The semicircular canals also report roll information (Coulter & Vogt, 2008)

Yaw, pitch and roll sensations can be stimulated depending on different GVS techniques. Regarding the study by Fitzpatrick et al. (2004) unipolar, bilateral bipolar, and bilateral unipolar stimulation are highlighted as general orientation sensations.

The most common type of the GVS is referred to as bilateral bipolar GVS and consists of 2 electrodes placed on either side of the head on the mastoid processes and a current of about ~1 mA is supplied for 1 to 2 seconds, through the electrodes with 600-900 mm^2 contact surface and generous amount of electrode gel (Hanes & McCollum, 2006). Bilateral bipolar stimulation was well described in the study by Johansson et al. (1995): ”*A galvanic stimulus causes an increase of the firing frequency mainly in the irregularly firing neurons of the vestibular nerve on the side of the cathode and a decreased firing frequency on the side of the anode*”.

Other types of stimulation supply the same amount of current at the same amount of voltage which usually does not exceed 9 V. Bilateral monopolar stimulation has the 2 electrodes as in bilateral bipolar stimulation, but these electrodes both receive either anodal or cathodal current, using a reference electrode somewhere on the body, usually at the back of the neck. Unilateral monopolar stimulation has 3 electrodes, too, but current is passed only between the reference electrode and one of the 2 attached to the mastoid processes (Fitzpatrick & Day, 2004), (Curthoys & MacDougall, 2012). The perception of this stimulation results in sway if the users are standing or illusory movements if not.

First GVS Device

The device, as described above, is simple in principle, and the effects are major. Even though a simple device, complex processes take place during the stimulation. For further complications, human subjects have not been measured electrophysiologically, but elaborate research has been conducted on a wide range of species, including primates. The methods for measurements vary, because of implications that are presented, but they generally agree. The consensus in neuropsychology is that GVS activates primary otolithic neurons as well as primary semicircular canal neurons (Curthoys & MacDougall, 2012), (Fitzpatrick & Day, 2004).

Following the above mentioned we have made a prototype of a bipolar bilateral GVS device. Knowing what the effects are, the amount of current and ways to measure the effects were evident. As the first prototype, a simple electronic setup was built (Figure 3).

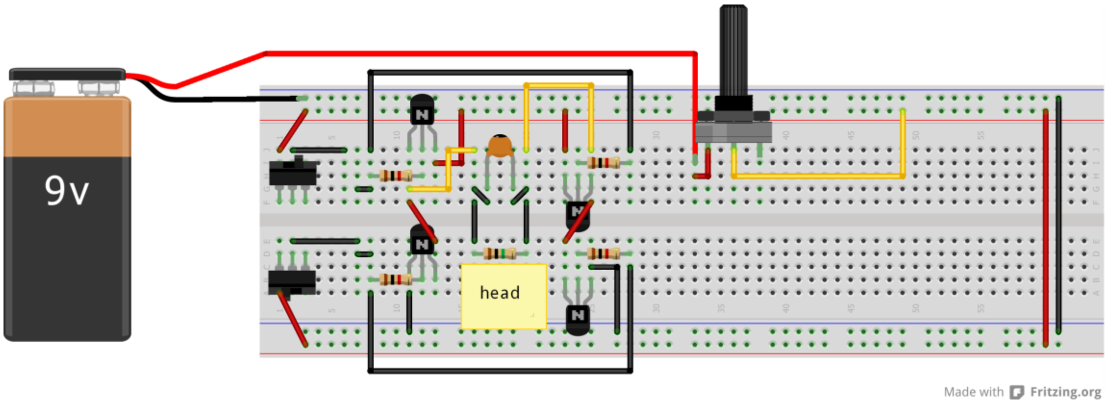

Figure 3. Layout of the first GVS device. All currents and voltages were measured prior to attaching the electrodes

The device was capable of exactly what the description explained it could do. Using transistors, two switches, resistors and a potentiometer, the output signal could be tweaked between 0-5 mA over 9V with changing polarity by toggling the switches. The electrodes that were available, suited our needs. The 3M Red Dot 2239 ECG monitoring electrodes (Figure 4) have a conductive surface area of 0.5 cm^3 (see Appendix Figure 26 on page B).

Figure 4. The 3M RedDot electrode has a big diameter, but can ensure adhesion on uneven surfaces

Preliminary Test

The initial test was conducted in order to try if the prototype of our first GVS device (see First GVS Device on p. 10) was working properly. If the users were experiencing pain, discomfort or anything else that might have interfered with the test-results and if there was a difference between a trivial cognitive task in two different conditions: with stimulation from the GVS device and without any GVS.

In order to get relevant knowledge of GVS device working effect we prepared a small in between group experiment, where one group (5 subjects) was testing one experiment condition being connected to the device and had to find five differences in presented two pictures, while the other group (5 subjects) was not connected to the device, but only had to find five differences in the same pictures, which were presented to the first group.

Test participants were healthy subjects from the Aalborg University. They had to perform a given task and complete a questionnaire. The purpose of the questionnaire was to collect qualitative data regarding the possible pain and other discomforts that test participants could feel while wearing GVS device. The results were gathered based on five points Likert scale. None of the participants felt significant pain and any discomfort while wearing GVS device. This showed that the device was working properly. All participants in both test groups found all five differences in presented pictures.

In the test group, stimulated with GVS device, four out of five participants were feeling the swaying of their body. One out of five test participants stated that it was quite difficult to find five differences in the pictures, three out of five test subjects were thought that it would be much easier to perform the task without being attached to the GVS device. These results showed that GVS has an impact on users attention, as the task was requiring specifically this cognitive skill.

The time, which participants spent while performing the task, was also calculated in order to compare the difference between two experiment groups. For the group trying the GVS device the time was started to calculate from the moment when participants began to sway. The results showed that participants in the first experiment group had spent more time during the task performance comparing with the time, which was spent by the second experiment group.

What was noticed from the qualitative analysis of this test was that the attention needed for the cognitive task was affected by the GVS. For a better understanding of how these two seemingly unrelated brain-processes are interdependent, an in depth look on human attention was taken, explained in the following chapter.

4. Attention

An important aspect of our study was to investigate the correlation between balance and attention in order to confirm the difference in decision making while comparing non-conflicting stimuli that users are receiving.

One of the main aspects of our project revolves towards attention, which is one of the most investigated cognitive processes of human cognitive psychology (Sternberg & Sternberg, 2009). Eysenck et al. (2005) presented the definition of attention: "*It is the taking possession of the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought.*" Focalization and concentration are considered to be essential.

According to W. James (1890) (Eysenck & Keane, 2005) attention can be divided into two modes: "active" and "passive". Active attention is experienced when the individual is following his/her goals or expectations. This is also known as a top-down way of attention control. Thus, passive attention is controlled in a bottom-up way when an external stimulus is involved in the process. Theoretical framework proposed by Posner and Pederson (1990) (Eysenck & Keane, 2005) presents three abilities that might be in control of passive attention: disengagement, shifting and engaging. Disengagement can appear when the external visual stimulus appears. The individual can also shift his/her attention from one target stimulus to another. And finally, the new visual stimulus can engage individuals' attention.

Attention can also be focused and divided. Focused or selective attention is exploring individuals' response to one stimulus while provided with more than that. According to Eysenck and Keane (2005), work investigation regarding the focused attention can provide us with information of effects on nature of selection process. Divided attention explains the phenomena of responding to multiple stimuli simultaneously, thus providing useful information about processing limitations. Divided attention in dual task performance can depend on dual task similarity, practice and task difficulty (Eysenck & Keane, 2005). As the central capacity theory suggests, the level of performance vary depending on the complexity of the two tasks on the central processor (Tombu & Jolicoeur, 2003).

The study by Lvandowsky (2011) has accentuated two significant categories of attention in category learning. Learning is closely interrelated with working memory, which is essential for many higher-level cognitive functions, ranging from mental arithmetic to problem solving. According to Lvandowsky (2011) attention is conceptualized into dimensional attention and representational attention. Dimensional attention is most common type of attention and it refers to the stimulus dimension. Representational attention refers to the more complex process involving associations with different representational elements. Stimuli can be classified based on one or another type of rule, such as string instruments or for example, shape can distinguish one instrument from another better than size.

Attention is also a significantly important component of humans' everyday life. Recent studies have presented results regarding the cognitive tasks requirement in the human balance. (Woollacott & Shumway-Cook, 2002), (Redfern, Talkovski, Jennings, & Furman, 2004).

The study by Redfern et al. (2004) has investigated the importance of attention in postural control. By involving dual-tasking experiments it was found that balance tasks and cognitive tasks impede with each other in patients with confirmed vestibular lesions. The study has mentioned past studies investigation of minimal interference between cognitive tasks and human balance while standing on a stable surface. The experiment was conducted with an intention to observe interference between standing and walking balance tasks combined with cognitive tasks (Redfern, Talkovski, Jennings, & Furman, 2004). The hypothesis of the study was: *"Attention processes would play a greater role in postural control of patients with unilateral vestibular loss compared to healthy age-matched controls"*. In order to investigate the hypothesis, users were provided with dual-tasks that combined different postural challenges. It was established that when the difficulty of postural task increased, the interference with the attention processing also increased. Therefore, this study has mentioned that it is still unclear the degree to which attention processing is involved in human balance and what specific movements engage attention resources.

Aging has been shown to have an effect on correlation between attention and postural control. (Redfern, Talkovski, Jennings, & Furman, 2004), (Verghese, et al., 2002), (Woollacott & Shumway-Cook, 2002), (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997), (Holtzer, et al., 2007), (Mak, Yeh, Boulet, Cluff, & Balasubramaniam, 2011).

The correlation between attention and falls in older individuals was discussed in the study by Verghelse et al. (2002). The research was exploring the influence of cognitive processes clarification a mechanism of falls and identification of the group of individuals who are at risk. The hypothesis in the research study was defined as: "*Limited attention resources in older persons may increase risk for falls*". The purpose of this research was to identify a risk of falls by dividing attention task into walking while talking. The results of the experiment have shown positive outcomes in predicting falls in older people.

Gained results are contradicting to findings by Shumway et al. (1997), where effects of two types of cognitive tasks on postural stability were measured and compared between young adults and older adults with and without a history of falls. In order to examine changes in attention, test participants were asked to perform two tasks: a sentence completion and a visual perceptual matching task. The results have shown the decrement in balance, not in the cognitive deficit as it was found in the experiment conducted by Verghese et al. (2002). The significant difference was found between two groups. Older adults with a history of falls were under a higher risk of falling down while performing dual task based on balance and attention keeping. Shumway et al. (1997) concluded their work suggesting that even small cognitive tasks can have an impact on human balance if there exists a deficit in postural stability.

The study by Holtzer et al. (2007) extended previously mentioned experiment and examined the relationships between specific cognitive functions and falls in aging by conducting single task and dual task tests. The study hypothesized that speed of executing the task requiring attention would be associated with falls. It was found that identifying relations between cognitive functions and falls in normal aging has important inferences. These implications confirm the significance of neuropsychological evaluation for prevention of risk for falls. The study consisted in performing a single task that measured Verbal IQ, speed of attention, and memory. In order to find difference between the performances of the tasks and the performances of these tasks while dual tasking, the speed of attention, memory and postural stability were examined in dual task. It was found that speed of attention aspect was the most effective predictor of falls in healthy older people. Based on gathered results, a new research path was suggested for future investigation: "*The Speed/Executive Attention factor encapsulated cognitive functions that depend on speed of processing and visuospatial abilities.*" These findings lead to explore more in the area of cognitive functions effect on falls risk in order to identify deficits in attention, which may help to revive specific deficits associated with balance problems.

The latest research intended to determine whether the association between executive dysfunction and risk of falling is independent of balance (Buracchio, et al., 2011), (Eysenck & Keane, 2005). Previous works have determined two main factors of falls: physical impairments and cognitive damages. Physical impairments are based on impairment of gait and balance, vision deficiency, orthostatic hypotension, musculoskeletal deficits, and the use of some medications (Brandt, et al., 2002). Both cognitively intact and cognitively impaired individuals are under the risk of falls while showing a lower level of performance in tasks requiring attention, executive function, memory and visuospatial functions.

During their experiment (Brandt, et al., 2002) participants with and without balance impairment were provided with cognitively demanding attention tasks while performing on force plates. The study found that individuals with bad, or lower than the baseline performance on executive functions had an increased risk of falling. Thus, for the group of people with balance impairment higher executive function test results showed lower risk of falls.

Explored dual tasking experiments have shown the correlation between human balance and cognitive tasks (Brandt, et al., 2002), (Matthews, Sparkes, & Bygrave), (Buracchio, et al., 2011), (Holtzer, et al., 2007), (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997), (Verghese, et al., 2002). Attention is important for humans functioning in everyday life. Many daily situations require focus on more than one task at the same moment. For example people are paying attention to media devices (cell phones, media players, etc.) while driving a car. Attention is the correlate to be able to maintain concentration. Due to the multitasking nature of modern life, where media devices capture attention when another task might be more crucial for attention, a divided attention is needed to carry out each task equally effectively: this is why we have chosen to find a correlation between divided attention and vestibular sense of balance. Since balance has an effect on cognitive function, it has an effect on divided attention, but to what extent, and whether it could be positive, has not been found out yet. This has caught our interest; therefore we can state our final problem statement as follows:

How does the perturbation of human vestibular system affect divided attention?

Second Preliminary Test

Posners' Cueing Task with GVS

The following test was performed to further investigate a possible correlation between attention and vestibular balance.

Two groups were tested in the inbetween experiment design. The control group was participating in the condition, where only mental task was performed, while the second group was testing both mental task and GVS.

Groups had 10 subjects in the control and 11 subjects in the GVS group. The mean age was 25.2 years for the GVS and 27 for the control group. Both groups had 3 female participants. The control group only received the visual stimulus from the Posners' cueing task, and the other group also received the GVS (Figure 5). The GVS signal was triggered once every ten seconds for 1.5 seconds duration. The next GVS signal was using reversed polarity (more about the implementation of the GVS device in the chapter The Second GVS Prototype on p. 34). The Posners' test is based on cues that are given prior to a stimulus that the users must respond to. The prior cues can be congruent, non-congruent or neutral. When the response is requested from the users, they are expected to take longer to respond when the prior cues were incongruent with the secondary stimulus.

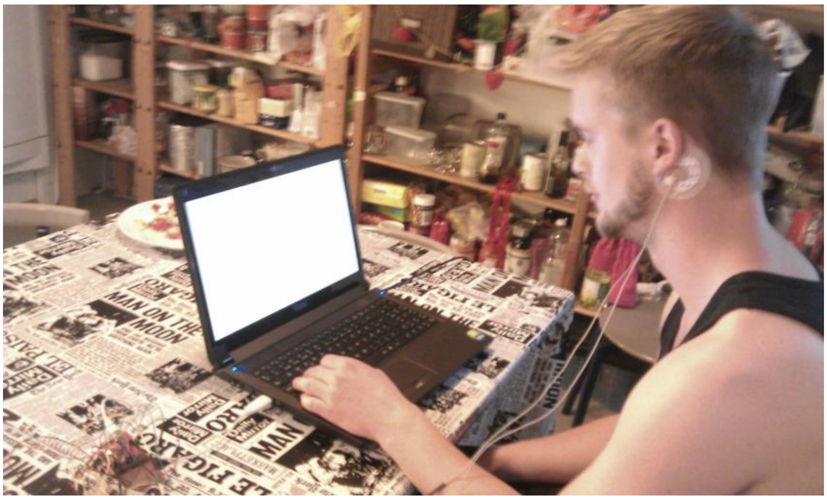

Figure 5. Preliminary test with a test-subject being attached to the device and receiving GVS

The users had to press the 'a' key on the keyboard to respond to the stimuli. A qualitative analysis revealed that the GVS group did not feel distracted and could perform just as good without the device being attached. On average, both the groups considered, where incongruent prior stimuli was presented, the response time was the biggest. The GVS group, on average, responded in 448 ms (deviation of 125.9 ms), where control responded in 364 ms (93 ms deviation). This shows an 84 ms difference in response time on average, which is significant ($p < 0.05$). This could show that the users were unconsciously being affected by the GVS. It could not have been because of the physical electrode attachment because of the users' claim that they could perform just as well without the GVS device.

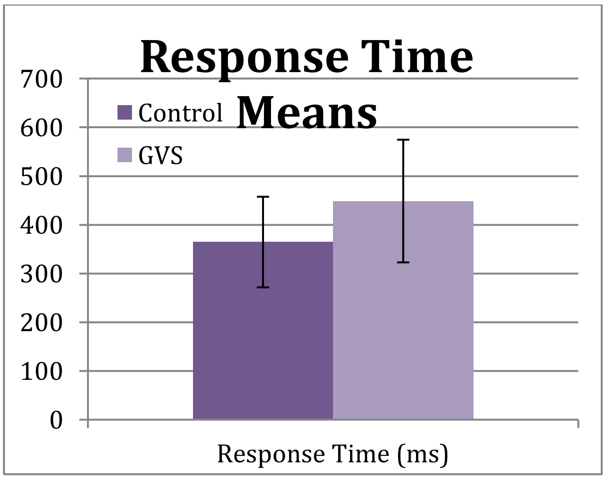

Figure 6. Second preliminary test. Graph showing response time averages on both groups

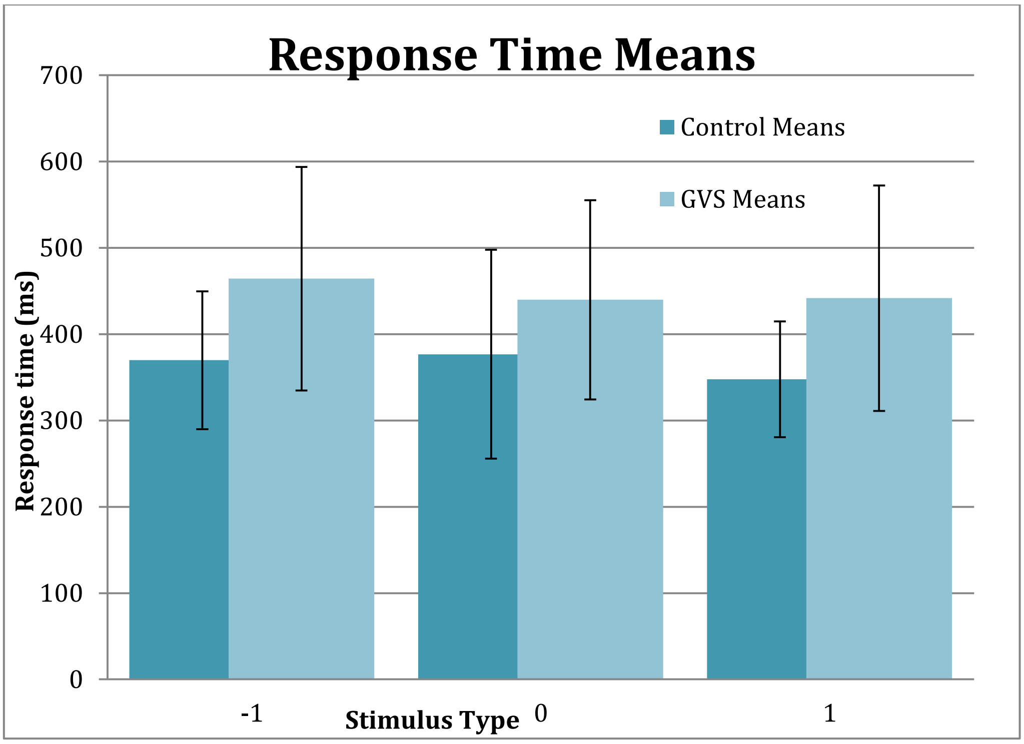

Figure 7. Response times per type of stimuli, where -1 is incongruent, 0 is neutral and 1 is congruent visual stimuli

Conclusions

These results showed that there were significant differences between the two groups. A trivial cognitive task about response time had an effect on the performance when receiving GVS signals while performing the task. Whether this effect was working as a distraction is still not certain. An extra condition would need to be tested, where the stimulus is known to have a disturbing effect on the test-subjects.

Relevance to Neuroergonomics

The topic of neuroergonomics is related to our project as it is a new and yet not well-developed research area, which review workload and vigilance, adaptive automation, neuroengineering, and molecular genetics and individual differences (Parasuraman & Wilson, 2008). Human factors and ergonomics have been analyzing behavior and mind at work, which led to exploring neuroergonomics in order to study brain computer interfaces that can investigate brain mechanisms: "*Neuroergonomics can provide rich observations of the brain and behaviour at work, at home, in* *transportation, and in other everyday environments involving human operators*" (Parasuraman & Wilson, 2008).

Application of neuroergonomics include: "*[…] assessment of operator workload and vigilance, implementation of real-time adaptive automation, neuroengineering for people with disabilities, and design of selection and training methods.*" (Parasuraman & Wilson, 2008)

Neuroergonomics study human behavior and the mind at work, thus bringing the technology to explain by visualizing neural bases of such cognitive skills as seeing, attending, memorizing, perceiving, planning and deciding. The vigilance is closely related to attention, as it is important component for being able to keep focus. It was found (Parasuraman & Wilson, 2008) that increased cerebral blood flow in the areas of the prefrontal cortex can be used for mental workload evaluation.

Previous findings in neuroergonomics have been exploring applications of real time physiological measures of cognitive load in order to improve training (Coyne, Baldwin, Cole, Sibley, & Roberts, 2009). It was found that augmented cognition and neuroergonomics can be extended into training using EEG data. Parasuraman and Wilson (2008) have found that problem solving, driving simulation and visual search can differentiate depending on humans' cognitive state by capturing eye metrics.

Our project has a potential to bring new investigations about the cognitive process correlation with human balance in order to build new methods for cognitive processes tracking with the purpose to build modern automated systems and machines in the future. Monitoring the correlation between cognitive skills and vestibular system using GVS device can be a new paradigm in the neuroergonomics field. Finding usable applications for the GVS would be the next step, but before this could be done, the impact of using the device needs to be investigated.

5. Galvanic Vestibular Stimulation in Use

Studies within the field of human balance have emphasized the growing interest in the real life human-machine interactions in which normal functioning of the vestibular system as a continuous feedback for balance, posture and navigation may be compromised due to rapid fluctuations of normal average thresholds.

The human vestibular system has been widely studied applying GVS (Ruhl & Lamers, 2011). The relevance of this technology for improving Human Computer Interaction (HCI) is gaining more and more interest. The study by Ruhl et al. (2011) was investigating effects of GVS on the balance system with a broad focus on daily activities as this area is little explored. The purpose of the study was to explore if human's body adapts to new conditions, if people perform better over time, also to create a meaningful correlation between the perceived balance and body orientation. The argument for their experiment consisted of finding appropriate confirmation for improved performance under the GVS in order to continue working on developing more applications where computers could provide input data for the devices that could be used as interfaces between a virtual environment and the user. Several tasks from everyday life were prepared for users to perform with and without GVS. With the task of reading in the bus, the decrease in time was found, meaning that GVS device might postpone the motion sickness. Not enough data collected in order to confirm these results. Interesting findings were discovered after performing the tasks where participants had to walk specific distance with their eyes opened under two conditions: with and without GVS device attachment. No significant difference was found between the outcomes of the task performance. Ruhl and colleagues (2011) speculated that the reason of such results might be the subject's reliance on the vision more than on the balance. The results of the discussed study also showed human's body adaptation to new situations.

People with vestibular disorders frequently have problems with postural stance (Verghese, et al., 2002). The studies, which use electricity to influence vestibular system, have shown positive results in preventing the elderly from falling (Scinicariello, Eaton, Inglis, & Collins, 2001). According to Scinicariello et al. (2001) findings GVS can be used as a method for reducing human postural sway resulting from a mechanical perturbation. Scinicariello et al. (2001) was testing the hypothesis:"*[...] that in subjects who are facing forward, bipolar binaural GVS can be used to eliminate or reduce mechanically-induced mediolateral postural sway.*" The future perspective of using GVS for reducing humans' postural sway opens new visions for using this device as a commercial product. People can train their balance, prevent seasickness, prevent older people from falling and get more other positive aspects from the usage of the small device, which could consist of accelerometers and/or gyroscope sensors that could monitor the postural sway of an individual and would provide personal feedback, which could trigger suitable galvanic stimulus.

There is also an entertainment value in the GVS device. GVS could be used for entertainment systems including not only for big devices but also for small devices like video games at home. For example a person playing a car simulation game could get a more realistic and engaging experience by using this device. When in the simulation the car turns, the stimulus for the GVS can be calculated from the virtual forces that act in the simulator, giving the person an according sense of acceleration, by varying the current and polarity of the GVS. The same principle can be adopted in pilots training simulators. Such application would have potential to increase players' engagement level and possibly to create a higher sense of reality. This implies that a correct mapping between the magnitude of the stimulus and the simulated situation is obtained prior to using the device in such a product.

The relationship between postural stability and virtual environment adaptation is strong. It has been found that postural stability of individuals can also be affected by the visual together with the vestibular stimulation in a virtual environment (VE). Engaging people in the VE using 3D real-time computer graphics and innovative display devices such as head mounted displays has been indicated to be valuable in different applications like education, engineering, entertainment, driving and flight simulation. Joseph J. La Viola (2000) has been exploring an important problem both during and after the VE experience, called cybersickness. He (2000) describes cybersickness as being: "*[…] distinct from motion sickness in that the user is often stationary but has a compelling sense of self motion through moving visual imagery*." The use of direct vestibular stimulation was found as a method to reduce or possibly eliminate cybersickness.

Joseph J. La Viola has discussed three theories that explain the reason for cybersickness phenomena. *The Sensory Conflict* theory is based on differences between senses that cause perceptual conflict because the body has to process both orientation and motion. The vestibular sense and the visual sense are initial senses that are involved with cybersickness. The example with driving simulator explains the phenomena of the sensory conflict: "*As the subject uses the simulation, the optical flow patterns of the road, buildings, and other parts of the environment move past the subject's periphery, which gives him/her a sense of vection. The visual system tells the subject a variety of information, which includes that he/she is moving in a certain direction, accelerating when pressing the gas pedal and decelerating when pressing the brake.* " However, in the real life the subject is not moving, thus expecting to be provided with the perception of his body movement. This is where the sensory conflict occurs causing cybersickness. This can also cause long after effects that can cause discomfort to function in other situations. Such discomfort can be expressed in inversed view of the world after the VE experience. According to such consequences people who are training with VE simulators are not allowed to drive or fly for the next 12 to 24 hours in the real world. In order to prevent this phenomenon, it is important that both vestibular and visual apparatuses agree with each other. According to Joseph J. La Viola (2000) findings, normal process of the vestibular system consists of one side of the head pushing while the other is pulling. Vertigo[1] can appear when both sides are pushed or pulled.

Another theory explaining cybersickness is called *The Poison Theory,* which can lead to an emetic response. When the coordination of all three sensory systems (vestibular, visual and proprioception) are involved in the process of stimulation, our body system gets an early warning, which invokes vomiting.

The Postural Instability is the last theory describing the cause of cybersickness. The theory explains the importance of postural stability, which can prevent people from side effects caused by VE. According to Riccio et. al (1991) postural stability is defined as: "*The state in which uncontrolled movements of the perception and action system are minimized.*" Based on these findings, in Joseph J. La Viola (2000) view, postural stability depends on the environment, for example, walking on concrete and ice require different techniques in order to prevent from falling.

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[1] Vertigo is experienced as loss of orientation with respect to vertical upright (Baloh, 1998).

Regarding the findings in cybersickness (La Viola Jr., 2000), the vestibular and visual systems are not the main factors that are significant. Individual factors are playing an important role in cybersickness perception, as every individual can experience it subjectively. On every subject, the reason for becoming sick could be different, depending on their prior experiences and thus different fine tunings of different brain processes.

Conclusion

As we have discovered the GVS can be used in multiple applications: navigation, computer games, simulations, preventing falls, training balance, rehabilitation and cure for cyber- and motion sickness. However, it is noted that there is always another stimulus involved. The GVS device cannot work alone, since other sensory input is always involved, making an isolated study impossible. A "black box" would remain in the study, until the whole balance system is known together with its influence on other regions and processes in the brain. Below, we have investigated the possible influences on cognitive functions and ways to measure them.

6. Vestibular System Influence on Cognitive Functions

Vestibular disorders are often associated with difficulties with cognitive abilities, such as concentration, arithmetic, etc. (Hanes & McCollum, 2006). Cognitive processes are defined as internal processes that are implied in the human perception of the environment and decision-making in choosing an appropriate action (Eysenck & Keane, 2005). Internal processes include attention, perception, learning, memory, language, problem solving, reasoning and thinking. All of them form human information processing approach, where one is required for an attention, perception, thought process, decision making and responding or acting, after the stimulus appears. Attention is essential element in the information processing as it works as a filter, which lets the information be treated before other cognitive skills.

Discussed studies have found that attention has a significant meaning in resolving sensory conflict, which includes humans balance (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002), (Redfern, Talkovski, Jennings, & Furman, 2004), (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997), (Woollacott & Shumway-Cook, 2002).

This paragraph reviews previous research that emphasizes the interaction between vestibular system and cognitive skills, indicating that vestibular damage leads to some forms of cognitive deficits. Cognitive skills control normal human functioning by helping memorizing, focusing on particular points of interest, planning, dividing attention while performing more than one task, and making other necessary things in life.

This would mean that the vestibular system has a role in the performance of cognitive skills. By selecting a distinct, well-known, measurable subset among the cognitive functions, we could provide a valuable insight as to how the GVS is affecting that cognitive skill in a healthy subject.

Several studies like Hanes & McCollum (2006), Yardley et al. (2002), Shumway-Cook et al. (1997), Andersson (2002), Okada et al. (1999) have been exploring the correlation between cognitive tasks performance and vestibular balance function. The reason for such studies investigations is: "*[...] both raise awareness of the cognitive effects of vestibular disease and to focus scientific attention on aspects of cognitive-vestibular interactions indicated by a wide range of results in the literature.*" (Hanes & McCollum, 2006)

While performing dual-tasks that include balance keeping while accomplishing cognitive assignments, it was noticed that people with balance deficits perform worse comparing with healthy subjects (Hanes & McCollum, 2006). Similar results were confirmed in the earlier works by Yardley et. al (2001), (2002). The study (Yardley, et al., 2002) investigated whether attention is required for continuously processing vestibular information concerning orientation, or it is required only when vestibular balance is damaged, or by conflicting visual and vestibular orientation cues. The research has found that patients with and without vestibular dysfunction resulted in decreased accuracy on performing cognitive tasks with a need of more time to respond while the difficulty of maintenance of postural orientation was increased. These results confirmed previous findings regarding the interference between postural control and mental task performance in patients with vestibular disorder and healthy subjects (Yardley, et al., 2001). The purpose of the study was to analyze if general capacity limitations, motor control interference, competition for spatial processing resources, or a combination of all these aspects cause the interference between balance and cognitive task performance in people with balance deficit and healthy subjects. It was found that performing simple arithmetic task aloud, healthy adults resulted in misbalance comparing to the performance of silently performing difficult calculations. Similar experiment was conducted by Andersson et al. (2002), where the hypothesis was that younger adults would demonstrate dual-task performance decrement on the backward silent counting task while performing a balance task. In a study by G. Andersson et al. (2002) the effect of cognitive load on postural control was tested on healthy subjects. All of the subjects had never had medical reports of balance dysfunction or any other central peripheral dysfunction. A mental task was administered while the postural sway was being measured on a force plate for the first group. The task was to silently count backwards with increments of 7, starting from a random number. For the second group the task was to turn attention to keeping balance while a vibratory stimuli was given to the calf, and the users had to report on a scale from 0 to 5 how much it affected their balance. The trials were: only standing with vibration, silent counting with vibration and vibration only. The balance was assessed by variance in anterior-posterior and lateral torque, calculated from the strain gauges in the force plate. The results from the study showed that the mental task is impaired while the balance is perturbed. The amount of sway was less when the mental task was performed. Concentrating on keeping balance had an insignificant effect. The evidence suggests that the cognitive load affects standing balance, but keeping balance has a higher priority than the mental task, so balance is maintained, but the mental task performance suffers.

The study by Wilkinson et al. (2010) has uncovered a new connection between vestibular information processing and visual task performance. The purpose of the study was to find whether GVS can improve humans visual performance in order to investigate in the little-known variety of visual tasks that are affected by GVS in brain-damaged patients. In order to find the correlation between visual task performance and galvanic vestibular stimulation Wilkinson et al. (2010) designed the test where brain damaged patients had to copy figures by being stimulated with bipolar binaural direct current, which was applied to the left and right mastoids. Gathered results showed no dependence on the polarity changes. Thus, it was found that drawing task performance was improved with increased stimulation and specifically after having a break between task performances. Conducted studies by Duinmeijer et al. (2012) and Brandt et al. (2002) have also found the positive results in correlation between vestibular and visual systems.

Akiduki et al. (2003) was examining the level to which visual-vestibular interaction and vestibular stimulation while processing cognitive tasks in young and older healthy people. The purpose of the experiment was to measure subjective sickness and balance related symptoms together with evaluation of objective loss of balance (ataxia) induced by visual-vestibular conflict stimulation when experiencing virtual reality. The notion that ataxia are difficult to approve based on objective tests of balance is derived from the study by Kantor et al. (1989). Akiduki et al. (2003) where the use of a VR system was utilized to induce motion sickness and postural instability. The evaluation was processed in a form of counting the time between subjective symptoms on motion sickness and observed humans misbalance. The results were contradicting to the previous findings, where the time amount of postural instability had a significant importance in causing a motion sickness. However, results gathered from the Akiduki et al. (2003) experiment showed the contrary outcomes, suggesting that motion sickness produces postural instability.

Above-mentioned studies showed results in decrease of cognitive tasks performance while keeping balance. Thus, the study by Shumway et al. (1997) was exploring the effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. The experiment was based on dual task design, where cognitive tasks, such as a sentence completion and a visual perception matching task were performed to create modifications in attention during quiet standing under flat and moving surface conditions. Three groups of people were participating as the experiment subjects: young adults, older adults with the history of falls and older adults without history of falls. Results from the test condition under the postural stability on the firm surface showed no significant difference between the young and the older healthy adults. Thus, older adults with history of falls were affected by both cognitive tasks. It was also found that increment of both cognitive tasks difficulties had an impact on the postural stability in all three groups. The measurements of this study rely on the multitasking effects and dividing attention, which are apparent to be worse when conflicting signals are coming in from the sensory inputs in unhealthy subjects, meaning that more processing power is needed to process the conflicting signals.

Attention has been observed in different studies including the study by Furman et al. (2003), where the role of attention in sensory-motor processing of vestibular and combined visual-vestibular information in the dual-task conflict based experiment. The hypothesis has been raised in order to figure out if the auditory information perception would be affected by visual, vestibular and visuo-vestibular processing. The experiment consisted on simple cognitive tasks that included auditory tasks while moving and standing still being connected to GVS. The goal of this study was to examine if the age has an impact on the interaction of attention and vestibular processing. The time has been used as a parameter to measure the difference and analyze the data. Gathered results showed a significant difference between the tasks completion time, thus confirming the hypothesis.

Interference between vestibular stimulation and the time of humans' response to the tasks required auditory processing were also confirmed in the study by Marchetti et al. (2011). The conception about the effect of human balance, which was influenced by the intervening between auditory sensation and vestibular processing was also mentioned in the Redfern et al. work. (2002).

Interesting observations were made in the study by Mackrous and Simoneau (2011), where the brain selection in prioritizing visual over vestibular information to provide the position of a visual target while the body was passively rotated. Visuo-vestibular interaction was found to be essential for keeping track of targets position with respect to humans' body position while they were moving. Visual and vestibular systems cannot function separately in regards to perceive motion, because we perceive and update space around us with the assistance of our head motion and position. This is why: "*[…] the processing of vestibular information alone cannot accurately update the internal representation of object positions in relation to the body following passive whole-body rotations* " (Mackrous & Simoneau, 2011). In order to establish if cognition can assist the brain performance while processing the sensory information, the study by Mackrous and Simoneau (2011) have conducted the experiment. Test experiment was based on passive body rotation and participants' estimation of the position of an earth-fixed target. No significant difference was found between visual-only and vestibular-only groups. Thus, during the preliminary test an overestimation of subjects' body rotation was found in too early responses. It was also found that visual system could be controlled better, because it was easier to concentrate on the visual cues. The difference between two participant groups (visual-only and vestibular-only) occurred in shorter time for reducing spatial error in visual-only group. These findings show that our vestibular system is less controllable comparing to our visual system.

All the above mentioned studies were performing dual tasks including maintaining a balance while performing some sort of cognitive assignment, such as arithmetic, memory tasks, reaction time to the auditory stimulus, etc. Results of previously mentioned and similar studies showed:

- A possibility to indicate some basic cognitive tasks on which individuals with vestibular deficit perform worse.
- A possibility to indicate difficulty of the balance task, which can affect cognitive performance.
- In healthy subjects perturbation of vestibular sense affects the cognitive tasks' performance negatively.
- In subjects with vestibular or cognitive dysfunction the perturbation of vestibular sense affects the cognitive tasks' performance positively.

Most of the studies are using balance boards while experimenting with human balance. Thus, it was found (Hanes & McCollum, 2006) that patients might be very scared to fall and shift all their attention to the balance task while performing cognitive assignment. These results cannot be taken into consideration without bearing in mind that there could have been factors that made the test-subjects concentrate more on keeping balance. In cases where the test-subject could foresee harm to them when losing balance, the attention would be concentrated on balance, even if told otherwise.

7. Vestibular Stimulation in Simulators

We wanted to use simulator in our final test, since it is a universal tool and can perfectly fit a scenario where visual perception of balance is altered. Therefore applying GVS would increase the realism and potentially have a congruent effect with visual stimuli.

Vestibular stimulation is widely used in simulators for training and entertaining purposes. In the natural environment our vestibular system is stimulated while driving, flying or sailing. In order to create an environment as similar to the real one as possible with naturalistic driving behavior, GVS is often used as a tool for that in vehicle simulators. However, some drivers can experience simulator adaptation syndrome (SAS): "*[...] a condition, which may result in nausea, disorientation, dizziness, headache, and/or difficulty focusing when in a simulator (especially fixed base simulators)*" (Reed-Jones, Reed-Jones, Trick, Toxopeus, & Vallis, 2009).

According to Reymond et al. (2001) in the real world driving the vestibular system provides information, which is required for an evaluation and adjustment of vehicular speed when calculating the possibilities on the turns, as well as ensuring proper control of the vehicle. Though, it was also found that if the absence of vestibular motion cues exists while driver negotiate curves, the speed is not properly reduced, which result in reduced vehicular control. In an attempt to solve these problems, Reed-Jones et al. (2008), have showed positive results in using GVS in order to reduce the occurrence of SAS and improve steering control.

Reed-Jones et al. (2009) were comparing two techniques to reduce SAS and improve naturalistic behavior during simulated driving. One of the techniques was electrical stimulation of the neck or galvanic cutaneous stimulation. Another technique was galvanic vestibular stimulation.

After applying and exploring how these two techniques might reduce SAS, it was found that galvanic neck stimulation same as galvanic vestibular stimulation reduce SAS. However, cutaneous stimulation reflects in the change of head position and perception, meaning that naturalistic driving behavior is not detected during neck stimulation. As follows if naturalistic driving behavior in curves remains to be the point of interest, then galvanic vestibular stimulation is better because it is more assimilated with the real world driving. This is the main reason for choosing GVS as the stimuli for our project.

Another similar study was observing the GVS impact on simulator sickness in the flight simulators (Cevette, et al., 2012). The purpose of the study was to investigate the method for the use of GVS in order to synchronize the vestibular system with moving visual cues in order to reduce simulator sickness. The importance of the synchronization between galvanic vestibular stimulation and the speed and direction of moving visual target was found after conducted experiments. It was also found that the proper synchronization can significantly reduce simulator sickness. The implementation of our GVS device is trying to mimic real world forces (see Design & Implementation on p. 34).

In the real time driving people are usually dividing their attention. Surrounded by the new technologies, they have to pay attention to the road and at the same time answer their cellphone, determine the navigation or some other similar tasks related to the emergence of many new devices. Many improvements have been made to visual displays in vehicles, however the impact of the visuo-vestibular conflict remains the leading cause of simulator sickness. Virtual reality is a proper real world environment simulator. Lengenfielder et al. (2002) was using virtual environment technology for studying divided attention and driving. The purpose of the study was to investigate an impact of divided attention on driving performance, as the lack of drivers' attention causes vehicle accidents. Another important aspect was to more closely investigate this research field and potential advantages of using virtual environment for such experiments. Brain injured subjects and healthy controls were chosen for the experiment design. Driving speed was measured and compared between two test subject groups. In order to divide attention, cognitive tasks (verbal fluency and cancellation tasks) were added to the process of the experiment task performance.

Driving task was perceived as a primary task, while cognitive tasks were perceived as secondary tasks. The driving speed increment was observed in both groups when the secondary task was added while performing the primer task.

8. Conclusions

We have already concluded that attention is an integral link in the information processing in everyday life. Many daily situations, like driving a car, require concentration on more than one task at the same moment. In the world of modern technology people are surrounded by media devices, which provide extra stimuli for the days length. People are overloaded with information and need to divide their attention in order to be able to function.

Modern technology provides us with different innovative solutions that make our life easier. For example navigational systems provide drivers with audio feedback that does not require extra visual attention on the navigation device, so driver can concentrate on the road. Innovative solutions are being discovered and implemented more often and on a faster scale. One of such devices is GVS, which is gaining more interest in different fields of entertainment, vehicle simulation training, rehabilitation, or other devices that require human-machine interaction. However, before starting to use the GVS device in the real world it is important to investigate more in the field of galvanic vestibular stimulation and find appropriate confirmation for improved performance due to the GVS with its own pros and cons.

Studies discussed above have found a significance of correlation between visual stimuli and vestibular stimuli, which are an integral part of our everyday functioning (Ruhl & Lamers, 2011), (Wilkinson, Zubko, DeGutis, Milberg, & Potter, 2010), (Duinmeijer, Jong, & Scheper, 2012), (Brandt, et al., 2002), (Mackrous & Simoneau, 2011). The positive GVS effect on visual system was found in the brain damaged individuals. Thus, it was also found that visuo-vestibular interaction leads to the stimuli conflict that might adversely affect humans cognitive processing. It was investigated that people with balance deficits perform cognitive task worse than healthy people (Hanes & McCollum, 2006), (Yardley, et al., 2001), (Yardley, et al., 2002). However cognitive processing in healthy subjects was observed as a cause for balance impairment, but the opposite response can also happen: when the balance is disturbed the cognitive task is impaired (Yardley, et al., 2001), (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002). As our interest is in how the GVS can affect divided attention, we can hypotesize that divided attention will be affected negatively during the vestibular system perturbation.

In order to measure this phenomena during the final experiment we will follow the methods used in the previous studies. In order to test if the GVS device was not functioning as a mosquito effect we have prepared two conditions, where in the second condition we have used an audio stimuli instead of the galvanic vestibular stimulation (Furman, Muller, Redfern, & Jennings, 2003), (Marchetti, Whitney, Redfern, & Furman, 2011), (Redfern, Talkovski, Jennings, & Furman, 2004).

Based on the Lengenfielder et al. (2002) findings we assumed that driving speed of the final test participants would increase while adding cognitive task. For the cognitive task we chose to use an arithmetic task asking test subjects to count backwards with an increment of 7 (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002).

Even if the final test findings will provide us with significant results, this research field needs more and deeper investigations in order to conclude positive or negative effects that can be caused by GVS correlation with human divided attention.

9. Design & Implementation

The Second GVS Prototype

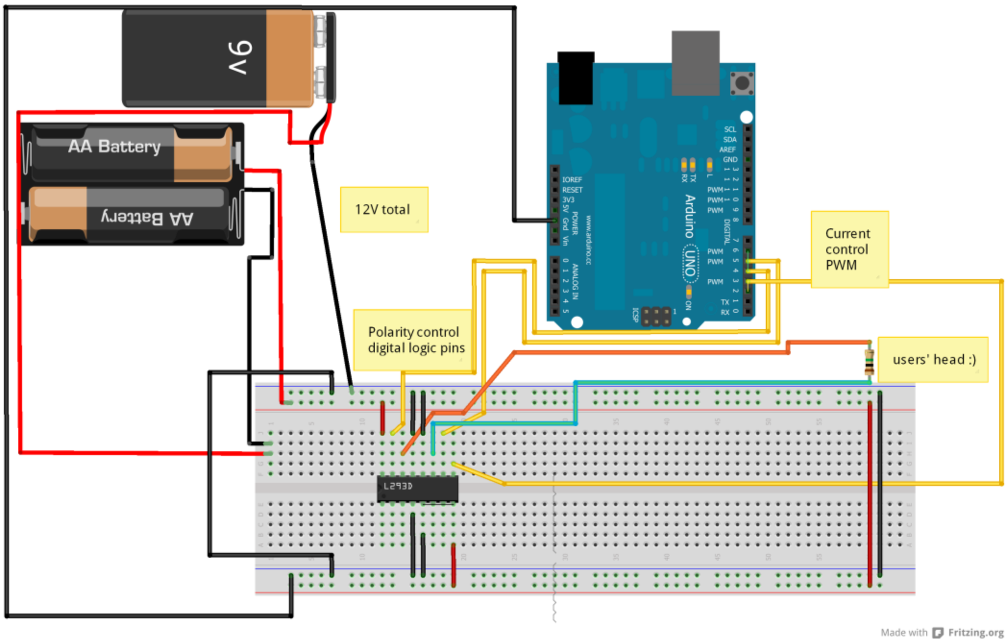

Figure 8. Layout for the second GVS device. Note that 9V was used instead of 12V, as shown on the figure

After assembling the first prototype (see First GVS Device on p. 10) and getting an understanding of what goes on in the device, a second prototype was made, following the same principles but having automated controls. A half H-bridge has the same functionality as the prior GVS device, but the controls use a digital signal (Williams, 2002). The input pins on the half h-bridge[2] control two logic pins (see Figure 25 in the Appendix on page A) that fulfil the same purpose as the toggle switches on the previous prototype. When a digital signal is 0 on one pin and 1 on the other, the current is passed to the output pins, and the amount of current depends on the PWM signals' wavelength. Since the microcontroller unit that was chosen was CUI32, the signal could be any integer value between 0 and 3300[3], corresponding to the output

[2] See the 'H-bridge_datasheet.pdf' in folder 'Papers' on the CD for a detailed data sheet.

[3] Acquired from https://code.google.com/p/cui32/ on 06.03.2013

voltages that are used as a multiplier in volts to the h-bridge. A PWM signal is needed for controlling the output voltage from the h-bridge[4].

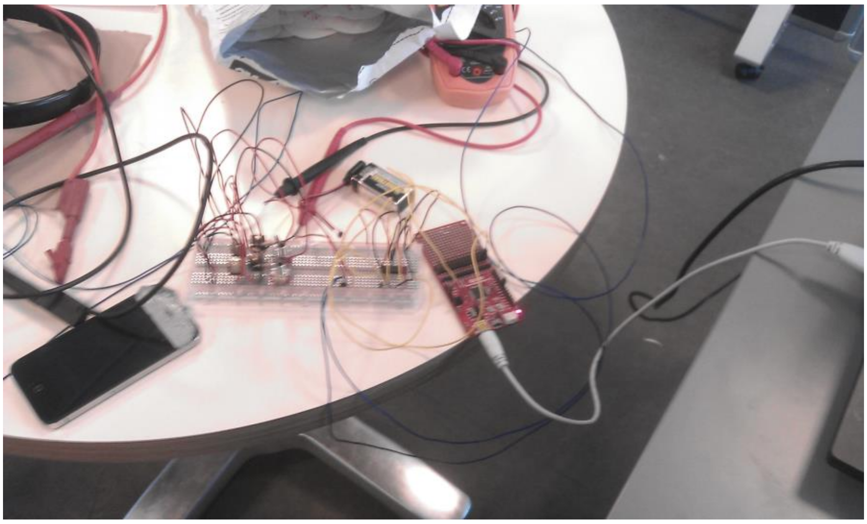

Figure 9. The second GVS Device on the right side of the breadboard, connected to CUI32

Controlling the GVS

Pure Data was chosen as a signal processor to be responsible for changing the values that the h-bridge needed. For being able to provide a consistent signal to all the test-subjects, a 10 second interval was used to trigger a change in polarity (Figure 10). The rest of the Pure Data patch is explained in more detail in Design & Implementation on page 34. The only change that was made from this iteration was changing the control of variables from delayed intervals to the simulators messages.

[4] See folder '/Papers' document 'H-Bridge_datasheet.pdf' for a detailed description about why pulse-witdh modulation signal is used for controlling the output voltage.

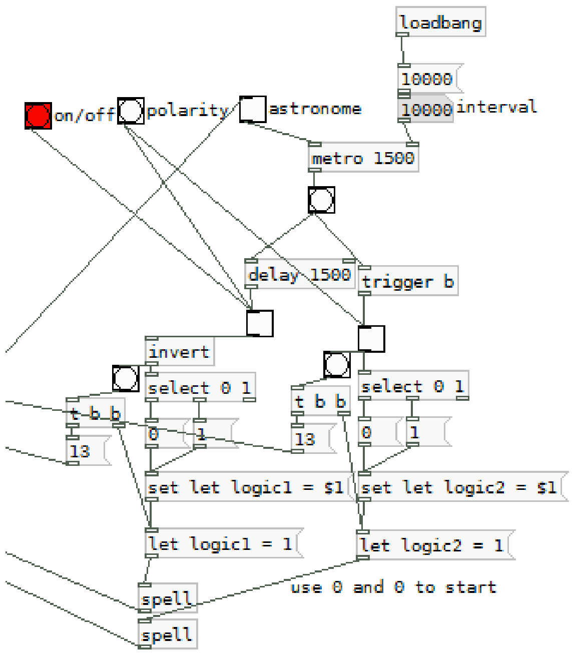

Figure 10. A Pure Data patch showing a 10 second time interval for triggering the signal on for 1.5 seconds and off for the remaining 8.5 seconds

The Driving Simulator Setup[5]

The simulator was acquired from the Unity website as a tutorial for car games and simulators, and did not need much to be changed. The view was 3rd person, but needed to be made into first person camera. Unity is a game-engine and a development platform that is especially dedicated to interactive computer graphics – videogames in the plainest form.

Forces & Perspectives

For being able to accomodate the behaviour of the camera as a first person camera, its behaviour script needed a few adjustments.

```
float speedFactor =
Mathf.Clamp01(target.root.rigidbody.velocity.magnitude /
70.0f);
```

[5] See folder 'Built Applications' for full implementation and most important scripts

```
...

newPosition = newTargetPosition + (currentVelocity *
Mathf.Lerp(0.05f, 0.5f, -speedFactor*2));

newPosition.z = newTargetPosition.z +(currentVelocity.z *
Mathf.Lerp(0.05f, 0.5f, speedFactor*0.1f));

Quaternion newRotation = target.rotation;
```

The target in the code above means the car, and refers to its local coordinate system. The velocity is calculated from the acceleration and the drag reacting from where the velocity vector is pointing. The position of the camera was dependent on the centrifugal force (Young, Freedman, & Ford, 2010) that was present. The velocity in the local coordinate system along z-axis got applied as a fraction of 70 of the actual velocity magnitude limited between 0.05 and 0.5 of the local z axis. The First-Person (FP) camera was also rotated towards the velocity vector, with the pivot point anchored to the center of the car. An illustration of the different forces acting on the car is presented on Figure 11. The location of the camera is perceived as a direct impact of the centrifugal force and is therefore sufficient to be forwarded on to the Pure Data patch, to be processed as a signal and passed on to the GVS device. The virtual sideways G-force that the driver experiences, is calculated from the z-axis velocity vector, as an acceleration (Equation 1) (Young, Freedman, & Ford, 2010).

$$a_z = \frac{V_{\Delta z}}{t_\Delta}$$

Equation 1. Calculating sideways acceleration

The acceleration was calculated as a derivative of velocity, using the smallest possible t_Δ. This was achieved by using Time.fixedDeltaTime function in Unity. The previous velocity was stored and used as V_0, from which the current velocity was subtracted. When knowing the acceleration, to get the G-value, the acceleration was divided by the acceleration constant (9.81 $\frac{m}{s^2}$) (Young, Freedman, & Ford, 2010), which yielded a scalar G-value. Given a mass of a body, the feeling of sideways pull can be given by multiplying the G-value with the scalar (Table 1).

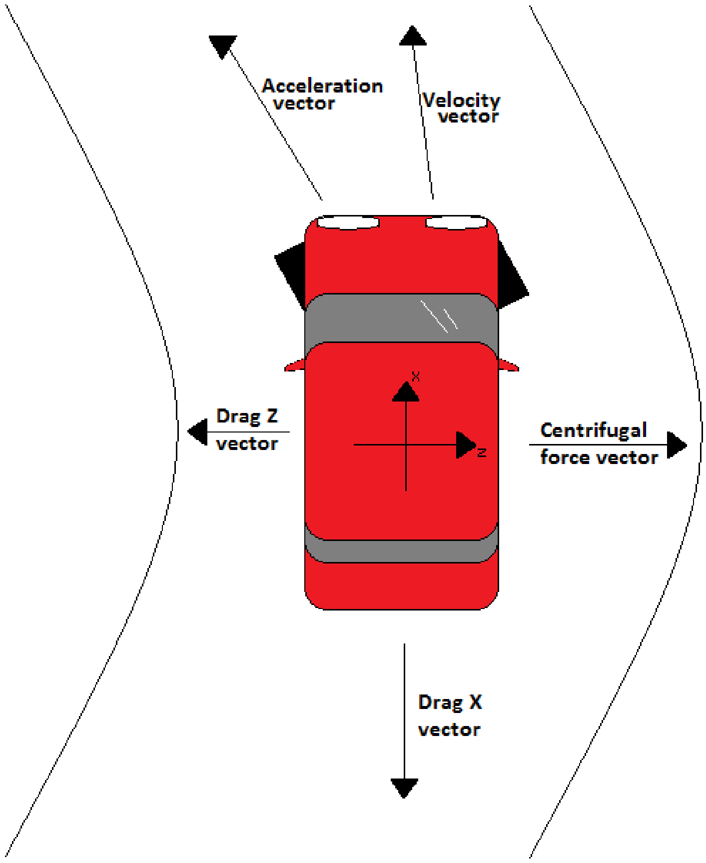

Figure 11. Most important forces acting in the simulator

The values calculated and measured show a configuration that was used for the GVS device (Table 1). Note that the sideways G-force is acting orthogonal to the gravitational pull, so a value of 0 does not equal to free fall or weightlessness, but simply no pull to either side. The amount of measured current was higher than what was measured before, passing the recommended amount of current, but staying below the pain threshold. These measurements were different prior to the testing, but during the test a new battery was used, resulting in giving more current. Nonetheless, the virtual forces experienced by the drivers were more than 4 times their body weight, so using a higher current could be excused by this.

Local camera position (absolute)	CUI32 PWM value (mV)	Measured current (mA)	Corresponding sideways G-force	Sideways weight with given G-value (kg)
0.01	1000	3.1	0.05	3.5
0.02	1176	3.6	0.09	6.3
0.03	1251	3.7	1	70
0.04	1378	4.0	2	140
0.05	1502	4.2	3	210
0.06	1666	4.45	4	280
0.07	1753	4.67	5	350
0.08	1876	4.9	6	420

Table 1. GVS configuration for the simulator

The graph illustrates the current given through the GVS, depending on the pull by G-force. A linear model was used, except for the lower values, since the GVS was turned on only when the G-force was more than 0.5.

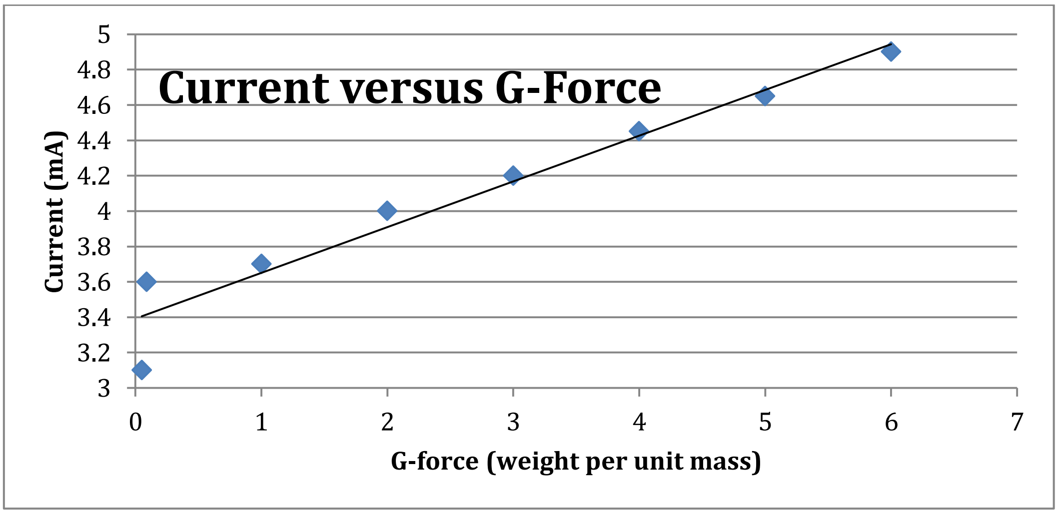

Figure 12. Plot of the simulator G-force present versus the current given. A linear model was used (trendline in black)

Data transfer

A script attached to the car super-object was used to set up a TCP client and establish a connection to the server, which was set up in the Pure Data patch (Figure 13). The TCP client was responsible for delivering the information and maintaining the connection. A UDP protocol could have been used since the amount of data was big and not every packets' arrival was important, but none of the packets were delivered when doing so. The packet sent from unity had an '!' sign at the end of every message, which was used as a separator of the numerical values.

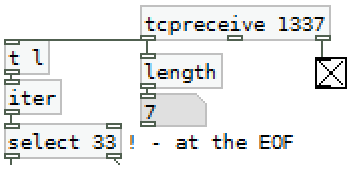

Figure 13. TCP server in Pure Data

Logic & Mapping

Once the data was made from a byte array into a float value, the sign was observed and used as a trigger for the half H-bridge. Figure 14 shows a delay object with a value of 100, meaning that the corresponding logical value was turned back to 0 after 100 ms once the incoming stream had changed sign. If no delay signal was used, the value would have stayed at whatever it was before, therefore leaving the logic switch toggled.

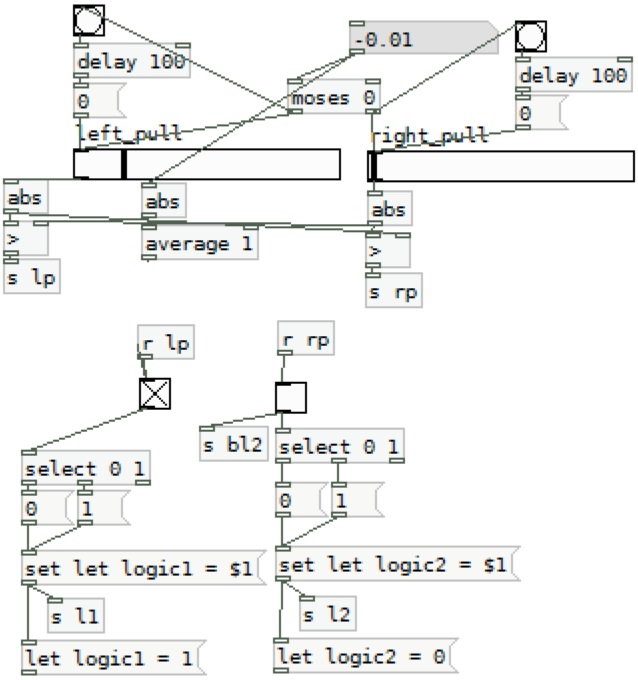

Figure 14. Changing the polarity using the 'moses' object to divide the signal into two separate streams

Managing the PWM signal was a straight-forward scaling between minimum and maximum values. We knew that the minimum absolute value that came from unity was 0, for when no force was present, and did not exceed 0.08. We also had the PWM values from the previous tests, so that the incoming camera position values could be scaled into corresponding PWM values. There was no need to consider the polarity, since it was already considered, when dividing the signal stream into 2 streams: one with a positive and one with a negative sign. During the initial testing, the GVS values that were used remained between 1000 and 2000 mV, to produce between 1 and 2 mA current between the electrodes.

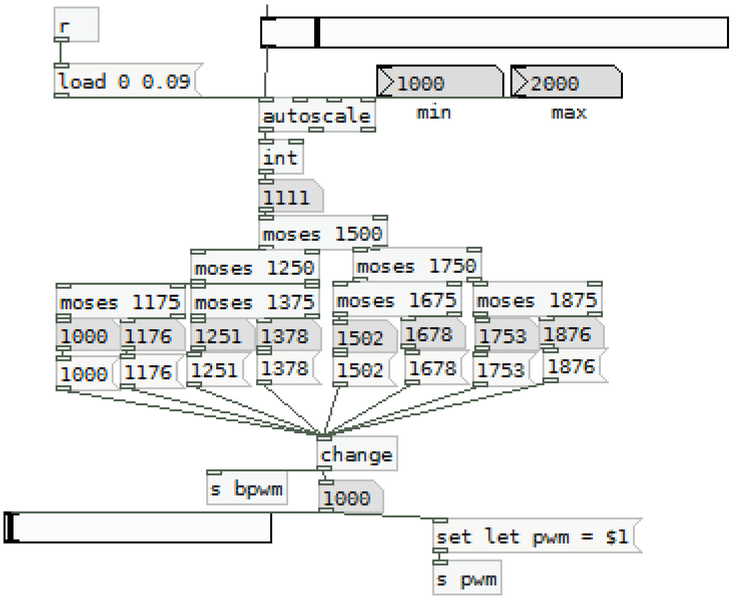

Figure 15. Scaling the input numbers to values for the half H-bridge

We noticed an issue when changing the GVS values rapidly: the device seemed to set the PWM signal value to 0 each time before setting a new value, this meant that the more rapid wheel movements were present, the more change often the GVS was triggered, giving an illusion of stronger current. We could limit the change of current and resetting the device, by using threshold values for when the PWM signal gets a new value (Figure 15). This also eliminated the resetting of the PWM signal each time the value was changed.

Sending Data

All that was left was to make sure the data gets forwarded to the right serial port whenever there was a change in the values. On Figure 14, there is an ‘s’ object named ‘bl2’, which is short for bang logic2 and its purpose is to notice a change and forward a message with the new information at the same time that the change has occurred.

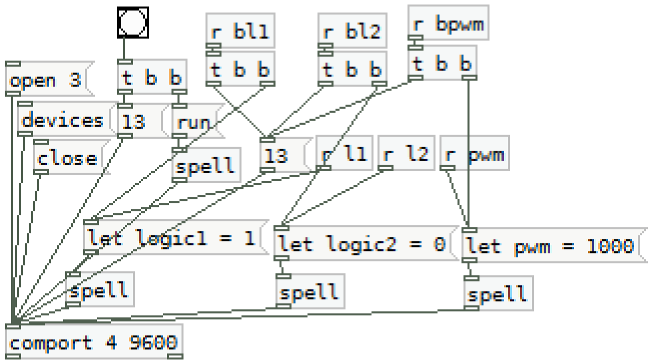

Figure 16. Communication through serial port

On Figure 16 there is a an ‘r’ object named ‘bl2’, which is reading when the ‘bl2’ value is changed, after which a corresponding message gets forwarded to the serial port as a byte array, by using the ‘spell’ function.

Variables on the MCU

The setup on the MCU is simple: 3 variables are needed to operate the half H-bridge. 2 variables are needed for changing the polarity and 1 for changing the amount of current for the electrodes.

```
10 dim pwm as pin rd1 for analog output

20 dim logic1 as pin an0 for digital output

30 dim logic2 as pin an1 for digital output
```

The 3 lines of code above are configuring the MCU to use the specified pins with the specified variable names in order to put to use the byte-arrays that are communicated from Pure Data. Since the communication with serial port is using byte messages, then the Pure Data messages can be applied without any further processing.

10. Final Test

From what was found before (see Conclusions on page 32), we have hypothesized that **divided attention is negatively affected during the vestibular system perturbation in healthy subjects**. The research also suggested that the driving speed was expected to increase. Since the divided attention was expected to be negatively affected, the total driving time is expected to be more than in the second condition group. The arithmetic task is also expected to be worse than in the second condition group. The following chapters explain how such a hypothesis was prepared for testing.

Test Methodology

To be able to physically measure the effects of GVS during the test, it was best to set up a uniform environment for all the test-subjects. Driving a car while doing other tasks seemed like an interesting approach, and comparing the vestibular stimulation with divided attention was what could be imagined going on while driving a car. A car simulator potentially has the forces like acceleration and centrifugal force which would encourage the use of GVS, without being as dangerous as driving an actual car while dividing attention between other tasks. The test-subjects needed to feel as if sitting in the real car driver seat. Personal preferences have taken effect when considering the possible options, since there are several platforms that we have already been used to, that is why not many other choices were considered.

Unity website[6] offers a selection of tutorial projects for the Unity game engine, among them are partially implemented car driving games. By using an existing tutorial as a basis for the simulator, only few adjustments needed to be made to connect the centrifugal force to a GVS signal. Also any kind of Heads-Up Display (HUD) information that we could find necessary would be easily added to the Graphical User Interface (GUI).

The information that was necessary to reach the test-subject from the simulator was not only audio-visual, but also an electrical current carried on to the test-subject as a potentially interpretable feeling of acceleration through the GVS. Therefore another application was used to communicate between the GVS device and Unity. Pure Data[7] is mostly designed to process sound, but any other signal-processing would also be

[6] http://unity3d.com/gallery/demos/demo-projects retrieved on 1st of April, 2013

[7] http://puredata.info/ retrieved on 21st of February, 2013

possible. By establishing a connection between the two applications it could be possible to exchange data between Unity and Pure Data.

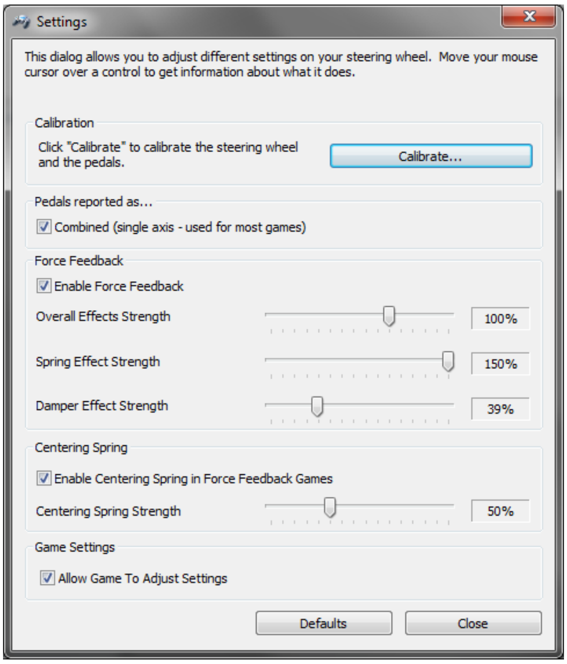

Figure 17. Settings for the Driving Wheel.

Since the simulator should have resembled driving a real car as closely as possible, wheel and pedals (Logitech G25) were necessary to be used. The wheel and pedals were sufficient to interact with the driving simulator, but a few settings were changed (see Figure 17) to make the simulator more believable, per personal experience.

A microphone and screen-capture software were used to make it possible to gather and analyse, in depth, the performances of different tasks.

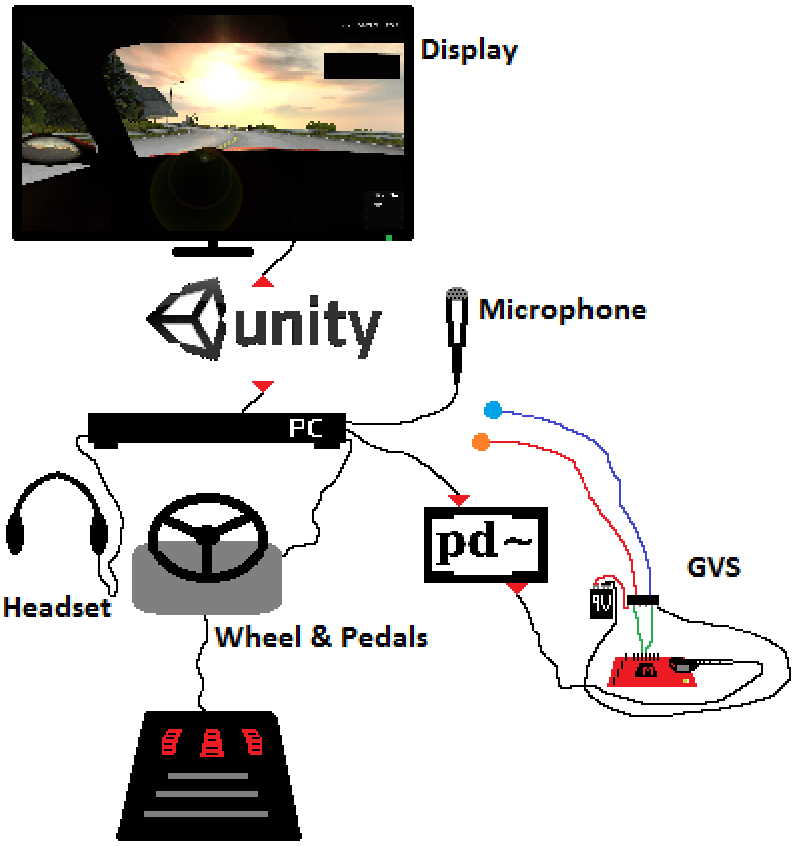

Figure 18. Design Idea, showing the key elements of setup

Test Design

The aim of this project was to see if the GVS can have an impact on humans divided attention. For the test we chose to use quantitative methods for the data gathering to have the test results more reliable. We have combined two test designs: within test design and inbetween test design.

Within test design was applied for two groups separately. All in all we have tested 20 Aalborg University students and staff members. Each of the experiment subject was testing two conditions, so the number of test participants was increased twice. 40 individual conditions were tested in total.

First group with 10 test participants was performing in two conditions, where one of them was control trial and another – stimuli trial. Other 10 participants were performing the same tasks, but instead of receiving GVS, they received an extra auditory stimulation. Both of the groups were asked to fill out a questionnaire after completing the stimulation trial. The questions included:

Age – this was asked to confirm that the test-subjects fell into the young adults sample of the population. The subjects had to answer their age in full years.

Gender – this was asked in case there would have been any significant differences between the genders test results, and also to have an equal distribution of the sample population. This was a binary question, and the options were 'male' and 'female'.

Did you feel that the device was attached to your head? – a question regarding the perception of the physical device as a possible cause for extra distraction. This was asked as a binary 'yes'-'no'. It was not a scaled question, since the question can have too much of subjective interference with the results. We found it sufficient to keep it as a binary choice to avoid unnecessary complications that subjectivity might have added.

How did you divide your attention to driving compared to counting? – we asked this question to be able to confirm that the test-subjects were actually trying to focus more on the driving task than the counting. The analysis of this question was ranging from -99 to 99, with increments of 33, leaving the test-subjects with 6 possible choices (see 'Final Test Questionnaire' in the Appendix on page C).

The questions above were asked from all the users, but additional questions were asked from the first condition group regarding simulator sickness. The groups were divided between GVS (first condition group) and sound (second condition group) stimulation groups.

Condition 1:

- **Stimuli trial:** driving in the car simulator and counting backwards by an increment of 7. This group of people was receiving GVS while performing both driving and counting task.

- **Control trial:** driving in the car simulator and counting backwards by an increment of 7, but without being attached to the GVS device.

In order to check if the GVS was not functioning as a distraction, we have prepared a similar test for the second group which consisted of 10 people, who also participated in two trials.

Condition 2:

- **Stimuli trial:** driving in the car simulator and counting backwards by an increment of 7. This group of people was receiving audio stimulation during their cognitive performance. For the audio stimulation we chose a TED talk, which was short and distracting and we found it to be suitable as a control.
- **Control trial:** driving in the car simulator and counting backwards by an increment of 7, but without receiving the audio stimuli.

Since the in the second condition test-subjects were receiving audio stimulation, that we expected to function as a distraction from the driving and arithmetic task, the test-subjects were expected to perform differently while receiving the audio stimulation, to show that the GVS does not have distracting effect – to have an **inbetween test design**.

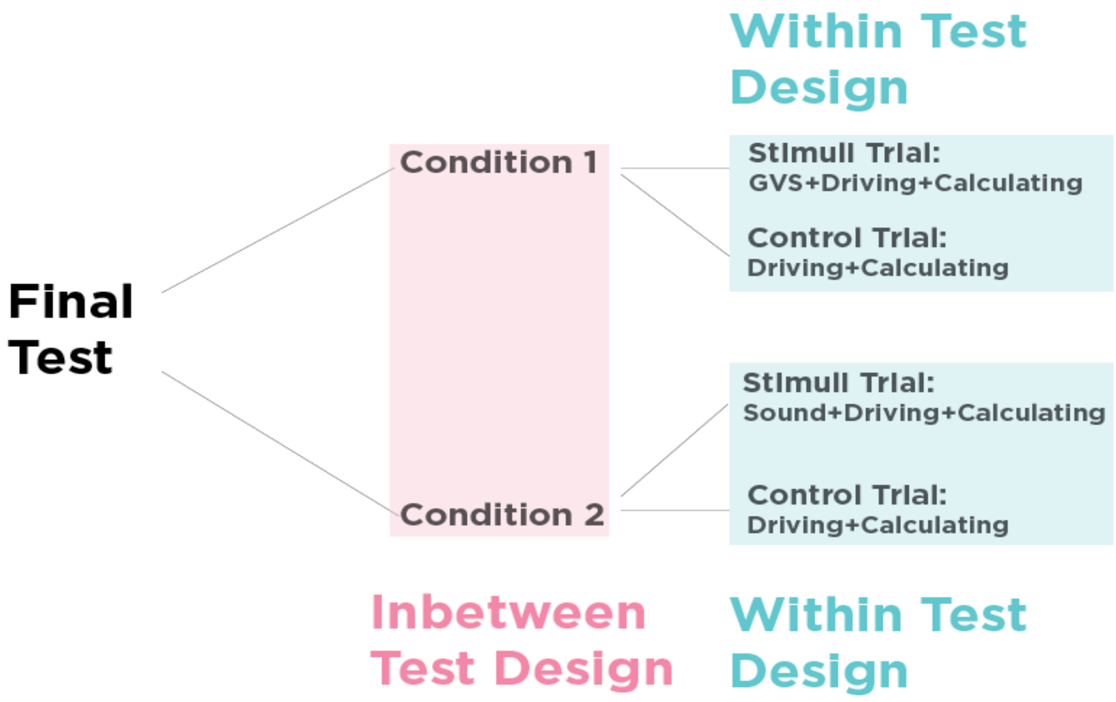

Figure 19. Visualisation of the test into different groups and trial order

The results were analysed for the groups within test designs and then inbetween test design.

In addition, we also decided to use an enhanced method for quantifying simulator sickness – Simulator Sickness Questionnaire (Kennedy & Lane, 1993). The reason why we chose it was to evaluate if the GVS device affected test participants by inducing simulator sickness. The questionnaire included an evaluation of such physiological symptoms, as: general discomfort, fatigue, headache, eye strain, difficulty focusing, salivation increasing, sweating, nausea, difficulty concentrating, "fullness of the head", blurred vision, dizziness with eyes open, dizziness with eyes closed, vertigo, stomach awareness[8], burping. All of the mentioned 16 items were evaluated on a scale of 0 to 3.

[8] Stomach awareness is usually used to indicate a feeling of discomfort, which is nausea.

Figure 20. Test subject from first condition group receiving GVS while driving and having to verbally express arithmetic task results

Results[9]

We tested 10 people in each condition group, where the first condition group (7 males) received GVS and the second condition group received sound stimuli (6 males). All test-subjects had a control trial, so a subjective performance could be measured. The trials were alternated for each subject, so half of the test-subjects received the stimuli first and the other half received the stimuli second. The mean age for the first condition group was 25 (deviation of 2.83 years) and 23.5 (deviation of 2.25 years) for the second condition group. To analyse the driving and counting performance together and between subjects, a performance was calculated in percentages, for each trial. In both groups, the driving completion time improved by at least 3% in the second trial. On average, the driving completion time improved by 18% (deviation of 9.73%) for the first condition group and 14% (deviation of 5.43%) for the second condition group, in total the second trial had a 16% better time than the first trial and deviated 8%. There were more variations regarding the counting task – one test-subject had a better counting result during the first trial. The counting

[9] For detailed test-results with raw data, refer to the CD folder '/Test Material' document 'FinalTestAnalysis.xlsx'

performance was measured by taking the highest number of total answers from either trial and comparing them to the correct answers in each trial, in percentages. For overall performance, the counting performance percentage was subtracted from the driving completion time percentage, where a smaller number meant a better result. For example, a test-subject who performed a trial in 75% of their total driving time (all subjects performed at 100% time in the first trial) and had 100% performance in counting gets a score of -25. All the test-subjects performed better during the second trial, meaning that a learning curve was evident. The mean increase in performance during second trial was 27.8% for the first condition group and 36.2% for the second condition group (deviation of ~18% for both groups). Removing the mean performance increase would not yield an accurate result due to the big deviation. Nonetheless, bearing the aforementioned in mind, test cannot be further evaluated, unless the mean performance increase is removed from each group. When removing the mean performance increase (different for the 2 groups) from each trial, the average performance was at 37.9% for the first condition group and 49.3% for the second condition group during the stimulation trials. The control performance was 29.6% for the first condition group and 48.3% for second condition group, showing that the reliability was questionable.

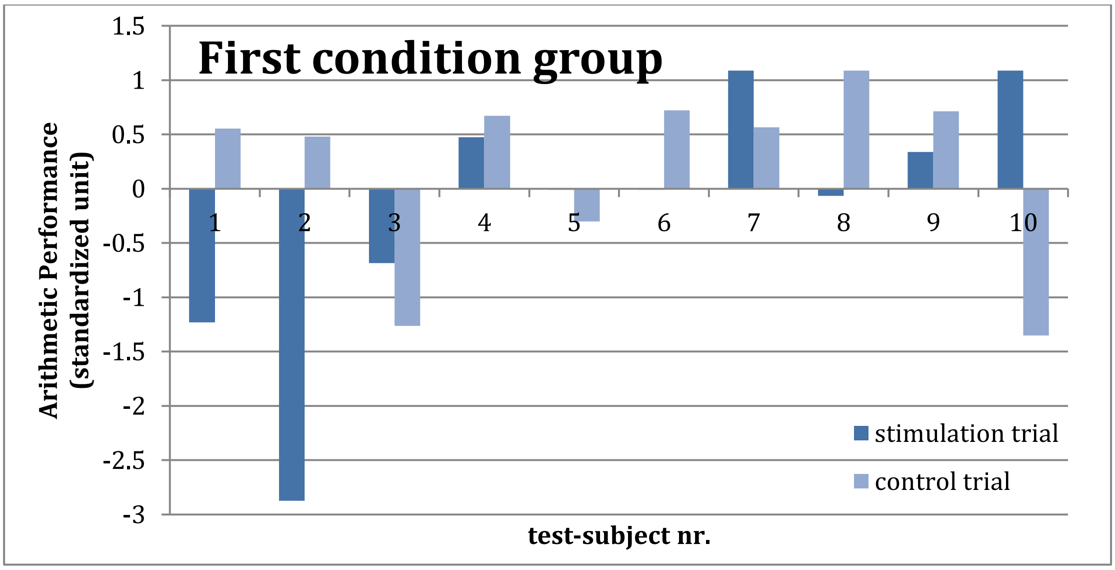

Figure 21. Standardized arithmetic performance in the GVS group, showing a large variation in both trials

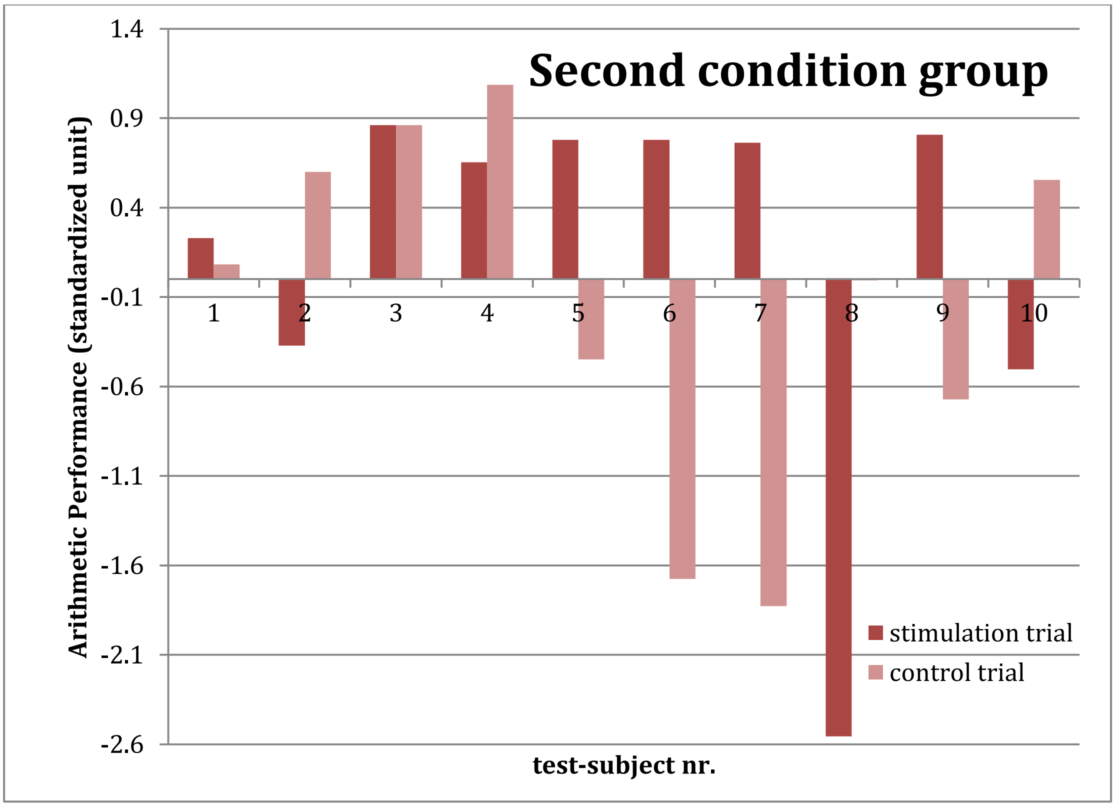

Figure 22. Standardized arithmetic performance in the sound stimulation group. The data shown has a removed learning curve, but shows no difference in performances, still.

It was expected to have a uniform control performance between the 2 groups, since alternating trials were used. Apparently there were not enough test-subjects to generate a reliable dataset, due to not having enough test-subjects.

Even though we cannot conclude if the GVS is working as a distracting effect for dual-task performance, we have found an interesting difference between the reported division of attention between the two groups (mean of 28.05 for the first condition group and -16.5 for the second condition group). Standard deviation could not be considered, due to the categorical nature of the question.

Simulator Sickness Questionnaire Results

Test participants, who were experiencing galvanic vestibular stimulation showed a small impact on symptoms, which were induced during the experiment. Test subjects were filling out the questionnaire, where they had to evaluate each of the symptoms in 4-point Likert scale, choosing from none to severe effect on their physiological state. We calculated subjective and non-subjective averages of simulator sickness to see how much impact the GVS device had on the physiological state of subjects. Figure 4 visualizes non-subjective simulator sickness evaluation, where we calculated averages for each of the symptom in the simulator sickness questionnaire for all test participants. In non-subjective simulator sickness evaluation the most notable differences emerged between difficulty focusing, difficulty concentrating, "fullness of the head". Rest of symptoms did not rate as high (Figure 23).

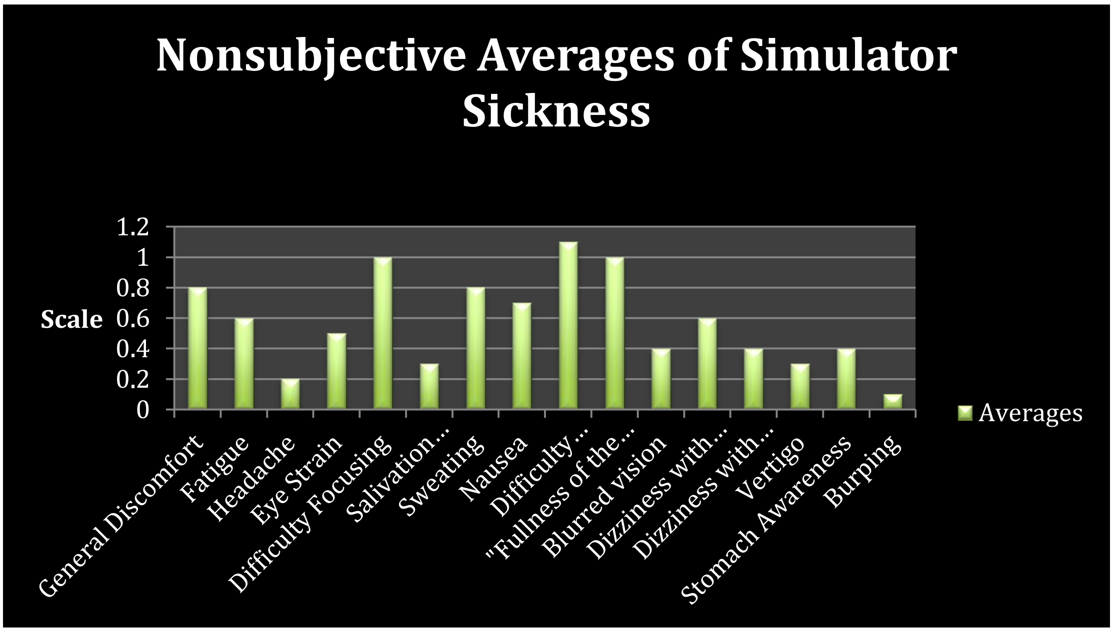

Figure 23. Nonsubjective Averages of Simulator Sickness

Therefore, calculating averages of simulator sickness for each of the individuals' separately provided us with results which showed that two out of ten participants were experiencing moderate simulator sickness. Seven out of ten test participants were experiencing slight simulator sickness and one participant did not experience any of the sickness symptoms (Figure 24).

Results gained from the simulator sickness questionnaire provided us with the information regarding how much impact it had on subjects' physiological characteristics, telling us that the impact was not significant.

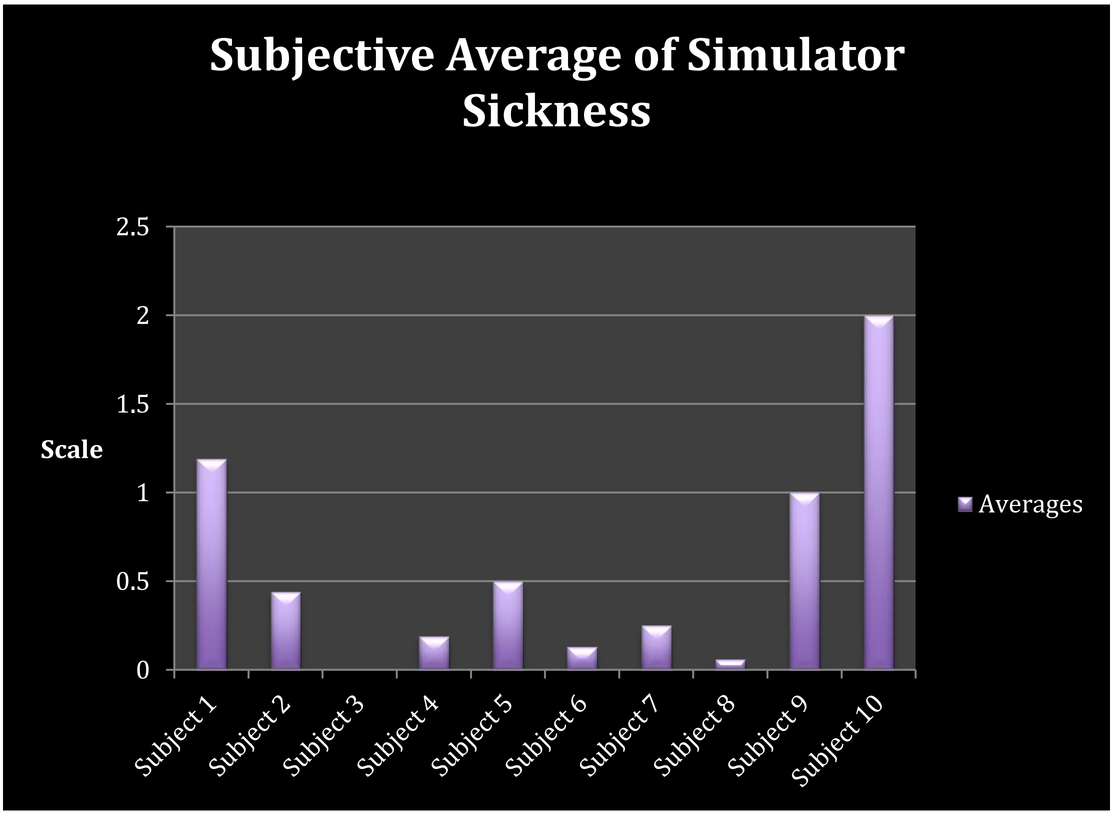

Figure 24. Subjective Average of Simulator Sickness

Discussion

Findings from the test were inconclusive, but the framework and setup of the test need no adjustments for any future testing. When removing the average increase in performance, the first and second trial should have become comparable. We expect this to still be true, but the test needs to be conducted on more subjects, since the variability and subjective choices for dividing the attention can still vary and have an effect on the final results. If more subjects could be tested, then the attention division between driving and arithmetic question could be used as a divider into groups, where standardization could be applied on their results separately before comparing the groups to each-other.

11. Conclusions & Future Perspectives

The future perspective of the GVS device usage in real life world is various, but as it was already mentioned, before using it more investigation is required. However, it is already found that GVS can be used in the vehicle simulators. If the training simulation tasks will not require complicated cognitive processing, the GVS can be very helpful in simulating an environment whether it would be a flight, a road trip, or other type of locomotion.

GVS could also help people with seasickness. As it was established, this device has positive impacts for decreasing movement perturbations. If a proper algorithm would be developed, and the GVS could be designed as a small, comfortable and portable device, people with seasickness could have an opportunity to forget about this discomfort. We considered the forces exerted to our virtual driver to be above the values that the GVS device could portray. However, this device has not been used as a simulation of a measurable force before, and we had to take our chances with using the virtual forces that were present in the simulator. The currents that would have been needed, would have exceeded the pain threshold, and possibly rendering a distraction factor into the VE. Nonetheless, the number of test-subjects needs to be increased to confirm the above mentioned, plus any of the distracting factors the device might have.

Entertainment field could become more engaging with the GVS support. Video games could be more realistic if people would be able not only to control but also be controlled. Vehicle simulation, fighting and games from other genres could have more potential to catch attention of not only the enthusiasts, but also people who have no interest in the game industry. The new perspective of game hardware that the GVS device potentially has would open the doors into even wider possibilities, than available now, in the game industry.

The GVS implemented into a small portable device could become an integral part of older peoples' lives in order to prevent them from falling. Disabled people – visually challenged, for example, could have an opportunity to navigate as healthy people. By being connected to the GVS device they would be navigated to their destination. The many options that the GVS device holds are interesting and could easily associated as part of a solution for several problems, but more tests need to be made and agreed upon, to establish standards and help the product find practical uses.

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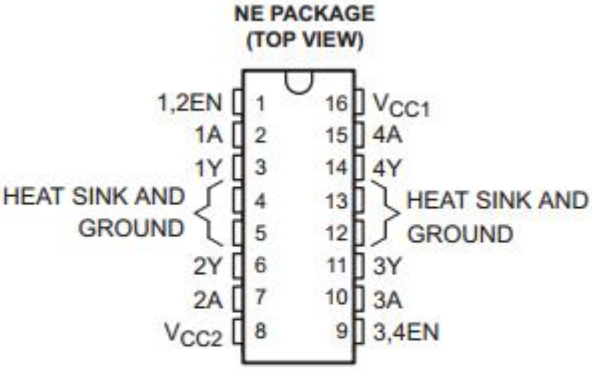
13. Appendix



FUNCTION TABLE
(each driver)

INPUTS†		OUTPUT
A	EN	Y
H	H	H
L	H	L
X	L	Z

H = high-level, L = low-level
X = irrelevant
Z = high-impedance (off)
† In the thermal shutdown mode, the output is in a high-impedance state regardless of the input levels.

Figure 25. The pin configuration of the h-bridge[10]

[10] See the CD folder '/Papers' for the complete datasheet named 'H-bridge_datasheet.pdf'

3M™ Red Dot™ Adult Solid Gel Electrode 2239

NPC Code		FDK148
Indication for Use		Short Term Monitoring
Dimensions	Electrode Size: Skin Contact Size: Adhesive Area: Height excluding connector:	6.1cm diameter 6.1cm diameter 23.87 sq cm 0.013cm
Electrode Materials	Backing Material: Backing Material Adhesive: Connector: Release Liner: Sensor Material:	3M™ Micropore™ Tape Micropore tape adhesive Stainless Steel Snap Si coated paper Silver/silver-chloride coated plastic
Sensor	Gel system: Gel area: Sensor area:	Crossed linked guar gum (solid gel) 0.503 sq cm 2.45 sq cm
Lifetime	Recommended max application time: Sealed pouch:	3 days 2 years
X-Ray and MRI	X-Ray: MRI:	NO NO
Environmental Issues	PVC-free electrode: Latex-free electrode: PVC-free packaging	YES YES YES
Packaging Quantities	Pouch:	50

Figure 26. The datasheet for the 3M electrode[11] used in our GVS devices

[11] See the CD folder '/Papers' for the whole datasheet named '3M_RedDot_datasheet.pdf'

Final Test Questionnaire

Subject: Correct Answer:

Age: Time:

Gender: F/M

1. How realistic was the sense of acceleration? (0-not at all, 4-very realistic)

0 1 2 3 4

2. Did you feel that the device is attached to your head?

Yes/No

3. How did you divide your attention to driving compared to counting? (Circle appropriate vertical marker)

Driving |----------|----------|----------|----------|----------|----------| Counting

Simulator Sickness Questionnaire

Instructions: Circle how much each symptom below is affecting you right now.

General Discomfort	**None**	**Slight**	**Moderate**	**Severe**
Fatigue	**None**	**Slight**	**Moderate**	**Severe**
Headache	**None**	**Slight**	**Moderate**	**Severe**
Eye strain	**None**	**Slight**	**Moderate**	**Severe**
Difficulty focusing	**None**	**Slight**	**Moderate**	**Severe**
Salivation increasing	**None**	**Slight**	**Moderate**	**Severe**
Sweating	**None**	**Slight**	**Moderate**	**Severe**
Nausea	**None**	**Slight**	**Moderate**	**Severe**
Difficulty concentrating	**None**	**Slight**	**Moderate**	**Severe**
“Fullness of the head”	**None**	**Slight**	**Moderate**	**Severe**

Blurred vision	**None**	**Slight**	**Moderate**	**Severe**
Dizziness with eyes open	**None**	**Slight**	**Moderate**	**Severe**
Dizziness with eyes closed	**None**	**Slight**	**Moderate**	**Severe**
* Vertigo	**None**	**Slight**	**Moderate**	**Severe**
** Stomach awareness	**None**	**Slight**	**Moderate**	**Severe**
Burping	**None**	**Slight**	**Moderate**	**Severe**

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort, which is nausea.