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A Neuroergonomics Study of Brain EEG's Activity During Manual Lifting Tasks

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NEUROERGONOMICS STUDY: ANALYSIS OF BRAIN EEG'S ACTIVITY DURING MANUAL LIFTING TASKS

by

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ABSTRACT

Electroencephalography (EEG) has been shown to be a reliable tool in neuroergonomics studies due to the relatively low cost of brain data collection and limited body invasion. The application of EEG frequency bands (including theta, alpha and beta), enjoyed a wide range of interest in physical and cognitive ergonomics. The psychophysical approach has been used for decades to improve safe work practices by understanding human limitations in manual materials handling. The main objective of this research project was to study the brain's EEG activity expressed by the power spectral density during manual lifting tasks related to: 1) the maximum acceptable weight of lift (MAWL) and 2) isokinetic and isometric lifting strength tests measurement outcomes.

The first study investigated the changes in EEG power spectral density during determination of MAWL under low, medium, and high lifting frequencies. A high-density wireless dry cell EEG device has been used to record EEG signals. Twenty healthy males participated in this study. Subjects repeated the same experiment after two weeks. Analysis of variance (ANOVA) showed significant differences in EEG power spectral density between different lifting frequencies at three main brain areas (frontal, central, and parietal). The second study revealed differences in brain activities during isokinetic and isometric strength measurements, based on the recording and analysis of EEG power spectral density.

This research project is the first study of EEG activity during manual lifting tasks, including the assessment of MAWL by the psychophysical method, as well as the measurement of human isokinetic and isometric strengths. The results of this project are considered critical to our increased understanding of the neural correlates of human physical activities, and consequently

should have a positive impact on workplace design that considers brain activity related to specific human capabilities and limitations in manual lifting tasks.

To my beloved father, Mutlaq Aljuaid

To my lovely mother, Ghazwa AlOtaibi

To my lovely wife, Kholod Althobaity

To my lovely kids, Bader and Abdullah

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Lastly, I want to dedicate this work to my parents and my family for their continuous support and their sincere prayers.

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CHAPTER 1: INTRODUCTION

1.1 Manual lifting in ergonomics

Over the last five decades, the field of ergonomics has been playing an important role in minimizing occupational injuries by aiding in the design of safe work environments. One important area that has garnered thousands of studies in ergonomics is manual lifting. In manual lifting tasks, severe and long-term injuries could happen due to lack of proper job design and safe standardization. Manual material handling jobs are associated with two quarters of lower back disorders (Bigos et al., 1986). In order to control these remarkable injuries, material handling tasks have been ergonomically redesigned through studying human physiology and anthropometry. Body posture, heart rate, oxygen consumption, and muscular contraction were the major factors used to evaluate occupational manual lifting.

Muscular strength is “the maximum force that [a] group of muscles can develop under prescribed conditions” (Chaffin, Andersson, & Martin, 1999). Muscular strength is necessary in jobs involving manual handling of heavy materials. If an operator’s strength is not enough to meet the loads of these jobs, then task related injuries are more likely to happen. Consequently, in order to reduce these injuries, it is important to define the capacity limits of workers (Nicholson & Legg, 1986). This can be done through classification and definition of human muscular strengths by Mital and Kumar (1998); human muscular strengths can be broadly classified according to two criteria:

1. **Characteristics of the effort.**

(a) Static strengths (isometric strengths)
(b) Dynamic muscle strengths
  i. Isotonic muscle strengths
  ii. Isokinetic muscle strengths

2. Characteristics of application.

(a) Static functional strength

i. Simulated job static strengths
ii. Continuous static muscular strength.
iii. Repetitive static muscle strengths

(b) Dynamic functional strength.

i. Isoinertial muscle strengths
ii. Psychophysical muscle strengths
iii. Simulated job dynamic strengths
iv. Repetitive dynamic strengths

1.1.1 Static muscle strengths

Static or isometric muscle strength is the capability of producing force by a single maximal voluntary isometric exertion. It is a transformation of the internal effect of the mechanical advantage of the body to be measured as the external force. The static effect alternates in response to the quantity of the muscular force (Caldwell et al., 1974; Chaffin, 1975; Chaffin, Herrin, & Keyserling, 1978b; Karwowski & Mital, 1986; Mital & Kumar, 1998; Schanne, 1972).

1.1.2 Dynamic muscle strengths

Body segments' motion and muscle length change significantly in dynamic exertions. The measured force is referred to as dynamic strength. Dynamic strength is more complex than static strength as per biomechanical studies; dynamic (psychophysical) limits will be most often less than static strength measured in similar postures (Chaffin et al., 1999; Mital & Vinayagamoorhty, 1984).

1.1.2.1 Isokinetic muscle strengths

Isokinetic muscular exertion is a constant exertion rate shortening or lengthening the muscle either to a constant speed of the force being applied or resisted or to a constant angular velocity of the joint when the body parts involved move at a constant velocity (Pytel & Kamon, 1981).

1.1.3 Psychophysical muscle strengths

Ergonomic studies relied on the psychophysical theory by Stevens (1957) to redesign the tasks of material handling. This psychophysical theory has been applied to many areas, including the development of scales for useful attributes such as temperature, loudness, brightness, heaviness, and ratings of perceived exertion. The psychophysical power law describes the relationship between the strength of a perceived sensation (S) and the intensity of a physical stimulus (I)

$S = k.I^n$

Where *n* is power of the equation and depends on the modality; *n* is about 1.6 for perception of muscular force and ranges between 0.33 and 3.5 in the case of brightness evaluation. The coefficient *k* is a constant percentage depending on the nature of measurement. For example, *k* is 2.5% in weight measurement, 3% in brightness, and 7% in length (Krawczyk, 1996; Stevens, 1957).

Regarding material handling tasks, Snook and Irvine (1967) defined psychophysical muscle strength as "a person's measure of psychophysically determined maximum acceptable level of force application. This maximum force is considered a measure of a person's maximum dynamic strength in the category of activity."

For the past 40 years, the psychophysical approach has been used extensively to determine the load handling capacities of individuals and to measure the Maximum Acceptable Weight of Lift (MAWL) to reduce occupational risks and on-the-job injuries (Ayoub, 1978; Ayoub, Selan, &

Liles, 1983; Ciriello, Snook, Buck, & Wilkinson, 1990; Garg & Saxena, 1979; Karwowski & Yates, 1986; Mital & Manivasagan, 1983; Snook & Irvine, 1967). Several significant factors affect estimating the maximum acceptable weight to lift, including lifting zone, vertical distance, box width, and lifting frequency (Ciriello & Snook, 1983).

The psychophysical method aims to measure lifting capacity depending on perception of exertion, assuming that workers have the capability to determine accurate MAWL under the highest acceptable workload. The psychophysical approach may lead to overestimation of lifting capacity even for limited tasks due to gender, stress, or motivation. As a result, taking into consideration the instantaneous perception of exertion, an assessment measure of MAWL should also take into consideration subjects' cognitive judgment (Karwowski, 1991; Karwowski et al., 1999). However, in the last ten years, relatively little research has been done on brain activity during mental or physical tasks.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Introduction

Neuroergonomics can be defined as “the study of brain and behavior at work. It combines two disciplines: neuroscience, the study of brain function, and human factors, the study of how to match technology with the capabilities and limitations of people so they can work effectively and safely” (Parasuraman & Rizzo, 2003). Neuroergonomics is an important area to study communication networks between humans and technology. There are many areas of research in neuroergonomics, including aviation, driving, neuroengineering, virtual reality, and physical neuroergonomics.

2.2 Human Brain

The human brain is the most complex part of the human body; every day something new is discovered about it. It is the part that makes us human, giving people the ability to do art, speak, make moral judgments, and think rationally. It is also responsible for each person's personality, memories, movements, and feelings about the world. The human brain uses 20% of the oxygen that enters the bloodstream even though it only makes up about 2% of human body mass. The brain consumes the most oxygen in comparison to any other organ in the body (Raichle, 2001).

2.3 Electroencephalography (EEG)

Electroencephalography (EEG) is “the recording of electrical activity along the scalp” An electroencephalogram (EEG) is a device or instrument that measures signals of voltage oscillations occurring with ionic current flows inside the brain’s neuron, Figure 2.1 (Niedermeyer & da Silva, 2005). In medical perspectives, EEG relies on recording the brain's normal electrical activity over a limited period of time using electrodes attached to the scalp. EEG has been used for decades in the clinical diagnosis of epilepsy, coma, encephalopathies, brain death, and Alzheimer's. However, the use of EEG has decreased nowadays after the invention of magnetic resonance imaging (MRI) and X-ray computed tomography (CT) (Freeman & Quiroga, 2012).

Studying the human brain was a challenging task in the last century. Most recent research has concentrated on the applications of EEG in the medical arena, while fewer studies focus on EEG applications in ergonomics.

Research on the human brain with the help of EEG technology revealed diverse alterations in brain activity due to physical exertions , such as coherence between EEG and EMG, decrease or increments of the brain frequencies (alpha, beta, and gamma) from brain regions accountable for body movement; (C3 and C4). Also, new conclusions can be drawn about the high spatial scatterings of the brain's activation center due to physical exertions.

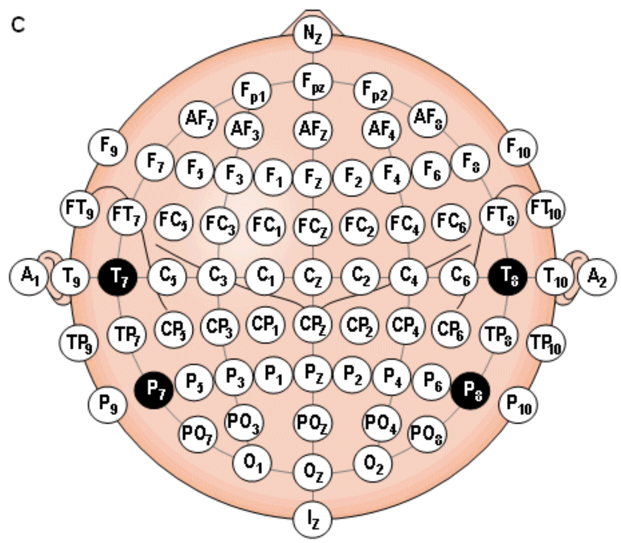


Figure 2.1: EEG locations by American Electroencephalographic Society redrawn from Sharbrough (1991)

2.4 Physical Neuroergonomics:

The brain exerts control over its environment by creating behavioral control systems, which functionally spread out of the body, creating an archive of reliable properties of the environment as well as the behavior of other creatures. These systems and the control they allow are the very reason for having a brain. “Application of the neuroergonomics approach can help assess suitability of the variety of designs of human-machine systems and determine possible workplace improvements. The functioning of our brain must be reflected in the system design and operational requirements for the human operators. The road to success in ergonomics depends, to a large extent, on our ability to embrace the most precious element of system design, the human brain” (Karwowski, Siemionow, & Gielo-Perczak, 2003).

“Human physical capability may be extended in both strength and speed such that, with sufficient gain, minute muscular responses could produce physical activity beyond the limits of human-range” (Hancock, 1997). “Individuals would gain the ability to execute physical behaviors directly from the brain, thereby expanding their ability to act on their environments beyond computer-based information processing tasks to any physical task currently beyond their action capabilities” (Hancock & Szalma, 2003).

2.5 Previous research in neuroergonomics

Most studies on the human brain using the EEG in the last decades concentrated on the mental stress more than physical exertion; Lorist et al. (2009) studied the consequences of mental stress and effects on neural network behaviors which initiated in a particular task. After two hours of a continuous task, mental stress could occur; coherence of EEG signals was adopted as a test of synchronization of behavioral activity of the brain. Most of the EEG bands (alpha, beta, and gamma) affected by the mental stress and the coherence and power were an example of that.

An earlier study by Craing, et al. (2006) concentrated on driving problems which may involve injuries and accidents on drivers and innocent people. In their research, they investigated the relationship between mental stess and psychological factors. In the study, subjects volunteered and after a period of time and a particular task experienced stress. The research recommended a future investigation in order to address the factors by measuring the outcomes of each factor.

The use of EEG in physical physiological studies has increased significantly over the last twenty years. Some researchers used the relationship between the brain's electrical signals at different frequencies (alpha, beta, and gamma) with muscle signals using electromyography (EMG); while others tried to analyze the EEG signals using statistical analysis before and after exertion.

The objectrive of a study by Johnston, Rearick, and Slobounov (2001) was to discuss the general experiential topic considering the neurophysiological criteria and tools that contribute to counterbalance for physical exertion by testing isometric exercise and finding the correlation between EMG and EEG correlates during a particular task. As a result of this experiment, they found that there is an increment in (RMS) calculated from the EMG experimental data during physical exertion. Also, there was an increase in electrical signals activity over the motor cortex areas.

One of the interesting studies was on peak alpha frequency: Using EEG, Ng and Raveendran (2007) investigated if Peak Alpha Frequency (PAF) would reduce when physical exertions set in. Eight volunteers, who were right-handed, healthy males 23-30 years old, were requested to close their eyes for two minutes, and open their eyes for two minutes. Electrooculogram (EOG) artifacts were collected to remove noise. Handgrip devices were used until the two ends touched as much as possible; subjects were requested to use both hands 30 times for 30 sec. After the experiment, they were requested to close their eyes for two minutes, and then open their eyes for two minutes to track the changes in the brain's signals. EEG data was recorded using 64 channel electrodes (fifty-five on the scalp, two at earlobe, three around the eyes, and four on the forearms). Data was segmented into 10-sec intervals with 1 sec steps; each step windowed using Gaussian window. Signal was transformed to frequency domain using Fourier Transform. They concluded in their experiments that there is indication of PAF decreases when physical exertion sets in.

A more recent study by Gwin and Ferris (2012a) compared cortico-muscular coherence for isometric in addition to isotonic dwindling just as both dwindling varieties were self-paced and in the lack of external power feedback. They hypothesized that, despite related seen and sensual motor combination needs for the two tasks, the isotonic dwindling may evoke γ-range cortico-muscular coherence whilst the isometric dwindling would evoke β-band coherence.

Eight healthy right-footed and right-handed subjects (seven men and one woman) between 21–31 years old participated in the study. EEG was recorded using high-density 264-channel active electrodes. EMG was recorded for the legs and coherence was calculated for EEG/EMG. Maximum coherence in the β-γ range was calculated to evaluate the impact of variances in total coherence's average by applying a two-way ANOVA.

Clear coherence between EEG/EMG was witnessed in the β-γ band, yet not in the band. Strong coherence was noticed between the leg's EMG signals and contralateral motor cortex in the β-γ band for the two isotonic and isometric activities. Nevertheless, γ coherence was higher for isotonic exercises compared to isometric exercises. The β-γ shift was consonant among six of the eight subjects' EMG signals.

Focusing on the amplitude of Motor Related Cortical Potentials (MRCP), Slobounov, Hallett, and Newell (2004)) conducted a group of tests in which subjects achieved isometric force tasks. The degree of force increment and signal gain were checked, as was degree of exercise for every task achieved. The hypotheses tested were: (a) force-related noticed exertion may selectively affect

MRCP, and (b) the MRCP may straight indicate the power of observed effort compared with produced force. In their findings, they explained that: (a) observed exertion proportionally grows with the increase of degree of force increase and force error, however, not with the real force level; (b) the degree of the MRCP raised when a considerable value of force was completed by an improved degree of force increment; (c) the degree of initial elements of MRCP leading the force start developed as a use of expected effort, though, the degree of movement following the force raised as a use of original force level.

Another approach in time-dependent relation between EEG data and MVC from the muscles, by Wang, Yang, Fan, Sun, and Yue (2009), estimated EEG data that may be the cause of power during the different levels of muscle contractions; later they developed "a functional random-effects model approach" that includes all selected effects in the records. Then a two-step method and linear mixed regression models was discussed in the study with the assessment of the ANOVA model.

The effect of physical exertion plus the contribution of other factors, such as heat (hyperthermia), on brain activity was the main focus of Ftaiti, Kacem, Jaidane, Tabka, and Dogui (2010), and a large scale of subjects participated (25 subjects) in a Nybo and Nielsen (2001) study to investigate the brain's activity, especially the motor cortex (C3 , FC3) areas and track the changes of electrical signals of the EEG before and after physical exertion using the MVC simultaneously with the EMG signals. In their study, they analyzed the variations of (α, β, and γ) power from the EEG using the RMS method. They found that the RMS of α, β, and γ increased during physical exertion significantly with β band and slightly with the γ band. This increment probably comes from the motor cortex to compensate the desired energy of neural fatigue. Seven healthy women between 22 and 24 years old participated in this study. A statistical model was used to analyze alpha and beta (α, β) bands from the EEG with the consideration of other factors, according to their study. They suggested that the variation in α/β index was because of the physical exertion and other factors of temperature and environment.

An example of time series analysis of EEG activity is the study by Ramanand, Nampoori, and Sreenivasan (2004); they used Sample Entropy Analysis in this study. The indicated statistic quantifies the consistency in data measured from methods that can change from deterministic to the stochastic area. In their investigation, measurement is carried out with the goal of getting insight into intricacy changes compared to varying brain dynamics for EEG shown from three events of influenced, eyes closed state, "a mental arithmetic task accepted after a physical exertion task". It is remarked that the statistic is a robust quantifier of intricacy readjusted for small physiological signals like the EEG in addition to pointing to the particular brain areas that show reduced intricacy as the case of mental task status as linked to a passive, relaxed mood.

According to Feige, Aertsen, and Kristeva-Feige (2000), there is a synchronization between motor cortex areas of activation in beta frequency (16–28 Hz), seen by using the EEG data recording, and the muscle activity using EMG after the end of the movement. Seven healthy, right-handed subjects participated in this study (six males and one female), and analysis was done by applying phase-reference analysis to find the coherence between EEG/EMG.

Liu et al. (2005) hypothesized that physical exertion has an impact on cortical electrical signals before exertion less than that of signals during the exertion. Eight subjects performed 200 handgrip MVCs until fatigue in the same time EEG data was recorded. The power of EEG bands did not change significantly before fatigue; however, it declined significantly during fatigue. The MRCP negative potential (NP) linked to motor task preparing only explained minimum differences. The results propose that MVC encouraged fatigue has differential impacts on cortical electrical signals during motor task development corresponding to its performance and maintenance.

Negro and Farina (2011) used a mathematical derivation besides motor unit record-keeping in vivo to study the source of direct frequency of cortical raw data to the neural approach to muscle. This technical origin explained that a general input expanded to a relatively small amount of motoneurons is partially carried in a linear trend, succeeding the resistance signal caused by the non-linearity. Then they estimated the corticomuscular coherence of EEG related to data of muscles of seven healthy individuals. The empirical outcomes point out that only 4-5 motor segments were enough to approach the corresponding coherence as expected from the exterior EMG. The outcomes illustrate that linearity in the frequency of the cortical data to motoneurons is obtained because (a) the present input is considerably common to every motoneuron, and (b) its signal content needs only a minor motoneuron to be correctly tested. Hence, the central nervous system can carry oscillations to the controller of signals to muscles for almost functionally related forces.

A study by Slobounov, Johnston, Chiang, and Ray (2002) analyzed interactive and electro-cortical reactions in producing deferent MVC levels at a stable rate of force increment with four fingers during ramp phase and static phase. They were interested in explaining in detail the interaction between force finger and power on different parts of movement-related potential (MRP) linked with the formation and exertion of isometric tasks. In conclusion, they compared the force and EEG time series by peak correlations observed in the weakest force with the related finger. The correlation was significantly decreased as the force level increased.

A study of time association between EEG and EMG was conducted by Yang, Liu, Sahgal, and Yue (2007), and a positive relationship between the EEG cause of power and handgrip force was seen as immediately as 891 ms before the EMG start. Those conclusions confirm motor control mechanism associated time reliant cortical activation in humans, as the initial are in line with earlier research that suggested a general population of cortical neurons is involved in controlling higher levels of voluntary muscle force. This study shows that it is reasonable to detect the connection between the origin power of scalp EEG and muscle amount with high time analysis using the popular density rehabilitation technique. It is likely possible to identify the relevance of brain root power and muscle amount in the event setting using the current consistency repair method. This research additionally suggests that greater strength level corresponds to greater brain cause power or brain activation, and this happens as quickly as 891 ms before the start of muscle activation, turning active around EMG start time and remaining almost the whole course of the muscle flexing.

Jiang, Wang, Kisiel-Sajewicz, Yan, and Yue (2012), tested the assumption by applying the cross-correlation based useful connectivity analysis approach. Crossing is connecting the time series data of the least created activation maps and major fatigue steps across all the voxels. Histogram and quintile regression examination were done to examine the value between the minimum and important fatigue steps, and the effects explained a notable increment in value among various cortical areas. This increased value means that when fatigue degrades, several brain areas develop their link with the left area of M1, the prime motor output power midpoint for the right-handgrip, to counterbalance for reduced strength size of the muscle in a synchronized manner by improving the settling command for larger muscles to have similar force (Jiang et al., 2012).

Halder et al. (2005) used 64-channel performance-related possible mapping to study these impacts of changing recurrence on similar brain exercise in individuals. Ten healthy right-handed subjects conducted a power grip task under seen force power to ensure consistent behavior during the test. The sitting consisted of two segments divided by a break. For study, each segment was divided into two series to control for possible alertness impacts, which would be assumed to leave during the rest.

Yang et al. (2011) used high-density EEG and EMG simultaneously at various stages of MVCs on eight healthy subjects who completed isometric handgrip. Sources of the EEG were analyzed at several time points starting with preparation, then execution, ending with sustaining phases of the handgrip. A distributed current density model, low-resolution electromagnetic tomography LORETA L1 norm method was applied to the data that pre-processed by independent component analysis (ICA). Statistical analysis using a mixed-effects polynomial regression showed a consistent and significant dependent on time source strength variation pattern in different phases of the handgrip. The source strength increased at the preparation phase, peaked at the force at beginning time and decreased in the sustaining phase. Yang et al. (2011) concluded the results show a high time resolution increasing and decreasing pattern of activation at the sensorimotor areas which are the motor and primary receiving areas for general sensations, respectively with the maximum activity happened at the muscle activity onset.

Recent research using technology was also used to study brain activity during physical exertion such as functional magnetic resonance imaging (fMRI), functional near-infrared topography (fNIRT), Magnetoencephalography (MEG), and X-ray computed tomography (CT); this research was consistent in results with the mentioned results of the EEG. In the research of the fMRI Liu, Dai, Sahgal, Brown, and Yue (2002) explained in their study the brain activation was included by fMRI during handgrip contraction during the time that handgrip force in addition to finger muscle

EMG signals were recorded. The results explained decoupled development in brain / muscle results at the same time the muscle was exerted and associated responses among the cortical zones were analyzed. Throughout the time that handgrip force and EMG data decreased side by side during the development of muscle exertion, fMRI-measured brain actions first considerably developed and then declined. This related signal intonation happened not just in the original sensorimotor regions but additionally in the secondary and related cortices.

Furthermore, Di Sante, Limongi, Ferrari, and Quaresima (2009) studied the application of fNIRT in brain activity during muscle exertion. The impact of exerted muscle training on the brain, and particularly on the ipsi- and contralateral frontal cortex has been proved. The study inspected fNIRT frontal cortex oxygenation reaction to a prolonged fatiguing handgrip exercise conducted at the MVC with two hands. As a result, they verified the earlier results by applying fMRI and presented additional proof for verifying the hypothesis that the frontal cortex acts as a supporting force of the forearm muscles, also assuring good finishing of motor tasks with motor coordination.

Recent research on the human brain using magnetoencephalography (MEG) was done by Tanaka, Ishii, and Watanabe (2013). They attempted to explain the neural structure of central interference during physical exerting with the MEG and a standard conditioning method. Twelve subjects underwent MEG recording during the comparison of MVC hand grips. One day after, MEG recording during MVC was conducted. Degrees of the exertion in sympathetic nervure action on the next day were significantly greater than already stated on the opening day. The alpha-band event-related desynchronization (ERD) level had positive correlation to the variation in individual levels of exertion.

2.6 Research Gap

Most previous research covered the neuroergonomics and brain analysis during physical tasks of the upper or lower limbs. Most of the research used traditional linear analysis methods such as EEG and EMG coherence; Table 2.1 and Figure 2.1, 2.2.

Table 2.1: Summary of recent studies on brain electrical activity during physical task

Research	**# of subjects**	**Age**		**Type of Experiment**		**Methodology**	
(Ng & Raveendran, 2007)	8	23	29	Upper Limb	Handgrip	Liner	Center Gravity
(Liu et al., 2007)	7	24	42	Upper Limb	Handgrip	Other	Dipole IRL
(Yang et al., 2009)	9	33	63	Upper Limb	arm elbow flexion	Liner	EEG/EMG Coherence
(Gwin & Ferris, 2012a)	8	21	31	Lower Limb	Isometric & Isotonic	Liner	EEG/EMG Coherence
(Abdul-latif et al , 2004)	25	23	47	Upper Limb	Adductor Pollicis Muscle	Liner	RMS
(Wang et al., 2009)	8	29	33	Upper Limb	Handgrip	Other	LORETA IRL
(Ftaiti et al., 2010)	7	22	24	Cycling	Maximal aerobic power	Liner	Bands and Ratios
(Ramanand et al., 2004)	12	29	29	Lower Limb	Isometric leg extension	Non-Liner	Sample entropy
(Feige et al., 2000)	7	25	31	Upper Limb	Index finger	Liner	EEG/EMG Coherence
(Liu et al., 2005)	8	25	42	Upper Limb	Handgrip	Other	Power spectrograms
(Negro & Farina, 2011)	7	24	32	Upper Limb	Finger abduction	Liner	EEG/EMG Coherence
(Johnston et al., 2001)	6	18	25	Upper Limb	Handgrip	Liner	RMS/MRP correlation
(Slobounov et al., 2002)	6	19	25	Upper Limb	Handgrip	Liner	RMS/MRP correlation
(Ushiyama et al., 2011)	7	20	24	Lower Limb	Right Foot	Liner	EEG/EMG Coherence
(Yang et al., 2007)	8	18	18	Upper Limb	Handgrip	Other	LORETA IRL& MANOVA
(Slobounov et al., 2004)	6	19	25	Upper Limb	Index finger	Liner	RMS/MRP correlation
(Tuncel et al.,2010)	10	23	23	Upper Limb	Hand biceps brachia	Liner	EEG/EMG Coherence

Research	# of subjects	Age		Type of Experiment		Methodology	
(Hilty et al., 2011)	16	22	29	Cycling	Fatiguing cycling exercise	Other	sLORETA IRL
(Zhang, Zhou, & Song, 2010)	20	22	29	Lower Limb	Quadriceps Femoris	Liner	EEG/EMG Coherence
(Ng & Raveendran, 2011)	10	18	18	Upper Limb	Handgrip	Liner	SPR, RMS & HGF

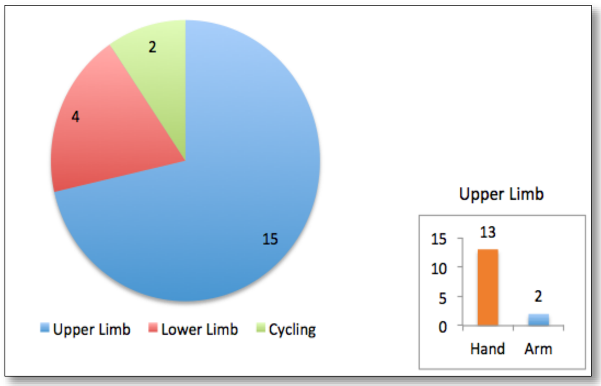


Figure 2.2: Type of Experiment

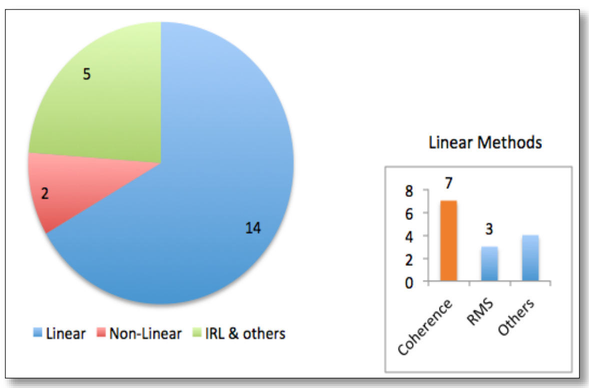


Figure 2.3: Method of analysis

From the previous summary of brain analysis during physical tasks, only upper or lower limbs have been studied in depth, as a result, research in the area of neuroscience and manual tasks such as psychophysical manual lifting and strength measurements is almost non-existent currently.

The objectives of this research are to study the brain's electroencephalographic activity during manual lifting tasks, the assessment of MAWL by psychophysical method, and the measurement of isokinetic and isometric strengths.

CHAPTER 3: STUDY I THE EFFECT OF LIFTING FREQUENCY ON BRAIN'S EEG

3.1 Introduction

For the past 40 years, the psychophysical approach has been used extensively to measure the MAWL to reduce occupational risks and on-the-job injuries. Snook found several significant factors that affect estimation of the maximum acceptable weight to lift. This method illustrated by Ciriello and Snook (1983) proposed the classical method of determining maximum acceptable weights using the psychophysical method. Subjects were given control on the following variables:

- Lifting zone: (low) from floor to knuckle height, (center) from knuckle to shoulder height, and (high) from shoulder to arm reach.
- Vertical distance: the height of lift.
- Box width: the distance of the lifted box away from the lifter. Lifting frequency: number of lifts per time interval (seconds, minutes, or hours).
- Lifting frequency varies between 5 seconds to 8 hours on Liberty Mutual Manual Materials Handling Tables (Snook & Ciriello, 1991).

The procedure of this test requires the individuals to adjust the load to the degree of physical strain that they feel. Simple tools and equipment have been used in psychophysical tests, such as a container (box), weights (lead shot, sand, rubber etc.), and a metronome to set consistent time frequency (Mital & Kumar, 1998). In this experiment, the high lifting frequency is one lift every 9 seconds (6.7 lifts/min), medium lifting frequency is one lift every 14 seconds (4.3 lifts/min), and low lifting frequency is one lift every 60 seconds (1 lift/min).

3.1.1 Objective

The objective of study #1 is to test the effect of lifting frequency (high vs medium) and (low vs medium) on EEG signals, and to test the effect of a lifting task repetition on EEG signals.

3.1.2 Design of Experiments

The experiment has been designed according to the following tables:

Two independent variables are verified in this study (Table 3.1). The first independent variable is the lifting frequency; low vs medium lifting frequency in experiment 1 and high vs medium lifting frequency in experiment 2. The second independent variable is the two trials.

Table 3.1: Independent variables

Independent variables	1. Lifting frequency		2. Trials	
	Low vs medium (Experiment 1)	High vs medium (Experiment 2)	First	Second

Two dependent variables were likewise verified to be measured in this study (Table 3.2). The first dependent variable is the EEG power spectral and the second dependent variable is MAWL.

Table 3.2: Dependent variables

Dependent variables	1. EEG Power Spectral	2. MAWL

3.1.3 Hypothesis

Hypothesis 1

H_o : There is a difference between EEG signals

- ☐ *(high vs medium) lifting frequency*
- ☐ *(low vs medium) lifting frequency*

H_1 : There is no difference between EEG signals

- ☐ *(high vs medium) lifting frequency*
- ☐ *(low vs medium) lifting frequency*

Hypothesis 2

H_o: There is a difference between EEG signals due to task repetition

H_1: There is no difference between EEG signals due to task repetition

3.1.4 Subjects

Twenty healthy right handed volunteers (ten males in Experiment 1, and ten males in Experiment 2) passed medical screening of cardiovascular problems, such as heart disease or high blood pressure; back pain or hernia; or any mental or neurological disorders/diseases such as epilepsy, Alzheimer's, multiple sclerosis, etc.. All subjects were provided with written informed consent prior to the experiment. All procedures were approved by The Institutional Review Board at the University of Central Florida IRB Number (SBE-14-10799) (Appendix A).

3.2 Experiment I: The Effect of Psychophysical Lifting Low Vs Medium Frequency On Brain's Electroencephalography

3.2.1 Introduction

In this experiment the medium lifting frequency is one lift every 14 seconds (4.3 lifts / min) and low lifting frequency is one lift every 60 seconds (1 lift / min).

The objective of this experiment is to test the effect of lifting frequency (low vs medium) on EEG signals and to test the effect of lifting task repetition on EEG signals.

3.2.2 Method

3.2.2.1 Subjects

Ten healthy volunteers underwent medical screening of cardiovascular problems, such as heart disease or high blood pressure; back pain or hernia; or any mental or neurological disorders/diseases such as epilepsy, Alzheimer's, multiple sclerosis, etc. Then subjects were provided written informed consent prior to the experiment. All procedures were approved by The Institutional Review Board at the University of Central Florida IRB Number (SBE-14-10799). (Appendix A).

3.2.2.2 Task

This experiment includes medium and low frequency psychophysical weight lifting test in two replicates, with the total estimated time being three hours including rests. Tools of the experiment are lifting box with approximate dimensions of 20x14x14 in., iron/rubber weight plates and hit timer. Subjects were given a short illustration on how to perform the psychophysical test and given time to ask any related questions. The general procedure of the psychophysical weight lifting test can be found in Appendix B.

3.2.2.2.1 Medium lifting frequency

The following variables are considered:

1. Lifting Zone: we applied only the low zone in this study (floor to knuckle)
2. Vertical distance: between 20-32 in. from floor to table.
3. Box dimensions: Approximately 20x14x14 in.
4. Frequency: medium frequency is considered in lifting and the lifting frequency is 1 lift per 14 seconds (1 lift / 4.3 min)

Half of the participants were started with low weight and the other half started with heavy weight. The heavy weight is the maximum acceptable weight of lift as per Snook and Ciriello in Liberty Mutual Manual Materials Handling tables (Snook & Ciriello, 1991). For example, the table assumed that more than 90% of the male population would consider the task of lifting 12 Kg (26 lb) with hand distance away from body of 34cm (14 in) and with a frequency of once every minute between floor level to knuckle height for a distance of 51cm (20 in.) to be acceptable. Participants were instructed to adjust the weight by adding and/or removing iron/rubber weight plates for 40 minutes until they obtained the maximum weight that they could lift without "strain or discomfort and without becoming tired, weakened, over-heated, or out of breath."

3.2.2.2.2 Low lifting frequency

The following variables are considered:

1. Lifting Zone: we applied only the low zone in this study (floor to knuckle)
2. Vertical distance: between 20-32 in. from floor to table.
3. Box dimensions: Approximately 20x14x14 in.
4. Frequency: low frequency is considered in lifting, and the lifting frequency is one lift per 60 seconds (1 lift / min)

3.3 Experiment II: The Effect of Psychophysical Lifting High Vs Medium Frequency On Brain's Electroencephalography

3.3.1 Introduction

In this experiment the medium lifting frequency is one lift every 14 seconds (4.3 lifts / min) and high lifting frequency is one lift every 9 seconds (6.7 lifts / min).

The objective of this experiment is to test the effect of lifting frequency (high vs medium) on EEG signals and to test the effect of lifting task repetition on EEG signals.

3.3.2 Method

3.3.2.1 Subjects

Ten healthy volunteers underwent medical screening of cardiovascular problems, such as heart disease or high blood pressure; back pain or hernia; or any mental or neurological disorders/diseases such as epilepsy, Alzheimer's, multiple sclerosis, etc. The subjects were provided with written informed consent prior to the experiment. All procedures were approved by The Institutional Review Board at the University of Central Florida IRB Number (SBE-14-10799) (Appendix A).

3.3.2.2 Task

This experiment includes a high and medium frequency psychophysical weight lifting test in two replicates, with total estimated time being three hours including rests. Tools of the experiment are a lifting box with approximate dimensions of 20x14x14 in., iron/rubber weight plates, and a hit timer. Subjects were given a short illustration on how to perform the psychophysical test and given time to ask any related questions. General procedure of psychophysical weight lifting test can be found in Appendix B.

3.3.2.2.1 Medium lifting frequency

Ciriello and Snook (1983) proposed the classical method of determining maximum acceptable weights using psychophysical methods; the following are the variables:

1. Lifting Zone: we applied only the low zone in this study (floor to knuckle)
2. Vertical distance: between 20-32 in. from floor to table.

3. Box dimensions: Approximately 20x14x14 in.
4. Frequency: medium frequency is considered in lifting and the lifting frequency is 1 lift every 14 seconds (4.3 lifts / min)

The experimental procedure was the same as described in section 3.2

3.3.2.2.2 High lifting frequency

Ciriello and Snook (1983) proposed the classical method of determining maximum acceptable weights using psychophysical method; the following are the variables:

1. Lifting Zone: we applied only the low zone in this study (floor to knuckle)
2. Vertical distance: between 20-32 in. from floor to table.
3. Box dimensions: Approximately 20x14x14 in.
4. Frequency: high frequency is considered in lifting, and the lifting frequency is one lift every 9 seconds (6.7 lifts / min)

Half of the participants started with low weight, and the other half started with heavy weight. The heavy weight is the maximum acceptable weight of lift as per Snook and Ciriello in Liberty Mutual Manual Materials Handling Tables (Snook & Ciriello, 1991). For example, the table assumed that more than 90% of the male population would consider the task of lifting 10 Kg (22 lb) with hand distance away from body of 34cm (14 in) and with a frequency of once every minute between floor level to knuckle height for a distance of 51cm (20 in.) to be acceptable. Participants were instructed to adjust the weight by adding and/or removing iron/rubber weight plates for 40 minutes until they obtained the maximum weight that they can lift without "strain or discomfort and without becoming tired, weakened, over-heated, or out of breath."

The experimental procedure was the same as described in section 3.2. Figure 3.1 illustrates the three lifting tasks.

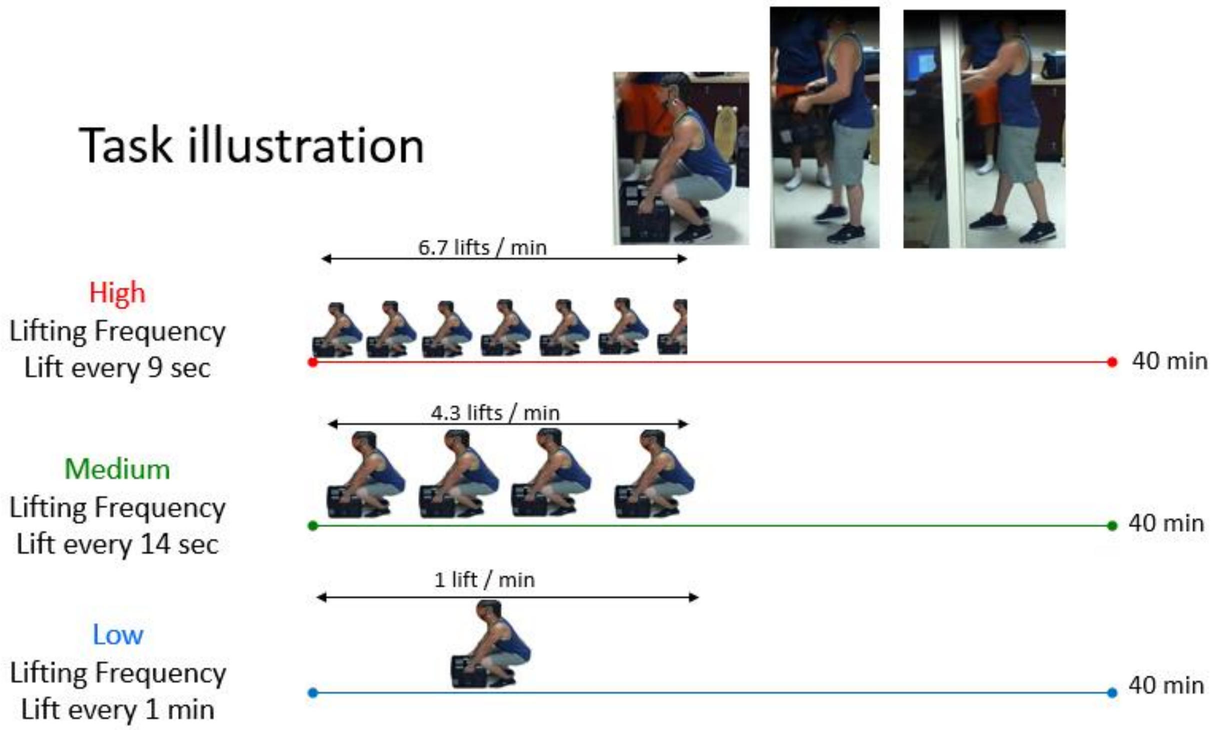


Figure 3.1: Illustration of three lifting tasks

3.4 MAWL Measurements

Maximum acceptable weight of lift of each participant was determined using the psychophysical approach. Then subjects repeated the test after a period of time of about two weeks.

3.4.1 Anthropometry

Anthropometry relates to the measurement of the human body. It has been used to understand human physical variation in psychophysical weight lifting and the estimation of MAWL. Various anthropometries have been measured such as body weight, shoulder height, hip height, knee height, arm length, knuckle height, and body height for all subjects before conducting the psychophysical weight test. Table 3.3 shows the anthropometry of all subjects.

Table 3.3: Twenty subjects' anthropometry measures

Age	Body weight (kg)	Shoulder height (cm)	Hip height (cm)	Knee height (cm)	Arm length (cm)	Knuckle height (cm)	Body height (cm)
27	52.6	141.0	99.0	41.0	72.0	70.0	171.0
27	72.6	144.0	101.0	55.0	75.0	76.5	172.0
28	77.1	148.0	103.0	51.5	74.0	74.0	179.0
30	59.9	149.0	107.5	52.5	80.0	74.5	175.0
27	76.7	150.0	100.0	53.0	70.0	72.0	178.0
29	56.2	134.0	92.0	45.5	67.0	69.5	163.0
29	101.2	148.5	104.5	57.0	74.0	78.5	177.5
28	88.5	146.0	107.0	52.0	71.0	76.0	174.0
29	95.3	153.0	109.0	57.0	77.0	80.0	180.0
27	92.1	142.0	93.0	49.0	68.0	76.0	169.5
21	79.4	141.5	104.5	52.5	71.5	74.0	169.5
20	65.8	143.5	99.5	51.5	72.0	70.5	171.0
40	67.1	150.0	106.0	54.5	72.0	78.0	177.0
32	76.2	136.0	92.0	45.5	67.0	61.0	161.5
31	79.4	141.5	99.0	54.5	70.0	74.0	170.0
28	65.8	158.0	113.0	56.5	81.0	83.0	187.0
25	72.6	140.0	93.5	48.5	70.0	63.5	163.0
29	75.7	144.5	101.0	48.0	73.0	75.5	174.0
34	97.5	157.0	104.0	57.0	75.0	85.0	184.0
26	68.9	148.0	104.0	56.0	76.0	80.0	175.5
28.4 ± 4.1	76.0 ± 13.2	145.8 ± 6.1	101.6 ± 5.7	51.9 ± 4.3	72.8 ± 3.7	74.6 ± 5.7	173.6 ± 6.5

The selected participants in this study were consistent in most of the anthropometry measures with low variation and normally distributed with no outliers except the age; one of the subjects was forty years old, but most of the subjects were within a 95% confidence interval (Figures 3.2 and 3.3).

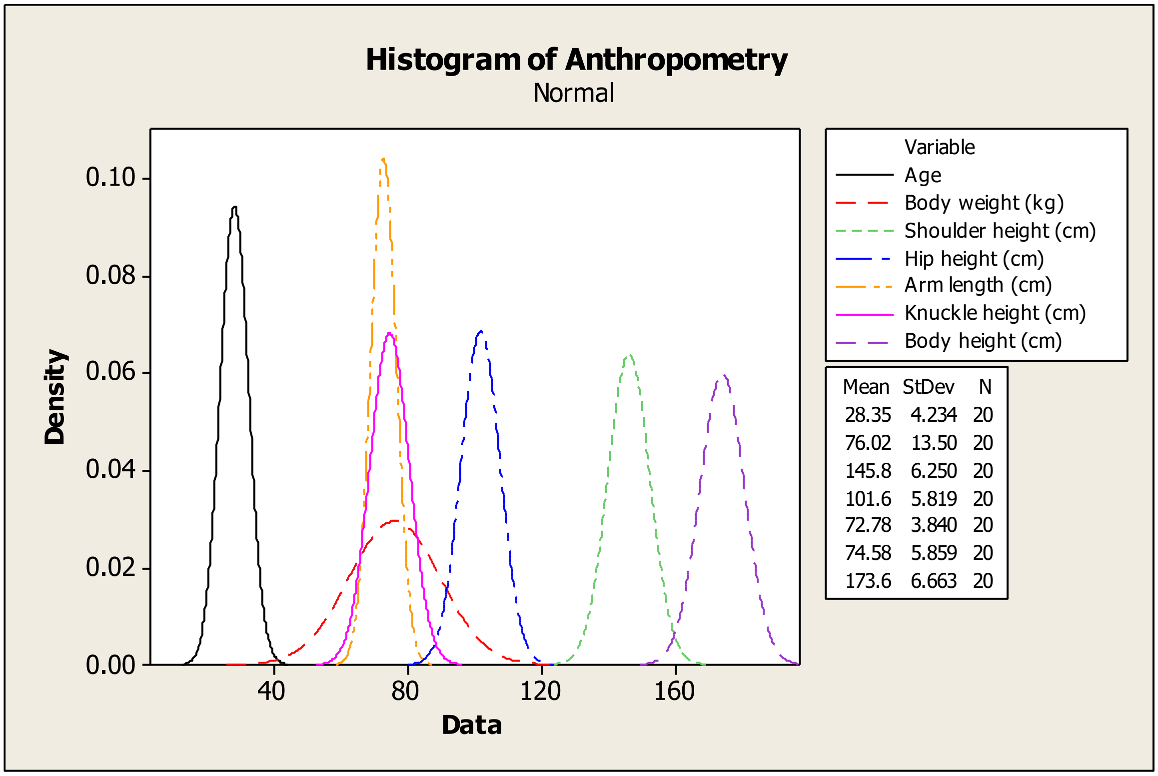


Figure 3.2: Histogram of the anthropometry

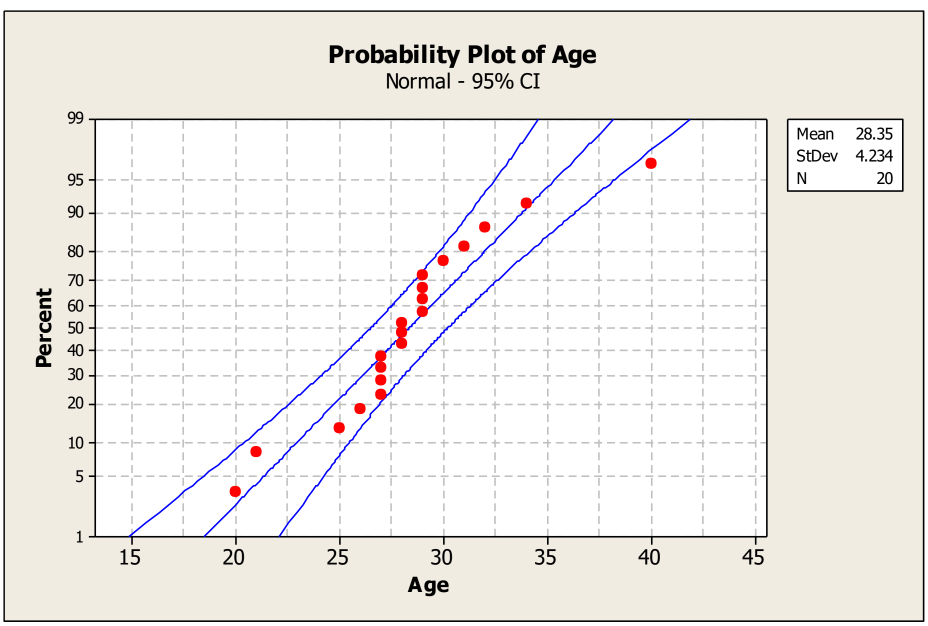


Figure 3.3: Normal probability plot of age

3.5 EEG data acquisition

EEG was recorded using a (Cognionics Data Acquisition Software Suite) and a Cognionics High-Density 64-channel Dry Headset 64-channel EEG (COGNIONICS, Inc. San Diego, CA). Electrodes were attached to the scalp using a custom subset of the 10-5 configuration. The flex sensor is designed to touch through hair with proper pressure while maintaining the ability to flatten for safety and comfort. Patent-pending materials and construction techniques to reduce contact impedances and noise without using electrolytic gels were employed. During the experimental setup, electrode impedance was monitored within the acceptable resistance limits; contact impedances with both sensors typically range from 100 k to 1 M Ohm (Mullen et al., 2013). EEG signals were sampled at 500 samples/sec. All processing and analysis was performed in Matlab (The Mathworks, Natick, MA) using EEGLAB 13 scripts based on (toolbox) from (sccn.ucsd.edu/eeglab), an open source environment for processing electrophysiological data (Delorme and Makeig, 2004).

Subjects were given a five-minute training of how to minimize artifacts such as eye blinking, chowing, and any other facial movements. The experiment started with 10-15 sec resting before any physical task. After that, participants were requested to evaluate the weight as to whether it was optimum for a 40 minute lifting interval. This evaluation was marked by a manual triggering procedure during the whole session and EEG recording marked by #2 in Figure 3.2. After that, the timer was set for a 40 minute interval with a beep every 9 seconds for the high lifting frequency and every 14 seconds for the medium lifting frequency. The total EEG recording time for this experiment for all participants was approximately 40 hours. For every single observation, EEG signals were subject to visual monitoring of any suspicious artifacts, and EEG cap movement led to high impedance using triggering procedure with #4 of each lift without errors.

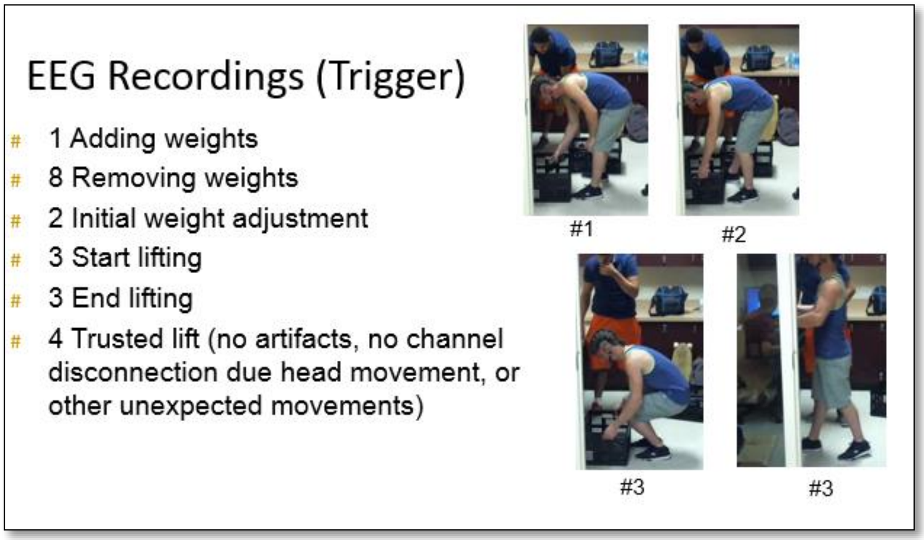


Figure 3.4: Manual triggering procedure at psychophysical test

3.6 EEG data pre-processing

During the experimental setup, electrode impedance was monitored within the acceptable resistance limits. EEG was recorded at 500 Hz with a bandpass filter of 0.03-100 Hz. All processing and analysis is performed in Matlab (The Mathworks, Natick, MA) using EEGLAB 13 scripts based on (toolbox) from (sccn.ucsd.edu/eeglab), an open source environment for processing electrophysiological data (Delorme & Makeig, 2004).

3.6.1 Artifacts correction using ASR

The artifacts correction in experimental EEG data was done using the Artifact Subspace Reconstruction method (ASR) by Mullen et al. (2013). ASR uses an algorithm to remove non-stationary high-variance signals from EEG and rebuilds the missing data with a spatial mixing matrix (assuming volume conduction). Calibration statistics are estimated in a robust manner (to minimize any effect of artifacts). Using the Geometric Median (3.1) by Haldane (1948) over windowed (1-second) estimates. It also uses iteratively reweighted least square (3.2) by (Green, 1984).

$$\mathcal{G}(\mathrm{x}) = \arg\min_{y} \sum_{i=1}^{m} \left\| x_i - y \right\|_2 \tag{3.1}$$

$$y_{i+1} = \frac{\left(\sum_{j=1}^{m} \frac{x_j}{\| x_j - y_i \|} \right)}{\sum_{j=1}^{m} \frac{1}{\| x_j - y_i \|}} \tag{3.2}$$

Five minutes recording includes: resting with closed eye, eye blinking, chowing body motion (walking), and physical task (lifting): Figure 3.3, 3.4, 3.5, 3.6, and 3.7.

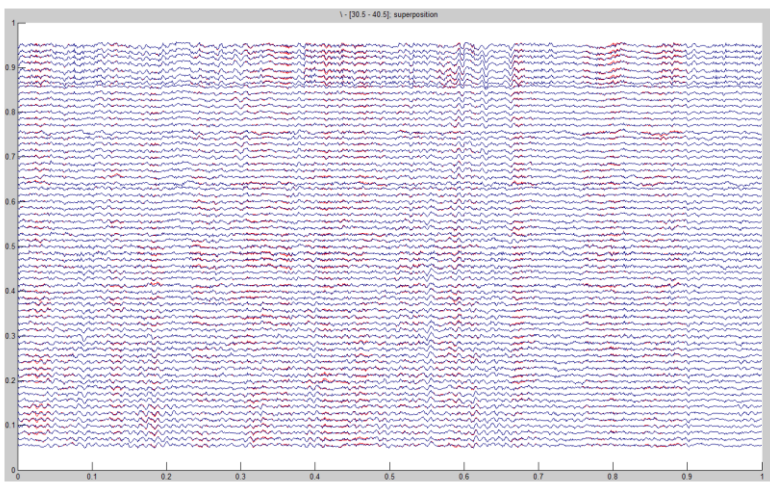


Figure 3.5: Recording at rest (setting and closed eye)

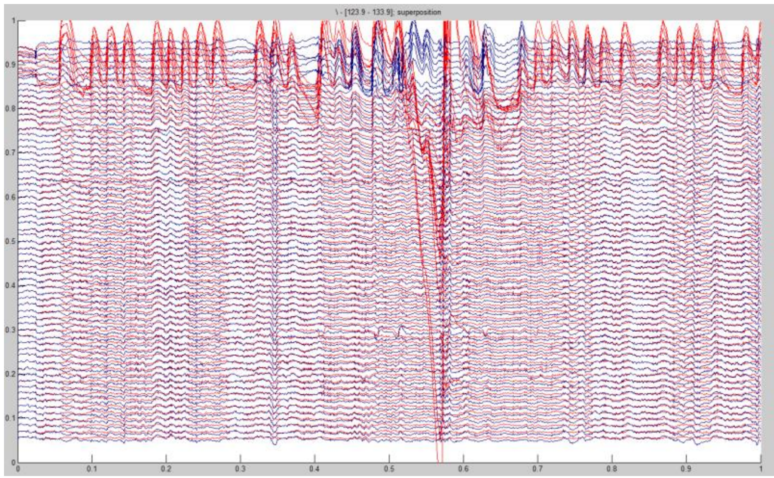


Figure 3.6: Eye blinking

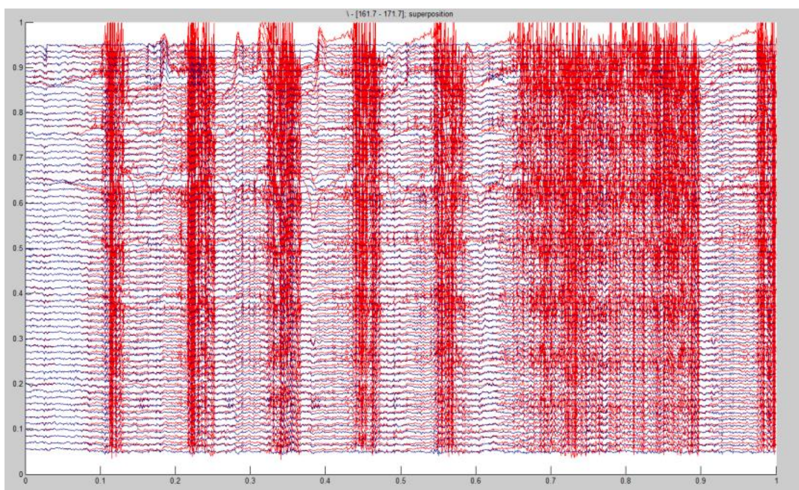


Figure 3.7: Chowing

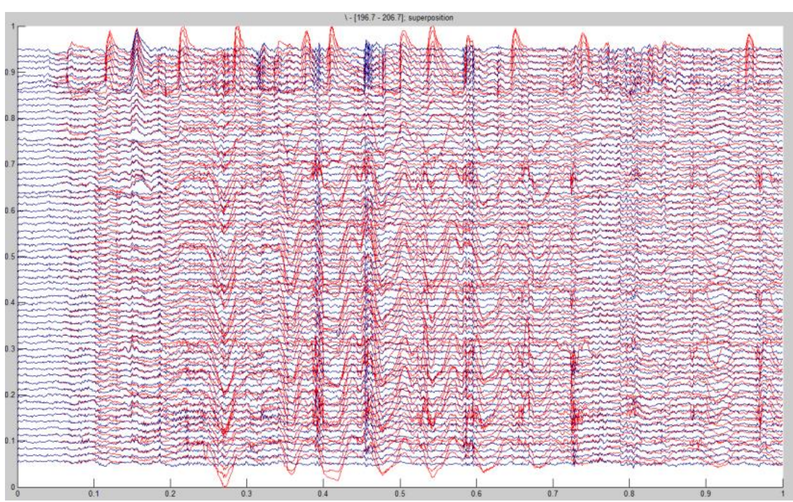


Figure 3.8: Body motion (walking)

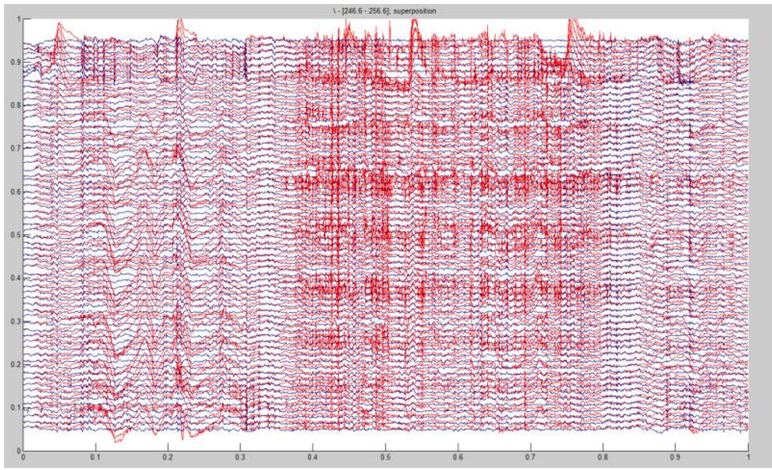


Figure 3.9: Physical task (lifting)

The criteria of ASR was in channels where tolerated flat line duration of more than 5 seconds is considered a bad channel and then rejected. Transition band for the initial high-pass filter is in Hz. This was formatted as [0.25 Hz-start, 0.75Hz-end]. If a channel is correlated at less than 80% to its robust estimate (based on other channels), it is considered abnormal if a channel has more line noise relative to its signal than 4 standard deviations from the channel population mean, and it is considered abnormal and then rejected.

Deviation cutoff was set for removal of bursts using ASR algorithm so data portions whose variance is larger than this threshold relative to the calibration data are considered missing data then removed. If the artifact in a window was composed of too many simultaneous uncorrelated sources, this is the maximum fraction of contaminated channels that are tolerated in the final output data for each considered window. Figure 3.8 shows EEG recording for one subject during low lifting task (one left every one minute) before and after ASR.

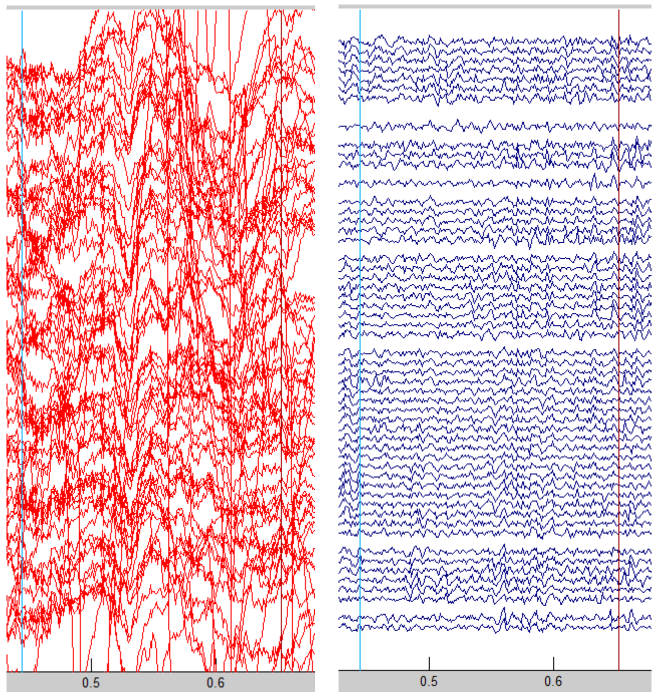


Figure 3.10:EEG recording before and after ASR for one lift

3.6.2 Additional artifacts removal based on epochs rejection

All EEG recordings were segmented, time-locked to starting lift onset of the extracted epoch start from time 0 which is the onset of lifting event up to 1 second. After that, epochs with extreme values of ±100 µV were rejected using standard thresholding of potential values. Improbable data channels vs epochs were represented using joint log probability $J_e\ (i)$ of the activity (A_i) per epoch i and electrode/channel e by the equation

$$J_e(i) = -\log\left(\prod_{x \in A_i} p_{D_e}(x)\right) \tag{3.3}$$

Where, $p_{De}\ (x)$ is the probability of detecting the value x in the probability distribution D_e of (A_i) at electrode/channel e; any epoch with more than 5 standard deviation limits is rejected.

Abnormally distributed peaked observed using kurtosis statistical measure

$$K = m_4 - 3m_2^2 \tag{3.4}$$

$$m_n = E[(x - m_1)^n] \tag{3.5}$$

Where, m_1 is the mean, and m_n are the n^{th} central moments of all activity values in the epoch, and E is an expected average. A high positive kurtosis value (leptokurtic) indicates an abnormal distribution in a data epoch, whereas a high negative kurtosis (platykurtic) value indicates abnormally flat activity distribution; any epoch 5 standard deviation limits is rejected. Finally, epochs with suspicious muscle artifacts were rejected based on power spectral pattern. Spectra should not deviate from the mean by ± 50 dB in the 0-2 Hz frequency window and should not deviate by +25 or -100 dB in the 20-50 Hz frequency window (Delorme, Sejnowski, & Makeig, 2007).

All the above described artifact detection methods performed by add-ons within the EEGLAB toolbox (Delorme & Makeig, 2004).

Visual inspection was the final step in artifacts detection and removal (Figure 3.11); all EEG recordings were inspected for any bursts or abnormal trends and manually rejected. After these aggressive processes of artifact correction and removal, most of the subject's EEG recordings passed except one subject in experiment 1 (low vs medium) lifting frequency. The missing channels at each dataset were rejected because they contained high artifacts, or due to loss of contact during the experiment nature were substituted using the spherical interpolation algorithm with data of its four nearest neighbors' channels (Perrin, Pernier, Bertrand, & Echallier, 1989), which was sourced from an EEGLAB toolbox.

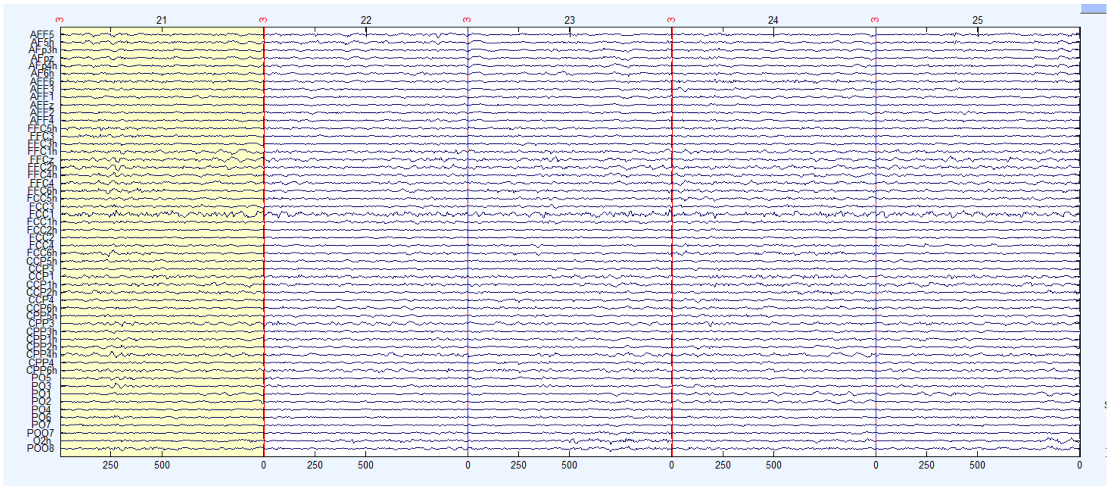


Figure 3.11: Visual inspection

3.7 Data Analysis

The brain’s areas of interest are the frontal, which is responsible for attention, judgment, and motor planning; the central, which is initiates sensorimotor control; and the parietal which performs cognitive processing (Figure 3.12).

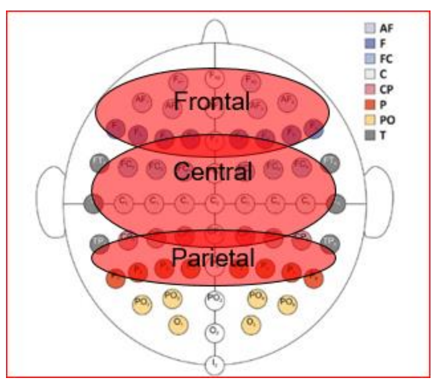


Figure 3.12: Brain's area of interest

The EEG frequency bands of interest are Theta θ-band 4-8 Hz , Alpha α-band 8-13 Hz, Beta β-band 13-30 Hz, and Gamma γ band 30-50 Hz. Theta and lower alpha or alpha 1 activity may be related to attention, cognition, and memory (Klimesch, 1999, 2012). Theta is also associated with workload and other cognitive processing such as self-monitoring (Sammer et al., 2007).

Alpha α-band, Beta β-band 13-30 Hz, and Gamma γ band 30-50 Hz are associated to movement and sensorimotor areas (Durka, 2003; Durka, Ircha, Neuper, & Pfurtscheller, 2001; Niedermeyer & da Silva, 2005).

EEG recordings were analyzed based on the frequency domain; all channels' Power Spectral Density (PSD) was computed using Fast Fourier Transform (FFT) using MATLAB (The Mathworks, Natick, MA); computing all frequency bands (theta, alpha, beta, and gamma) in Figures 3.13, 3.14, and 3.15.

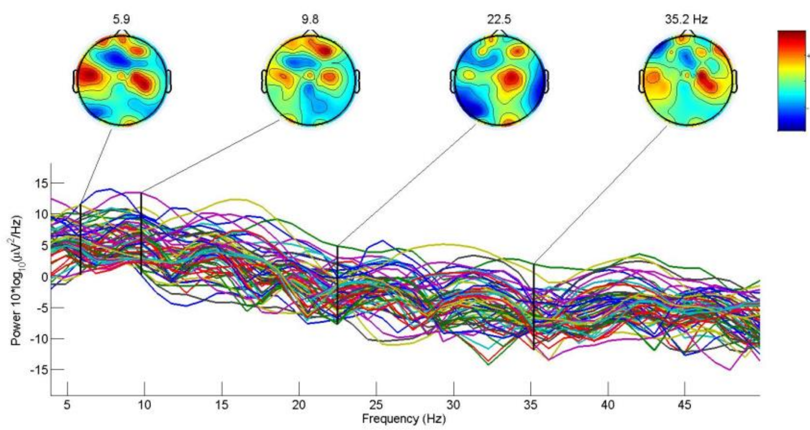


Figure 3.13: low lifting task PSD

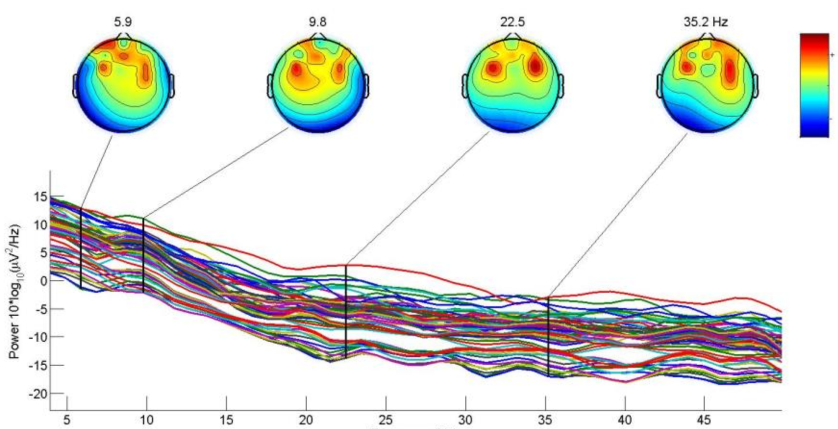


Figure 3.14: Medium low lifting task PSD

```
EDU>> sampRate = 500; %sampling rate of your data
lowerFreq = 4; %lower bound of your frequency band of interest
higherFreq = 8; %upper bound of your frequency band
chanNr = 1; %channel number of your lead

%computing log spectrum for different frequencies
[power, freq] = spectopo(EEG.data(chanNr, :), 0, sampRate);
%average power within the predefined frequency range
meanPower = mean(power(freq >= lowerFreq & freq <= higherFreq))
sumPower = sum (power(freq >= lowerFreq & freq <= higherFreq))
maxPower = max (power(freq >= lowerFreq & freq <= higherFreq))
Computing spectra (window length 512; fft length: 1024; overlap 0):
```

Figure 3.15: Example of MATLAB command to compute PSD at theta band at channel 1

All subjects' mean PSD was computed then filtered based on EEG channels and frequency band. Table 3.4 shows an example of PSD at one channel all bands. EEG was reported in the form of log transformed power spectral values or decibels (dB or $\mu V^2/Hz$).

Table 3.4: Example of PSD (dB) filtering per channel for all subjects

	Theta		Alpha		Beta		Gamma	
Subject	Low	Med	Low	Med	Low	Med	Low	Med
1	-3.972	9.063	-4.399	4.164	-10.380	-1.535	-16.230	-6.751
2	2.123	6.084	-0.521	2.718	-5.728	-2.877	-9.829	-8.237
3	3.611	1.854	1.758	2.049	-4.844	-5.399	-10.614	-10.992
4	-2.623	10.155	-1.015	6.570	-5.387	0.710	-10.480	-4.203
5	-3.168	6.090	-3.314	6.417	-8.926	1.115	-13.440	-3.845
6	-0.952	1.401	-1.595	-1.420	-7.248	-7.382	-11.259	-11.684
7	0.988	4.399	0.872	3.590	-4.721	-1.273	-8.401	-5.381
8	2.483	8.002	0.778	4.463	-6.491	-4.352	-10.781	-8.255
9	1.300	8.473	1.624	6.296	-2.100	0.668	-6.843	-4.980

The normality assumption of all mean PSD within every band and for each channel were tested in order to apply any statistical test. Therefore, most of the channels tested (Figure 3.16 and 3.17) show the normal probability plot for all subjects performing low and medium lifting tasks of FCCz channel at theta band. The probability plots showed no significant outlier within subjects; as a result, we proceeded to the next step.

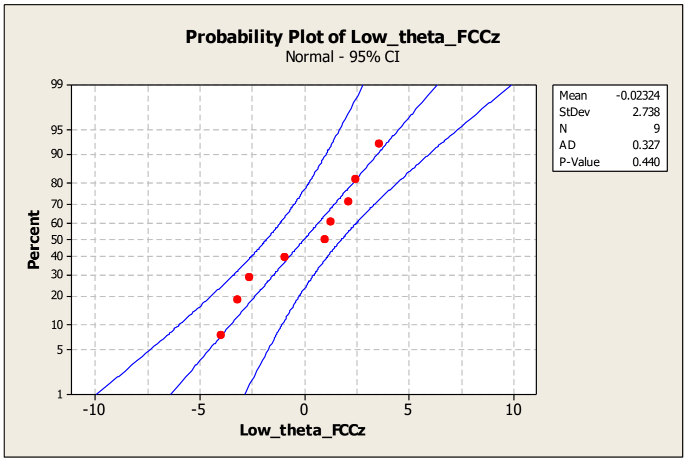


Figure 3.16: Normal probability plot of PSD (dB) for all subjects who performed low lifting task of FCCz channel at theta band

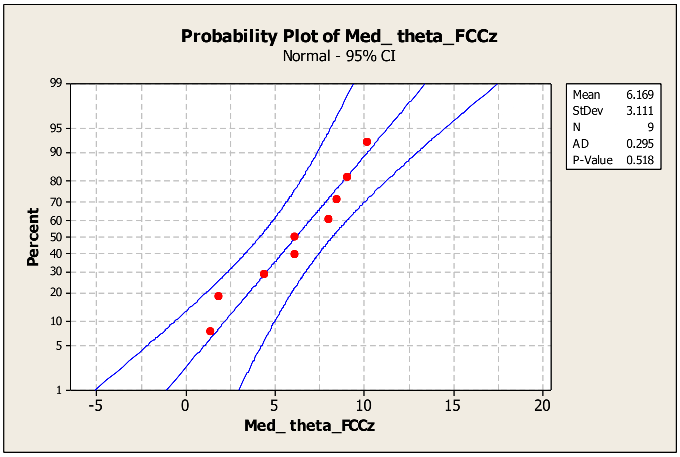


Figure 3.17: Normal probability plot of PSD (dB) for all subjects who performed medium lifting task of FCCz channel at theta band

After assuming the normality of PSD data within subjects per channels, one-way Analysis Of Variance (ANOVA) was used to test the study hypothesis. Finally, before we carry on to the results, we verified the ANOVA model adequacy by testing the most common graphical techniques such as histogram, normal probability plot, and residual fits plot (Figure 3.18).

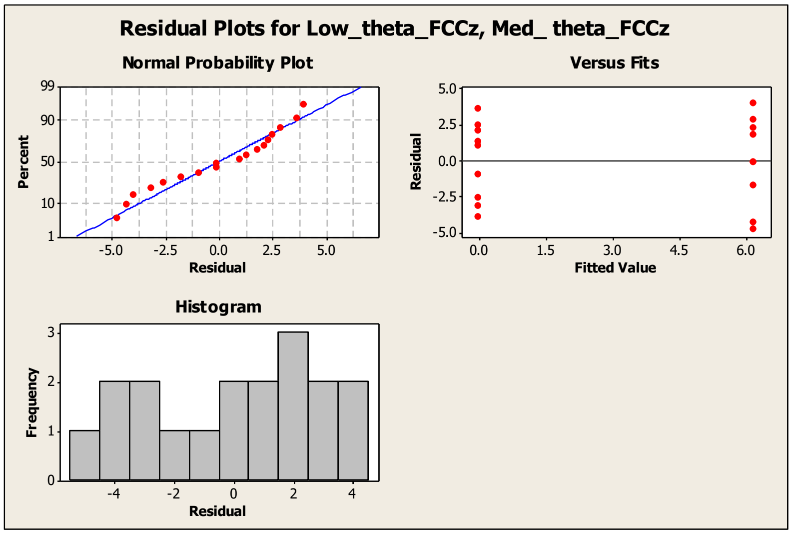


Figure 3.18: Example of ANOVA model adequacy used in data analysis

3.8 Results

Two independent variables were verified in this study, which are lifting frequency and trials: Low vs medium lifting frequency in experiment 1 and high vs medium lifting frequency in experiment 2. Correspondingly, two dependent variables were verified to be measured in this study. The first dependent variable is the EEG power spectral and the second dependent variable is MAWL.

3.8.1 Experiment I

EEG power spectral and MAWL varies between subjects at low and medium lifting frequencies. ANOVA shows significant differences between the two lifting frequencies at several bands; also ANOVA shows a few differences between the same lifting tasks at different trials. The following sections will cover all results in details.

3.8.1.1 Power Spectral Density (PSD)

The grand average of PSD from all subjects and all channels resulting from both low and medium lifting frequencies was computed, and Figure 3.19 shows the first trial of this experiment; EEG was reported in the form of linear power spectral values $\mu V^2/Hz$. This graph shows a remarkable difference between the medium lifting task and low lifting task, especially at theta band (between 4-8 Hz). The detailed results for each band at the first trial are the following:

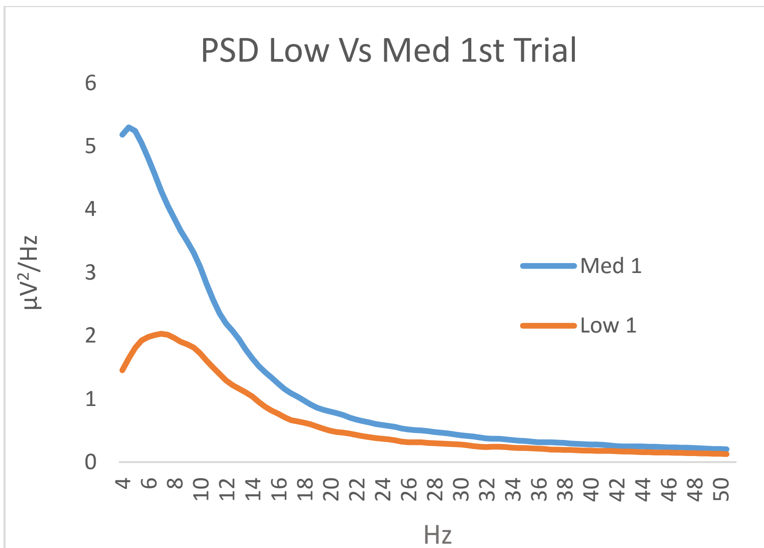


Figure 3.19: Grand average of PSD at low and medium lifting frequencies from all participants and all channels 1st trial

Table 3.5 and (Figure 3.20, 3.21, and 3.22) shows significant changes between low and medium lifting tasks in theta activity power were found in most of the brain regions: frontal, central, and parietal. As well, significant changes in alpha activity power were found in the frontal and central regions. No significant changes in beta and gamma activity power were found in most of the brain regions: frontal, central or parietal.

Table 3.5: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in Experiment I 1st trial

Region	Band	Low lifting mean PSD	Medium lifting mean PSD	*p-value*
Frontal	theta	2.71	7.12	0.002
	alpha	2.09	4.87	0.009
	beta	-3.16	-0.96	0.079
	gamma	-7.62	-5.51	0.102
Central	theta	2.10	6.20	0.008
	alpha	1.51	4.08	0.047
	beta	-3.68	-1.75	0.188
	gamma	-8.11	-6.43	0.249
Parietal	theta	2.15	6.05	0.012
	alpha	1.45	3.84	0.079
	beta	-3.70	-2.03	0.282
	gamma	-8.05	-6.66	0.354

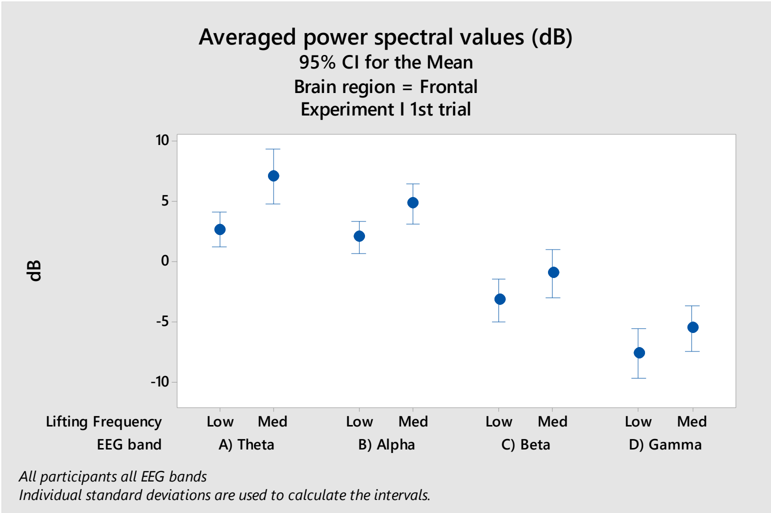


Figure 3.20: Averaged power spectral values (dB) for all bands activity in frontal region for all participants in Experiment I 1st trial

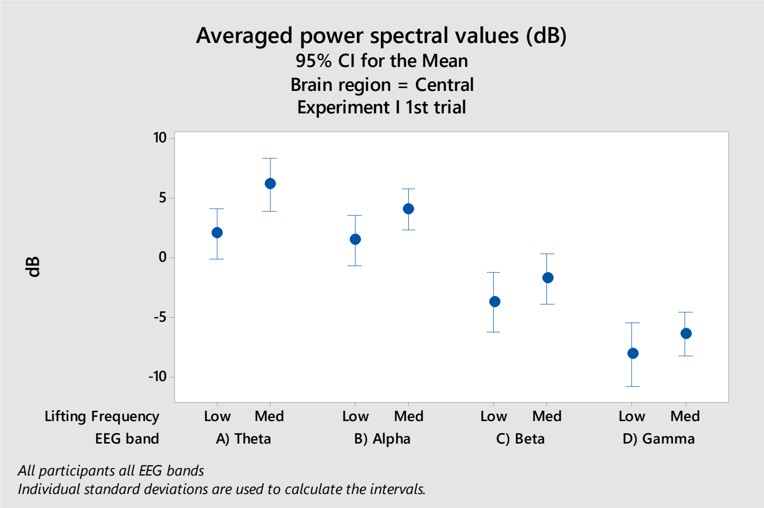


Figure 3.21: Averaged power spectral values (dB) for all bands activity in central region for all participants in Experiment I 1st trial

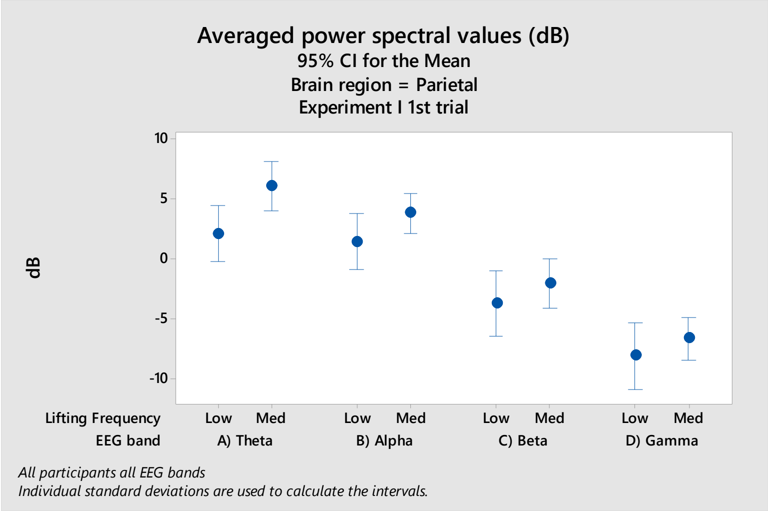


Figure 3.22: Averaged power spectral values (dB) for all bands activity in parietal region for all participants in Experiment I 1st trial

Detailed analysis on the channel level at theta, alpha, beta, and gamma bands as per the following sections:

3.8.1.1.1 Theta band results at first trial

Significant changes in theta activity power were found in most of the brain regions: frontal, central, and parietal. Table 3.6 shows the data for the low lifting versus medium lifting EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD at medium compared to low lifting task; Figure 3.23 shows a topographical head map of the significant areas and the significant level of changes for theta activity during low lifting task vs medium lifting task for all participants.

Table 3.6:Averaged power spectral values (dB) for theta band activity across 32 channels all participants

channel	**Theta averaged PSD (dB)**				**channel**	**Theta averaged PSD (dB)**			
	Low	**Med**	**P-value**			**Low**	**Med**	**P-value**	
AF5h	4.85	9.29	<0.001	↑	FCC2	0.76	5.09	0.004	↑
Afpz	5.19	10.17	0.001	↑	FCC4	2.13	6.37	0.023	↑
AF6h	4.81	9.00	0.005	↑	CCP3	1.77	6.25	0.009	↑
AFF3	3.06	7.38	0.004	↑	CCP1	2.60	6.71	0.026	↑
AFFz	2.06	7.24	0.002	↑	CCP1h	2.03	5.84	0.051	↑
AFF4	3.63	7.85	0.010	↑	CCPz	1.54	5.83	0.036	↑
FFC3			NS		CCP2h			NS	
FFC3h	2.61	6.06	0.035	↑	CCP2			NS	
FFCz	0.55	6.40	0.018	↑	CCP4	1.87	6.02	0.040	↑
FFC2h	2.55	7.08	0.034	↑	CPP3h	2.41	6.08	0.041	↑
FFC4			NS		CPP1h			NS	
FCC3			NS		CPPz	1.86	7.01	0.001	↑
FCC1			NS		CPP2h	2.01	6.04	0.034	↑
FCC1h			NS		CPP4h			NS	
FCCz	-0.02	6.17	<0.001	↑	Poz	2.30	6.45	0.016	↑
FCC2h	-0.51	5.57	<0.001	↑	Oz	2.02	6.46	0.010	↑

Notes. The arrows (↑) show the direction of change, medium lifting task compared to low lifting task. (NS) No significant change

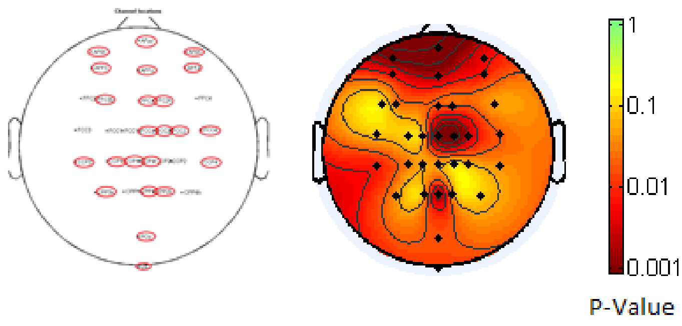


Figure 3.23:Topographical head map of the significant areas of changes for theta activity during low lifting task vs medium lifting task for all participants

3.8.1.1.2 Alpha band results at first trial

Significant changes in alpha activity power were found mostly in the frontal and central regions with few in the parietal. Table 3.7 shows the data for the low lifting versus medium lifting EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD at medium compared to low lifting task; Figure 3.24 shows a topographical head map of the significant areas and the significant level of changes for alpha activity during low lifting task vs medium lifting task for all participants.

Table 3.7: Averaged power spectral values (dB) for alpha band activity across 32 channels all participants

channel	**Alpha averaged PSD (dB)**			**channel**	**Alpha averaged PSD (dB)**		
	Low	**Med**	**P-value**		**Low**	**Med**	**P-value**
AF5h	3.89	6.26	0.010 ↑	FCC2	0.54	3.23	0.023 ↑
Afpz	4.08	7.09	0.033 ↑	FCC4	1.48	4.62	0.045 ↑
AF6h	3.58	6.16	0.024 ↑	CCP3	0.77	4.00	0.025 ↑
AFF3	2.30	4.92	0.020 ↑	CCP1			NS
AFFz	1.45	4.91	0.015 ↑	CCP1h			NS
AFF4	2.80	5.50	0.012 ↑	CCPz			NS
FFC3			NS	CCP2h			NS
FFC3h			NS	CCP2			NS
FFCz			NS	CCP4			NS
FFC2h			NS	CPP3h			NS
FFC4			NS	CPP1h			NS
FCC3			NS	CPPz	1.30	4.50	0.054 ↑
FCC1			NS	CPP2h			NS
FCC1h			NS	CPP4h			NS
FCCz	-0.65	3.87	0.001 ↑	Poz			NS
FCC2h	-1.33	3.38	<0.001 ↑	Oz			NS

Notes. The arrows (↑) show the direction of change, medium lifting task compared to low lifting task. (NS) No significant change

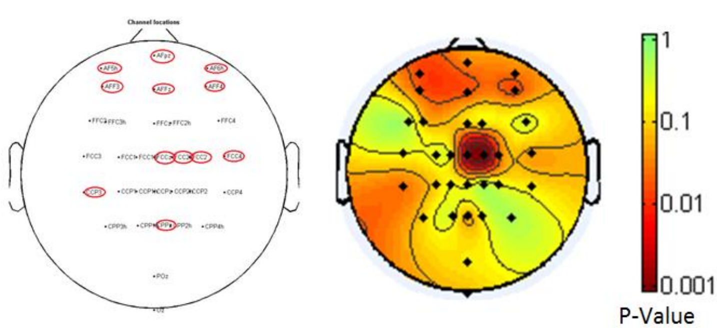


Figure 3.24: Topographical head map of the significant areas of changes for theta activity during low lifting task vs medium lifting task for all participants

3.8.1.1.3 Beta band results at first trial

Significant changes in beta band activity power were found at a few frontal areas such as channels AFFz at low lifting (PSD = -4.14 dB), medium lifting (PSD= -1.02 dB) with p-value 0.03. Also a few areas at central regions such as FCCz at low lifting (PSD = -6.20 dB), medium lifting (PSD= -2.26 dB) with p-value equals 0.007; and FCC2h at low lifting (PSD = -6.48 dB), medium lifting (PSD= -2.59 dB) with p-value equals 0.003. These channels recorded a greater average value of PSD at medium compared to low lifting task, with a trend for the increase in beta significance change level to become greater towards the central region of the brain. Figure 3.25 shows a topographical head map of the significant areas and the significant level of changes for beta activity during low lifting task vs medium lifting task for all participants.

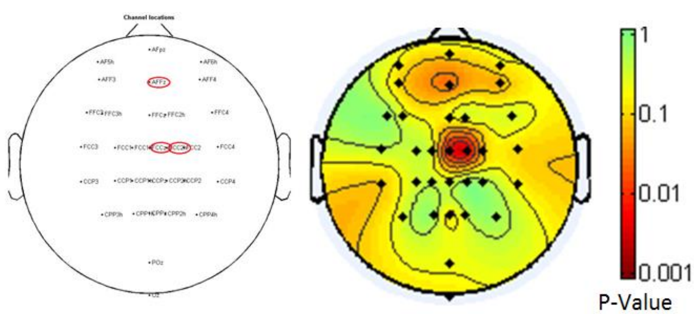


Figure 3.25: Topographical head map of the significant areas of changes for beta activity during low lifting task vs medium lifting task for all participants

3.8.1.1.4 Gamma band results at first trial

Significant changes in gamma band activity power were found at a few frontal areas such as channels AFF3 at low lifting (PSD = -7.05 dB), medium lifting (PSD= -5.05 dB) with p-value 0.049, and AFFz at low lifting (PSD = -8.79 dB), medium lifting (PSD= -6.00 dB) with p-value 0.043. Also included were a few areas at central regions such as FCCz at low lifting (PSD = 10.88

dB), medium lifting (PSD= -7.15 dB) with p-value equals 0.012; and FCC2h at low lifting (PSD = -10.94 dB), medium lifting (PSD= -7.44 dB) with p-value equals 0.006. These channels recorded a greater average value of PSD at medium compared to low lifting task, with a trend for the increase in gamma significance change level to become greater towards the central region of the brain. Figure 3.26 shows a topographical head map of the significant areas and the significant level of changes for gamma activity during low lifting task vs medium lifting task for all participants.

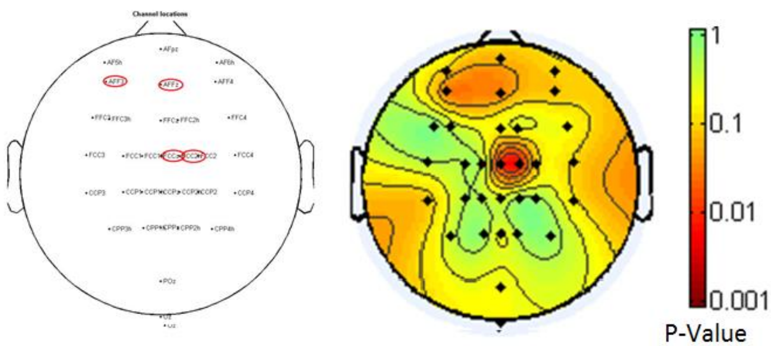


Figure 3.26: Topographical head map of the significant areas of changes for gamma activity during low lifting task vs medium lifting task for all participants

The second trial of the same experiment shows a consistent result to the first trial. Figure 3.27 shows the second trial of this experiment and the grand average of PSD all subjects all channels resulting from both low and medium lifting frequencies.

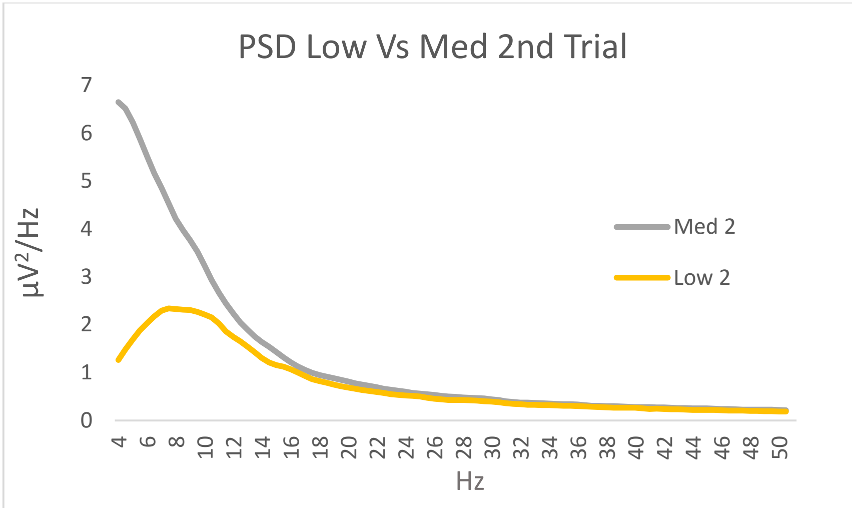


Figure 3.27: Grand average of PSD at low and medium lifting frequencies from all participants and all channels 2nd trial

Table 3.8 and (Figure 3.28, 3.29, and 3.30) shows significant changes between low and medium lifting tasks in theta activity power were found in most of the brain regions: frontal, central, and parietal. No significant changes in alpha, beta, or gamma activity power were found in most brain regions: frontal, central, or parietal.

Table 3.8: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in Experiment I 2nd trial

Region	Band	Low lifting mean PSD	Medium lifting mean PSD	*p-value*
Frontal	theta	2.86	7.91	<0.001
	alpha	3.20	5.07	0.059
	beta	-1.68	-0.87	0.534
	gamma	-5.94	-5.40	0.681
Central	theta	2.66	7.37	<0.001
	alpha	3.01	4.68	0.165
	beta	-1.75	-1.22	0.722
	gamma	-6.07	-5.81	0.855
Parietal	theta	2.72	7.30	<0.001
	alpha	3.08	4.52	0.263
	beta	-1.71	-1.41	0.851
	gamma	-6.05	-5.90	0.925

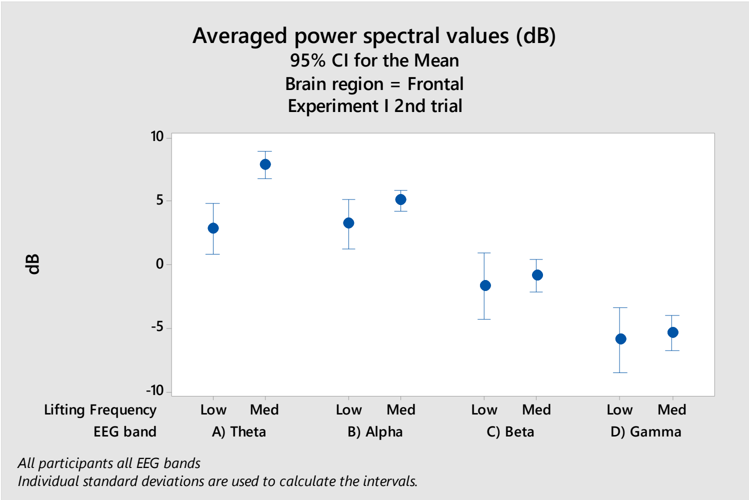


Figure 3.28: Averaged power spectral values (dB) for all bands activity in frontal region for all participants in Experiment I 2nd trial

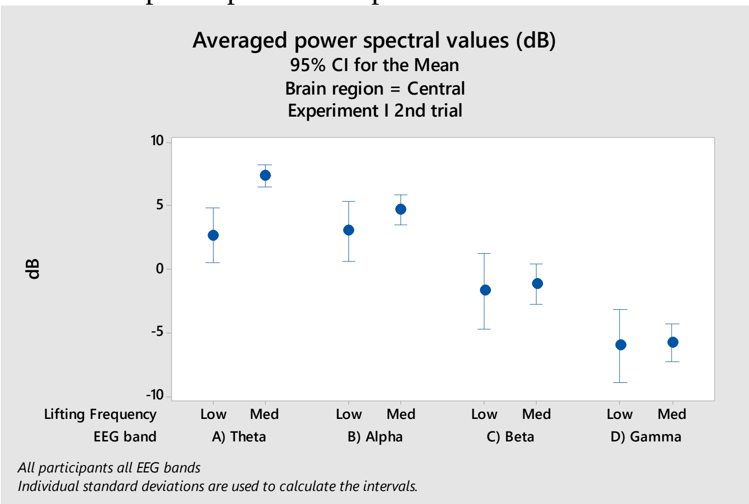


Figure 3.29: Averaged power spectral values (dB) for all bands activity in central region for all participants in Experiment I 2nd trial

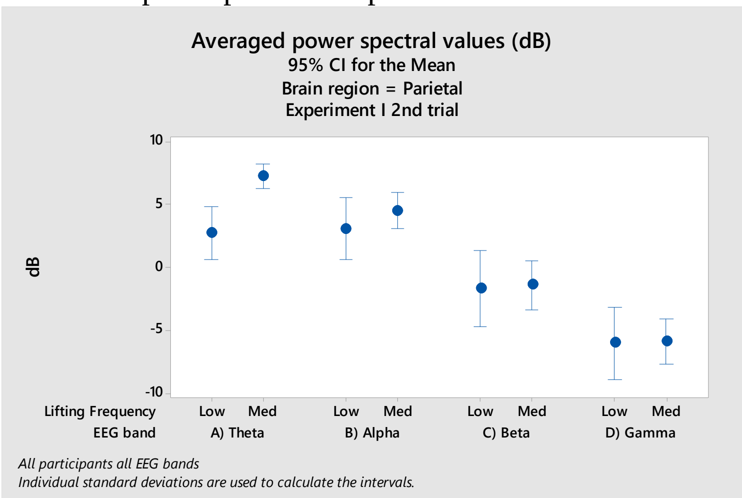


Figure 3.30: Averaged power spectral values (dB) for all bands activity in parietal region for all participants in Experiment I 2nd trial

Detailed analysis on the channel level at theta, alpha, beta, and gamma bands as the following sections:

3.8.1.1.5 Theta band results at second trial

Significant changes in theta activity power were found in most brain regions: frontal, central, and parietal. Table 3.9 shows the data for the low lifting versus medium lifting EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD at medium compared to low lifting task. Figure 3.31 shows a topographical head map of the significant areas and the significant level of changes for theta activity during low lifting task vs medium lifting task for all participants.

Table 3.9: Averaged power spectral values (dB) for theta band activity across 32 channels all participants

channel	Theta averaged PSD (dB)				channel	Theta averaged PSD (dB)			
	Low	Med	P-value			Low	Med	P-value	
AF5h	4.00	9.15	<0.001	↑	FCC2	3.01	6.80	0.001	↑
Afpz	4.68	10.37	<0.001	↑	FCC4	2.36	8.23	0.003	↑
AF6h	3.95	9.69	<0.001	↑	CCP3	1.68	7.29	<0.001	↑
AFF3	2.00	6.94	0.002	↑	CCP1	3.31	7.55	0.014	↑
AFFz	2.03	8.20	<0.001	↑	CCP1h	3.53	7.78	0.007	↑
AFF4	3.84	8.44	0.009	↑	CCPz	3.83	6.77	0.051	↑
FFC3	2.84	8.75	0.004	↑	CCP2h	3.48	7.39	0.016	↑
FFC3h	2.03	7.95	<0.001	↑	CCP2	3.13	8.46	<0.001	↑
FFCz	1.91	6.29	0.014	↑	CCP4	3.45	7.12	0.015	↑
FFC2h	2.49	6.89	0.007	↑	CPP3h	2.73	6.39	0.014	↑
FFC4	2.79	6.75	0.041	↑	CPP1h	1.74	7.54	<0.001	↑
FCC3	4.42	8.53	0.017	↑	CPPz	0.99	6.92	0.002	↑
FCC1			NS		CPP2h	2.12	7.31	0.005	↑
FCC1h	2.19	6.94	0.007	↑	CPP4h	1.85	6.96	0.008	↑
FCCz	0.18	6.39	0.001	↑	Poz	1.39	7.30	0.003	↑
FCC2h	2.26	8.24	0.003	↑	Oz	1.32	6.29	0.018	↑

Notes. The arrows (↑) show the direction of change, medium lifting task compared to low lifting task. (NS) No significant change

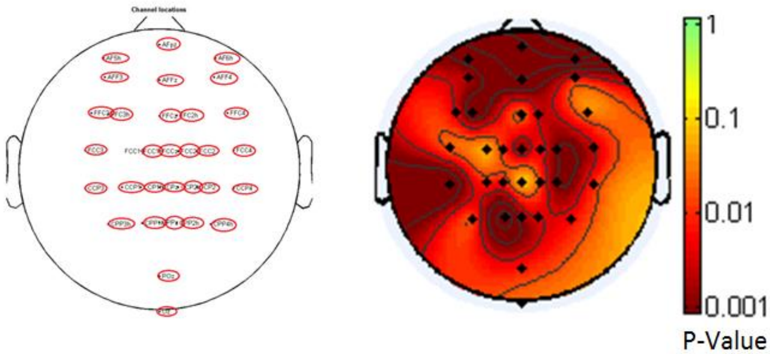


Figure 3.31: Topographical head map of the significant areas of changes for theta activity during low lifting task vs medium lifting task for all participants

3.8.1.1.6 Alpha band results at second trial

Significant changes in alpha band activity power were found at a few areas of the frontal region, such as channels AF6h at low lifting (PSD = 3.78 dB), medium lifting (PSD= 5.96 dB) with p-value 0.006; and AFFz at low lifting (PSD = 2.75 dB), medium lifting (PSD= 5.39 dB) with p-value equals 0.023. Also a few areas at central regions such as FCCz at low lifting (PSD = 0.09 dB), medium lifting (PSD= 3.71 dB) with p-value equals 0.043. These channels recorded a greater average value of PSD at medium compared to low lifting task, with a trend for the increase in alpha significance change level to become greater towards the frontal region of the brain; Figure 3.32 shows a topographical head map of the significant areas and the significant level of changes for alpha activity during low lifting task vs medium lifting task for all participants.

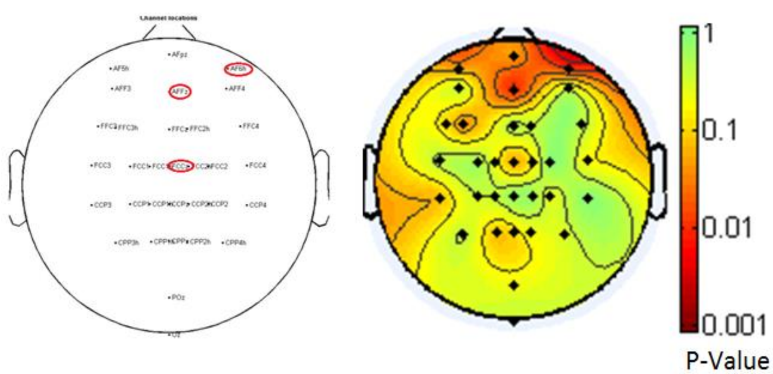


Figure 3.32: Topographical head map of the significant areas of changes for alpha activity during low lifting task vs medium lifting task for all participants

3.8.1.1.7 Beta band results at second trial

No significant changes occurred in the beta band associated with low and medium lifting for all brain areas: frontal, central, or parietal (Figure 3.33).

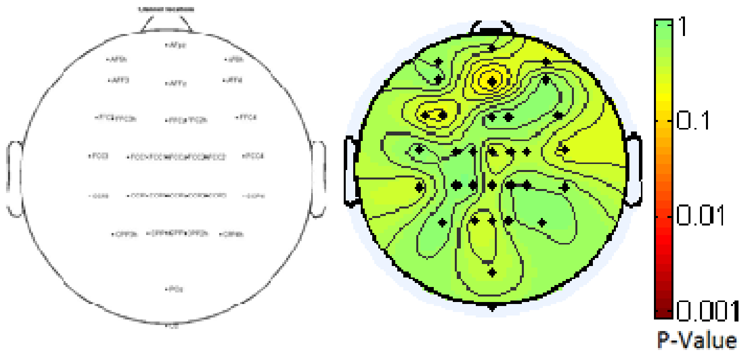


Figure 3.33: Topographical head map of the significant areas of changes for beta activity during low lifting task vs medium lifting task for all participants

3.8.1.1.8 Gamma band results at second trial

No significant changes occurred in the gamma band associated with low and medium lifting for all brain areas: frontal, central, or parietal (Figure 3.34).

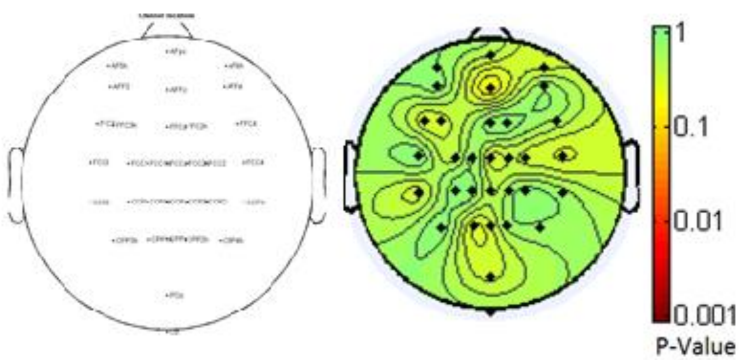


Figure 3.34: Topographical head map of significant areas of changes for beta activity during low lifting task vs medium lifting task for all participants

3.8.1.2 Difference between trials

No significant differences between the two trials at low lifting tasks was found, except in channels FCC2 and FCC2h at the central area of the brain at alpha, beta, and gamma. In alpha band FCC2 channel at low lifting 1st trial was (PSD = 0.54 dB), 2nd trial was (PSD= 4.14 dB) with p-value 0.014; and FCC2h channel at low lifting 1st trial was (PSD = -1.33 dB), 2nd trial was (PSD= 2.42 dB) with p-value 0.018. In beta band FCC2 channel at low lifting 1st trial was (PSD = -4.84 dB), 2nd trial was (PSD= -0.70 dB) with p-value 0.018; and FCC2h channel at low lifting 1st trial was (PSD = -6.48 dB), 2nd trial was (PSD= -2.30 dB) with p-value 0.011. In gamma band FCC2 channel at low lifting 1st trial was (PSD = -9.26 dB), 2nd trial was (PSD= -5.10 dB) with p-value 0.015; and FCC2h channel at low lifting 1st trial was (PSD = -10.94 dB), 2nd trial was (PSD= -7.05 dB) with p-value 0.020. A topographical head map of the significant areas of changes for alpha, beta, and gamma activity during 1st trial of low lifting vs 2nd trial of low lifting for all participants can be seen in Figure 3.35.

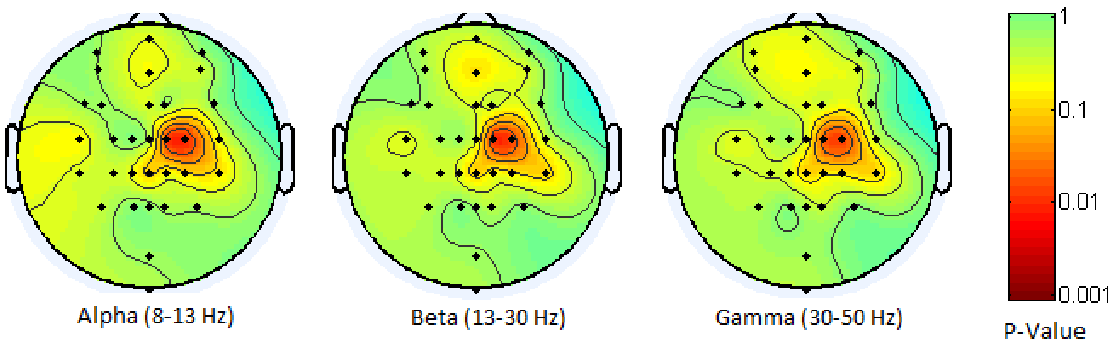


Figure 3.35: Topographical head map of the significant areas of changes for alpha, beta, and gamma activity during 1st trial vs 2nd trial of low lifting for all participants

On the other hand, medium lifting task resulted in almost no significant difference between trials; however PSD was slightly greater at the 2nd trial than the 1st trial at all bands.

3.8.1.3 MAWL

The maximum acceptable weight for all tasks and all trials in this experiments is presented in Table 3.10. The data was analyzed using ANOVA to test if there is a significant difference between trials. In the first trial, low lifting MAWL was significantly higher than medium lifting for all participants with average (MAWL =15.42 Kg) verses average (MAWL =7.16 Kg) at medium lifting; the significant difference between the two lifting tasks was (p-value =0.001). In the second trial, low lifting MAWL also was significantly higher than medium lifting for all participants with average (MAWL =13.41 Kg) verses average (MAWL =7.26 Kg) at medium lifting; the significant difference between the two lifting tasks was (p-value < 0.001). These results are consistent with Liberty Mutual Manual Materials Handling Tables. Snook and Ciriello (1991) found that in one lift per minute lifting frequency MAWL is 16 kg; in 4.3 lifts per minute lifting frequency MAWL is 12 kg. No significant differences were found between trials at low or medium lifting. In low lifting task, the two trials are equals with (p-value = 0.348); and in medium lifting task the two trials are also equals with (p-value = 0.930).

Table 3.10: Maximum acceptable weights (kg) for all participants performing low and medium lifting for 40 min

	Low lifting 1st trial	Medium lifting 1st trial	Low lifting 2nd trial	Medium lifting 2nd trial
	10.89	7.26	9.07	6.35
	9.07	5.44	10.89	6.35
	19.05	7.26	13.61	9.98
	27.22	9.07	15.42	8.16
	15.42	9.98	11.79	4.54
	17.24	10.89	13.61	10.89
	10.89	3.63	12.7	4.54
	17.24	3.63	18.14	8.16
	11.79	7.26	15.42	6.35
Mean	**15.42**	**7.16**	**13.41**	**7.26**
S.D	**5.31**	**2.44**	**2.56**	**2.1**

Note: S.D is the standard deviation

In addition, participant's age and body weight found to have a significant effect on the estimation of MAWL at low and medium lifting frequency respectively. MAWL is significantly increase with the increase of participant age with (p-value = 0.007) and the regression equation is:

$$MAWL_{Low\ lifting} = -52.6 + 2.384\ Age \quad (3.6)$$

Figure 3.36 shows the effect of age on MAWL at low lifting frequency; also, no significant effect of the age on MAWL at medium lifting frequency with (p-value = 0.466).

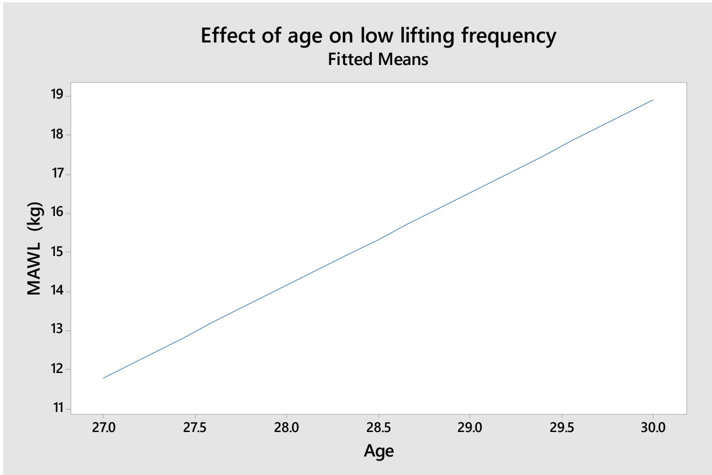


Figure 3.36: The effect of age on MAWL at low lifting frequency

MAWL is significantly decrease with the increase of participant body weight with (p-value = 0.015) and the regression equation is:

$$MAWL_{\text{Medium lifting}} = 13.05 - 0.0769 \ \text{Body weight} \quad (3.7)$$

Figure 3.37 shows the effect of body weight on MAWL at medium lifting frequency; also, no significant effect of the body weight on MAWL at low lifting frequency (p-value =0.870).

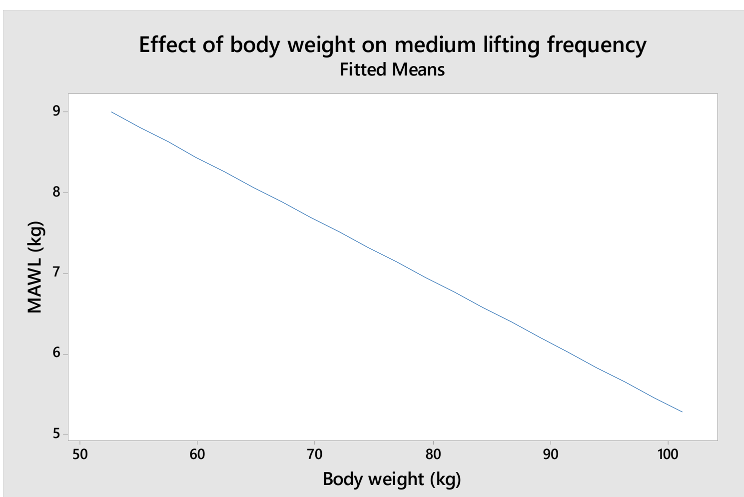


Figure 3.37: The effect of body weight on MAWL at medium lifting frequency

3.8.2 Experiment II

EEG power spectral and MAWL varies between subjects at medium and high lifting frequencies. ANOVA shows significant differences between the two lifting frequencies at several bands; also ANOVA shows a few differences between the same lifting tasks at different trials. The following sections will cover all results in details.

3.8.2.1 Power Spectral Density (PSD)

The grand average of PSD from all subjects and all channels resulting from both medium and high lifting frequencies was computed, and Figure 3.38 shows the first trial of this experiment; EEG was reported in the form of linear power spectral values $\mu V^2/Hz$. This graph presents a remarkable difference between medium lifting task and high lifting task, especially at theta band; then a swap between the two powers starting at alpha band. The detailed results for each band at the first trial is the following:

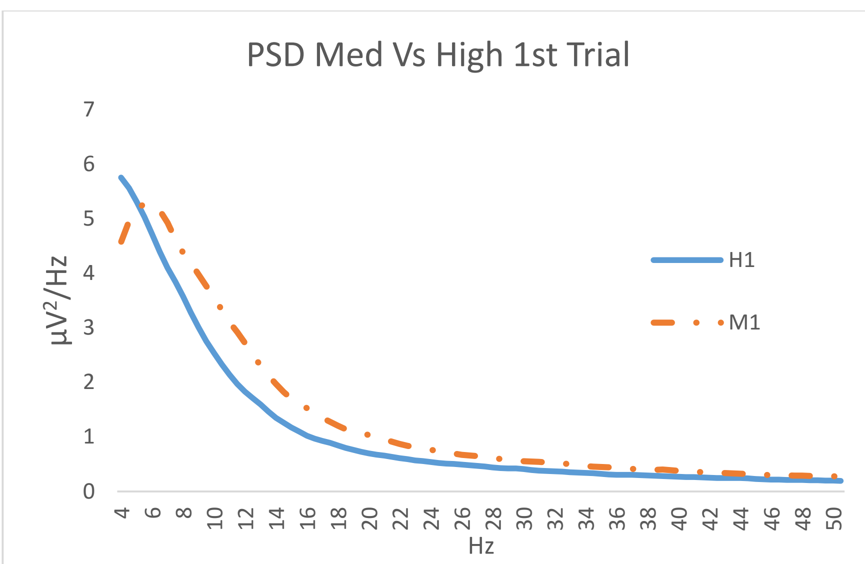


Figure 3.38: Grand average of PSD at medium and high lifting frequencies from all participants and all channels 1st trial

Table 3.11 and (Figure 3.39, 3.40, and 3.41) shows significant changes between medium and high lifting tasks in alpha and beta activity power were found in central and parietal brain regions. No significant changes in theta and gamma activity power were found in most brain regions: frontal, central, or parietal.

Table 3.11: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in Experiment II 1st trial

Region	Band	Medium lifting mean PSD	High lifting mean PSD	*p-value*
Frontal	theta alpha beta gamma	7.19 5.43 0.12 -4.12	6.90 3.86 -1.63 -5.72	0.822 0.127 0.089 0.111
Central	theta alpha beta gamma	6.98 5.36 -0.12 -4.65	6.32 3.47 -2.04 -6.30	0.563 0.042 0.044 0.074
Parietal	theta alpha beta gamma	6.98 5.29 -0.32 -4.79	6.36 3.46 -2.17 -6.41	0.575 0.039 0.048 0.077

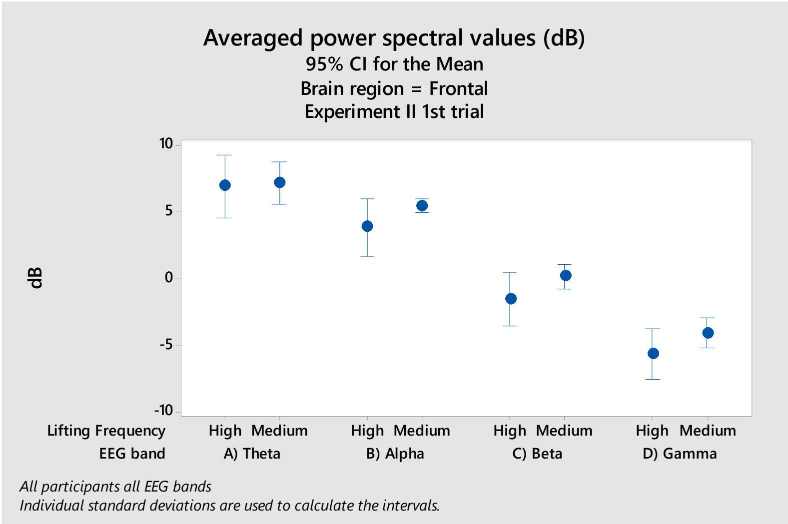


Figure 3.39: Averaged power spectral values (dB) for all bands activity in frontal region for all participants in Experiment II 1st trial

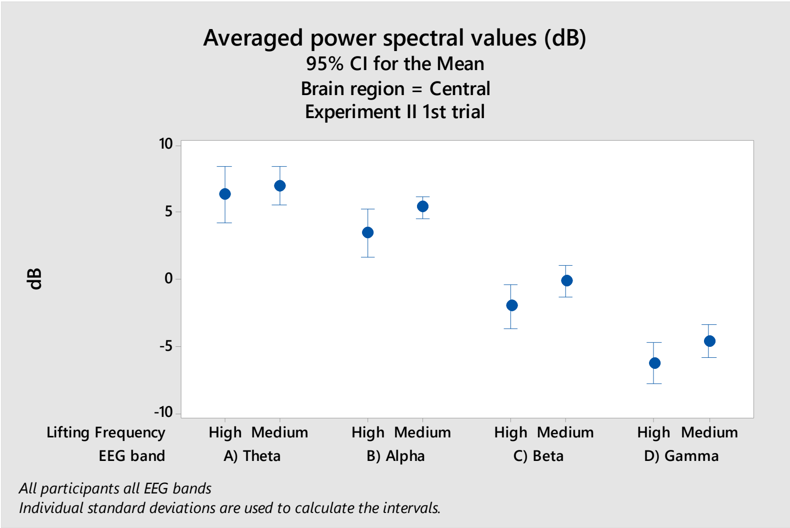


Figure 3.40: Averaged power spectral values (dB) for all bands activity in central region for all participants in Experiment II 1st trial

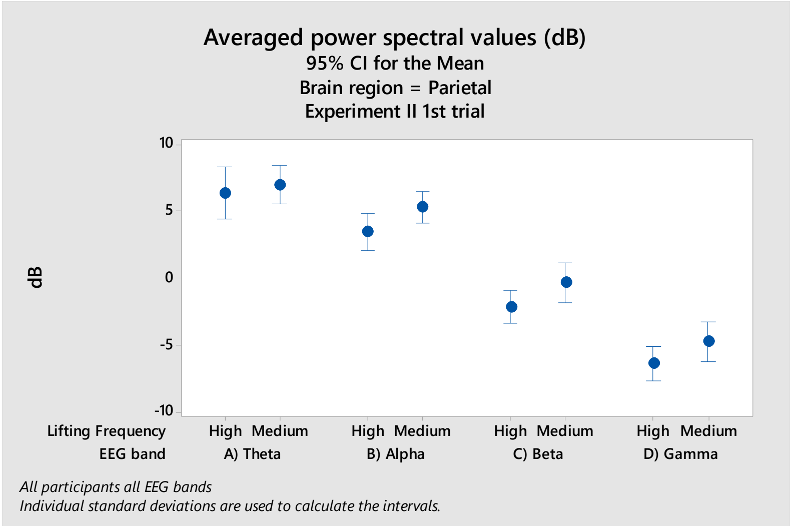


Figure 3.41: Averaged power spectral values (dB) for all bands activity in parietal region for all participants in Experiment II 1st trial

Detailed analysis on the channel level at theta, alpha, beta, and gamma bands as per the following sections:

3.8.2.1.1 Theta band results at first trial

No significant changes occurred in the theta band associated with medium and high lifting for all brain areas frontal, central, and parietal Figure3.42.

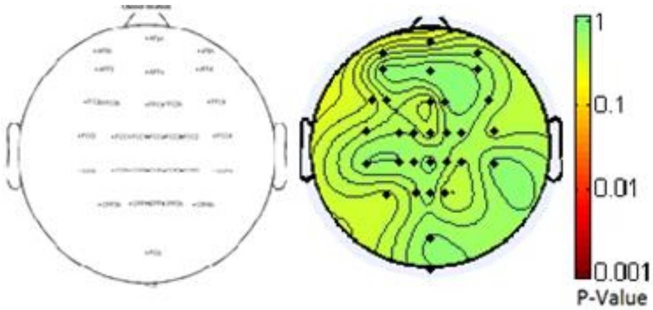


Figure 3.42: Topographical head map of significant areas of changes for theta activity during medium lifting task vs high lifting task for all participants

3.8.2.1.2 Alpha band results at first trial

Significant changes in alpha activity power were found mostly in parietal regions, with few at central. Table 3.12 shows the data for the medium lifting versus high lifting EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD at medium compared to high lifting task; Figure 3.43 shows a topographical head map of the significant areas and the significant level of changes for alpha activity during medium lifting task vs high lifting task for all participants.

Table 3.12: Averaged power spectral values (dB) for alpha band activity across 32 channels all participants

channel	**Alpha averaged PSD (dB)**			**channel**	**Alpha averaged PSD (dB)**		
	Med	**High**	**P-value**		**Med**	**Hig**	**P-value**
AF5h			NS	FCC2			NS
Afpz			NS	FCC4			NS
AF6h			NS	CCP3			NS
AFF3			NS	CCP1			NS
AFFz			NS	CCP1h			NS
AFF4			NS	CCPz			NS
FFC3			NS	CCP2h			NS
FFC3h			NS	CCP2	5.64	3.12	0.026 ↓
FFCz			NS	CCP4			NS
FFC2h			NS	CPP3h	6.24	3.77	0.045 ↓
FFC4			NS	CPP1h			NS
FCC3			NS	CPPz			0.055
FCC1			NS	CPP2h	6.01	3.69	0.004 ↓
FCC1h			NS	CPP4h	6.37	3.80	0.037 ↓
FCCz			NS	Poz			NS
FCC2h			NS	Oz			NS

Notes. The arrows (↓) show the direction of change, high lifting task compared to medium lifting task. (NS) No significant change

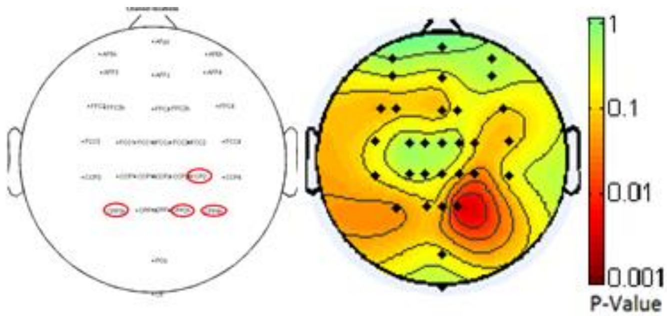


Figure 3.43: Topographical head map of significant areas of changes for alpha activity during medium lifting task vs high lifting task for all participants

3.8.2.1.3 Beta band results at first trial

Significant changes in beta activity power were found mostly in parietal regions with few at frontal and central. Table 3.13 shows the data for the medium lifting versus high lifting EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD at medium compared to high lifting task; Figure 3.44 shows topographical head map of the significant areas and the significant level of changes for beta activity during medium lifting task vs high lifting task for all participants.

Table 3.13: Averaged power spectral values (dB) for beta band activity across 32 channels all participants

channel	**Beta averaged PSD (dB)**			**channel**	**Beta averaged PSD (dB)**		
	Med	**High**	**P-value**		**Med**	**High**	**P-value**
AF5h			NS	FCC2			NS
Afpz			NS	FCC4			NS
AF6h			NS	CCP3			NS
AFF3			NS	CCP1			NS
AFFz			NS	CCP1h			NS
AFF4			NS	CCPz			NS
FFC3			NS	CCP2h			NS
FFC3h	-0.01	-2.37	0.046 ↓	CCP2	0.01	-2.65	0.034 ↓
FFCz			0.054	CCP4			NS
FFC2h			NS	CPP3h	0.91	-1.50	0.026 ↓
FFC4			NS	CPP1h			NS
FCC3			NS	CPPz			NS
FCC1			NS	CPP2h	-0.02	-2.19	0.017 ↓

channel	Beta averaged PSD (dB)			channel	Beta averaged PSD (dB)		
	Med	High	P-value		Med	High	P-value
FCC1h			NS	CPP4h	0.65	-1.91	0.047 ↓
FCCz			NS	Poz			NS
FCC2h			NS	Oz			NS

Notes. The arrows (↓) show the direction of change, high lifting task compared to medium lifting task. (NS) No significant change

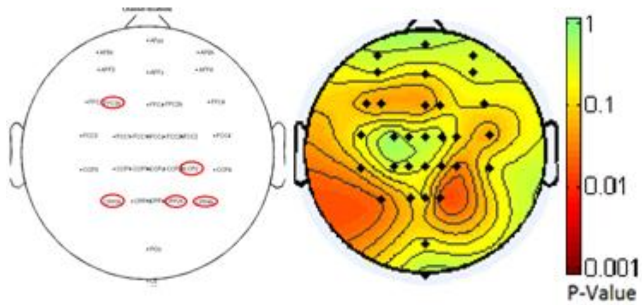


Figure 3.44: Topographical head map of significant areas of changes for beta activity during medium lifting task vs high lifting task for all participants

3.8.2.1.4 Gamma band results at first trial

Significant changes in gamma activity power were found mostly in parietal regions with few at frontal and central. Table 3.14 shows the data for the medium lifting versus high lifting EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD at medium compared to high lifting task; Figure 3.45 shows a topographical head map of the significant areas and the significant level of changes for gamma activity during medium lifting task vs high lifting task for all participants.

Table 3.14: Averaged power spectral values (dB) for gamma band activity across 32 channels all participants

channel	Gamma averaged PSD (dB)			channel	Gamma averaged PSD (dB)		
	Med	High	P-value		Med	High	P-value
AF5h			NS	FCC2			NS
Afpz			NS	FCC4			NS
AF6h			NS	CCP3			NS
AFF3			NS	CCP1			NS
AFFz			NS	CCP1h			NS
AFF4			NS	CCPz			NS

channel	Gamma averaged PSD (dB)				channel	Gamma averaged PSD (dB)			
	Med	High	P-value			Med	High	P-value	
FFC3			NS		CCP2h			NS	
FFC3h			NS		CCP2	-4.72	-7.13	0.051	↓
FFCz	-4.12	-6.89	0.050	↓	CCP4			NS	
FFC2h			NS		CPP3h	-3.28	-5.44	0.019	↓
FFC4			NS		CPP1h			NS	
FCC3			NS		CPPz			NS	
FCC1			NS		CPP2h	-4.69	-6.64	0.039	↓
FCC1h			NS		CPP4h	-3.79	-6.33	0.044	↓
FCCz			NS		Poz			NS	
FCC2h			NS		Oz			NS	

Notes. The arrows (↓) show the direction of change, high lifting task compared to medium lifting task. (NS) No significant change

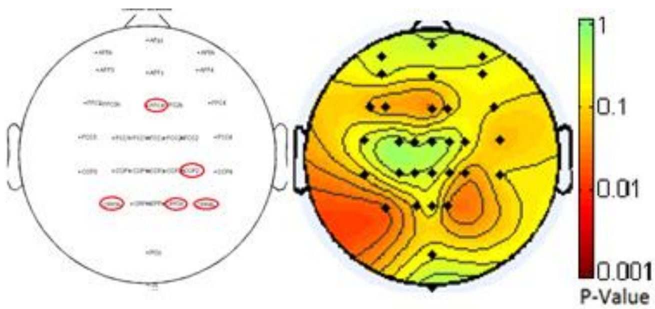


Figure 3.45: Topographical head map of significant areas of changes for gamma activity during medium lifting task vs high lifting task for all participants

The second trial of the same experiment shows a result consistent with the first trial; also the same swap between the two powers accrued at alpha band. Figure 3.46 shows the second trial of this experiment and the grand average of PSD all subjects all channels resulting from both medium and high lifting frequencies.

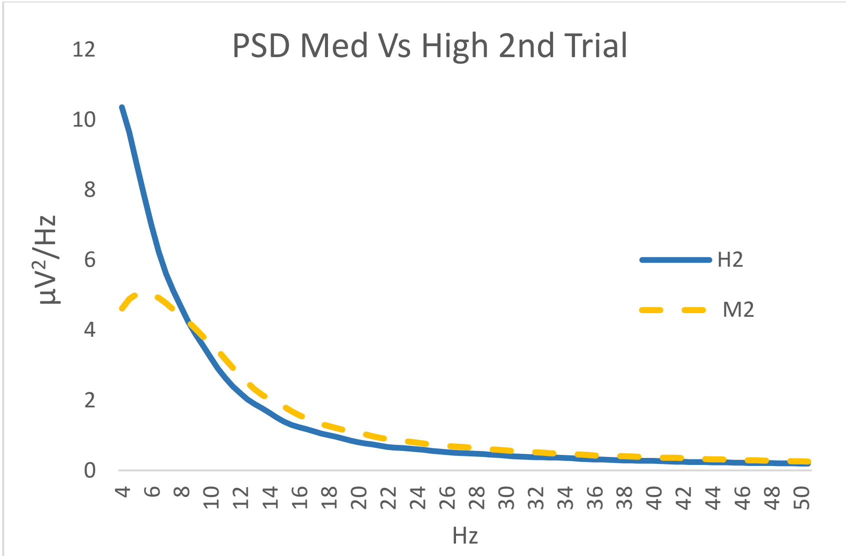


Figure 3.46: Grand average of PSD at medium and high lifting frequencies from all participants and all channels 2nd trial

Table 3.15 and (Figure 3.47, 3.48, and 3.49) shows significant changes between medium and high lifting tasks in gamma activity power were found in both the central and parietal brain regions. No significant changes in theta, alpha, or beta activity power were found in most brain regions: frontal, central, or parietal.

Table 3.15: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in Experiment II 2nd trial

Region	Band	Medium lifting mean PSD	High lifting mean PSD	*p-value*
Frontal	theta	6.94	9.02	0.057
	alpha	5.35	5.03	0.662
	beta	0.06	-0.87	0.219
	gamma	-4.35	-5.58	0.118
Central	theta	6.95	8.44	0.128
	alpha	5.51	4.71	0.282
	beta	0.18	-1.17	0.115
	gamma	-4.36	-5.98	0.037
Parietal	theta	7.15	8.37	0.234
	alpha	5.64	4.67	0.251
	beta	0.24	-1.28	0.108
	gamma	-4.25	-5.98	0.030

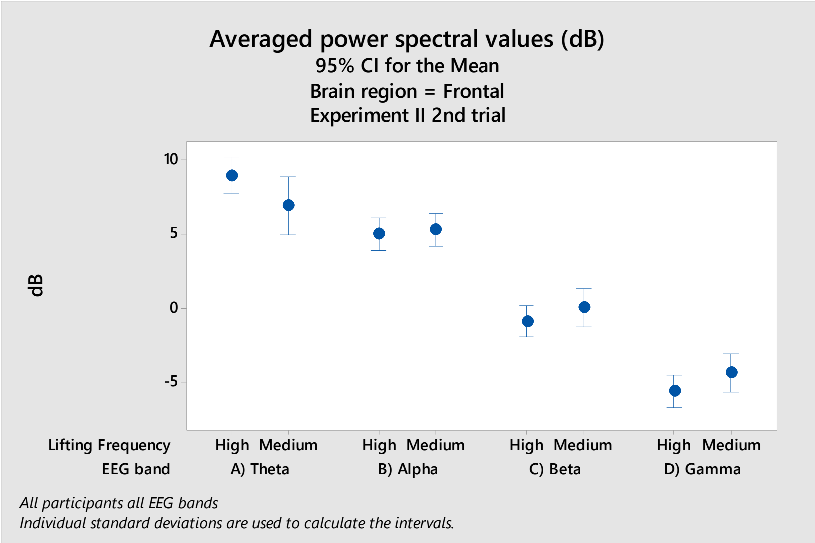


Figure 3.47: Averaged power spectral values (dB) for all bands activity in frontal region for all participants in Experiment II 2nd trial

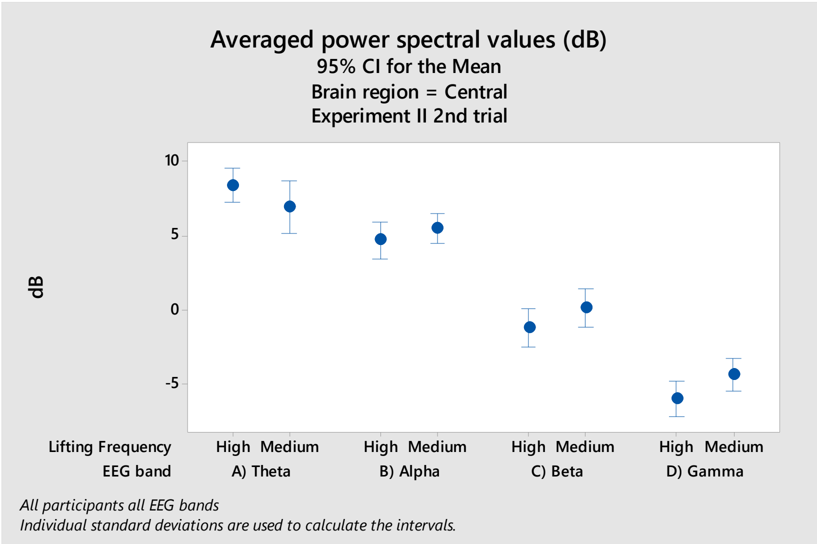


Figure 3.48: Averaged power spectral values (dB) for all bands activity in central region for all participants in Experiment II 2nd trial

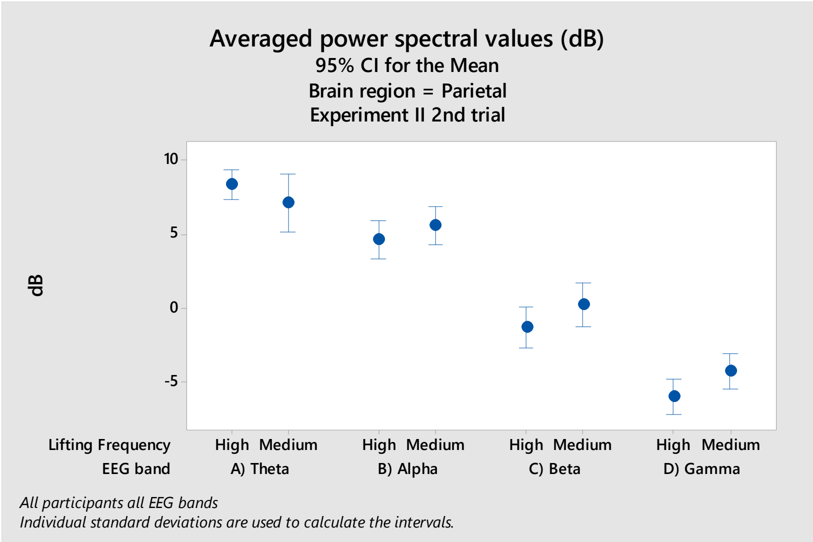


Figure 3.49: Averaged power spectral values (dB) for all bands activity in parietal region for all participants in Experiment II 2nd trial

Detailed analysis on the channel level at theta, alpha, beta, and gamma bands as per the following sections:

3.8.2.1.5 Theta band results at second trial

Significant changes in theta band activity power were found in few areas of the frontal region, like channel AFF3 at medium lifting (PSD = 5.56 dB), high lifting (PSD= 8.66 dB) with p-value 0. 052. Also a few areas at central regions such as FCCz at medium lifting (PSD = 5.70 dB), high lifting (PSD= 8.75 dB) with p-value equals 0.031. Similarly a few areas at parietal regions such as CPP4h at medium lifting (PSD = 7.09 dB), high lifting (PSD= 9.69 dB) with p-value equals 0.038. These channels recorded a greater average value of PSD at high compared to medium lifting task. Figure 3.50 shows a topographical head map of the significant areas and the significant level of changes for theta activity during medium lifting task vs high lifting task for all participants.

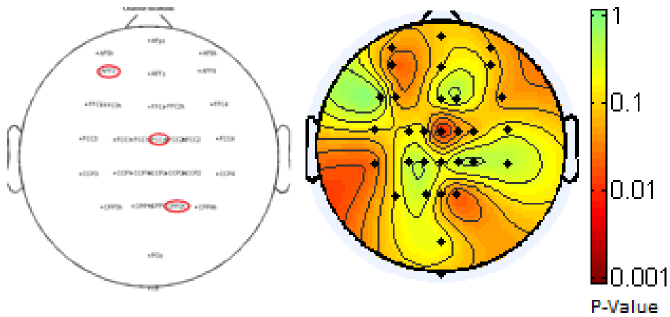


Figure 3.50: Topographical head map of significant areas of changes for theta activity during medium lifting task vs high lifting task for all participants

3.8.2.1.6 Alpha band results at second trial

Significant changes in alpha band activity power were found at few areas of the frontal region like channel FFC3 at medium lifting (PSD = 7.73 dB), high lifting (PSD= 3.89 dB) with p-value 0. 005. Also a few areas at central regions such as CCP2 at medium lifting (PSD = 5.76 dB), high lifting (PSD= 4.00 dB) with p-value equals 0.047. These channels recorded a greater average value of PSD at medium compared to high lifting task, with a trend for the increase in alpha significance change level to become greater towards the frontal region of the brain; Figure 3.51 shows a topographical head map of the significant areas and the significant level of changes for alpha activity during medium lifting task vs high lifting task for all participants.

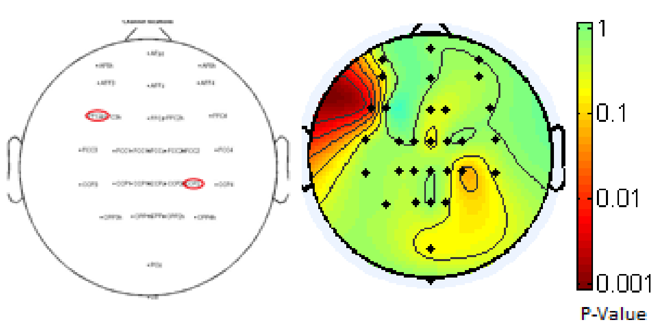


Figure 3.51: Topographical head map of significant areas of changes for alpha activity during medium lifting task vs high lifting task for all participants

3.8.2.1.7 Beta band results at second trial

Significant changes in beta band activity power were found at few areas of the frontal region like channel FFC3 at medium lifting (PSD = 2.73 dB), high lifting (PSD= -1.85 dB) with p-value 0. 003. Also a few areas at central regions such as CCP2 at medium lifting (PSD = 0.40 dB), high lifting (PSD= -1.85 dB) with p-value equals 0.018. These channels recorded a greater average value of PSD at medium compared to high lifting task, with a trend for the increase in beta significance change level to become greater towards the frontal region of the brain; Figure 3.52 shows a topographical head map of the significant areas and the significant level of changes for beta activity during medium lifting task vs high lifting task for all participants.

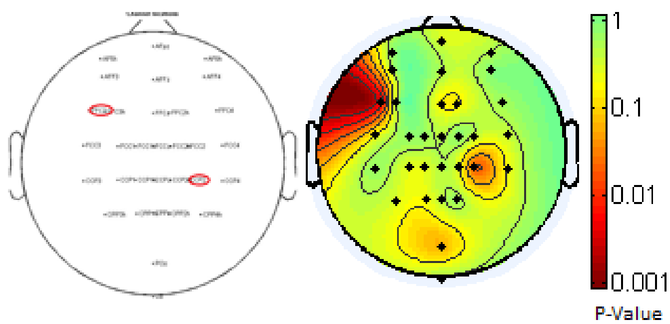


Figure 3.52: Topographical head map of significant areas of changes for beta activity during medium lifting task vs high lifting task for all participants

3.8.2.1.8 Gamma band results at second trial

Significant changes in gamma band activity power were found at few areas at frontal like channel FFC3 at medium lifting (PSD = -1.91 dB), high lifting (PSD= -6.51 dB) with p-value 0.003. Also a few areas at central regions such as CCP2 at medium lifting (PSD = -4.04 dB), high lifting (PSD= -6.71 dB) with p-value equals 0.003. Similarly a few areas at parietal regions such as Poz at medium lifting (PSD = -4.54 dB), high lifting (PSD= -5.74 dB) with p-value equals 0.048. These channels recorded a greater average value of PSD at medium compared to high lifting task, with a trend for the increase in gamma significance change level to become greater towards the frontal and central regions of the brain; Figure 3.53 shows topographical head map of the significant areas and the significant level of changes for gamma activity during medium lifting task vs high lifting task for all participants.

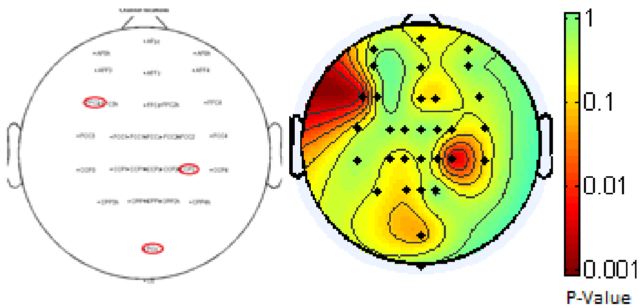


Figure 3.53: Topographical head map of significant areas of changes for gamma activity during medium lifting task vs high lifting task for all participants

3.8.2.2 Difference between trials

In general, no significant differences were found between the two trials at high lifting tasks, except theta at frontal, central, parietal, and occipital. In theta, Table 3.16 shows the data for the high lifting in 1st trial versus high lifting in 2nd with EEG average power spectral densities across 32 selected channels, and the significant level (p-value). All the channels recorded a greater average value of PSD 2nd trial compared to the 1st trial.

Table 3.16: Averaged power spectral values (dB) for theta band activity across 32 channels all participants

channel	**Theta averaged PSD (dB)**			**channel**	**Theta averaged PSD (dB)**		
	High 1	**High 2**	**P-value**		**High 1**	**High 2**	**P-value**
AF5h			NS	FCC2	5.63	9.38	0.015 ↑
Afpz			NS	FCC4			NS
AF6h			NS	CCP3			NS
AFF3			NS	CCP1			NS
AFFz			NS	CCP1h			NS
AFF4			NS	CCPz			NS
FFC3			NS	CCP2h			NS
FFC3h			NS	CCP2			NS
FFCz			NS	CCP4			NS

channel	Theta averaged PSD (dB)			channel	Theta averaged PSD (dB)		
	High 1	High 2	P-value		High 1	High 2	P-value
FFC2h	5.49	9.05	0.048 ↑	CPP3h			NS
FFC4	5.48	9.03	0.027 ↑	CPP1h			NS
FCC3			NS	CPPz	6.64	8.86	0.034 ↑
FCC1			NS	CPP2h	6.79	9.69	0.014 ↑
FCC1h			NS	CPP4h			NS
FCCz			NS	Poz			NS
FCC2h			NS	Oz	5.88	8.52	0.049 ↑

Notes. The arrows (↑) show the direction of change, 1st high lifting task compared to 2nd high lifting task. (NS) No significant change

In alpha band CPP2h channel at high lifting 1st trial was (PSD = 3.69 dB), 2nd trial was (PSD= 6.02 dB) with p-value 0.017. In beta band CPP2h channel at high lifting 1st trial was (PSD = -2.19 dB), 2nd trial was (PSD= 0.14 dB) with p-value 0.036. A topographical head map of the significant areas of changes for theta, alpha, and beta activity during 1st vs 2nd trial of high lifting for all participants in Figure 3.54.

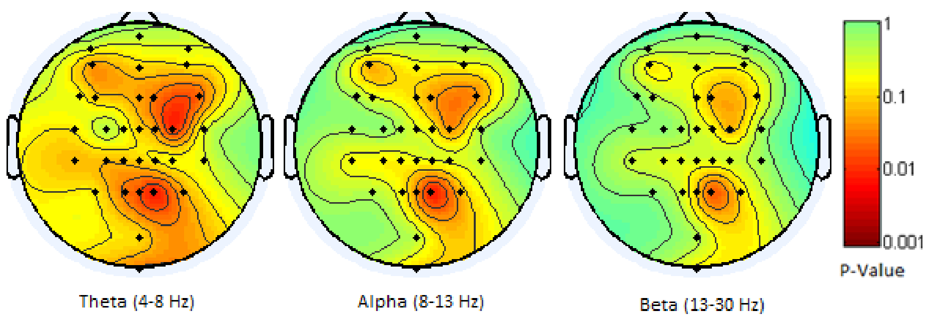


Figure 3.54: Topographical head map of the significant areas of changes for theta, alpha, and beta activity between 1st trial vs 2nd trial of high lifting for all participants

On the other hand, medium lifting task showed almost no significant difference between trials; however PSD was slightly greater at 2nd trial than 1st trial at all bands.

3.8.2.3 MAWL

The maximum acceptable weight for all tasks and all trials in this experiment is presented in Table

3.17. The data was analyzed using ANOVA to test if there is a significant difference between trials. In the first trial, medium lifting MAWL was significantly higher than high lifting for all participants with average (MAWL =9.89 Kg) verses average (MAWL =6.99 Kg)). In the second trial, medium lifting MAWL also was significantly higher than high lifting for all participants with average (MAWL =7.89 Kg) verses average (MAWL =5.53 Kg) at medium lifting; the significant difference between the two lifting tasks was (p-value =0.015). These results are consistent with Liberty Mutual Manual Materials Handling Tables. Snook and Ciriello (1991) found in 4.3 lifts per minute lifting frequency MAWL is 12 kg, and in 6.6 lifts per minute lifting frequency MAWL is 10 kg. No significant differences were found between trials at medium or high lifting. In medium lifting task, the two trials are equals with (p-value = 0.111); and in high lifting task the two trials are equals with (p-value = 0.220).

Table 3.17: Maximum acceptable weights (kg) for all participants performing medium and high lifting for 40 min

	Medium lifting 1st trial	High lifting 1st trial	Medium lifting 2nd trial	High lifting 2nd trial
	5.44	3.63	6.35	4.54
	13.61	9.07	10.89	8.16
	12.7	9.98	6.35	5.44
	7.26	6.35	6.35	5.44
	11.79	6.35	10.89	6.35
	9.07	4.54	8.16	4.54
	12.7	14.51	10.89	7.26
	9.07	4.54	5.44	3.63
	6.35	4.54	4.54	4.54
	10.89	6.35	9.07	5.44
Mean	**9.89**	**6.99**	**7.89**	**5.53**
S.D	**2.88**	**3.34**	**2.42**	**1.38**

Note: S.D is the standard deviation

Furthermore, participant's body weight found to have a significant effect on the estimation of MAWL at medium lifting frequency. No significant effect of the participant's age on MAWL found at medium and high lifting frequencies. MAWL is significantly decrease with the increase of participant body weight with (p-value = 0.016) and the regression equation is:

$$MAWL_{\text{Medium lifting}} = 20.79 - 0.1590\ Body\ weight \qquad (3.8)$$

Figure 3.55 shows the effect of body weight on MAWL at medium lifting frequency; also, no significant effect of the body weight on MAWL at high lifting frequency (p-value =0.153).

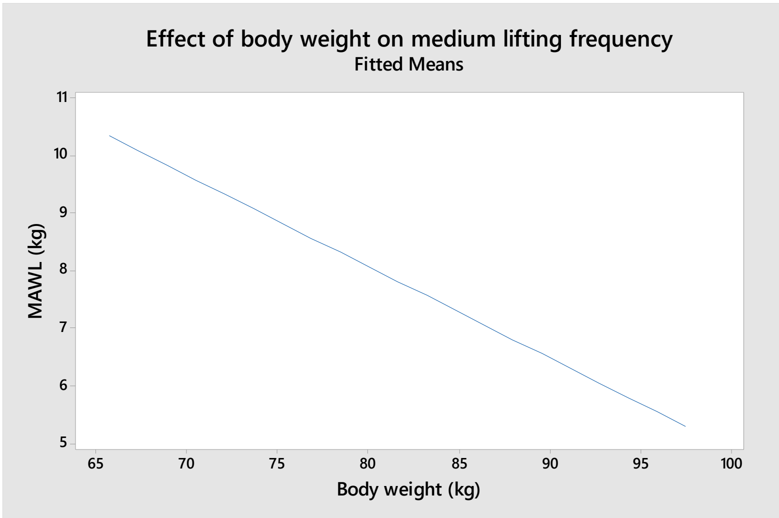


Figure 3.55: The effect of body weight on medium lifting frequency

3.9 Discussion and conclusion

This study investigated the brain EEG power spectral activity changes associated with manual lifting frequencies and repetition during the assessment of Maximum Acceptable Weight of Lift (MAWL) by psychophysical method. In experiment I two lifting frequencies were used, medium lifting frequency is one lift every 14 seconds (4.3 lifts / min) and low lifting frequency is one lift every 60 seconds (1 lift / min). In experiment II two lifting frequencies were used, medium lifting frequency is one lift every 14 seconds (4.3 lifts / min) and high lifting frequency is one lift every

9 seconds (6.7 lifts / min). Twenty healthy right handed volunteers participated; ten males participated in experiment I, and ten males participated in experiment II.

MAWL is known to decrease with the increase of lifting frequency, as was proven by many studies over the last 40 years (Ayoub, 1978; Ayoub et al., 1983; Ciriello et al., 1990; Garg & Saxena, 1979; Karwowski & Yates, 1986; Mital & Manivasagan, 1983; Snook & Irvine, 1967). Likewise, this study confirmed the findings of prior research in MAWL; we found that MAWL is greater in low lifting than MAWL in medium lifting which is greater than MAWL in high lifting frequency. Also MAWL results in this study are consistent with Liberty Mutual Manual Materials Handling Tables Snook and Ciriello (1991) found that in one lift per minute lifting frequency MAWL is 16 kg, in 4.3 lifts per minute lifting frequency MAWL is 12 kg, and in 6.7 lifts per minute lifting frequency MAWL is 10 kg. Similarly, this study confirmed that repeating the lifting task after a period of time does not significantly affect the measurements of MAWL. Moreover, we found that MAWL is significantly decrease with the increase of participant body weight at two different groups in experiment I and II ; also MAWL increases with the increase of participants age at low lifting frequency.

EEG was recorded using a (Cognionics Data Acquisition Software Suite) and Cognionics High-Density 64-channel Dry Headset 64-channel EEG. Sources of artifact in the EEG signal, such as body movement and eye blinks, were successfully removed by using ASR algorithm with additional artifact removal based on epoch rejection.

Power Spectral Density (PSD) was used to quantify the EEG variability between lifting tasks and task repetition.

Table 3.18: Summary of Experiment I

Brain Region	**Comparison between low and medium lifting frequency in PSD**	**Associated with**
Frontal	θ (Medium > Low) α (Medium > Low)	Attention, judgment, and motor planning
Central	α (Medium > Low)	Sensorimotor control
Parietal	θ (Medium > Low)	Cognitive processing

Low: Low lifting frequency (1 lift/ min) ;Med: Medium lifting frequency (4.3 lifts/ min) ;θ : Theta band (4-8 Hz);α :Alpha band (8-13 Hz)

In experiment I we found that brain's EEG power in medium lifting is significantly greater than it is in low lifting task in all bands: theta θ, alpha α, beta β, and gamma γ at frontal, central, and parietal areas in channels level. Also, brain's EEG power in medium lifting is significantly greater than it is in low lifting task in theta θ at frontal, central, and parietal areas in region level; it is also significantly greater than it is in low lifting task in alpha α at the frontal area; summary of experiment 1 is presented in Table 3.18. The increase in theta and alpha at medium lifting is due to increase of attention; Klimesch (1999) found that the 4–13 Hz band associated with alert functioning. Theta increases with workload and is associated with cognitive processes such as self-monitoring (Sammer et al., 2007).

Table 3.19: Summary of Experiment II

Brain Region	**Comparison between medium and high lifting frequency in PSD**	**Associated with**
Frontal	θ (High > Medium)	Attention, judgment, and motor planning
Central	α (High < Medium) β (High < Medium) γ (High < Medium)	Sensorimotor control
Parietal	α (High < Medium) β (High < Medium) γ (High < Medium)	Cognitive processing

High : High lifting frequency (1 lift/ min) ;Med: Medium lifting frequency (4.3 lifts/ min) ;θ : Theta band (4-8 Hz);α :Alpha band (8-13 Hz); β :Beta band (13-30 Hz); γ :Gamma band (30-50 Hz)

In experiment II we found that brain's power in medium lifting task is significantly greater than it is in high lifting task in alpha α, beta β, and gamma γ bands at central and parietal; however, it is less in theta at frontal and central areas in channels level. Also, the brain's EEG in medium lifting task is significantly greater than it is in high lifting task in alpha α, beta β and gamma γ in region level; summary of experiment 1 is presented in Table 3.19. Limited significant differences between trials were found at low and high lifting. No significant difference between trials at medium lifting even with different group at experiment I and experiment II were found. Also, we found that 2^{nd} trial was always greater in EEG power -- but not significantly -- than the 1^{st} trial at all bands in all lifting tasks.

One of the remarkable findings in this study is the brain's power at high lifting task (6.7 lifts /min) found to be less than medium lifting task (4.3 lifts /min) in alpha α, beta β and gamma γ bands. Studies which relate changes in the electroencephalogram with fatigue revealed that brain's activity changes significantly as a person fatigues (Craig et al., 2006; Craig, Tran, Wijesuriya, & Nguyen, 2012). A study by Ng and Raveendran (2007) found that peak alpha frequency is decreasing after physical task leads to fatigue. Another study revealed that the power of frequencies between (11 to 35 Hz) is decreased significantly with fatigue during the sustained phase of the muscle contraction (Liu et al., 2005) (Jap, Lal, Fischer, & Bekiaris, 2009). Tuncel, Dizibuyuk, and Kiymik (2010) conducted analyses and found that with increased fatigue level, the alpha (8–13 Hz) band activity is decreased relatively, and they found an increasing in theta (4–8 Hz) bands in medium and high fatigue stage and the alpha (8–13 Hz). Tuncel et al. (2010) stated in their findings, "with increased fatigue level, the alpha (8–13 Hz) band activity is decreased relatively due to the learning effect or central adaptation counteracting the decrease of cortical efficiency during repetitive contractions." Other studies show that deterioration in performance is related to increased theta and decreased alpha power (Carriero, 1977; Ftaiti et al., 2010; Gale, Davies, & Smallbone, 1977). These results supported similar physiological results in old MAWL research; they concluded that "Psychophysical should not be used to set lifting standards for frequency's higher than 6 lifts/min due to high oxygen consumption 33% VO2" because it is not recommended based on the National Institute for Occupational Safety and Health (NIOSH) (Ciriello et al., 1990; Karwowski & Yates, 1986). From the above findings we conclude that the decline of the brain's power at high lifting (6.7/min) may be because of fatigue induction.

CHAPTER 4: STUDY II EEG-BASED STUDY OF ISOKINETIC AND ISOMETRIC STRENGTH TESTS

The static or dynamic muscular strength tests of individuals can deliver a process of pre assessment as to whether individuals are capable of carrying out a physical task at the job without experiencing injurious strain. If a person's strength is not satisfactory to meet job working load and demand, then exertion-associated injuries are more likely to accrue. The objective of study II is to determine the association between EEG signals during isokinetic strength test and isometric strength test at two different lifting positions (arm and leg) and identify the activation area of the brain during a strength test.

4.1 Method

4.1.1 Subjects

Twenty healthy volunteers (the same subjects who participated in study I) underwent medical screening of cardiovascular problems, such as heart disease or high blood pressure; back pain or hernia; or any mental or neurological disorders/diseases such as epilepsy, Alzheimer's, multiple sclerosis, etc. All subjects were provided written informed consent prior to the experiment. All procedures were approved by The Institutional Review Board at the University of Central Florida IRB Number (SBE-14-10799) (Appendix A).

4.1.2 Task

This experiment includes an isometric strength test and an isokinetic strength test in three replicates with the total estimated time being 20-30 min including rests.

4.1.2.1 Isometric strength test:

Isometric strength tools in this experiment included The Jackson Strength Evaluation System. This system consists of a wooden stand, a chain, a handle, a hand dynamometer, and a control unit. The system is designed to meet the needs of National Institute of Occupational Safety and Health (NIOSH). Time duration of this experiment is between 3-10 min. Participants were asked to lift the chain in multiple positions to measure isometric strength in two areas: arm and leg (Chaffin, Herrin, & Keyserling, 1978a).

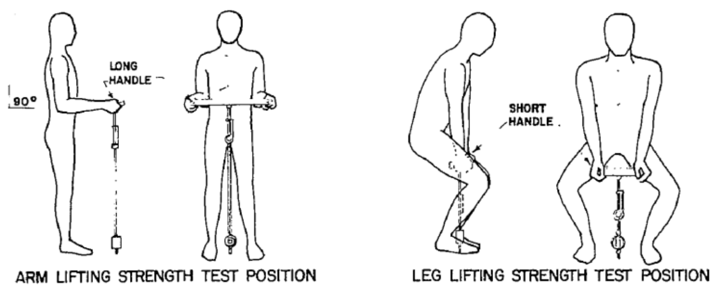


Figure 4.1 arm, and leg isometric strength test by Chaffin (1978)

Participants were instructed to increase the exertion for each arm and leg test to maximum without jerk for 1-4 sec, then maintain a steady state of exertion for 3-4 sec (Caldwell et al., 1974; Stobbe, 1982) (Schanne, 1972). Adequate rest intervals between tests were given, between 30 sec to two min (Schanne, 1972) (Stobbe, 1982). General procedure of the isometric lifting can be seen in Figure 4.1 and Appendix B. EEG of brain activity was recorded, and this task is also recorded on video simultaneously to track the brain signal during participant body motion. Figure 4.2 shows the triggering procedure.

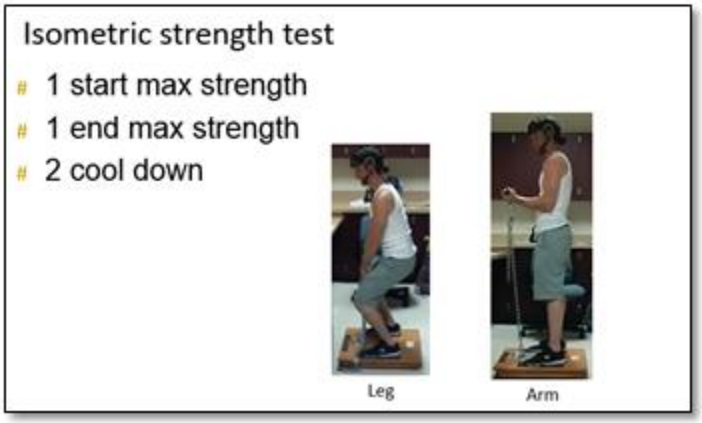


Figure 4.2: Manual triggering procedure at isometric strength tests

4.1.2.2 Isokinetic strength test:

Time duration of this experiment was between 5-10 min. The Mini-Gym system first used by Pytel and Kamon (1981) was used to measure the maximum isokinetic lift in this experiment. This tool consists of a handle coupled by a rope to a winch that spins at a quantified constant speed at pulling. The first element of this system is an electronic load cell and velocity transformer attached to a display device to control both velocity and instant forces over the period of motion. The second component is a constant-velocity motor with adaptable speed control approximately 0.86 m/s. Participants performed one task of movement called dynamic lift strength (DLS), which is similar to the low zone lifting task from floor to knuckle starting from 5 cm above the ankle with bent knees and ending the pull at chest level (Figure 4.3).

Participants were asked to pull the handle as quickly and as much as they can with no pain or discomfort, and adequate resting time was given between trials; general procedure of isokinetic lifting is in Appendix B.

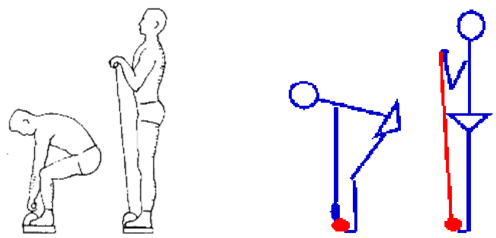


Figure 4.3 Dynamic Lift Strength (DLS) Pytel (1981)

EEG of brain activity is recorded, and this task is also recorded on video simultaneously to track the brain signal during participant body motion.

4.2 Strength pre measurements

Various anthropometries have been measured such as body weight, shoulder height, hip height, knee height, arm length, knuckle height, and body height for all subjects before conducting the psychophysical weight test. Table 3.3 in section 3.4 shows the anthropometry of all subjects. The selected participants in this study were consistent in most of the anthropometry measures with low variation and were normally distributed with no outliers except the age; one subject was forty years old, but most of the subjects were within a 95% confidence interval (Figures 3.2 and 3.3 in section 3.4).

4.3 EEG data acquisition

EEG was recorded using a Cognionics Data Acquisition Software Suite and Cognionics High-Density 64-channel Dry Headset 64-channel EEG (COGNIONICS, Inc. San Diego, CA). Electrodes were attached to the scalp using a custom subset of the 10-5 configuration. The flex sensor is designed to touch through hair with proper pressure while maintaining the ability to flatten for safety and comfort. Patent-pending materials and construction techniques to reduce contact impedances and noise without using electrolytic gels was utilized. During the experimental setup, electrode impedance was monitored within the acceptable resistance limits; contact impedances with both sensors typically range from 100 k to 1 M Ohm (Mullen et al., 2013). EEG signals were sampled at 500 samples/sec. All processing and analysis was performed in Matlab (The Mathworks, Natick, MA) using EEGLAB 13 scripts based on (toolbox) from (sccn.ucsd.edu/eeglab), an open source environment for processing electrophysiological data (Delorme and Makeig, 2004).

Subjects were given a five-minute training on how to minimize artifacts such as eye blinking, chowing, and any other facial movements. The experiment started with 10-15 sec resting before any physical task. After that, the timer was set to beep every 5 seconds (3 seconds for the exertion plus 2 seconds to maintain exertion). Figure 4.4 shows the triggering procedure. The total EEG recording time for this experiment is approximately 20 hours.

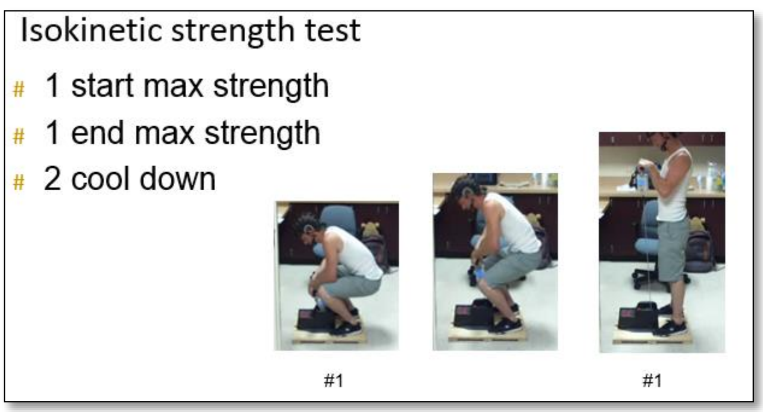


Figure 4.4: Manual triggering procedure at isokinetic strength tests

4.4 EEG data pre-processing

During the experimental setup, electrode impedance was monitored within the acceptable resistance limits. EEG was recorded at 500 Hz with a bandpass filter of 0.1-100 Hz. All processing and analysis is performed in MATLAB (The Mathworks, Natick, MA) using EEGLAB 13 scripts based on (toolbox) from (sccn.ucsd.edu/eeglab), an open source environment for processing electrophysiological data (Delorme & Makeig, 2004).

4.4.1 Artifacts correction using ASR

The artifacts correction used in experimental EEG data was done using the Artifact Subspace Reconstruction method (ASR) by Mullen et al. (2013). ASR uses an algorithm to remove non-stationary high-variance signals from EEG and rebuilds the missing data with a spatial mixing matrix (assuming volume conduction). Calibration statistics are estimated in a robust manner (to minimize any effect of artifacts) using the Geometric Median (3.1) by Haldane (1948) over windowed (1-second) estimates. It also uses iteratively reweighted least square (3.2) by (Green, 1984).

All EEG records were epoched, time-locked to starting lift onset (#1 Figure 4.4). The criteria of ASR was in channels where tolerated flat line duration of more than 5 seconds was considered as a bad channel and then rejected. Transition band for the initial high-pass filter was in Hz. This was formatted as [0.25 Hz-start, 0.75Hz-end]. If a channel is correlated at less than 80% to its robust estimate (based on other channels), it is considered abnormal if a channel has more line noise relative to its signal than 4 standard deviations from the channel population mean, and it is considered abnormal then rejected.

Deviation cutoff for removal of bursts using ASR algorithm so data portions whose variance is larger than this threshold relative to the calibration data are considered missing data then removed. If the artifact in a window was composed of too many simultaneous uncorrelated sources, this is the maximum fraction of contaminated channels that are tolerated in the final output data for each considered window. Figure 4.5 shows five seconds of EEG recording for one subject during isometric testing for arm before and after ASR.

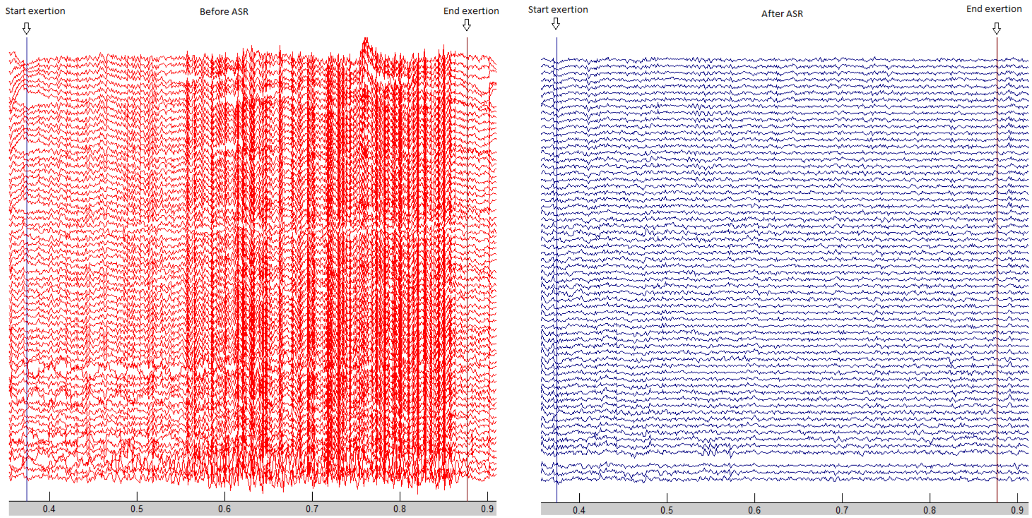


Figure 4.5: Five seconds of EEG recording for one subject during arm isometric test before and after ASR

4.4.2 Additional artifacts removal based on epochs rejection

The artifacts removal based on epochs rejection procedure was the same as described in section 3.6.2. After these aggressive processes of artifacts correction and removal, most of the subject's EEG recordings passed except for one subject whose data was rejected in the isokinetic strength test due to high artifacts.

4.5 Data Analysis

The brain's areas of interest are frontal (which is responsible for attention, judgment, and motor planning); central (which is responsible for the sensorimotor), and parietal (which performs cognitive processing). EEG recordings were analyzed based on the frequency domain, targeting simply the bands associated to movement and sensorimotor areas which are Alpha α-band, Beta β-band, and Gamma γ band (Durka, 2003; Durka et al., 2001). All channels Power Spectral Density (PSD) was computed using Fast Fourier Transform (FFT) using MATLAB (The Mathworks, Natick, MA) for all frequency bands (theta, alpha, beta, and gamma).

4.6 Results

4.6.1 Strength results

Nineteen participants performed three strength tests in three replications presented in Table 4.1, with the average of the three replicates of each strength.

Table 4.1: Isometric and Isokinetic strength measurements in kg for 19 participants

Isometric strength (leg) (kg)				Isometric strength (Arm) (kg)				Isokinetic Strength (kg)			
	Replication				Replication				Replication		
Average	R1	R2	R3	Average	R1	R2	R3	Average	R1	R2	R3
34.96	30.35	33.70	40.82	**20.82**	18.82	24.40	19.23	**30.95**	24.22	33.70	34.93
90.34	98.75	90.72	81.56	**30.54**	28.71	30.80	32.11	**46.61**	46.72	48.44	44.68
92.74	88.86	99.06	90.31	**31.74**	33.25	31.75	30.21	**62.34**	57.11	65.41	64.50
83.07	67.00	84.64	97.57	**37.26**	37.65	38.74	35.38	**40.45**	45.45	38.46	37.42
47.08	41.00	51.98	48.26	**30.77**	29.85	29.03	33.43	**38.27**	33.34	36.15	45.31
70.59	65.05	70.44	76.29	**28.29**	32.70	27.40	24.77	**44.85**	43.77	46.22	44.54
75.46	71.99	69.54	84.87	**31.86**	32.75	28.94	33.88	**42.06**	43.50	40.14	42.55
94.69	102.97	95.12	86.00	**26.22**	29.89	23.45	25.31	**47.61**	48.99	48.58	45.27
88.31	90.17	83.05	91.72	**30.07**	25.63	31.89	32.70	**47.79**	45.31	52.16	45.90
53.31	34.47	59.65	65.82	**21.49**	19.05	20.50	24.90	**43.59**	41.91	47.85	41.00
139.43	130.73	144.83	142.75	**41.62**	42.55	41.14	41.19	**65.83**	54.29	66.86	76.34
93.61	99.97	97.48	83.37	**27.02**	29.30	25.08	26.67	**43.74**	40.60	40.10	50.53
34.73	33.93	32.02	38.24	**16.44**	15.42	16.74	17.15	**28.97**	22.50	32.57	31.84
126.84	141.75	127.37	111.40	**48.23**	49.40	46.27	49.03	**48.08**	48.63	47.04	48.58
92.06	71.21	95.75	88.36	**28.94**	30.53	28.53	27.76	**50.73**	49.90	50.30	51.98
98.84	71.44	95.71	101.97	**43.77**	41.59	44.13	45.59	**60.51**	50.17	65.14	66.22
75.42	70.94	85.18	70.13	**26.69**	26.90	27.17	25.99	**46.83**	45.18	49.71	45.59
147.05	149.23	148.78	143.15	**49.62**	45.31	52.12	51.44	**86.20**	87.91	79.51	91.17
114.12	107.68	119.07	115.62	**29.71**	28.98	27.85	32.30	**51.66**	48.13	54.34	52.53
86.98 ± 30.53				31.64 ± 8.68				48.79 ± 12.64			

One-way ANOVA showed that the three replications of isometric leg test are not significantly different for all participants; Table 4.2 and Figure 4.6 present the results.

Table 4.2: Replications of isometric leg test in (kg)

Replication	# of participants	Average	Standard deviation	Significant between replications (p-value)
R1	19	82.50	34.15	
R2	19	88.64	31.37	0.83
R3	19	87.27	28.05	

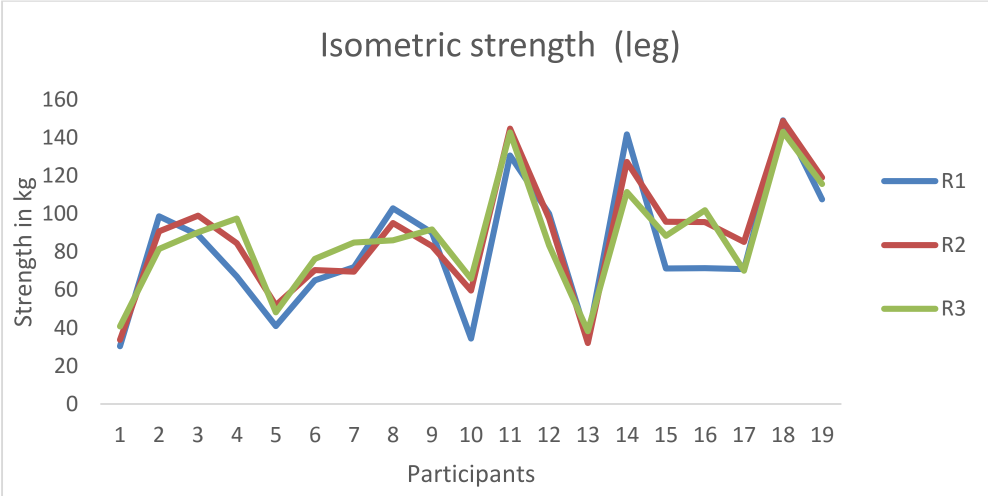


Figure 4.6: Replications of isometric leg test

One-way ANOVA showed that the three replications of isometric arm test are not significantly different for all participants; Table 4.3 and Figure 4.7 present the results.

Table 4.3:Replications of isometric arm test

Replication	# of participants	Average	Standard deviation	Significant between replications (p-value)
R1	19	31.49	8.69	
R2	19	31.36	8.93	0.97
R3	19	32.05	9.09	

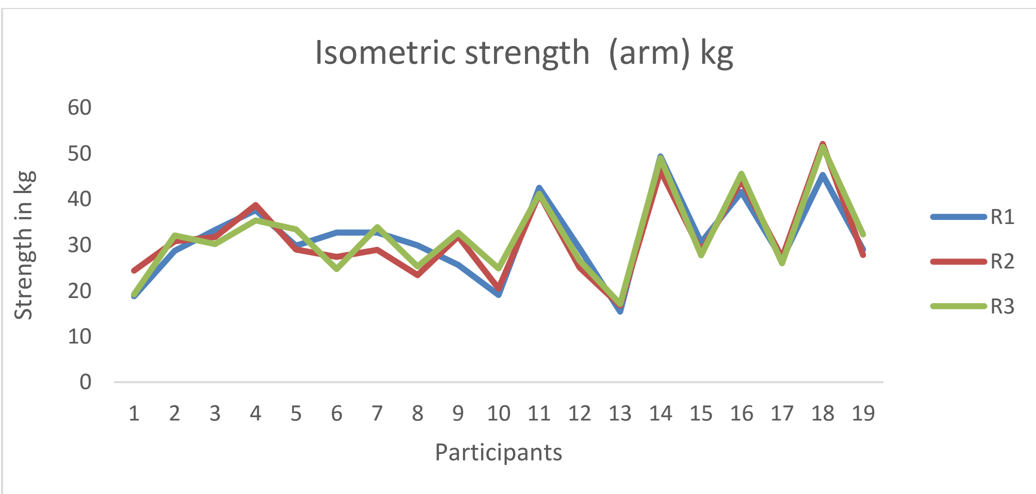


Figure 4.7:Replications of isometric arm test

One-way ANOVA showed that the three replications of isokinetic test are not significantly different for all participants; Table 4.4 and Figure 4.8 present the results.

Table 4.4: Replications of isokinetic test

Replication	# of participants	Average	Standard deviation	Significant between replications (p-value)
R1	19	46.19	13.07	
R2	19	49.61	12.06	0.58
R3	19	50.57	14.25	

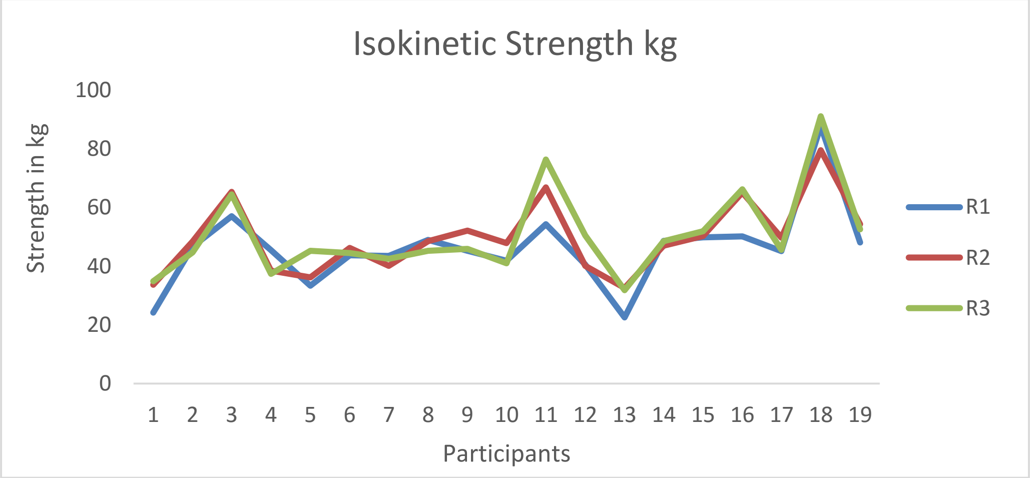


Figure 4.8: Replications of isokinetic test

The average of all replications per each strength test was computed taking the assumption of replicates equivalence; Figure 4.9 shows that the average of the isometric leg test is greater than all test for all participants, then the isokinetic test, then the isometric arm test. This result of isometric strength tests are consistent and similar to the findings of Chaffin et al. (1978a) ; they found the isometric leg strength 69.07±34.70 kg and isometric arm strength 38.92 ±12.97 kg. Likewise, the results of isokinetic strength test (dynamic lift strength DLS) are similar to Pytel and Kamon (1981) results; they found the isokinetic strength 49.90 ±12.25 kg taking into consideration the speed differences of the isokinetic measurement device (Mini-Gym system) by interpolating the speed 0.73m/s and 0.97 m/s in our device speed 0.86 m/s.

Note: (leg) isometric leg test, (arm) isometric arm test, and (isok) isokinetic test

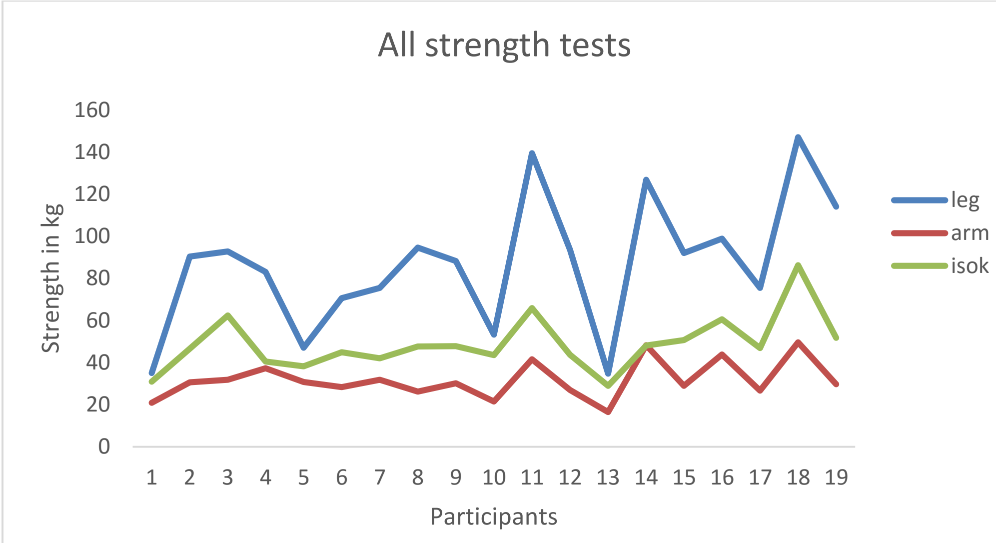


Figure 4.9: Average of three replications at strength tests for all participants

4.6.2 EEG results

The grand average of PSD from all subjects and all channels resulting from three strength tests was computed and is shown in Figure 4.10; EEG was reported in the form of linear power spectral values µV2/Hz. This graph shows similarities between isometric leg strength test and isokinetic strength test in PSD at most frequencies, however isometric arm strength test show a low PSD compared to other tests in all frequencies.

Note: (leg) isometric leg test, (arm) isometric arm test, and (isok) isokinetic test

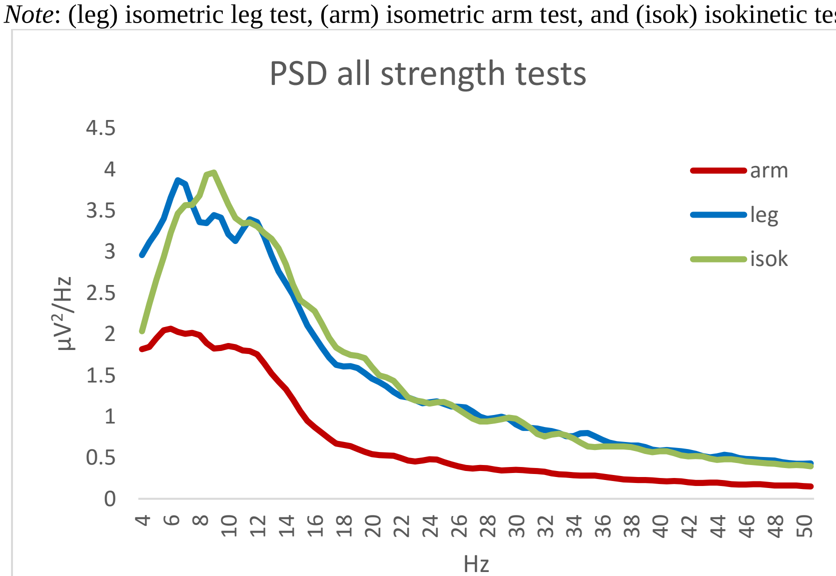


Figure 4.10: Grand average of PSD from all subjects and all channels from three strength tests

Topographical head map of the power spectral density in (dB) at three strength tests isometric leg test, isometric arm test, and isokinetic test at theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-50 Hz) bands are shown in Figure 4.11; EEG changes were localized mostly over the sensorimotor area. In isometric arm test, the activation areas were clearly seen at the sensorimotor area especially C3 and C4 locations, represented in our device custom 10-5 configuration the channels FCC1, FCC1h on left side and FCC2, FCC2h, CCP2, CCP2h on the right side.

Note: Top row is (isok) isokinetic test, middle row is (arm) isometric arm test, and bottom row is (leg) isometric leg test

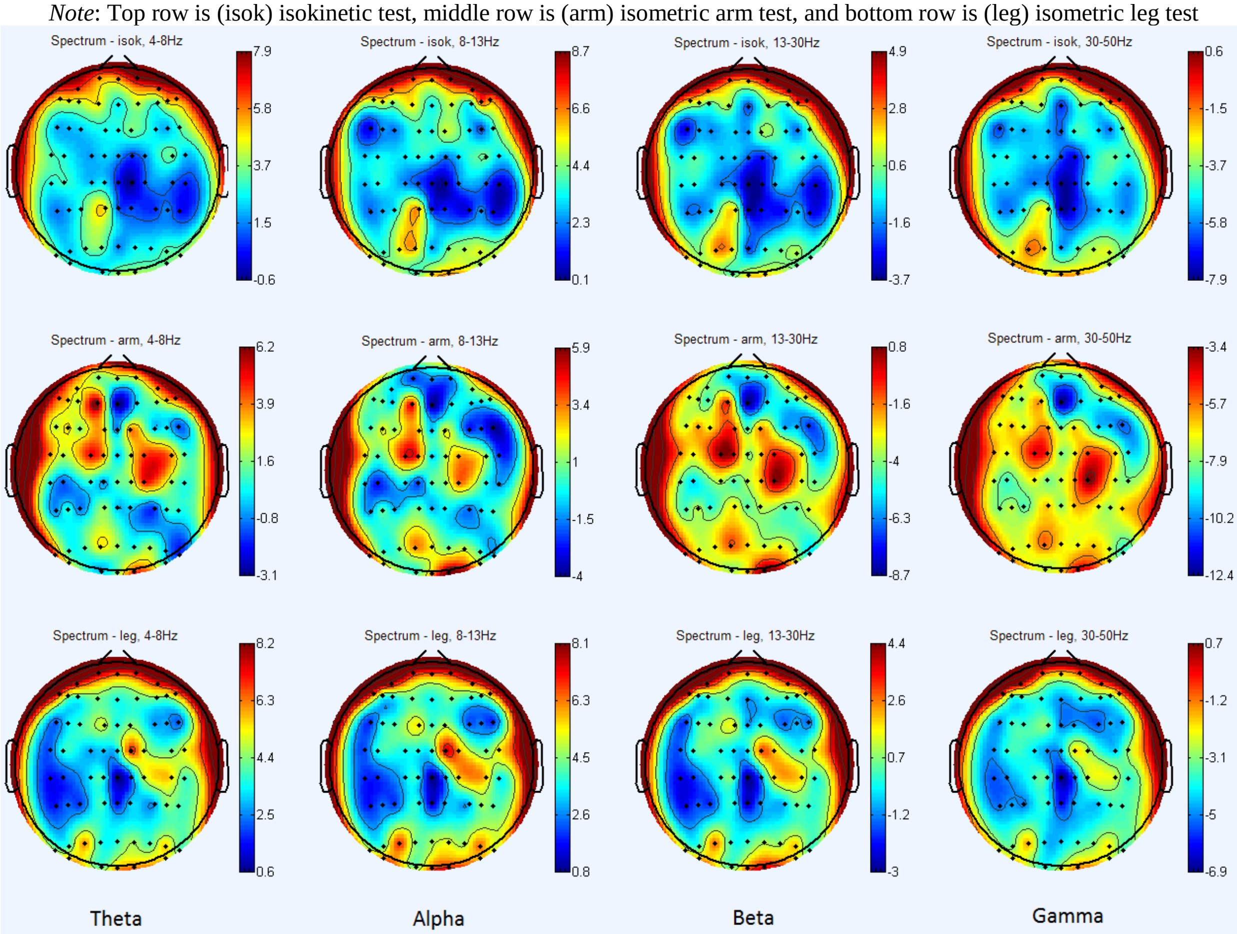


Figure 4.11: Topographical head map of the power spectral density in (dB) at three strength tests at theta, alpha, beta, and gamma bands.

In isometric leg test, the activation areas were clearly seen at the sensorimotor area, especially the Cz location, represented in our device custom 10-5 configuration the channels FCCz, FCC1, FCC1h, and FCC2h. In isokinetic test, the activation areas were separated between the frontal, sensorimotor, and parietal areas. Comparison between power spectral densities in (dB) at isometric arm and isometric leg tests is shown in Table 4.5. One-way ANOVA showed that the power spectral densities in isometric leg strength test is significantly higher than it is in isometric arm strength test at all brain areas (frontal, central, and parietal) and all frequency bands (theta, alpha, beta, and gamma).

Table 4.5: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in isometric arm and isometric leg tests

Region	Band	Isometric arm mean PSD	Isometric Leg mean PSD	*p-value*
Frontal	theta	1.82	4.70	0.01
	alpha	1.01	4.61	<0.01
	beta	-3.94	0.90	<0.01
	gamma	-7.90	-2.97	<0.01
Central	theta	1.44	3.94	0.03
	alpha	0.81	4.00	0.01
	beta	-3.93	0.27	<0.01
	gamma	-7.88	-3.66	<0.01
Parietal	theta	1.18	3.70	0.04
	alpha	0.55	3.81	0.01
	beta	-4.11	0.07	<0.01
	gamma	-7.93	-3.76	<0.01

Comparison between power spectral densities in (dB) at isometric leg and isokinetic tests is shown in Table 4.6. One-way ANOVA showed that the power spectral densities in isometric leg strength test is not significantly different than it in isokinetic strength test at all brain areas (frontal, central, and parietal) or all frequency bands (theta, alpha, beta, and gamma). Nevertheless, it was noted that PSD in isometric leg strength test is slightly higher.

Table 4.6: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in isometric leg and isokinetic tests

Region	Band	Isometric Leg mean PSD	Isokinetic mean PSD	*p-value*
Frontal	theta	4.70	4.05	0.54
	alpha	4.61	4.67	0.96
	beta	0.90	0.86	0.98
	gamma	-2.97	-3.48	0.64
Central	theta	3.94	3.02	0.38
	alpha	4.00	3.86	0.90
	beta	0.27	0.06	0.85
	gamma	-3.66	-4.26	0.58
Parietal	theta	3.70	2.81	0.42
	alpha	3.81	3.63	0.87
	beta	0.07	-0.11	0.88
	gamma	-3.76	-4.35	0.60

Finally, comparison between power spectral densities in (dB) at isometric arm and isokinetic tests is shown in Table 4.7. One-way ANOVA showed that the power spectral densities in isokinetic strength test is significantly higher than it is in isometric arm strength test at all brain areas (frontal, central, and parietal) and all frequency bands (theta, alpha, beta, and gamma), except that the theta band at central and parietal is higher but not significant.

Table 4.7: Averaged power spectral values (dB) for all bands activity in brain regions for all participants in isometric arm and isokinetic tests

Region	Band	Isometric arm mean PSD	Isokinetic mean PSD	*p-value*
Frontal	theta	1.82	4.05	0.05
	alpha	1.01	4.67	<0.01
	beta	-3.94	0.86	<0.01
	gamma	-7.90	-3.48	<0.01
Central	theta	1.44	3.02	0.16
	alpha	0.81	3.86	0.02
	beta	-3.93	0.06	<0.01
	gamma	-7.88	-4.26	<0.01

Region	Band	Isometric arm mean PSD	Isokinetic mean PSD	*p-value*
Parietal	theta	1.18	2.81	0.17
	alpha	0.55	3.63	0.03
	beta	-4.11	-0.11	<0.01
	gamma	-7.93	-4.35	0.01

4.7 Discussion and conclusion

This study investigated the brain EEG power spectral activity differences during three lifting strength measurements: isometric arm and leg strength tests, and isokinetic strength test. Participants performed the three lifting strength tests in three replications, then the average of all replications per each strength test was computed taking the assumption of replicates equivalence. The average of isometric leg test is greater than all other tests for all participants, then the isokinetic test, then the isometric arm test. These results of isometric strength tests are consistent and similar to Chaffin et al. (1978a), and the results of isokinetic strength test are similar to Pytel and Kamon (1981).

EEG was recorded using a Cognionics Data Acquisition Software Suite and Cognionics High-Density 64-channel Dry Headset 64-channel EEG. Sources of artifacts in the EEG signal, such as body movement and eye blinks, were successfully removed by using ASR algorithm with additional artifacts removal based on epoch rejection.

Previous studies in brain activity associated with body movement applied many methods such as Event-Related Synchronization (ERS); ERS is bands time-locked to an event or a task, representing increased activation of the corresponding cortical area during a power increase (Durka, 2003; Durka et al., 2001; Pfurtscheller & Aranibar, 1977; Pfurtscheller & Da Silva, 1999). After finger, arm, and foot movement ERS in beta band is dominant over the contralateral primary sensorimotor area. The gamma band appears as maximum just prior to movement-onset and during execution of movement (Pfurtscheller & Da Silva, 1999). For the arm (left and right) movement, studies revealed that the movement-specific locations are C3 and C4 which are the right and left sides of EEG central area (Divekar & John, 2013; Feige et al., 2000; Ng & Raveendran, 2007; Pfurtscheller, Brunner, Schlögl, & Da Silva, 2006; Pfurtscheller & Da Silva, 1999; Pfurtscheller & Neuper, 1997). These results support the results of isometric arm strength test as shown in Figure 4.11 EEG channels FCC1, FCC1h on left side and FCC2, FCC2h, CCP2, CCP2h on the right side. Also for the legs movement, studies found the movement-specific location at the medial sensorimotor cortex area, which is the center of EEG central area (Gwin & Ferris, 2012b; Pfurtscheller et al., 2006; Pfurtscheller & Da Silva, 1999). These results are similar to the results of isometric leg strength test in this study as shown in Figure 4.11 with channels FCCz, FCC1, FCC1h, and FCC2h.

Power Spectral Density (PSD) was used to quantify the EEG variability between the three lifting strength measurements. One-way ANOVA showed that the power spectral densities in isometric leg strength test is not significantly different than it in isokinetic strength test at all brain areas (frontal, central, and parietal) or in all frequency bands (theta, alpha, beta, and gamma).

Table 4.8: Summary of Study II isometric leg vs. isometric arm in PSD

Brain Region	**isometric leg vs. isometric arm in PSD**	**Associated with**
Frontal	(leg> arm) at all bands θ, α ,β , γ	Attention, judgment, and motor planning
Central	(leg> arm) at all bands θ, α ,β , γ	Sensorimotor control
Parietal	(leg> arm) at all bands θ, α ,β , γ	Cognitive processing

leg: isometric leg test; arm : isometric arm test;θ : Theta band (4-8 Hz);α :Alpha band (8-13 Hz); β :Beta band (13-30 Hz); γ :Gamma band (30-50 Hz)

Table 4.9: Summary of Study II isokinetic vs. isometric arm in PSD

Brain Region	**isokinetic vs. isometric arm in PSD**	**Associated with**
Frontal	(isokinetic > isometric arm) at all bands θ, α ,β , γ	Attention, judgment, and motor planning
Central	α (isokinetic > isometric arm) β (isokinetic > isometric arm) γ (isokinetic > isometric arm)	Sensorimotor control
Parietal	α (isokinetic > isometric arm) β (isokinetic > isometric arm) γ (isokinetic > isometric arm)	Cognitive processing

Isokinetic: isokinetic strength test; arm : isometric arm test;θ : Theta band (4-8 Hz);α :Alpha band (8-13 Hz); β :Beta band (13-30 Hz); γ :Gamma band (30-50 Hz)

Also, the power spectral densities in isometric arm strength test were significantly less than isometric leg strength test at all brain areas (frontal, central, and parietal) and all frequency bands (theta, alpha, beta, and gamma) (Table 4.8); and were significantly less than isokinetic strength test at all brain areas and all frequency bands, except that the theta band at central and parietal is less but not significant (Table 4.9).

The static or dynamic muscular strength tests of individuals can deliver a process of pre-assessment as to whether individuals are capable of carrying out a physical task at the job without experiencing injurious strain. Herrin, Chaffin, and Mach (1974) summarize the major components affecting manual material handling system which related to workers such as physical efforts, sensory and psychomotor task. In addition to those components, personality, training, experience, health status and leisure time activities are also considered major elements that affect the material handling system. Interestingly, psychomotor measures of operative abilities combine mental and motor practice, such as coordination, reaction-response time, and information processing.

This study revealed that during physical exertion not only the physiological aspects changes play a role, but also human brain activities vary based on the type of strength and the lifting position. In addition, brain areas associated with attention, motor planning, sensorimotor and cognitive processing at different brain regions frontal central and parietal have seen a remarkable activity during maximum strength tests. Consequently, precautions should be considered in the design stages of work environment that requires a high level of physical exertion by minimizing the tasks which involve a high level of cognitive and complicated mental decision to avoid falling into mistakes lead to accidents.

CHAPTER 5: SUMMARY AND FUTURE RESEARCH DIRECTIONS

5.1 Summary of Research

This dissertation research is considered to be the first study in the field of neuroergonomics that focuses on the understanding of human brain activity during physical exertions. Manual lifting tasks and lifting strength measurements were investigated using electroencephalographic recordings and analysis of brain waves, including theta, alpha, beta, and gamma frequency bands. The results showed significant differences in EEG power spectrum density at three main brain areas which have been attributed to different levels of lifting frequency, as well as different lifting strength measurements.

First, in the MAWL study the brain's EEG power in medium lifting is significantly greater than it is in the low lifting task in all bands (theta θ, alpha α, beta β, and gamma γ) at the frontal, central, and parietal areas in channels level. Similarly, brain's EEG power in medium lifting is significantly greater than it is in low lifting task in theta θ at frontal, central, and parietal areas in that region; it is also significantly greater than it is in the low lifting task in alpha α at the frontal area. The increase in theta and alpha at medium lifting may be due to increase of attention. The brain's power in medium lifting task is significantly greater than it is in high lifting task in alpha α, beta β, and gamma γ bands at central and parietal; however, it is less in theta at frontal and central areas in channels level. Similarly, the brain's EEG in medium lifting task is significantly greater than it is in high lifting task in alpha α, beta β, and gamma γ in region level. Limited significant differences between trials were found at low and high lifting, and no significant difference between trials at medium lifting were found even with different groupings at experiment I and experiment II. The decline of brain power at high lifting (6.7 lifts/min) may be because of fatigue induction.

Second, in the strength measurements the power spectral densities in isometric leg strength test were not significantly different than in isokinetic strength test at all brain areas (frontal, central, and parietal) or all frequency bands (theta, alpha, beta, and gamma). Moreover, the power spectral densities in isometric arm strength test were significantly less than isometric leg strength test at all brain areas (frontal, central, and parietal) and all frequency bands (theta, alpha, beta, and gamma); and it is significantly less than isokinetic strength test at all brain areas and all frequency bands, except that the theta band at central and parietal is less but not significant.

The results of this project are considered to be critical to our understanding of the neural correlates of human physical activities, and consequently, should have a profound impact on the success of workplace design that considers human capacity and limitations in manual lifting tasks.

5.2 Future Research Directions

From the results presented and the conclusion drawn from this research investigation, there is sufficient motivation for the following extensions of this research investigation.

The first extension of this study to justify the appearance of fatigue during MAWL estimation especially in high lifting frequency, it is recommended to use dynamic changes of fatigue-related functional coupling in the α/β band by calculating mean lagged phase synchronization.

One of the limitations of this experiment was the difficulty to track adding and removing of the weight during MAWL estimation. New solutions and technology may help to resolve this issue. Furthermore, in manual materials handling, several tasks may possibly be investigated in addition to lifting, such as pushing, pulling, and lowering; besides, several positions among these tasks can be investigated.

One of the important ways of analysis to understand the relationship between strength measurement and brain activity is to find the correlation between EEG power spectral density and strength. It is also recommended to find the correlation between MAWL, strength, and EEG power spectral density to give a more comprehensive understanding of human body strengths and limitations.

APPENDIX A INSTITUTIONAL REVIEW BOARD (IRB)

University of Central Florida Institutional Review Board

Office of Research & Commercialization

12201 Research Parkway, Suite 501

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Awad Aljuaid** and Co-PIs: **Petros Xanthopoulos, Waldemar Karwowski**

Date: **February 17, 2015**

Dear Researcher:

On 2/11/2015, the IRB approved the following human participant research until 02/10/2016 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	Linear and non-linear EEG analysis of the brain's activity during lifting tasks: determination of the maximum acceptable weights using the psychophysical method, and isokinetic and isometric strength measurements
Investigator:	Awad Aljuaid, PhD student
IRB Number:	SBE-14-10799
Funding Agency:	
Grant Title:	N/A
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 02/10/2016, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

APPENDIX B FORMS AND INSTRUCTIONS

Instructions
Psychophysical weight lifting test

"We are attempting to find out how much an individual can be expected to lift while they are performing their regular job. We are not interested in the maximum amount of weight that can be lifted, but only the amount that can be lifted comfortably and without strain".

"In other words, **WE WANT YOU TO WORK AS HARD AS YOU CAN** without straining yourself or becoming unusually tired, weakened, overheated, or out of breath".

"YOU WILL ADJUST YOUR OWN WORK LOAD. You will work only when the timer beeps. Your job will be to adjust the load; that is, to adjust the weight of the box that you are lifting. Adjusting your own work load is not an easy task. Only you know how you feel".

"IF YOU FEEL YOU ARE WORKING TOO HARD, reduce the load by removing weight from the box".

"WE DON'T WANT YOU LOAFING EITHER If you that you can work harder, as you might on piece work, put in more weight"

"DON'T BE AFRAID TO MAKE ADJUSTMENTS. You have to make enough adjustments so that you get a good feeling for what is too heavy and what is too light you can never make too many adjustments - but you can make too few".

"WE WANT YOUR JUDGMENT ON HOW HARD YOU CAN WORK WITHOUT BECOMING UNUSUALLY TIRED".

"The test will be demonstrated to you. If you do not understand what to do, ask questions. "

1. ***Low Frequency*** *psychophysical weight lifting test will consider the following variables*

a) Lifting Zone: we will apply only the low zone in this study (floor to knuckle)

b) Vertical distance: between 20-32 in. from floor to table.

c) Box dimensions: Approximately 20x14x14 in.

d) Frequency: in this session, low frequency will be considered in lifting as per Snook criteria. The lifting frequency will be 1 lift per minute.

2. ***High Frequency*** *psychophysical weight lifting test will consider the following variables*

   a) Lifting Zone: we will apply only the low zone in this study (floor to knuckle)

   b) Vertical distance: between 20-32 in. from floor to table.

   c) Box dimensions: Approximately 20x14x14 in.

   d) Frequency: in this session, high frequency will be considered in lifting as per Snook criteria. The lifting frequency will be 1 lift per 14 seconds (4.3 min^{-1}).

You will start with either low weight or heavy weight. The heavy weight will be the maximum acceptable weight of lift as per Snook and Ciriello in Liberty Mutual Manual Materials Handling Tables. You will be instructed as per (Ciriello & Snook, 1983) method to adjust the weight by adding and removing iron/rubber weight plates for 40 minutes until you obtain the maximum weight that you can lift without <u>"strain or discomfort and without becoming tired, weakened, over-heated, or out of breath."</u>

MEDICAL SCREENING QUESTIONNAIRE

Please circle your answer to the following health-related questions. Your answers will help determine your eligibility to participate in the study. Keep in mind that your participation is voluntary and you may choose not to answer questions you do not wish to answer. Please refer to your copy of the Consent Form for more details.

Yes | No — Do you presently have any known heart disease which could limit the amount of exertion (physical activity) you should expend?

Yes | No — Do you presently have or have you ever been diagnosed with high **blood pressure**?

Yes | No — Do you presently have any **chest or breathing conditions** which could restrict your physical activity?

Yes | No — In the last six months, have you recently had any **surgery** which could limit your physical activity?

Yes | No — Are you currently taking any **medications** that may cause physical weakness and/or may impede you from performing or limit your physical activities?

Yes | No — In the last six months, have you been administered any **injections** that may cause physical weakness and/or may impede you from performing or limit your physical activities?

Yes | No — Musculoskeletal Disorders (MSDs) refer to injuries or conditions that may develop over time and that often affect the back, neck, shoulders and/or upper limbs (e.g., carpal tunnel syndrome, tendonitis). In the last six months, have you developed any known **musculoskeletal problems or conditions**?

If YES, please explain

____

____

Yes | No — Have you ever had incidences of **low back pain** or been diagnosed with any **back condition**?

Yes | No — Have you ever been diagnosed with a **hernia**?

Yes | No — Do you presently have any known mental or **neurological** disorders/diseases such as Epilepsy, Alzheimer, Multiple sclerosis, etc.?

Participant Initial: ______
Participant Number: (   )

University of Central Florida

Data Collection Form

Participant Initial: ______
Participant Number: (   )

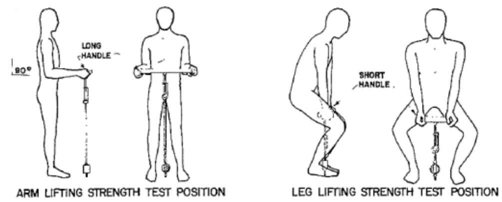
Variable	Magnitude		
Age (year)			
Body weight (kg/lb)			
Shoulder height (cm)			
Hip height (cm)			
Knee height (cm)			
Arm length (cm)			
Knuckle height (cm)			
Body height (cm)			
Hart Rates (beats/min)			
Oxygen Consumption (ml min^{-1})			
Static leg Strength (N) / Lb.			
Static arm Strength (N) / Lb.			
Dynamic Lift Strength (N) / Lb.			
Dynamic back Strength (N) / Lb.			
Low Frequency psychophysical MAWL Lb.			
High Frequency psychophysical MAWL Lb.			

Instructions
Isometric Strength Test

Prior to administering the first test, you will be given the following instructions:

"We are going to measure the maximum strength of your arm, and leg with isometric tests. This means you will be exerting force, but there will not be any movement. We will measure your maximum force with this apparatus. For each test, please follow these instructions. "

You will be asked to lift the chine in multiple positions to measure your isometric strength in two areas (Arm,and Leg)



Arm, and leg isometric strength test by chaffin (1978)

"The test will be demonstrated to you. If you do not understand what to do, ask questions. "

"We will give you four attempts. The first attempt will not count; we want you to try at only half (50%) effort. This attempt is a warm-up, and will help you figure out if you understand what to do. If you do not fully understand what to do, let me know."

"Next, you will be given three attempts on each test. Try your best on both as your score will be the average of the three measurements."

*"When a test is to be given, I will ask you if you are ready. Shortly after the command "ready," start to exert maximum force without jerk for **1-4** seconds then maintain a steady state of exertion for **3-4** seconds. You will have rest intervals between tests between 30 sec to two min"*

"Always stop a test if I tell you to, even if there is no apparent reason to do so. Also, if you feel pain or discomfort, stop exerting force immediately. But do not change your specified position or the muscle groups used during the test, even if you believe that you could apply a greater force and/or reduce discomfort with such changes."

The Jackson Strength Evaluation System

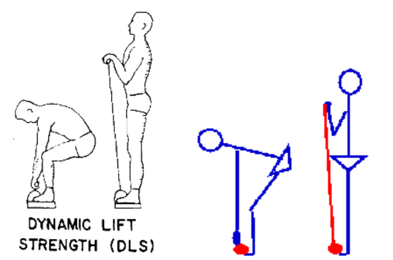
University of Central Florida

Instructions
Isokinetic Strength Test

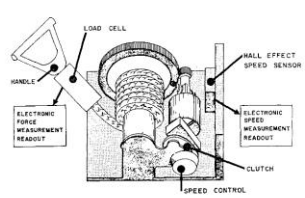
You will be asked to perform one task of movement called dynamic lift strength (DLS), which is similar to the low-zone lifting task from floor to knuckle.

This method will be demonstrated to you before you start the task. You will be asked to pull the handle as quickly and as much as you can with no pain or discomfort, and adequate resting time will be given to you between trials.

"Three trails Starting from 5 cm above the ankle with bent knees and ending the pull at chest level, Pull the handle as quick as much you can"
"Adequate resting time will be given between trails"
''Always stop a test if I tell you to, even if there is no apparent reason to do so. Also, if you feel pain or discomfort, stop exerting force immediately



DLS PyteL (1981)



A schematic internal preview of Mini-Gym

Liberty Mutual Manual Materials Handling Tables z Snook and Ciriello (1991)

Table 2. Maximum acceptable weight of lift for males (kg).

Floor level to knuckle height — One lift every

Width‡	Distance§	Percent¶	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h
		90	*6*	7	9	11	13	14	14	17
		75	*9*	11	13	16	19	20	21	24
	76	50	*12*	*15*	17	22	25	27	28	32
		25	*15*	*18*	*21*	28	31	34	35	41
		10	*18*	*22*	*25*	33	37	40	41	48
		90	6	8	9	12	13	15	15	17
		75	*9*	11	13	17	19	21	22	25
75	51	50	*13*	15	18	23	26	28	29	34
		25	*16*	*19*	22	29	33	35	36	42
		10	*19*	*22*	*26*	34	38	42	43	50
		90	8	9	11	13	15	16	17	20
		75	*11*	13	15	19	22	24	24	28
	25	50	*15*	18	21	26	29	32	33	38
		25	*18*	*22*	26	33	37	40	41	48
		10	*22*	*26*	*31*	38	44	47	49	57
		90	7	8	10	13	15	16	17	20
		75	*10*	12	14	19	22	24	24	28
	76	50	*14*	*16*	19	26	29	32	33	38
		25	*17*	*20*	*24*	33	37	40	41	48
		10	*20*	*24*	*28*	38	43	47	48	57
		90	7	9	10	14	16	17	18	20
		75	10	13	15	20	23	25	25	30
49	51	50	*14*	17	20	27	30	33	34	40
		25	*18*	*21*	25	34	38	42	43	50
		10	*21*	*25*	*29*	40	45	49	50	59
		90	8	10	12	16	18	19	20	23
		75	12	15	17	23	26	28	29	33
	25	50	*16*	20	23	30	34	37	38	45
		25	*21*	*25*	29	38	43	47	48	56
		10	*24*	*29*	*34*	45	51	56	57	67
		90	8	10	11	15	17	19	19	23
		75	*12*	14	17	22	25	28	28	33
	76	50	*16*	*19*	22	30	34	37	38	44
		25	*20*	*24*	*28*	37	42	47	47	55
		10	*24*	*29*	*33*	44	50	54	56	65
		90	9	10	12	16	18	20	20	24
		75	*12*	15	18	23	26	28	29	34
34	51	50	*17*	20	24	31	35	38	39	46
		25	*21*	*25*	*30*	39	44	48	49	57
		10	*25*	*30*	*35*	46	52	57	58	68
		90	10	12	14	18	20	22	23	27
		75	*15*	18	21	26	30	32	33	38
	25	50	*20*	24	28	35	40	43	44	52
		25	*26*	*30*	*35*	44	50	54	55	65
		10	*29*	*35*	*41*	52	59	64	66	76

Knuckle height to shoulder height — One lift every

Width‡	Distance§	Percent¶	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h
		90	8	10	12	13	14	14	16	17
		75	10	14	16	18	18	19	21	23
	76	50	13	17	20	22	23	24	26	29
		25	16	*21*	*24*	27	27	28	32	35
		10	*19*	*24*	*28*	31	32	33	37	40
		90	8	11	13	15	15	16	18	19
		75	11	15	17	20	20	21	23	25
75	51	50	14	19	21	25	25	26	29	32
		25	*17*	*23*	26	30	31	32	36	39
		10	*20*	*26*	*30*	35	36	37	41	45
		90	10	13	15	18	18	19	21	23
		75	13	17	20	23	24	25	27	30
	25	50	17	22	25	30	30	31	35	38
		25	*20*	*27*	*30*	36	36	38	42	46
		10	*23*	*31*	*35*	42	42	44	49	53
		90	8	10	12	13	14	14	16	17
		75	10	14	16	18	18	19	21	23
	76	50	13	17	20	22	23	24	26	29
		25	16	21	24	27	27	28	32	35
		10	*19*	*24*	*28*	31	32	33	37	40
		90	8	11	13	15	15	16	18	19
		75	11	15	17	20	20	21	23	25
49	51	50	14	19	21	25	25	26	29	32
		25	17	23	26	30	31	32	36	39
		10	*20*	*26*	*30*	35	36	37	41	45
		90	10	13	15	18	18	19	21	23
		75	13	17	20	23	24	25	27	30
	25	50	17	22	25	30	30	31	35	38
		25	*20*	*27*	30	36	36	38	42	46
		10	*23*	*31*	*35*	42	42	44	49	53
		90	8	11	13	15	15	16	18	19
		75	11	15	17	20	20	21	23	25
	76	50	14	19	21	25	25	26	29	32
		25	17	*23*	26	30	31	32	36	39
		10	*20*	*26*	*30*	35	36	37	41	45
		90	9	12	14	17	17	18	20	22
		75	12	16	18	22	23	23	26	29
34	51	50	15	20	23	28	29	30	33	36
		25	18	24	27	34	35	36	40	44
		10	*21*	*28*	*32*	40	40	42	46	51
		90	11	14	16	20	20	21	23	26
		75	14	18	21	26	27	28	31	34
	25	50	18	23	27	33	34	35	39	43
		25	*21*	*28*	32	40	41	42	47	52
		10	*25*	*33*	*37*	47	47	49	55	60

Shoulder height to arm reach — One lift every

Width‡	Distance§	Percent¶	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h
		90	6	8	9	10	10	11	12	13
		75	8	10	12	14	14	14	16	17
	76	50	10	13	15	17	17	18	20	22
		25	11	16	18	21	21	22	24	27
		10	*14*	18	21	24	24	25	28	31
		90	6	8	9	12	12	12	14	15
		75	8	11	12	15	15	16	18	20
75	51	50	10	14	16	19	20	20	23	25
		25	13	17	19	23	24	25	27	30
		10	*15*	19	22	27	27	29	32	35
		90	7	10	11	14	14	14	16	18
		75	10	13	15	18	18	19	21	23
	25	50	12	16	19	23	23	24	27	29
		25	15	20	22	28	28	29	32	35
		10	*17*	*23*	26	32	32	34	38	41
		90	7	9	10	12	12	13	14	16
		75	9	11	13	16	16	17	19	21
	76	50	11	15	17	20	21	21	24	26
		25	13	18	20	25	25	26	29	31
		10	*15*	*21*	23	28	29	30	33	36
		90	7	9	11	14	14	14	16	18
		75	9	12	14	18	18	19	21	23
49	51	50	12	15	18	23	23	24	27	29
		25	14	19	21	28	28	29	32	35
		10	*16*	*22*	25	32	32	34	37	41
		90	9	11	12	16	16	17	19	21
		75	11	14	16	21	21	22	25	27
	25	50	14	18	21	27	27	28	32	35
		25	16	22	25	33	33	34	38	42
		10	*19*	*25*	*29*	38	38	40	44	48
		90	8	10	12	14	14	15	16	18
		75	10	14	16	18	19	19	22	24
	76	50	13	17	20	23	24	25	27	30
		25	*16*	*21*	24	28	29	30	33	36
		10	*18*	*24*	*28*	33	33	34	38	42
		90	8	11	13	16	16	17	18	20
		75	11	14	17	21	21	22	24	26
34	51	50	14	18	21	26	27	28	31	34
		25	*17*	22	25	32	32	33	37	41
		10	*19*	*26*	*29*	37	37	39	43	47
		90	10	13	15	19	19	19	22	24
		75	13	17	20	24	25	26	29	31
	25	50	16	22	25	31	31	33	36	40
		25	*20*	*26*	*30*	37	38	39	44	46
		10	*23*	*30*	*35*	43	44	45	51	55

‡Box width (the dimension away from the body) (cm).
§Vertical distance of lift (cm).
¶Percentage of industrial population.
Italicized values exceed 8 h physiological criteria (see text).

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