The Effect of Haptic Feedback on sEMG Input Performance

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Abstract

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Commodity electromyography (EMG) armbands are inexpensive tools that can be integrated into user interfaces. EMG involves measuring electrical activity associated with muscle movement and thus presents a novel input channel in human computer interaction. However, using EMG interfaces could present a large cognitive load, as the EMG muscle movements may not translate well to the computer task. This work explores the use of the haptic sensory feedback channel to augment the performance of EMG input interfaces. A novel EMG controlled computer game that used a haptic sensory feedback loop in addition to the visual feedback was developed. To validate and more importantly evaluate the effectiveness of the haptic feedback, extensive user studies were conducted. The results of the user study showed that adding haptic feedback to sEMG control increased performance in some cases at minimum and increased performance in a statistically significant manner in other cases.

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Chapter 1. INTRODUCTION

As technology progresses people find new ways to interface with old and new technologies. Surface Electromyography (sEMG) is a popular method to interface with varying technology. sEMG has expanded its uses into prosthesis control, robotics control, fitness monitoring, and biomedical applications. With muscle movement we can control technology as common as our smart phones to change music or use it to control something more specialized such as a drone or prosthetic arm. Although current sEMG is making progress, there are still many hurdles. So far sEMG, due to its nature of only reading from the surface, is not very accurate, but more importantly not universal in terms of user-acquired signals. Reading sEMG signals can vary greatly depending on orientation, user skin, user hair, or user muscle to fat ratio [6]. With all these factors it is very difficult to build one application that could work with everyone reliably since the signal can vary so much from user to user.

Haptic technology is a field that has many potential uses. One potential use is augmenting prosthesis control to allow a user to “feel” their environment, thus allowing them to make corrections based on a combination of haptic and visual feedback rather than just visual. Nathan Copeland, a man that was paralyzed due to a car accident, recently was able to use a prosthetic arm to shake hands, fist bump Barack Obama, and “feel” his hands for the first time in over 10 years [5]. Although he did not utilize sEMG control, Copeland was able to feel the prosthesis touch the president's hand through some help of an electrical implant that stimulates his brain. With advances in emerging technologies people that have had similar injuries may be able to feel again. Although haptic technology has come a long way and allows people to “feel” once again, the process can be very invasive and expensive. In Copeland’s example, it required surgery to implant a chip that interfaces directly with his brain. Adding haptic feedback to devices also means buying actuators and sensors, which take up more space, weigh more, and add cost. However it is not understood whether adding haptic feedback to current sEMG prosthesis will help users when performing their day-to-day tasks.

1.1 RELATED WORK

Current research trends have shown that when comparing visual (V) versus haptic + visual (HV) feedback, HV feedback tends to increase performance depending on the situation. However, many papers conclude that adding haptic feedback to visual feedback has no statistically significant effect at all or may even decrease performance due to a number of factors such as cognitive load.

Wagner et al concluded that having force feedback reduced peak force, average force, and errors. When haptic feedback was removed average force increased by 50%, peak force increased by a factor of 2, and errors increased by a factor of 3 [7]. In Wildenbeestm et al, they concluded that overall task performance and control effort improved when providing low frequency haptic feedback [8].

Papers suggesting that haptic feedback has no effect include Vo et al and Corbett et al [3][1]. Vo et al tested the efficacy of haptic feedback in virtual reality assembly tasks. They reported inconclusive performance gains from adding haptic feedback to the virtual environments [3]. In Corbett et al, they concluded that augmenting a three-dimensional virtual environment with vibrational feedback was perceived negatively and had slight negative impact on movement time performance. However, a haptic attractive force significantly improved performance and was preferred by subjects [1].

Overall haptic feedback seems to have advantages in specific circumstances. There have not been many studies regarding how haptic feedback would help with sEMG input, a common modality to use for input control. This thesis investigates the effects of haptic feedback on an sEMG input task.

1.2 CONTRIBUTION

To the best of the authors' knowledge, this work is the first to integrate the Myo and Phantom Omni into a gaming platform in Unity3D to test performance in the haptic, haptic visual, and visual only modes.

Chapter 2. BACKGROUND

2.1 ELECTROMYOGRAPHY

Electromyography (EMG) is a technique that detects electrical potential that muscles cells create when those cells are electrically or neurologically activated. These types of signals are most commonly analyzed and used to detect medical abnormalities or to analyze human biomechanics. There are two types of EMG, intramuscular EMG and surface EMG. Intramuscular requires the subject to have their skin prepped and have a needle electrode inserted into the muscles directly. Although considered more accurate, intramuscular EMG is invasive and therefore not preferred for many applications. SEMG only requires an electrode to be placed on the surface of the skin. This may require skin preparation (depending on the electrode type). This allows sEMG to be used easily in subject testing and is ideal for this study. The use of sEMG assesses muscle function by recording muscle activity from the surface of the skin. Although the accuracy of sEMG isn’t as high as intramuscular EMG, it has enough resolution for basic control of a haptic game. Since EMG recording displays the potential differences between two separate electrodes, a minimum of two electrodes are needed to properly record sEMG. This study uses the Thalmic Lab's Myo, which uses sEMG to record muscle potentials from the surface of the skin. It uses 8 surface electrodes to read around the forearm. An example of the sEMG graphs from the 8 electrodes is shown in figure 1.

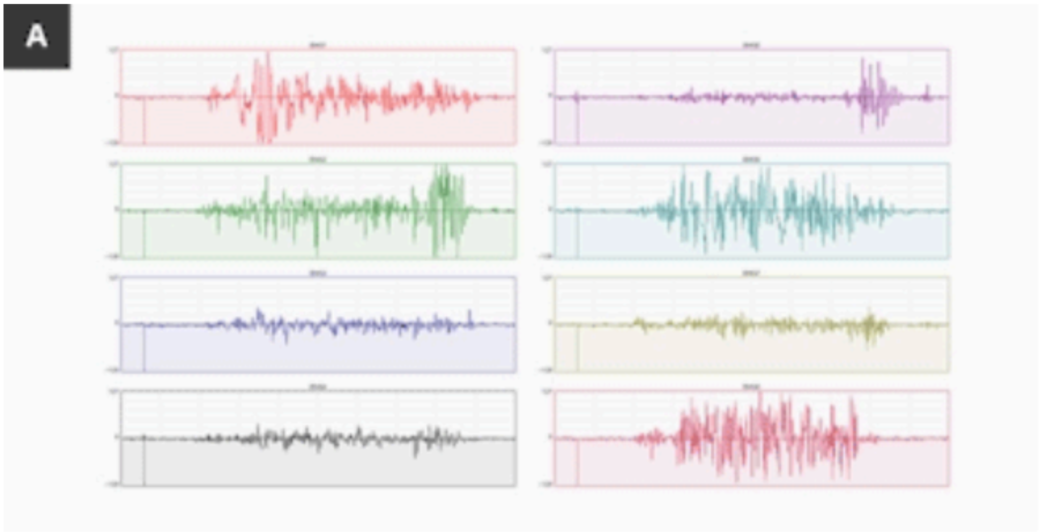

Figure 1: An example of sEMG signals acquired from the Myo

2.2 Haptic Feedback

Haptic is derived from the Greek word ἅπτεσθαι or haptestha*i* meaning to contact or to touch. Haptic systems can generally be split into two sensory systems of touch: cutaneous and kinesthetic. Cutaneous feedback refers to all information acquired through sensors in the skin. This includes pressure, temperature, traction, vibrations, or roughness. Kinesthetic feedback is the feeling of position of body and learning through doing. SEMG in relation to haptics is usually used to analyze the biomechanics of humans and then use it for some task or analysis. Haptics have a wide variety of uses. They can be used in games, teleoperation, robotic surgery, mobile devices, or even holograms. Haptics can be split into contact and non-contact haptics. Contact haptics is done through a physical connection while non-contact haptics can be achieved through gusts of air or ultrasound. In this work we focus on haptic feedback in the form of resistive forces being applied in specific directions as well as vibrations, which are all a form of contact haptics. This haptic feedback will be added to sEMG control in order to test subject performance while playing a haptic sling shot game. We investigate whether or not haptic feedback will increase user task performance when added to sEMG controls (via the Myo).

Chapter 3. METHODOLOGY

3.1 PHANTOM OMNI

The PHANToM Omni, shown in figure 2, is a 6-degree of freedom (DOF) haptic device produced by SensAble^{TM}. The first 3 DOF define the Cartesian position of the end-effector of the pen and the last 3 DOF define the orientation of the end effector. In this experiment, the last 3 DOF are not necessary for the experiment and ignored so the Omni is essential reduced to a 3 DOF system. The last 3 DOF are ignored because the Omni will be used as a haptic feedback device and so the orientation of the end effector is not relevant. Haptic feedback can be given to the user in the X, Y, and Z directions relative to the Omni but will be limited to the X direction for this experiment, so as to try to reduce cognitive load (since the user would only have to worry about one dimension of force). The Omni makes it possible for users to touch and control virtual 3D modeled objects, essentially “feeling” a virtual world. Using this capability, users are able to feel objects and some degree of texture. The Omni uses the OpenHaptics toolkit, software that enables haptics in a broad range of applications. One such application we will use is Unity3D, which will be explained in section 3.2. Due to its specs and popularity, the Omni is used in many research applications.

Figure 2: A picture of the Phantom Omni

3.2 MYO ARMBAND

The Myo armband is a device developed by Thalmic Labs. With 8 electrode sensors, the Myo can read sEMG signals and make use of a 9-axis IMU, which includes a 3-axis gyroscope, 3-axis accelerometer and a 3-axis magnetometer. Using this hardware, the Myo is able to detect hand gestures as well as arm movement data, which will help in learning about user performance as they play the games. The Myo's features allow it to be excellent for controlling different interfaces. One such example is drone control as shown in figure 3. The user can wave left or right and the drone would move left and right correspondingly.

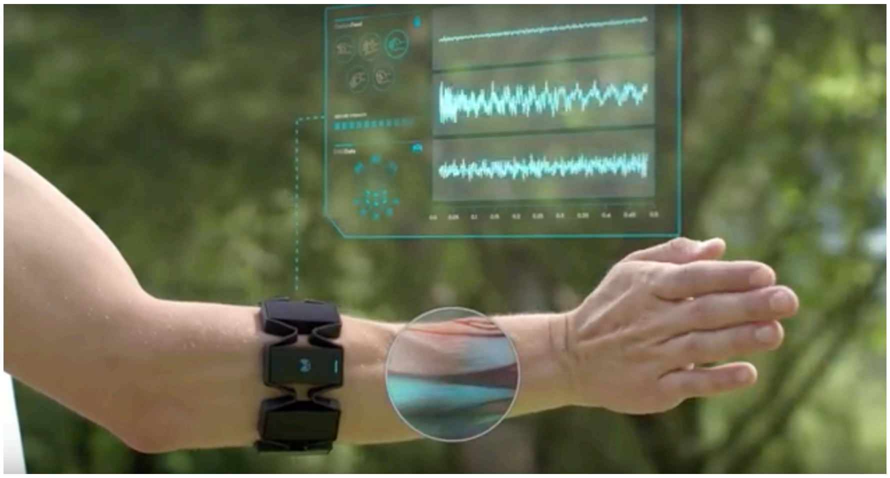

Figure 3: A user using the Myo to control a drone

Although the Myo is very convenient for use since it is non-invasive, it does require the user to make a calibration step before using the gadget for optimal accuracy. This is due to the fact that each user has a different type of skin, muscle to fat ratio, etc., that will vary the signals the Myo will receive as they use the device. Languages supported by the Myo for development include C++, objective-C, Lua, Matlab and a list of others, which are supported via unofficial tools and language bindings. However there is an official package provided by Thalmic Labs that allows the user to directly interface with Unity3D and allow easy access to its functions, which this experiment took advantage of.

3.3 UNITY 3D

Unity3D is a cross platform game-development engine developed by Unity Technologies Company and is widely used in 3D and 2D game development for either console, mobile, or desktop environments. In order to build games and programs users code in C#, JavaScript or Boo along with Visual Studio or Monodevelopment programming environments. Unity3D can also import C++ libraries and use them in C# code, which is important in using the Phantom Omni that is natively programmed in C++ as well as the Myo, which also uses C++. Unity3D has an active ecosystem of assets and plugin creators, rapid development speed, and cross-platform integration that supports 25+ platforms. This makes Unity3D ideal for quick one click development since the scripting isn't very difficult and many objects and assets that a user would usually create by hand are available on the Unity3D market for free or at a price. Unity3D was run on a system with Windows 7 professional-64bit, 8GB RAM, AMD Athlon II x4 645 3.1 GHz processor, ATI Radeon 3000 graphics, and a double monitor setup consisting of a Dell 1680x1050 and an Asus 1920x1080 monitor. The games were played on the Asus monitor and a sample of the workspace is shown in figure 4.

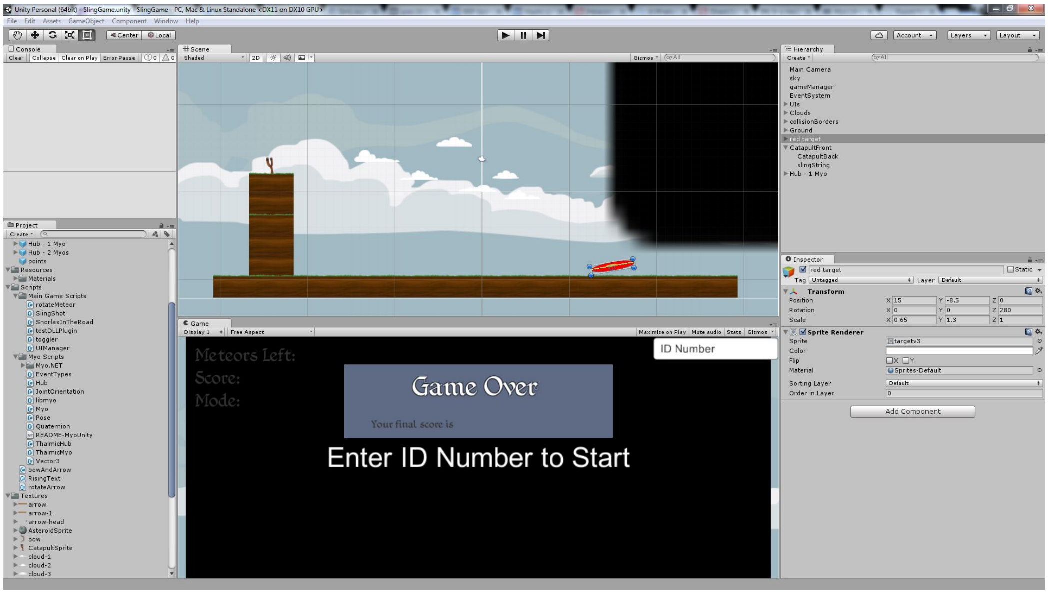

Figure 4: Sample of Unity3D Work Environment

3.4 EXPERIMENTAL SETUP

Unity3D has a different native language than the Phantom Omni or the Myo. In this work, the Phantom Omni uses C++, Unity3D uses C#, and the Myo uses C++. The communication flow is as such: the game displays through the computer monitor and Unity3D keeps track of the data. The Myo provides sEMG read hand gestures and the Phantom Omni provides haptic feedback. The block diagram is shown in figure 5 below.

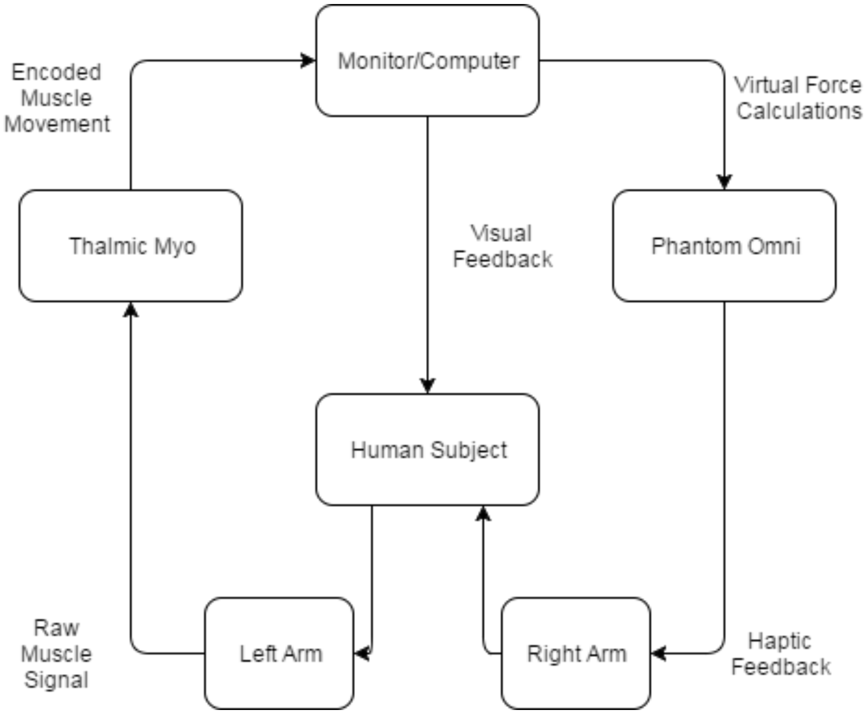

Figure 5: Block diagram of experimental setup

Thalmic Labs has an official Unity3D plugin, which allows the user to program the Myo through Unity3D's C# using the MyoSDK. This allows the user to easily integrate the Myo with Unity3D and start creating and controlling games with the Myo quickly. Integrating the Phantom Omni is more complicated since there is no direct plugin. Instead a custom DLL file was created to interface the C++ libraries of the Phantom Omni with the C# language in Unity3D. Once the DLL was created, this allowed the user to control the Phantom Omni through Unity3D's C#. Putting together all three components I created a test-bed haptic gaming platform to test the effects of haptic feedback on sEMG control.

3.5 SLING SHOT GAME

The Sling Shot game was developed in Unity3D and integrated with the Myo and Phantom Omni. In this game the subject tries to hit a target some distance away with a sling shot that shoots meteors. The subject controls the sling pull back distance by making hand gestures with the Myo. The controls are ‘wave in,’ ‘wave out,’ and ‘fist’, which corresponds to pull back, pull forward, and release respectively. If the target was hit, it would randomly move in the X direction to a new location. If the target was not hit it, it remains in the same location for the subject to try to hit again. The Myo is used in all experimental modes. The Phantom Omni, when enabled, provides haptic feedback. With the Phantom Omni, the subject is able to get a feel for how much tension is building up in the sling as they pull back or pull forward. Once the meteor is released, the haptic feedback will slack as it would in real life and the subject is able to tell when the meteor is launched haptically or visually. The subject plays one of three game modes: Haptic only, Haptic + Visual, and Visual only, with ten rounds of ten shots each round. The first round is a practice round to try and account for learning and the remaining nine rounds have two visual only modes randomly interspersed in them and seven mode specific rounds. A sample is shown in figure 6 below.

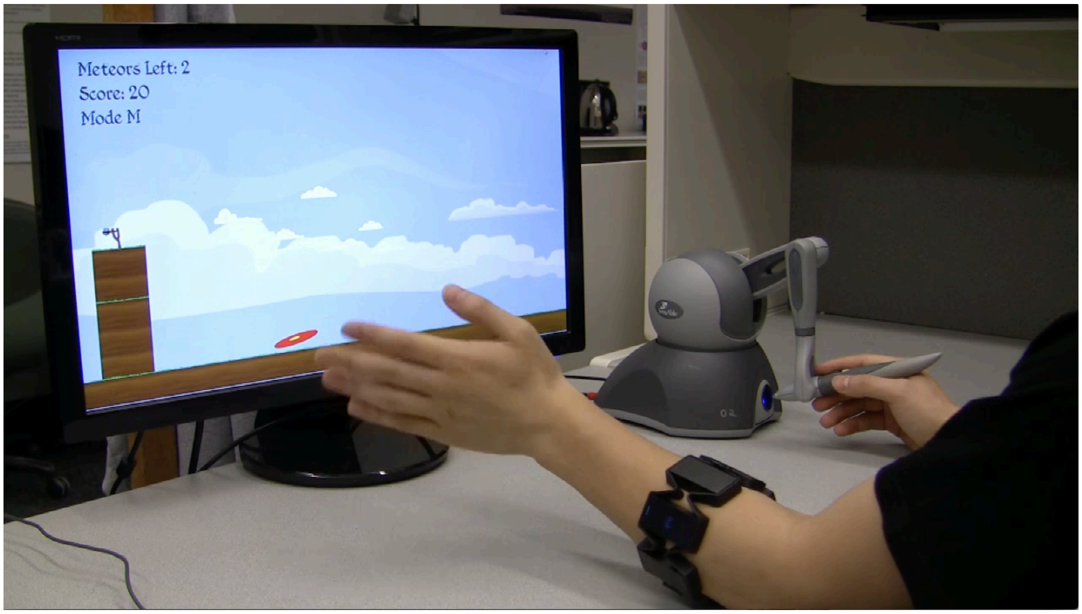

Figure 6: Sample Play Through in Haptic Visual Mode

3.5.1 *Haptic*

This mode focuses the subject on the haptic forces that are being rendered. The subject uses the Phantom Omni haptic forces to tell how far they have pulled back. Using this information they try to hit the target. In this mode a cloud covers the sling area so the subject is not able to visually tell how far they have pulled back. Visually they are only able to confirm the results of how far they have pulled back by where the meteor ends up after release. A sample screenshot of the view a subject sees is shown below in figure 7.

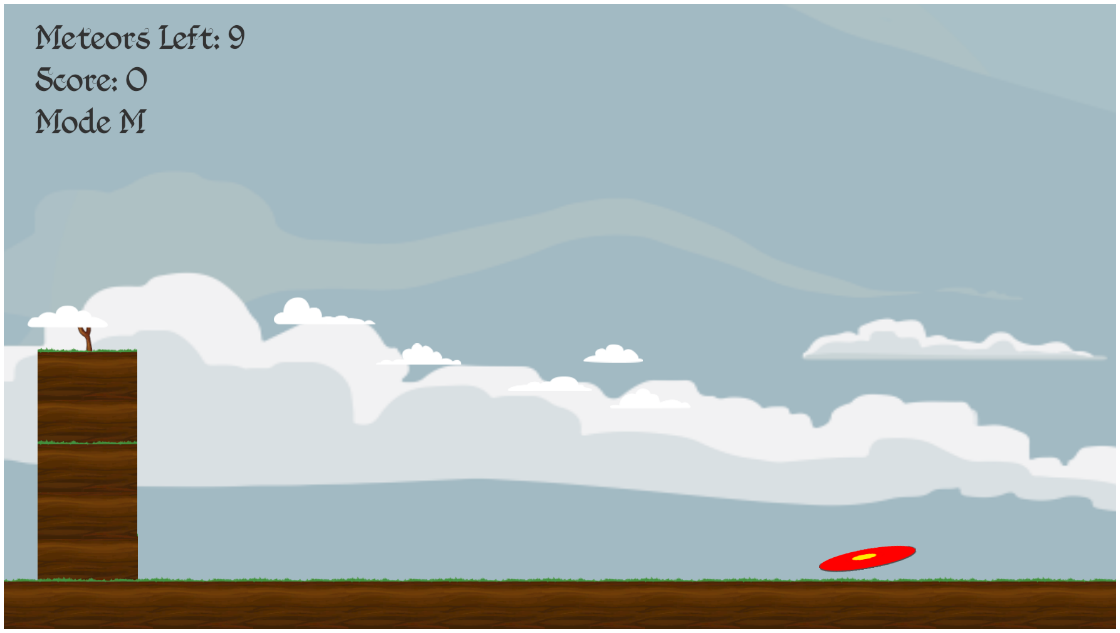

Figure 7: Screen shot of subject playing in haptic only mode

3.5.2 *Haptic + Visual*

This mode uses both haptic and visual feedback. In this mode the subject is able to fully see the game playing field with no obstructions. The subject uses a combination of visual and haptic feedback in order to judge how far the sling needs to be pulled back in order to hit the target. The purpose of this mode is to see if augmenting visual feedback with haptics creates a difference in performance. Figure 8 shows a sample screenshot of what a subject sees if they were playing this mode.

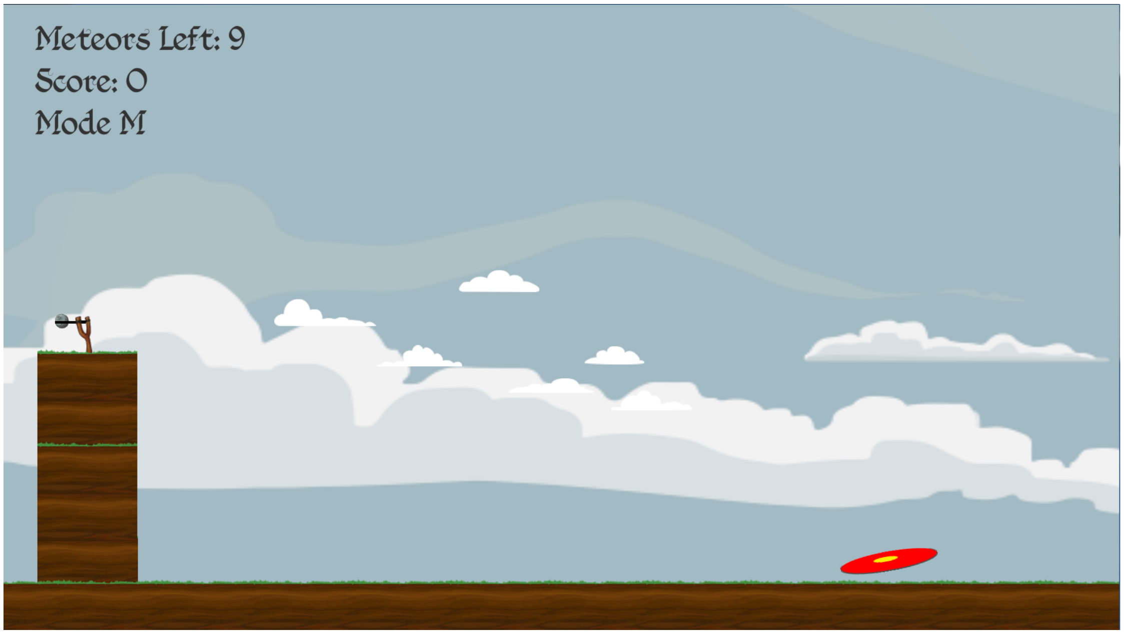

Figure 8: Screen shot of subject playing in visual only of haptic + visual mode

3.5.3 *Visual Only*

This mode uses visual only feedback. The subject plays the game but with no forces rendered by the Phantom Omni. That is, the Omni is not used in this game mode. Using only the Myo and vision, the subject shoots the meteors to try to hit the target. In this mode there is no obstruction to vision in the playing field. This mode has the same visuals as the haptic visual mode. Figure 8 shows what a subject sees if playing this mode.

Chapter 4. RESULTS

The total number of subjects for this experiment was 51 subjects. This experiment had 30 females and 21 males between the ages of 18 and 33, with an average age of 22.5. Of these subjects, 44 were right-handed, 4 left-handed and 3 had no preference in terms of daily activities. Subjects answered questions from the Edinburgh handedness scale. This scale asks subjects what hand they use in their everyday activities and assigns a more quantitative value to how left or write handed a subject is. The scale has values from -100 (left handed) to +100 (right handed) and the average value from this scale was 73.62, which follows what the users self rated their handedness. In terms of gaming experience, 7 subjects rated themselves with no experience, 21 rated themselves with low experience, 15 rated themselves with medium experience, and 8 rated themselves with high experience.

In this study, approximately half the comparisons were statistically significant for either accuracy or time to completion, and half were not. Using a two-tailed t-test to compare H vs HV, H vs V, and HV vs V the P values are listed below in table 1.

	Time	Accuracy
Haptic vs. Haptic Visual	0.1658	**<u>0.0048</u>**
Haptic vs. Visual	0.6233	**<u>0.0340</u>**
Haptic Visual vs. Visual	**<u>0.0462</u>**	0.6957

Table 1: Table of raw P values for H vs. HV, H vs. V, and HV vs. V

If taken as raw values we see that for accuracy, the H vs HV and H vs V modes were statistically significant while only HV vs V was significant only for time to completion. The statistically significant values are bolded and underlined. For HV vs V, which is a main interest of this study, only time had a significant P value of 0.0462, while accuracy did not have a significant P value of 0.6957. The box plots for time and accuracy are shown in figures 9 and 10 while the mean and standard deviations for each mode are in table 2 and 3.

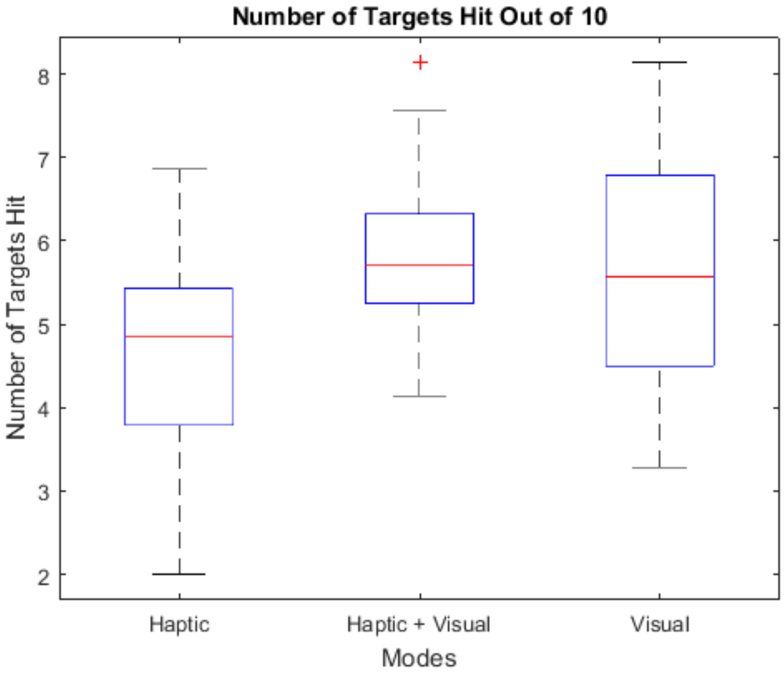

Figure 9: Box plot of accuracy for each haptic mode

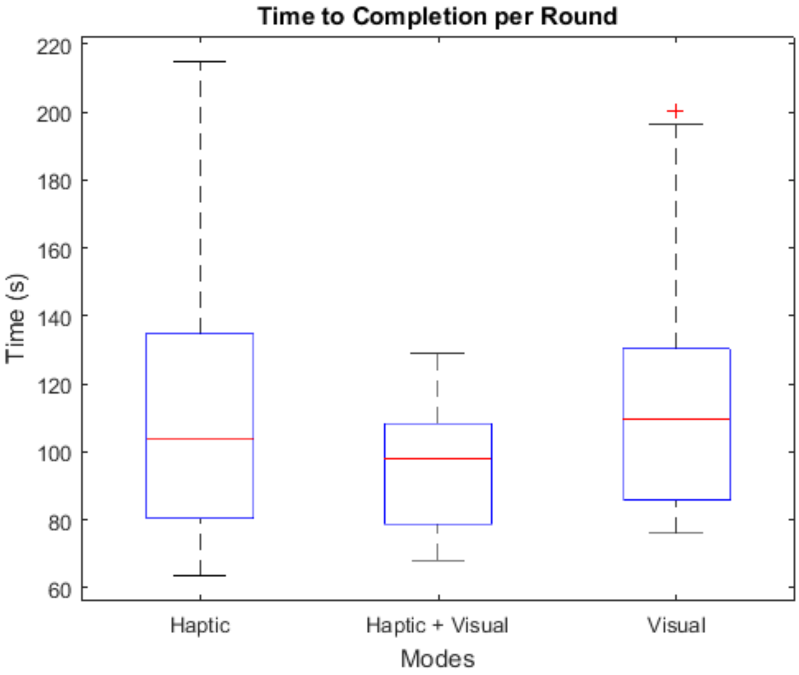

Figure 10: Box plot of time for each haptic mode

	Mean	Standard Deviation
Haptic	4.6218	1.2047
Haptic Visual	5.7899	1.0340
Visual	5.6218	1.4187

Table 2: Table of mean and standard deviation for accuracy (targets hit out of 10)

	Mean	Standard Deviation
Haptic	111.2233	37.9740
Haptic Visual	96.6612	18.7434
Visual	117.6180	37.1194

Table 3: Table of mean and standard deviation for time (seconds)

From table 1 we see that three modes had a P value of less than 0.05 initially. However, we may also have to consider multiple hypotheses testing correction due to the fact that two hypotheses were tested from the same data sets. In order to decide whether or not to use Holm-Bonferonni to adjust the P values, the correlation between each of the modes were tested, similar to table 1, using Spearman's rank correlation coefficient (Spearman's Rho) [2]. A very common way to correct for multiple hypotheses testing is to use the Bonferonni method but the Holm-Bonferonni method was found to be a more powerful and precise method [4]. Spearman's Rho was used since the data set could not be assumed to be Gaussian nor could the relationship between the data sets be assumed to be linear. Spearman's Rho was used since it was able to account for non-Gaussian and non-linear data sets, unlike Pearson or Kendall's. The resulting correlation values are in table 4 below.

	Time	Accuracy
Haptic vs. Haptic Visual	$\rho = -0.2990$	$\rho = -0.2983$
Haptic vs. Visual	$\rho = 0.5$	$\rho = -0.1363$
Haptic Visual vs. Visual	$\rho = -0.0319$	$\rho = 0.3701$

Table 4: Table of Spearman's Rho Coefficient for each mode

If the data set has a $|\rho|$ value less than 0.1 then it is considered to have minimal or no correlation. Small association has $|\rho|$ between 0.1 and 0.29. Moderate association has $|\rho|$ between 0.3 and 0.49. Large association has $|\rho|$ greater than 0.5. We assume that $|\rho|$ values under 0.1 means that there is there is no correlation or that the data sets are independent. Only data sets that had small, moderate, or large association were corrected. The corrected P value table is shown in table 5.

	Time	Accuracy
Haptic vs. Haptic Visual	0.1658	**0.0096**
Haptic vs. Visual	0.6233	0.0680
Haptic Visual vs. Visual	**0.0462**	0.6957

Table 5: Table of corrected P values for H vs. HV, H vs. V, and HV vs. V

Chapter 5. DISCUSSION AND FUTURE WORK

From the results of table 5 we can see that there are statistically significant values in the Haptic Visual vs. Visual comparison, in both time to completion as well as Haptic vs. Haptic Visual in accuracy. That is to say, adding haptics decreased time to completion, which meant an increase in performance (Haptic Visual scores were higher than Visual scores) and Haptics alone resulted in the worst accuracy performance (Haptic Visual accuracy was higher than Haptic accuracy). However this is not to say that there was no difference at all for the other modes.

From these results we can see that adding haptic feedback did on average increase performance, but not enough to be statistically significant in some of the modes. These results lead to the conclusion that haptic feedback for sEMG control in general helped performance and that for certain modes such as HV vs. V time to completion, it increased performance in a statistically significant manner.

Future work could include creating a game that is more complex. This would test the user under more difficult settings and might allow us to get a higher resolution of data (if the current game was too simple and bored the user).

Another possibility is that a one dimensional force feedback is not complex enough to fully test the effects of haptic feedback. In this case making the game a 2 or 3 dimensional force feedback game might increase the difficulty enough to provide better resolution. However we would need to be careful as to not increase the cognitive load too much that it interferes with the results. Increasing complexity in either game complexity of feedback dimension may make the game more interesting but also may increase the cognitive load to the point where performance data may get corrupted.

It should also be noted that multiple hypothesis testing only applies when testing multiple hypotheses. Due to the exploratory nature of this experiment we tested 2 hypotheses, time to completion and accuracy. As seen in table 1, the Haptic vs. Visual for Accuracy had a P value of 0.0340 initially but adjusted to 0.0680 due to the P value correction. If the experiment were redone and we got the same initial P value of 0.0340 we would have a $P < 0.05$ and this could be considered statistically significant. However, since accuracy was also tested we had to adjust the P value to a higher value. We also note that some P values were very close to 0.05 so retesting to verify the significance is recommended.

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