Analysis of the Effect of Visuals on the Stabilization of Trunk Muscles During Rotational Motion

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***Abstract*— Seated balance, especially for the application of wheelchair users, has become an area of interest for researchers. Numerous studies have been done to date, which analyze the effects of wheelchair propulsion on shoulders and limbs, but little study has been done in regards to trunk muscles and their stabilization effects. Therefore, for this study, motorized rotational motion at a rotational angle of 45 degrees was performed on nine subjects in both the forward and backwards directions of motion. Eight abdominal and back trunk muscles (rectus abdominis, external oblique, thoracic erector spinae, and lumbar erector spinae) were analyzed via electromyography (EMG). In addition, the effect of the presence of virtual reality was analyzed on the muscle activity. Each trial was made up of four randomized test, and were performed three times each on each subject for accuracy purposes. The acquired raw signals were processed in MATLAB, and their results were analyzed. It was found that the most muscle activity was present in the forward rotational direction while visuals were playing on the screen in front of the subject. This indicates, that it is under that condition that the muscles work their hardest in order to stabilize the body and maintain balance.**

Keywords-Electromyogram (EMG); electrode; virtual reality; muscle activity; seated balance.

I. INTRODUCTION

The study of seated balance with rehabilitation engineering has been an area of great interest to many researchers. One of the reasons for this is its wide are of application. Understanding seated balance and the factors which affect it become increasingly valuable when dealing with individuals in wheelchairs. Although wheelchairs were revolutionary in helping disabled individuals get around, they are not without their drawbacks, as their prolonged use can lead to possible injuries [1]. When a wheelchair travels over uneven surfaces, the inevitable motions which it causes the human body to endure can lead to tendinitis, carpal tunnel syndrome, and even back pain [2]-[6]. Moreover, when these users utilize ramps to go from one level to another, their bodies lean towards the direction opposite to the direction of motion in order to reduce tipping and maintain stability [7]. However, since these individuals tend to have weaker stabilizing trunk muscles either due to spinal cord injury, or atrophy [8]. This limits the amount of directional leaning their body can perform in order to shift their centre of mass and remain balanced [2].

Fortunately, a vast number of studies have been performed to date which assess the effect that wheelchair propulsion has on muscles [9, 10]. However, the focus of these studies has been on shoulder and upper limb muscles, and very little study has been done on trunk muscles, which is surprising as it has been suggested that these trunk muscles play a vital role in stabilization of balance during wheelchair propulsion [11][12].

Yang, et al. [11], and Howarth, et al. [13] both performed studies examining lower back and abdominal muscle contractions through electromyography (EMG). They did so while subjects were in forward wheelchair propulsion, and they found that the initial stages of motion produced the highest muscle activity. Moreover, other studies such as the ones mentioned have focused on manual wheelchair propulsion, and only on even surfaces. It is important to note though that as technology rapidly advances, motorized wheelchairs, as well as scooters are becoming more widely used. Furthermore, they travel over uneven surfaces and ramps on a regular basis.

This became the motivation behind our study, in which decided to focus on the effects of motorized rotational motion on the stabilizing trunk muscles. Specifically, the muscles which we focused on were the Rectus Abdominis (RA), External Oblique (EO), Thoracic Erector Spinae (TE), and Lumbar Eector Spinae (LE). To add another layer to this study, we decided to combine the motion with visuals achieved through virtual reality, which allowed us to perform a comparison on the effects that visuals have on stabilization.

All of the studies were performed on healthy subjects in order to set the baseline in determining how a healthy individual's muscles should be contracting. As a further step in the future, the study could be expanded to wheelchair users in order to analyze their muscle deficiencies as compared to a healthy individual.

Virtual reality allows for the study of the link between physical human behaviour and perception [14]. Furthermore, it allows for the recreation and analysis of the outside world in a lab setting which can be controlled [15]. Although virtual reality has been extensively studied for the purpose of training and rehabilitation, little has been done in the field to date in regards to seated balance for wheelchair users [16][18]. However, when testing during rotational motion, the chances of experiencing motion sickness increase according to the sensory conflict theory. This theory states that when there are conflicting visual and vestibular inputs, disequilibrium occurs, resulting in motion sickness [19][20].

This paper will proceed by looking at the methods used for this study in section II, including subject selection, experimental setup, and trials. Section III will move on to outlining the produced results of the trials. The results will be discussed in section IV and compared to previous studies, and finally section V will wrap up with the concluding remarks.

II. METHODS

A. Subjects

This study was performed on nine healthy subjects (two males, and seven females), between the ages 20 and 30 years old. None of the recruited subjects had any pre-existing medical conditions or injuries. Approval from the Ryerson University Research Ethics Board had been sought after and received prior to the commencement of this study.

B. Experimental Setup

For this study, a motorized rotational device, the MaxFlight FS-VC Dual System motion simulator, was used to mimic the motions that a typical wheelchair goes through on a daily basis. This world class simulator is the only one of its kind which can rotate a full 360 degrees in both the pitch and roll directions. It has an option in which the angle and direction of motion can be manually set to any value between 0 and 360 degrees. Figure 1 illustrates the simulator with an open cockpit, and Figure 2 shows the simulator while in motion.

Figure 1. MaxFlight Motion Simulator with an Open Cockpit

Once a subject has met the eligibility requirements, their muscles were wiped with alcohol swabs in preparation for electrode attachment. Two Ag/AgCl electrodes (3M™ Red Dot™ Monitoring Electrodes) were placed on each of the following trunk muscles with an approximate interelectrode distance of 3 cm: Rectus Abdominis (RA) – 3 cm lateral to the umbilicus (belly button), External Oblique (EO) – 5 cm lateral to the rectus abdominis, Thoracic Erector Spinae (TE) – 5 cm lateral to the T9 spinal disk, and Lumbar Erector Spinae (LE) – 3 cm lateral to the L4 spinal disk. As previously mentioned, these muscles play a key role in seated balance, and were chosen for that reason.

Figure 2. MaxFlight Motion Simulator During Motion

The electrodes were then connected to the CleveMed Bioradio 150 data acquisition device via snap-leads. The CleveMed Bioradio then transmitted the acquired signals to a nearby computer wirelessly.

C. Trials

Trials were performed in both the forward and backwards directions, each at a rotational angle of 45 degrees. Additionally, each trial in each direction was performed both wile visuals were playing on the screen in front of the subject, and also when visuals were not present. Moreover, each trial was performed three times for accuracy assurance. As subjects were not told which direction they were about to travel, and the order of the trials was randomized, this was a blind study. Subjects were given a ten minute break halfway between the study in order to minimize any possible motion sickness.

D. Signal Processing

A sampling frequency of 960 Hz was used for data acquisition of the raw signal. Once the raw signal had been obtained, it was rectified, and a low-pass Butterworth filter (4th order) with a cut-off frequency of 6 Hz was used to filter out the noise from the signal.

$$|H(\Omega)|^2 = \frac{1}{1+(\Omega/\Omega_c)^{2N}} = \frac{1}{1+\varepsilon^2\,(\Omega/\Omega_P)^{2N}} \quad (1)$$

Where N is the order of filter, Ω_c is the corner frequency, Ω_p is the pass-band edge frequency, and $1/(1+\varepsilon^2)$ is the band edge value of $|H(\Omega)|^2$.

Next, in order to visualize the overall shape and amplitude of the muscle activity, the envelope of the rectified signal was obtained. Subsequently, the three trials for each condition were averaged in order to reduce noise due to biological factors during data acquisition. This resulted in a single signal, which was representative of the muscle.

In order to analyze the amount of muscle activity, the root mean square (RMS) of the averaged signal was obtained.

$$x_{rms} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + x_3^2 + \cdots + x_n^2)} \quad (2)$$

Finally, the work done by the muscle (related to the amount of contractions) was determined by finding the integral of the signal, referred to as the iEMG.

$$iEMG = \int_0^t EMG\,dt \quad (3)$$

III. RESULTS

All of the calculations were performed in MATLAB, including the production of the figures. Since eight muscles of nine subjects were recorded under four conditions, a plethora of results and figures were produced. In the interest of saving space, the figures for subject 2, and the RMS ans iEMG values for subject 5 will be displayed only, as they were the most representative of the results overall. To recap, each of the previously mentioned eight muscles were analyzed under the following four conditions:

- Forwards direction, visuals present (FV)
- Backwards direction, visuals present (BV)
- Forwards direction, visuals not present (FN)
- Backwards direction, visuals not present (BN)

Furthermore, each of the eight channels represents the following muscles:

Ch.1: Right Rectus Abdominis (RA)
Ch.2: Left Rectus Abdominis (RA)
Ch.3: Right External Oblique (EO)
Ch.4: Left External Oblique (EO)
Ch.5: Right Lumbar Erector Spinae (LE)
Ch.6: Left Lumbar Erector Spinae (LE)
Ch.7: Right Thoracic Erector Spinae (TE)
Ch.8: Left Thoracic Erector Spinae (TE)

Figures 3-7 represents the produced results as a signal goes through the signal processing algorithm (FV used as an example).

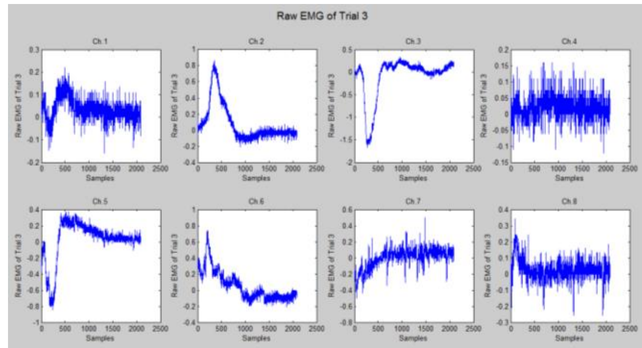

Figure 3. Raw EMG of Trial 1 for FV, Subject 2

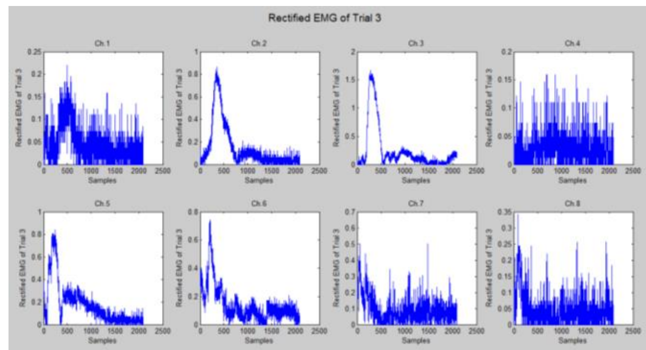

Figure 4. Rectified EMG of Trial 1 for FV, Subject 2

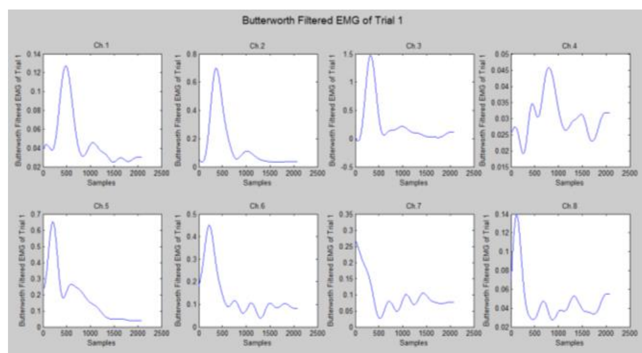

Figure 5. Butterworth Filtered EMG of Trial 1 for FV, Subject 2

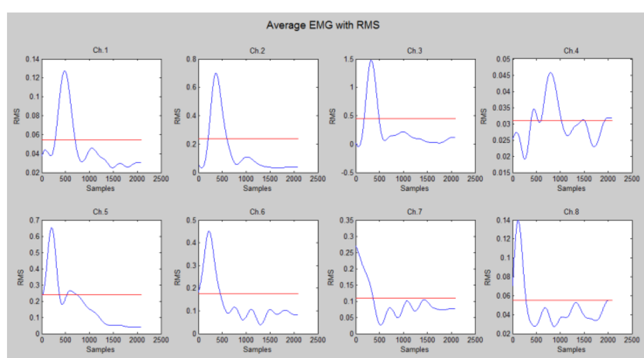

Figure 6. Averaged EMG with RMS for FV, Subject 2

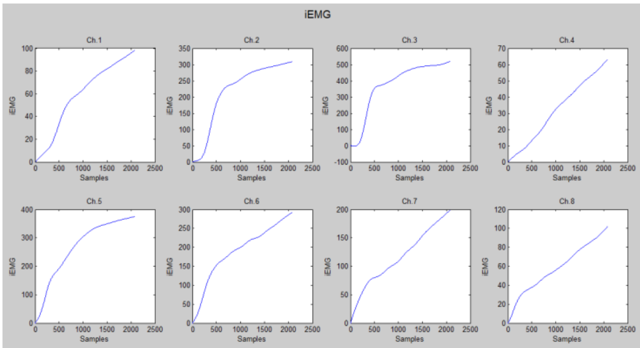

Figure 7. iEMG for FV, Subject 2

When comparing the raw signal in Figure 3 to the filtered averaged signal in Figure 6, it can be seen just how effective the signal processing algorithm was in cleaning the signal and removing unwanted excess noise from the signal.

As the RMS and iEMG values represent the work done by each muscles, they will be compared under the various conditions, as illustrated by Tables I and II.

TABLE I. RMS OF SUBJECT 5

	Ch.1	Ch.2	Ch.3	Ch.4	Ch.5	Ch.6	Ch.7	Ch.8
BV	0.03	0.03	0.03	0.03	0.06	0.17	0.11	0.05
BN	0.03	0.04	0.03	0.04	0.20	1.18	0.72	0.41
FV	0.03	0.03	0.04	0.03	0.06	0.11	0.10	0.06
FN	0.08	0.12	0.07	0.06	0.09	3.11	0.07	0.05

TABLE II. iEMG OF SUBJECT 5

	Ch.1	Ch.2	Ch.3	Ch.4	Ch.5	Ch.6	Ch.7	Ch.8
BV	59.4	60.5	60.0	61.3	92.3	310	124	86.4
BN	187	199	172	205	598	4817	2166	1388
FV	125	133	144	131	205	277	254	208
FN	3756	545	349	322	461	9486	402	287

IV. DISCUSSION

Upon analyzing the produced graphs of all nine subjects, it was noted that amongst the different conditions the overall shape of the muscle response was very similar for the same subject, which was expected.

Moreover, when looking at all of the RMS and iEMG tables for all nine subjects, it can be seen that the RMS values of the back muscles (Ch. 5-8) are consistently lower than those of the front abdominal muscles (Ch. 1-4). This finding illustrates the fact that it is the posterior back muscles that play a larger role in upper body stabilization.

Furthermore, higher RMS and iEMG values were produced when the subjects were travelling in the forwards rotational direction. It is important to note that when the subjects are travelling in the backwards direction, the back of the seat is there to support them, a possible reason as to why the trunk muscles do not need to work as hard to stabilize.

The final trend is that the RMS and iEMG values of the muscles tend to be higher when visuals were playing on the screen as opposed to when the screen was turned off. This was expected, as when the visuals are playing on the screen, it gives the subject the feeling that they are travelling/displaying more than they actually are. If the subject perceives their fall to be steeper, their muscles will work harder to stabilize the body, resulting in higher RMS and iEMG values. Moreover, when the screen was turned off, it was pitch black inside of the motion simulator cabin, so the subject was not able to place themselves in relation to the surrounding environment, and likewise, their muscles did not feel as though they had to work as hard to stabilize balance

V. CONCLUSION

When looking at the findings overall and summarizing them, it can be concluded that the FV (forward direction, visuals present) condition had the highest muscle activity, as determined by the RMS and iEMG values, and thus, the muscles had to work the hardest in that condition in order to stabilize and maintain balance. All of the findings could be used for the development of effective rehabilitation programs, including virtual reality training.

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