RESEARCH

Comfort Testing Project Report

Cotton Incorporated, USA.

ADDITIONAL RESULTS ANALYSIS

April 2014

Contents

1 | Scope

Following the findings of the Comfort Sensory Testing Project, we conducted further analysis of the results based on different sensory responses in males and females to the presented materials were requested. This document reviews our findings, focusing on the two biometric techniques adopted in this test - brain mapping and thermal imagery.

The two key activities - walking with increasing speed and sleeping – are also revisited by focusing on the granular differences between male and female physical responses.

2 | Research and Methodology

Our research team used a combination of neurological and physiological methods to collect, produce and analyze the data outlined above. In addition, traditional data collection by using questionnaires was also employed. This allowed us to compare the participant's subjective opinions to the objective data we collect. These tools and methodologies are discussed in detail below.

Materials Used

Testing Materials and Textures:

In both tests conducted by AAT Research - the Motion Stress test held in December 2013 and the Sleep Quality Testing in January 2014 – four materials were tested by analyzing neurological and physiological feedback from the participants attending both tests. The four textures provided by the client were in long-sleeved t-shirt form and thus were easily wearable by each participant. In this report, we refer to the materials used as follows:

- Material 1: Control Material for both testing sessions.
- Material 2
- Material 3
- Material 4

AAT's research team was not provided with any further information regarding the properties and specifications of each testing material. Also for testing purposes the tag or print at the top of each shirt was removed or rendered unreadable. Thus no unnecessary information was relayed to the participants, leaving the results obtained bias-free. These t-shirts were laundered in between sessions according to the specification provided by the client.

Completing the attire for testing, participants were also given black cotton shorts and white cotton socks. These clothing items were kept constant for all participants, creating a baseline throughout all the testing sessions.

Data Gathering Tools

HD EEG

High Density Electroencephalography can gather very accurate brain activity data while the user is interacting with a particular fabric. This EEG system has 128 HD EEG stereo channels and has a very deep brain signal analysis in relation to source localization. Each sensor is a stereo channel therefore each signal is split into two. Additionally, the data gathered will allow us to produce highly accurate heat map images of the brain processes which will also be included in our report.

Electroencephalogram (EEG) is a medically useful recording tool for brain function study. While 32-channel EEG is the more commonly used technology for brain activity analysis, more recent advances in recording hardware, data storage, and computer science have led to further expansion of EEG recording to high densities (as many as 256 electrodes), to concurrent recording of EEG and functional magnetic resonance imaging (fMRI) data, and to sophisticated signal processing approaches that allow modeling of the cortical sources of the recorded EEG signals and rejection or removal of non-brain EEG artifacts. Recent research shows that, with proper analysis, high-density EEG recordings can give valuable, much more spatiotemporally precise information about dynamic aspects of cortical activation and intracortical communication.

EEG recording measures brain patterns which form wave shapes that are commonly sinusoidal. Usually, these are measured from peak to peak and normally range between 0.5 to 100 microvolts in amplitude. By means of Fourier transform a power spectrum from the raw EEG signal is derived. Single waves with different frequencies are detectable. This spectrum contains the following basic groups into which the brain waves are categorized:

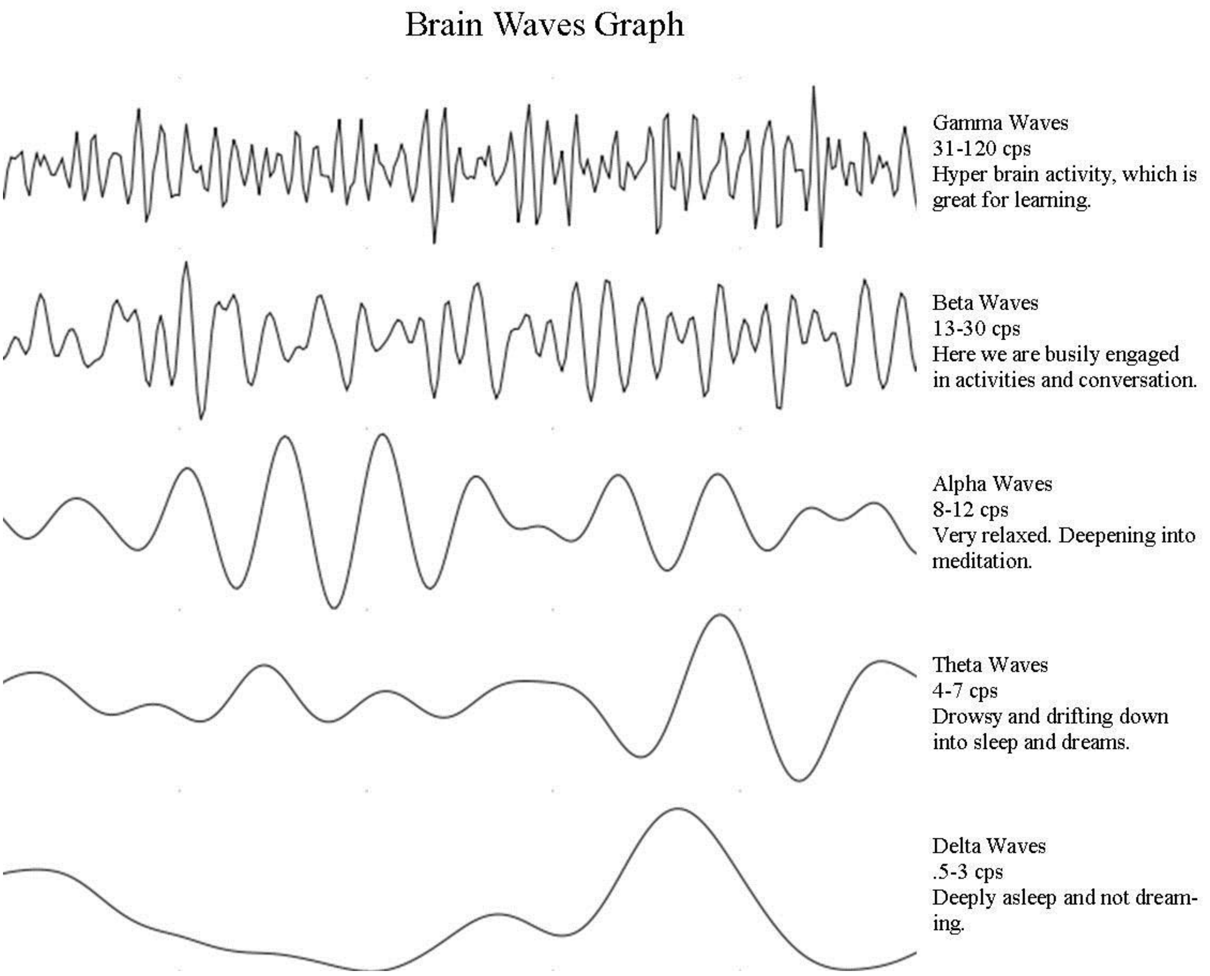


Figure 1: Brain Waves considered in this study

We took note of the most commonly studied brain wave frequencies: delta δ(0.5-3Hz), theta θ (4-7Hz), alpha α (8-12Hz), beta β (13-30 Hz), and gamma γ (31-120 Hz).

The analysis of the different brain band activity levels allowed us to determine how the participants were reacting to each material. This is because each brain frequency band is associated with different functions as follows:

1. **Alpha (α) waves** are rhythmical waves that occur at a frequency between 8 and 13 per second and are found in the EEGs of almost all normal adult people when they are awake and in a quiet, resting state of cerebration, especially with eyes closed and the mind wandering. These waves occur most intensely in the occipital region but can also be recorded from the parietal and frontal regions of the scalp. Their voltage usually is about 50 microvolts. During deep sleep, the alpha waves disappear. When the awake person's attention is directed towards some specific mental activity, the alpha waves are replaced by asynchronous, higher-frequency but lower voltage beta waves. They are also suppressed when a person opens his or her eyes or receives specific sensory stimulation.

2. **Beta (β) waves** have a frequency of 14 to 30 Hz. They are recorded mainly from the parietal and frontal regions of the scalp during extra activation of the central nervous system or during tension.

3. **Theta (θ) waves** have a frequency of 4 to 7 Hz. They occur normally in the parietal and temporal regions in children, but they also occur during emotional stress in some adults, particularly during disappointment and frustration. They are normal in children and in drowsy or sleeping adults, but a predominance of theta waves in adults who are awake suggests emotional stress or brain disorders.

4. **Delta (δ) waves** are high-amplitude "slow waves" with a frequency of less than 3.5 Hz. They often have voltages as much as two to four times those of most other types of brain waves. Infants exhibit delta waves when awake, and adults exhibit them in deep sleep. A predominance of delta waves in awake adults indicates serious brain damage.

5. **Gamma (γ) waves** have a frequency between 25 and 100 Hz. It is related to subjective awareness. Gamma waves are the highest frequency wave type, and are known to be broadly associated with cognition, information processing, attention and memory. (Saladin 2011)

Use of EEG for Movement Exertion Analysis

Brain activity has been proposed to be important in examining affective and perceptual responses to acute bouts of exercise. For example, changes in brain activity may occur secondary to the metabolic changes associated with "central fatigue" during prolonged exercise. Furthermore, activity in the frontal regions of the brain has been related to affective and perceptual responses to acute bouts of exercise. Electroencephalography (EEG) currently is the most pragmatic way to monitor changes in brain activity in humans while exercising. Although several studies have described EEG changes immediately after exercise, few studies have examined EEG during exercise. A study carried out in 2008 by Bailey, Hall, Folger and Miller tested the EEG frequencies of a number of participants while performing exercise of gradually increased intensity over a set period of time. This is similar to our procedure, in which our participants walked on a treadmill at 3 different speeds. The 2008 study demonstrated that EEG can be recorded during exercise while the findings documented increases in theta, alpha and beta frequency activity during exercise and at multiple electrode sites, thus concluding that brain activity may be related to exercise intensity. (Bailey et al. 2008)

Taking this study into consideration, our testing paid closer attention to the levels of brain wave frequencies and the level of activity in different sites of the brain. This allowed us to determine the mental states of the participants during the motion testing and consequently, the effect of the different materials on their mental states.

Chen and Rappelsberger (1994) carried out a study on the effects of pain on the brain, through topographic EEG amplitude and coherence mapping. Under painful stimulation their results showed: a most pronounced decrease of Alpha amplitude in the central areas and some **increase** of high Beta amplitude; an increase of local coherence for Alpha and Beta2 mainly in the central regions and centro-frontal leads; and an increase of interhemispheric coherence for Alpha and Beta2 in the central areas. The results of this study indicated clearly that peripheral painful stimulation is reflected by EEG changes. Decrease of EEG amplitude and simultaneous increase of EEG coherence in the central regions can be cortical correlates of human pain. While the participants in our study were not exposed to pain, an uncomfortable feeling such as that created by itchy or rough clothes is perceived as a low level of pain. This discomfort would increase during movement due to friction with the material. Therefore brain maps will be a clear indication of levels of discomfort felt by our participants. The brain maps created from our testing procedures can be found further on in this report.

Use of EEG for Sleep Quality Analysis

When we sleep, we go through **five sleep stages**. The first stage is a very light sleep from which it is easy to wake up. The second stage moves into a slightly deeper sleep, and stages three and four represent our deepest sleep. Our brain activity throughout these stages is gradually slowing down so that by deep sleep, we experience nothing but delta brain waves -- the slowest brain waves. About 90 minutes after we go to sleep and after the fourth sleep stage, we begin REM sleep.

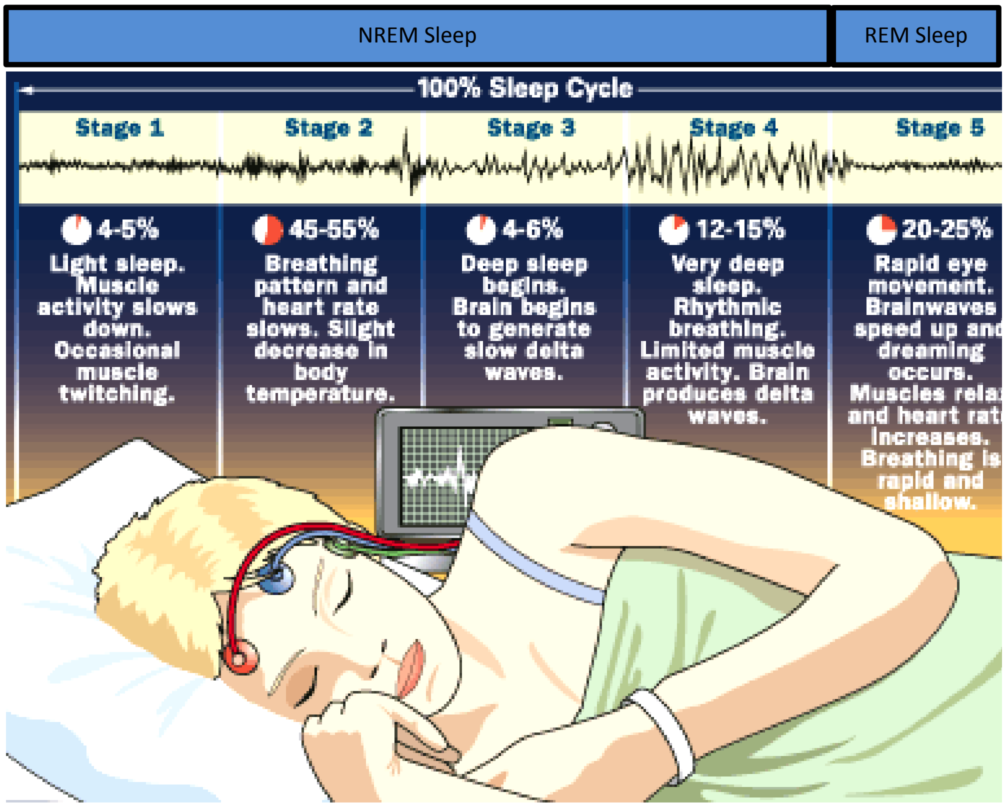


Figure 2 The 5 Stages of the human sleep cycle

Rapid eye movement (REM) was discovered in 1953 by University of Chicago researchers Eugene Aserinsky, a graduate student in physiology, and Nathaniel Kleitman, Ph.D., chair of physiology. REM sleep is primarily characterized by movements of the eyes and is the fifth stage of sleep. The four stages outside of REM sleep are called non-REM sleep (NREM). Aserinsky and Kleitman's all-night EEG recordings showed alternation of REM and NREM. More than 50 years later the EEG remains the primary tool for laboratory sleep evaluation. The increase in computing power has provided a means to quantify EEG activity. The activity in certain frequency bands provides information about the quality of the sleep beyond the information that sleep stage scoring provides. The most intensively investigated band has been the delta band (commonly 1-4 Hz) that characterizes NREM sleep. Delta EEG is thought to reflect a homeostatic process of sleep. Delta activity is highest at the beginning of the night when the need for recuperation is greatest and declines across the night as recuperation proceeds. Other frequency bands provide further information about the night's sleep. High frequency EEG such as beta (15-30 Hz) reflects within-sleep arousal level and is often increased in insomnia. (Campbell 2009)

For our sleeping quality test experiments, the participants tested each of the 4 materials by sleeping for 4 sessions of 35 minutes. During this time, the participants would remain in NREM sleep. A high increase in delta wave activity would immediately be recorded. The level of delta waves reflects the level of relaxation of the participants while sleeping and therefore gives an insight into the comfort level of the participants, depending on the material they were wearing. See Analysis and Discussion sections below.

Brain Mapping using EEG

Recent advances in signal analysis have engendered EEG with the status of a true brain mapping and brain imaging method capable of providing spatio-temporal information regarding brain (dys)function. Because of the increasing interest in the temporal dynamics of brain networks, and because of the straightforward compatibility of the EEG with other brain imaging techniques, EEG is increasingly used in the neuroimaging community. However, the full capability of EEG is highly underestimated. Many combined EEG-fMRI studies use the EEG only as a spike-counter or an oscilloscope. Several cognitive and clinical EEG studies use the EEG still in its traditional way and analyze grapho-elements at certain electrodes and latencies. This manner of using the EEG is not reliable as it leads to misinterpretations, since it largely ignores the spatial aspects of the signals. In fact, EEG primarily measures the electric potential field at the scalp surface in the same way as MEG measures the magnetic field. By properly sampling and correctly analyzing this electric field, EEG can provide reliable information about the neuronal activity in the brain and the temporal dynamics of this activity in the millisecond range.

The EEG is traditionally analyzed in terms of temporal waveforms at certain channels, looking at power of rhythms in the spontaneous EEG, at amplitude and latency of the peaks and troughs in event related potentials (ERPs), or at particular grapho-elements in pathological or sleep stages. There is no doubt that this type of analysis has provided many important insights regarding brain functioning in health and disease, but it has not been considered as an imaging method in the sense that one could infer active areas in the brain generating these waveform features. Recent developments have established High Density EEG as an ideal method for identifying the origins of activity in the brain.

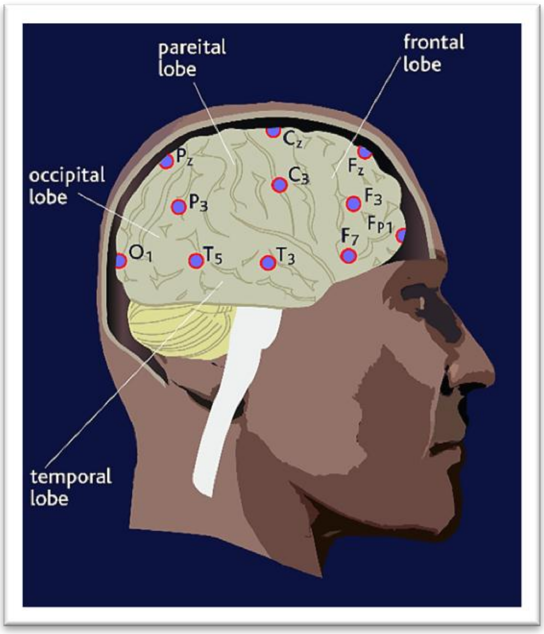


Figure 3: The brain's 4 lobes and corresponding locations of EEG sensors

The brain can be divided into four distinct areas which are the following:

The Frontal lobe: responsible for functions such as reasoning, problem solving, judgement and impulse control.

The Parietal lobe: involved in processing pain and touch sensation. It's where the Somatosensory (from skin and internal organs) Cortex resides.

The Temporal lobe: is involved in auditory sensation, language recognition, emotion, memory

The activity in these lobes will be most indicative for this study as it gives insight into the participant's feeling of discomfort and friction on the skin. We can identify which area of the brain is being activated by recording the brain activity in specific sensors on the EEG cap. For example, research has determined that normal participantsdisplay a significantly higher delta wave activity in the right frontal and central region than the left during sleep. (Sekimoto et al. 2011) This is used to interpret our results obtained during the sleep quality test.

This study has revealed that high levels of Beta waves are often recorded in a concentrated region in the frontal lobe that roughly corresponds with the Anterior Cingulate Cortex. This is indicative because this area is involved in the detection and processing of unpleasant and painful sensations. (Rainville et al. 1997)

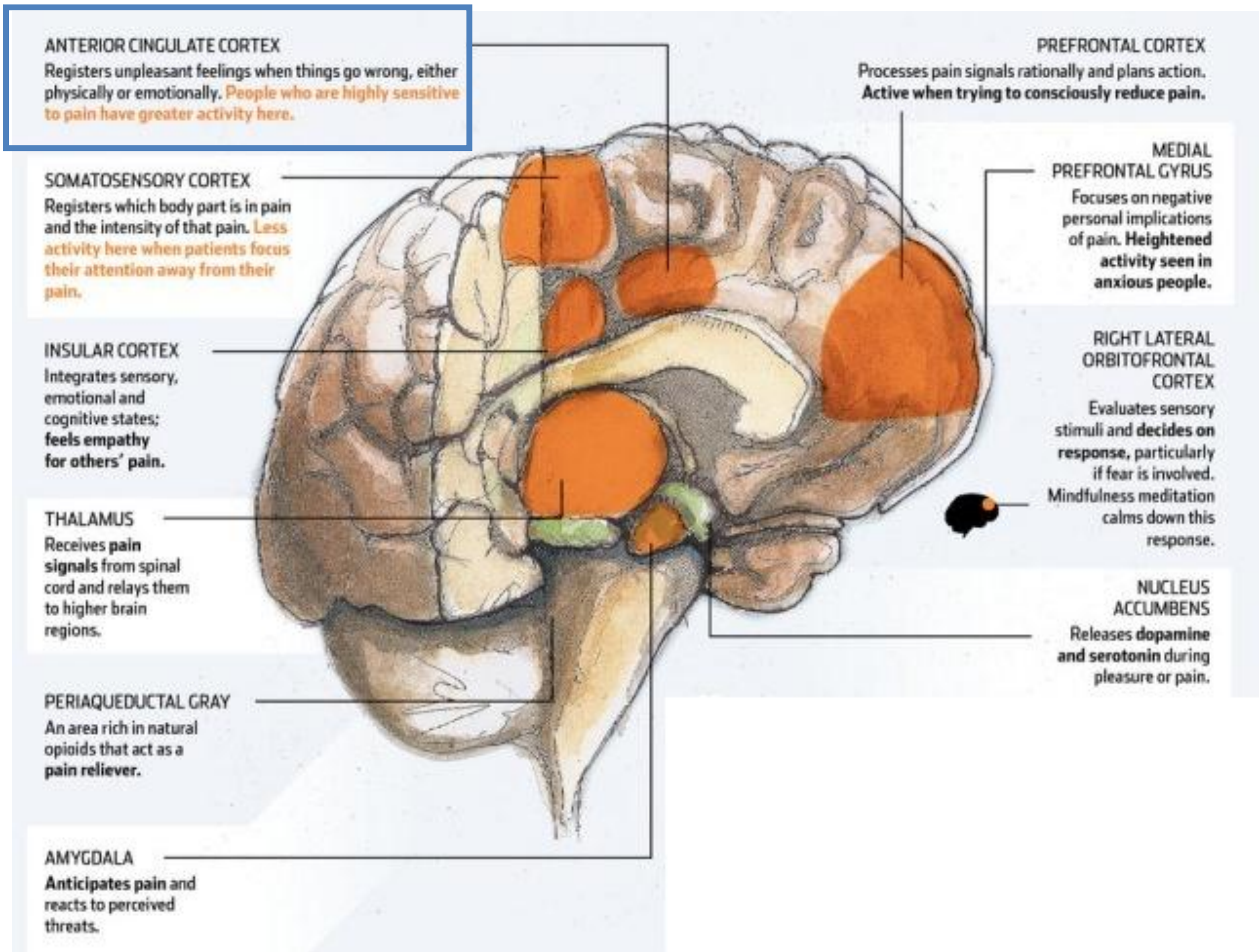


Figure 4: Areas of the brain that react to pain and discomfort

From a biophysical point of view, a given active electrode on the scalp measures the electric field that is generated by the sum of the momentary post-synaptic potentials in the brain. Due to volume conduction these electric fields spread in the brain and reach in attenuated form the scalp surface. Each electrode measures a local part of this field. Accordingly and with a sufficient number of electrodes distributed all over the scalp, this electric field can be measured and reconstructed as a so-called scalp potential map. A new map is generated at every time instant in the millisecond range (whatever the sampling rate of the EEG amplifiers). It is a physical law that whenever the map topography has changed, the distribution and/or orientation of the active dipoles in the brain have changed.

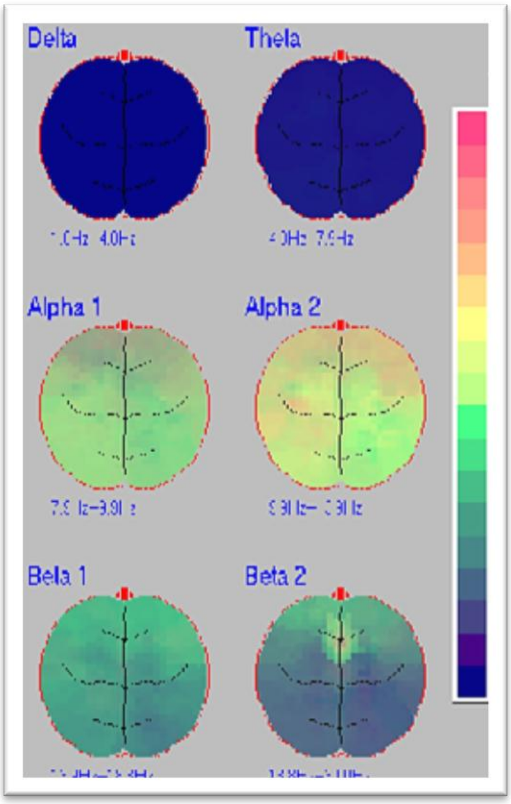


Figure 5: Brain wave frequencies of the average members of group1 while walking slowly and wearing material 1. This shows that there is a high level of alpha waves, meaning participants are awake but relaxed, not focusing on anything in particular. The predominance of these waves is in the frontal regions of the brain. Beta 2 waves are also observed in the region that roughly corresponds to the location of the Anterior cingulate cortex, indicating an increased level of discomfort.

Once the EEG is recognized as a metric of the brain's electric fields quantifiable at the scalp via high-density montages, it is easily seen how EEG can in turn provide information regarding its underlying generators. (Michel and Murray 2012)

EEG Recording technique

Encephalographic measurements employ a recording system consisting of:

- Electrodes with conductive media
- Amplifiers with filters
- A/D converter
- Recording device

Electrodes read the signal from the head surface, amplifiers bring the microvolt signals into the range where they can be digitalized accurately, the converter changes signals from analogue to digital form, and a personal computer (or other relevant device) stores and displays obtained data.

Scalp recordings of neuronal activity in the brain, identified as the EEG, allow measurement of potential changes over time in the basic electric circuit conducting between signal (active) electrode and reference electrode. An extra third electrode, called ground electrode, is needed for getting differential voltage by subtracting the same voltages showing at active and reference points. Minimal configuration for monochannel EEG measurement consists of one active electrode, one (or two specially linked together) reference and one ground electrode. The multi-channel configurations, such as our high density EEG system, can comprise up to 128 or 256 active electrodes. The Ag-AgCl electrodes are held in an electrode cap with flexible leads plugged into an amplifier. (Teplan 2002)

Participant preparation for EEG monitoring

It is very important that the participants' scalps are prepared appropriately before each session. This procedure involves the following steps:

Materials used:

- Isopropyl Alcohol
- Cotton pads
- Q-tips
- Conductive Gel
- Syringe
- EEG cap

1. Participant is seated and the Cotton pads dipped in Isopropyl alcohol are used to scrub the participant's scalp. This is done to dissolve and clean the participant's scalp from any products and to remove oil and dried skin.

2. The right amount of Conductive Gel has to be applied to the inner side of the electrodes on the cap. A little amount of gel could cause poor conductance while a lot of gel could spread and connect two electrodes. The conductive gel serves as a media to ensure lowering of contact impedance at electrode-skin interface.

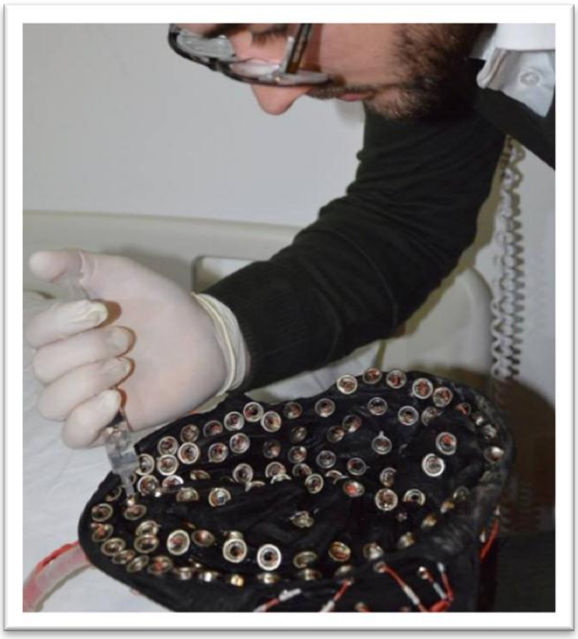


Figure 6: Filling the EEG cap with conductive gel

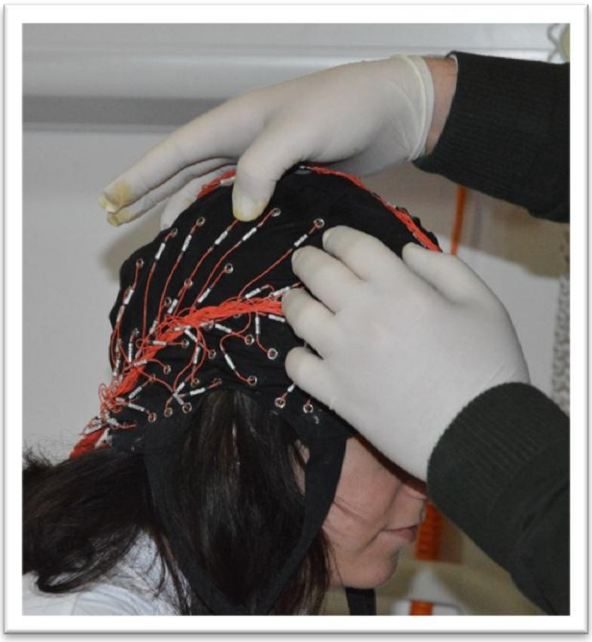


Figure 7: Fitting the EEG cap on the participant's head

3. Once finished, the research engineer secures the EEG cap on the participant's head.

4. The EEG cap is correctly positioned according to a map of electrode placement printed and made available for reference. This is based on the standard 10-20 montage system. The electrode CZ is placed halfway between the ears and halfway between the nasion (where the top of the nose meets the ridge of the forehead) and inion (the most prominent projecting point of the occipital bone at the base of the skull). Once correctly placed, the cap is left to rest low on the forehead. The figure below shows the correct position of each electrode:

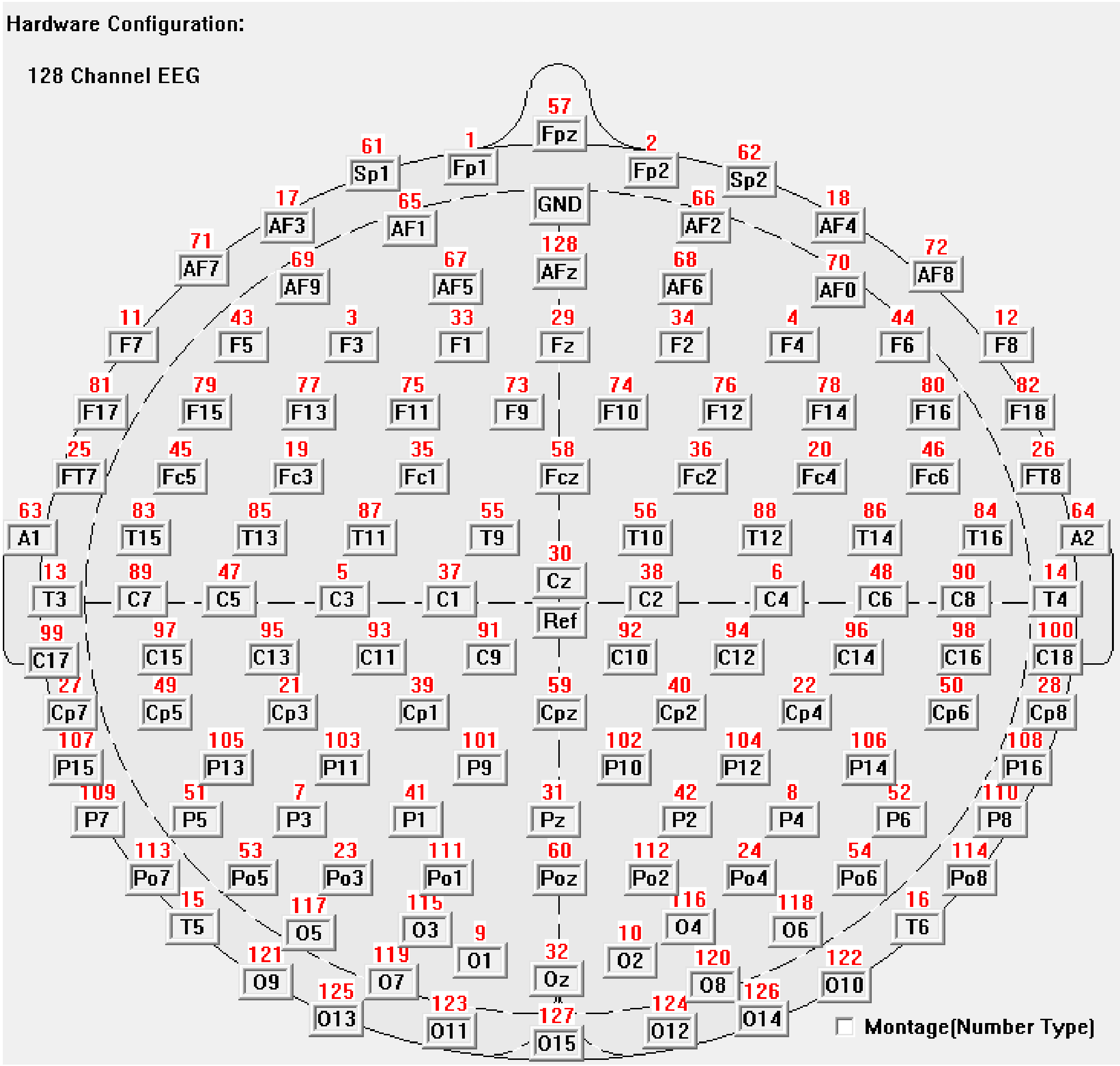


Figure 8: The 10-20 Montage system of the HD EEG used, with 128 Electrodes

5. Once the EEG 128-electrode cap is properly worn, the session is ready to start.

Collecting and saving EEG data

The collected EEG signals need to be amplified to make them compatible with a recorder and display, in this case a desktop computer. Amplifiers adequate to measure these signals have to be able to provide amplification selective to the physiological signal, reject superimposed noise and interference signals, and guarantee protection from damages through voltage and current surges for both participants and equipment.

Specific filters were applied while recording data in order to get a clear reading. Amplitude was recorded at a sensitivity of 70 μV/cm. A high pass filter with a cut-off frequency (Fc) of 0.16Hz was applied. This lets only signals with a higher frequency than the cut-off frequency pass through. A low pass filter with an Fc of 40Hz was also applied. This allows signals with frequencies lower than the Fc to pass through. Having both a low pass and a high pass we obtain a band pass recording filter with cut offs at 0.16 Hz and 40 Hz. This means that only signals with frequencies in between are recorded. This band contains all the relevant information we needed to collect as it incorporates the frequencies of the 5 brain frequency bands: alpha, beta, theta, delta and gamma.

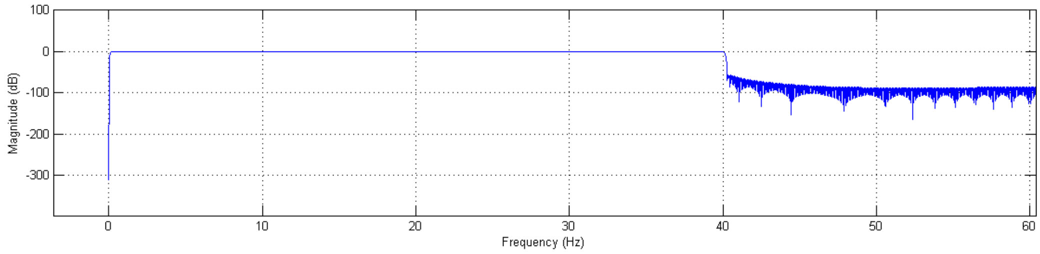


Figure 9: Brain wave frequencies filter

A notch filter was also applied. This was added as an extra precaution in order to impede any noise from power lines which has a frequency of 50Hz. Notch filters do not let frequencies of a certain value pass.

Data was saved according to participant and material ex. A36 – 1. The format was .NED. All data was then converted to .EDF (European Data Format). This is a standard EEG data format. All data was transported to MATLAB for processing. There were 132 .edf files in all, 4 files for each of the 33 participants. Each file was divided into 5 frequencies: delta, theta, alpha, beta and gamma. This was done by using band pass filters. Below are graphs representing the band pass filters for each brain frequency band:

	Fc1 Fc2
δ Delta	1 Hz – 4 Hz
θ Theta	4 Hz – 8 Hz
α Alpha	8 Hz – 13 Hz
β Beta	13 Hz – 30 Hz
γ Gamma	30 Hz – 40 Hz

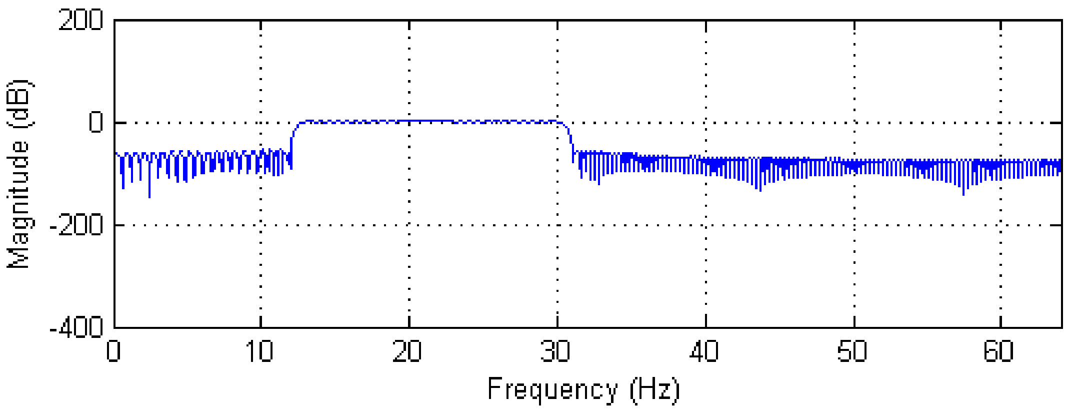


Figure 10: β Beta Filter

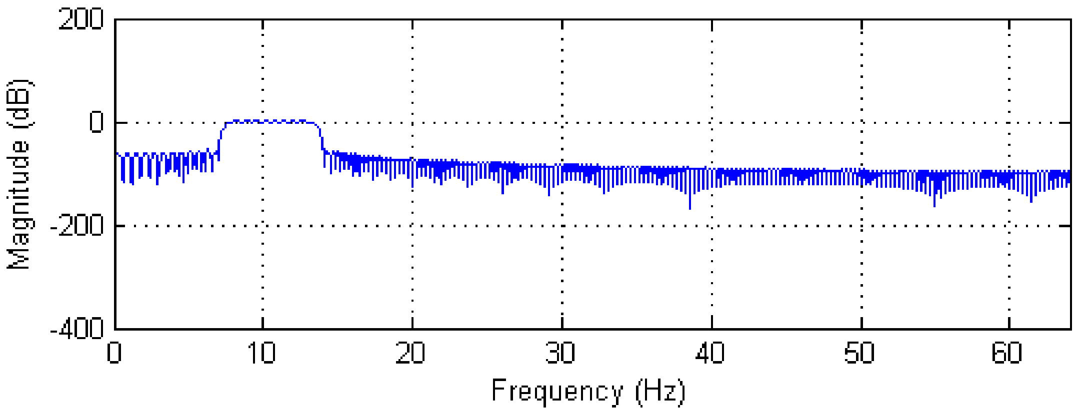


Figure 21: α Alpha Filter

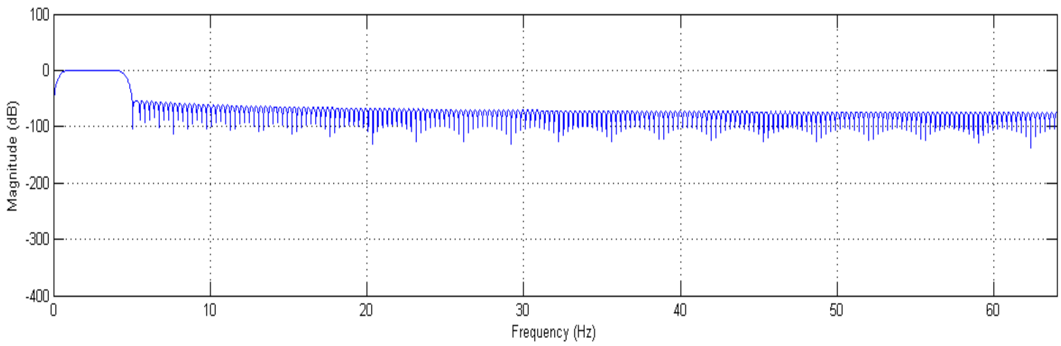


Figure 32: δ Delta Filter

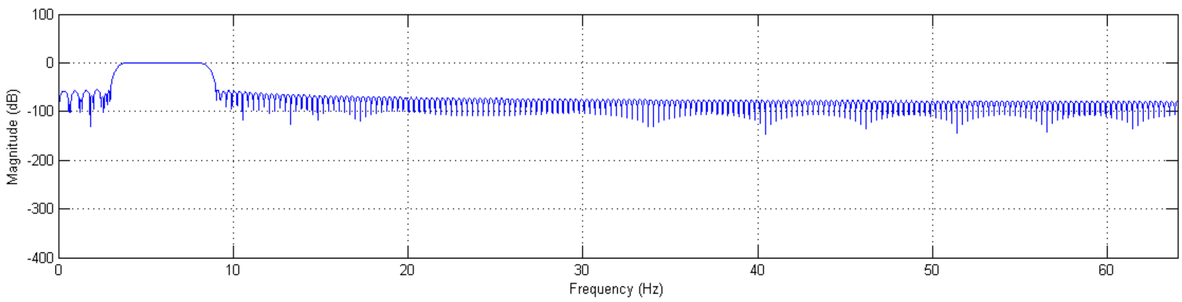


Figure 43: θ Theta Filter

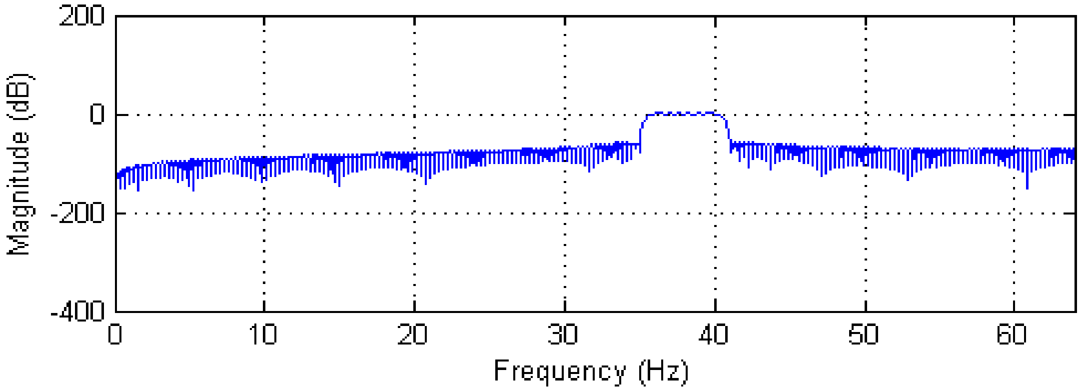


Figure 54: γ Gamma Filter

All .edf EEG files (132 x 5) were converted to an ASCII text file for further analysis. All files were trimmed to have the same dimensions (array of 129 (128 channels + time) x 12 mins of data (128Hz sampling freq. x 12mins x 60sec) = 92160samples).

All data from each group was added together and averaged. An Average was taken for each frequency band.

Material 1 was used as a control, therefore it was subtracted from each of material 2, 3 and 4. This showed us different activity in the brain for each band separately for each group.

Group 1/2/3:

Result for Material 2 = Average of Material 2 - Average of Material 1

Result for Material 3 = Average of Material 3 - Average of Material 1

Result for Material 2 = Average of Material 4 - Average of Material 1

Material 1 was used as a baseline. When it is subtracted from the readings generated by participants wearing the other materials, we are also rejecting other noise that was commonly generated by all the participants, such as EMG from movement, breathing etc. What remains in the result is the EEG reading caused by the particular material, 2, 3 or 4.

After this data processing, results can be displayed and analyzed in the form of frequency graphs or brain maps.

Thermal Camera

The Infrared thermal camera measures the temperature changes of the skin while the user is exposed to the material. This produces a heat map that changes during a specific period of time.

The type of thermal camera used in this experiment is of the commonly used Uncooled typology. This means that the infrared-detector elements are contained in a unit that operates at room temperature. In this context, 'uncooled' refers to not employing artificial means of reducing the temperature of the infrared array, such as by means of cryogenic solids or liquids, mechanical refrigerators, thermoelectric coolers, or Joule-Thomson coolers. The infrared array operates at the ambient temperature, whatever that might be. If unstated, the temperature is assumed to be 'room temperature,' generally considered to be 21oC or 26oC.

The term 'thermal imaging' refers to the ability of the array in its system to image room temperature scenes. Here again, 'room temperature' implies 21oC or 26oC. A thermal image of a scene refers to an image of that scene made entirely by detecting the thermal (infrared) radiation emitted by everything in the scene. Thus there is no use of artificial (lamps, lasers) or natural (sunlight, moonlight, starlight, airglow) illumination of the scene. (Kruse 2001)

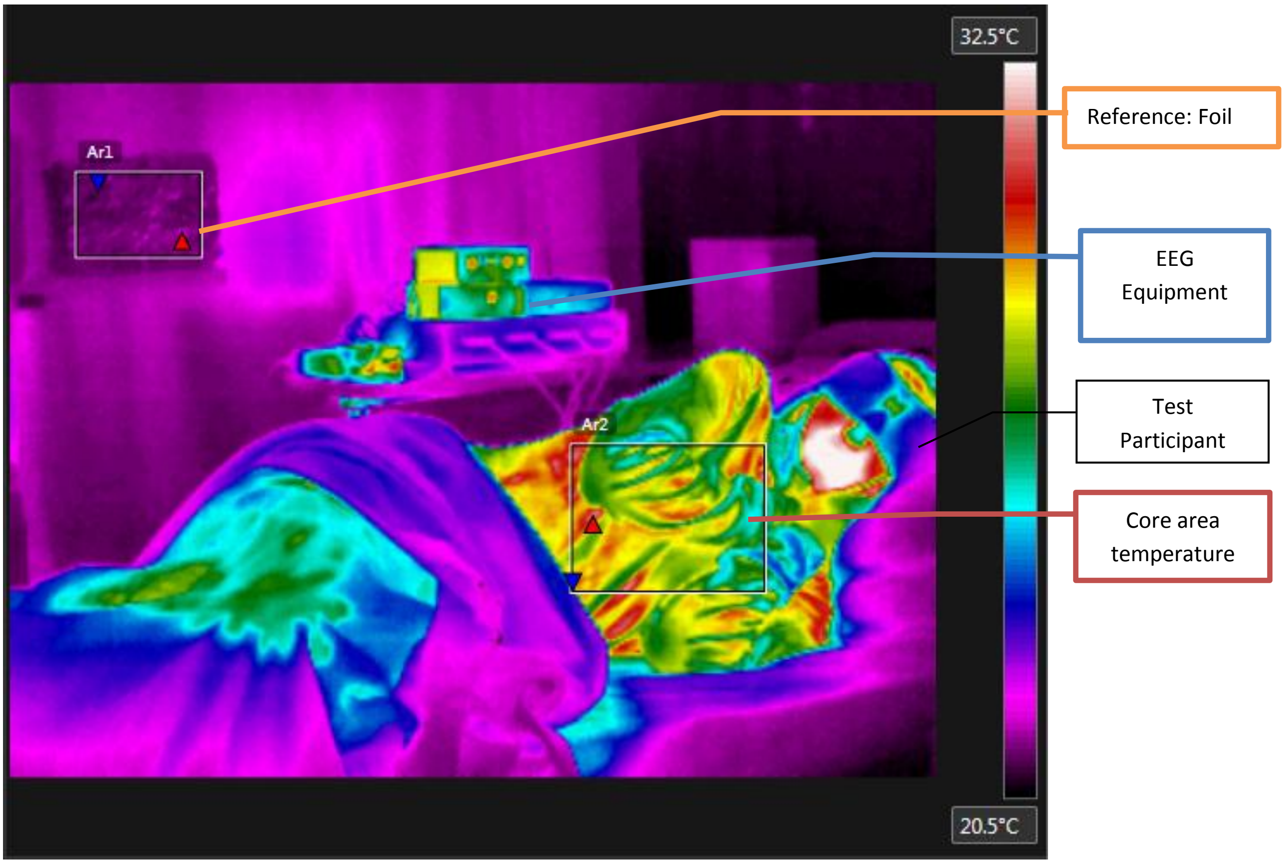


Figure 65: Heat Map and experiment set-up

Using Infrared Imaging in Physiological Research

Thermal imagery has been used in different areas of medicine and physiological research. In sleep studies, body and skin temperature regulation is associated with changes in sleep propensity; therefore, sleep research often necessitates concomitant assessment of core and skin surface temperatures. Attachment to thermistors may limit the range of comfort, introducing a potential confound that may prolong sleep initiation or increase wakefulness after sleep onset. It has been suggested that contact thermometry may artificially increase temperatures due to insulation. A more ideal method, such as that used in this testing, involves a method of remote sensing skin temperatures using a digital infrared thermal imaging (DITI) system, which can reduce these potential confounds. DITI can assess skin surface temperatures as accurately as contact thermometry, provided the interest is in relative and not absolute temperature changes. (Van den Heuvel et al. 2003)

Recently, advances in a couple of related areas have pushed forward the reappraisal of the role of IR imaging in medicine and physiological research. These advances, including the development of the new-generation infrared technology, smart image processing algorithms, and the pathophysiological-based understanding of IR images, provide a cost-effective, non-invasive, non-destructive, and participant-friendly approach to health monitoring and examination.

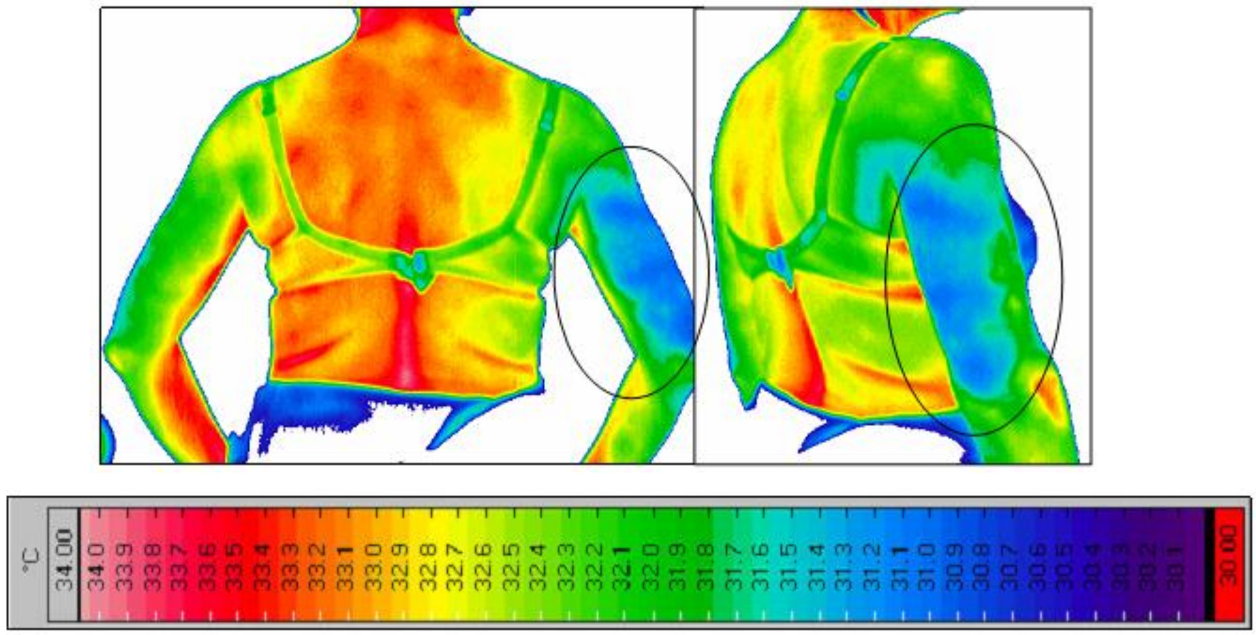


Figure 76: This is an example of non-specific muscle pain detected in upper right arm using thermal imagery. The area of discomfort closely matched the area of cooler skin (blue coloured area inside black circles).

Standard Requirements

Infra-red imaging can only produce reliable and valid results if the technique follows established standards. In physiological research applications these standards are based on the physics of heat radiation and the physiology of thermoregulation of the human body.

1. The room used for thermal imaging must meet certain basic requirements. These are: adequate size for working - where up to 2 meters may be needed between the participant and the operator and adequate space to locate the image processing equipment.

2. Ambient temperature control is a primary requirement for most clinical/research applications of thermal imaging. A range of temperatures from 18°C to 25°C should be attainable and held for at least one hour to better than 1^{0}C. At lower temperatures, the participant is likely to shiver, and over 25°C room temperature will cause sweating, at least in most European countries.

3. Indication of the air temperature is important, a display which is visible anywhere in the room should be used. Air temperature is affected not only by heat generated by electronic equipment, but also by the human body. For this reason the air-conditioning unit should be capable of compensating for the maximum number of participants and staff likely to be in the room at any one time. These effects will be greater in a small room of 2x3 meters or less. Air conditioning equipment should be located so that direct draughts are not directed at the participant, and that overall air speed is kept as low as possible.

4. Computer and Image processing equipment need space located away from the immediate participant area, to avoid heat disturbance.

5. A private rea within the temperature controlled area is essential to provide privacy for disrobing and rest through the acclimatization period. The Thermal camera needs to be set up in the experiment area on a steady stand. The height and angle of the camera is adjusted to be directed towards the participant.

6. The thermal camera requires a separate thermal reference source for calibration checks. Many systems now include an internal reference temperature, with manufacturers claiming that external checks are not required. Unless frequent servicing is obtained, it is still advisable to use an external source, if only to check for drift in the temperature sensitivity of the camera. The reference constructed for this experiment consisted in a piece of aluminum foil left in the same location throughout all the sessions. This acts as a reflector of the infra-red levels emitted by the thermal camera and can therefore be used as a reference.

7. Image processing was done using the software provided with the camera. Archiving of both images and relevant scientific data is an important requirement for physiological thermography (Ring and Ammer 2000).

Testing Procedures

1. Human skin temperature is the product of heat dissipated from the vessels and organs within the body, and the effect of the environmental factors on heat loss or gain. There are a number of further influences which are controllable, such as cosmetics, alcohol intake and smoking. These formed part of the request made to the participants when calling him or her for testing. The participants were advised to avoid all topical applications such as ointments and cosmetics on the day of testing to all the relevant areas of the body. They were also asked to avoid large meals and above average intake of tea or coffee.

2. On arrival, each participant was informed of the procedure, instructed to wear the appropriate clothing, and asked to sit or rest in the preparation area for a fixed time. The participants were given 10 minutes in order to achieve adequate stability in blood pressure and skin temperature.

3. The participant was then put in position, on the treadmill in the Motion Stress Test and on the bed in the Sleep Quality Test. Once it is confirmed that the thermal camera is functioning adequately, the test began. This test was conducted in conjunction with the HD EEG recording.

4. Any other material that came into contact with the participant was be allowed to acclimatize to the room temperature. Therefore, for the sleep test the sheets and pillows were allowed to cool off in between test participants or were replaced by fresh ones.

5. The recorded data was saved using the so-called rainbow or spectral order of colours.

6. Background temperatures which can obscure the image were avoided by giving the camera a range of temperatures to record. Any temperatures that fell out of this range were not recorded and appear black on screen. The chosen range was $19^{o}C$ to $35^{o}C$.

7. The thermal camera was set to take multiple images per second in order to produce a video of the whole session.

Questionnaires

"Clothing Comfort has been one of the fundamental needs for consumers" (Kaplan and Okur, 2007). The exponential rise of comfort-demand in the global market has set major fiber and textile marketers to seek and meet these key attributes within their products. Slater defined comfort as a "pleasant state of physiological, psychological and physical harmony between a human being and the environment" (Li 2001).

In both the Motion Stress Test and the Sleep Quality Test, participants were given a three part questionnaire to be filled in between and after the sessions. These questionnaires were specifically designed to obtain the participants' responses on different comfort-related attributes for each material they wore. The approach taken in compiling the questionnaires was that of a quantitative nature. These questionnaires were sent to the client for approval prior to commencing testing.

Questionnaire Structure

In the first section the participants were required to fill four close-ended rating scales, each assimilated to one particular material, as assorted by the order they wore them. Each scale was filled in-between and at the end of their sessions. It is important to note that the test participants were not given any details on the materials they were wearing.

The participants were instructed to tick the space holding the designated amount in respect to the characteristic value they perceived the material held. The below extracts depict one of the rating scales for both tests.

Motion Stress Test

Material __

	5	4	3	2	1	
Very comfortable (5)						Uncomfortable material (1)
High level of practicality (5)						Impractical (1)
High transpiration (5)						Low transpiration (1)
Ease of movement (5)						Restrains movement (1)
Smooth texture against skin (5)						Harsh texture against skin (1)
Highly elastic material (5)						Rigid material (1)
Low friction/low chaffing material (5)						High friction/ high chaffing material (1)
Lightweight (5)						Heavy feeling (1)
Low itching sensation (5)						High itching sensation (1)
Well fitting (5)						Poorly fitting (1)
Minimizes odors (5)						Has intense odor (1)
Controls body temperature (5)						Does not control body temperature (1)
Breathable material (5)						Not breathable material (1)
Very moisture wicking/ sweat absorbent (5)						Not at all moisture wicking/ sweat absorbent (1)

Sleep Quality Testing

Material __

	5	4	3	2	1	
Very comfortable (5)						Uncomfortable material (1)
Unrestricting feeling on skin(5)						Restricting feeling on skin (1)
Smooth texture against skin (5)						Harsh texture against skin (1)
Highly elastic material (5)						Rigid material (1)
Low friction/low chaffing material (5)						High friction/ high chaffing material (1)
Lightweight (5)						Heavy feeling (1)
Low itching sensation (5)						High itching sensation (1)
Controls body temperature (5)						Does not control body temperature (1)
Breathable material (5)						Not breathable material (1)
Gives a resting sensation on skin (5)						Irritable sensation on skin (1)
Soft texture to rest on (5)						Rigid texture to rest on (1)

Sections 2 and 3 held direct questions asking the participants their preferences on which material they found most comfortable (Question 2) and which of the materials they preferred in general and why (Question 3). Data gathered was then analyzed and constructed in a report, shedding light on the intricate details that arose from the responses given. Below are the questions found in Sections 2 and 3. There is a full copy of the questionnaires in the appendix section.

3 | Group Set Up

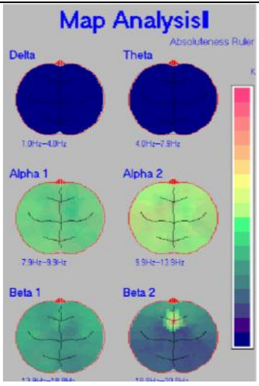
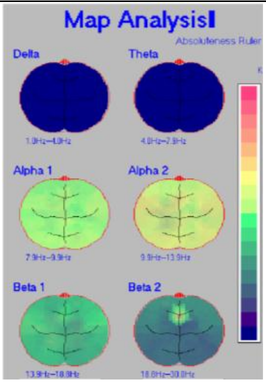
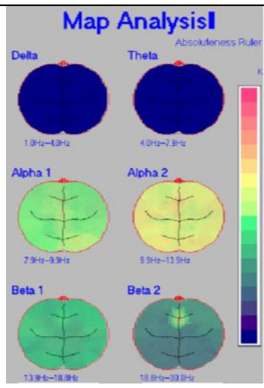
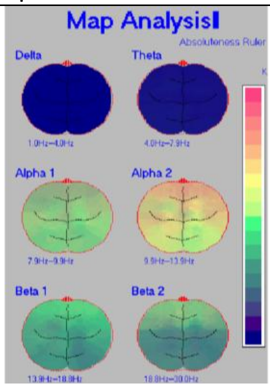
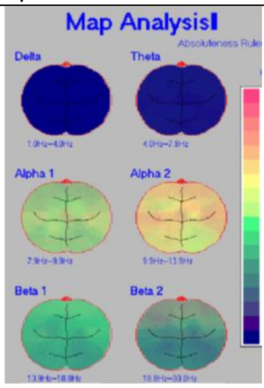
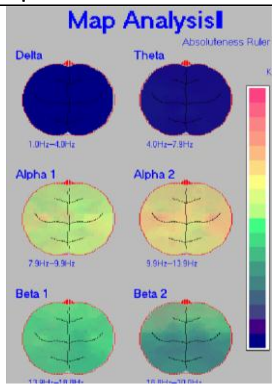
In this further analysis of the experiment results, the subjects were grouped with the discrimination factor being sex as opposed to age.

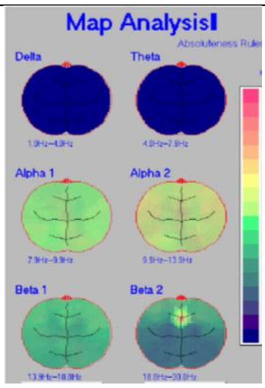
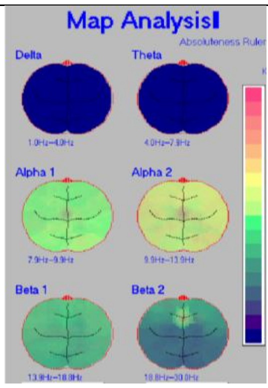
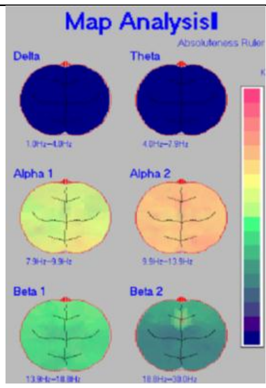
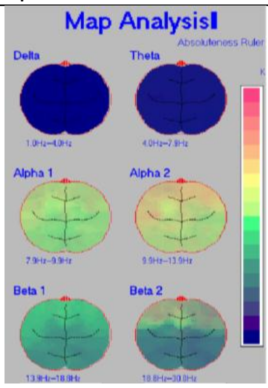
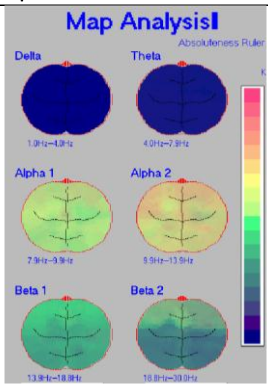
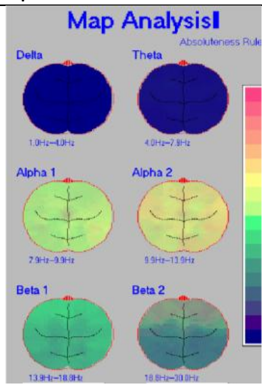
Three groups were formed; this time Group A comprising of only males, Group B of females and Group C made up of males and females as follows:

A: Males	B:Females	C:Mixed
B29	A12	A18
A4	A16	B25
B36	A6	A14
A35	AA	A34
A17	AC	A28
A36	B20	B31
B6	B24	B19
B16	B26	B32
B1	B37	A1
A7	B5	B35
A26	B7	B38

4 | Brain Mapping Analysis

For the purpose of this analysis, results for Groups A and B were compared to highlight differences between male and female data sets. Group C, a mixed group, was used as a reference.

Material 1			
Group A (Males)	 Speed 1	 Speed 2	 Speed 3
Group B (Females)	 Speed 1	 Speed 2	 Speed 3

Material 2			
Group A (Males)	 Speed 1	 Speed 2	 Speed 3
Group B (Females)	 Speed 1	 Speed 2	 Speed 3

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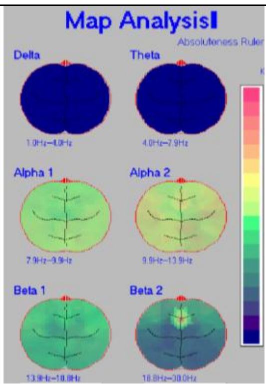
<td>
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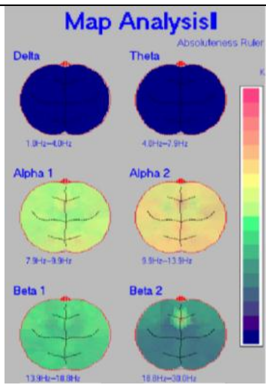
<td>
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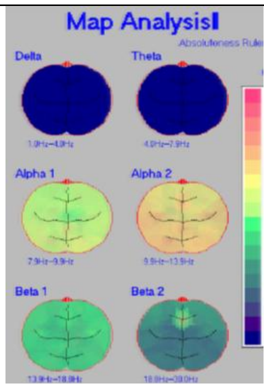
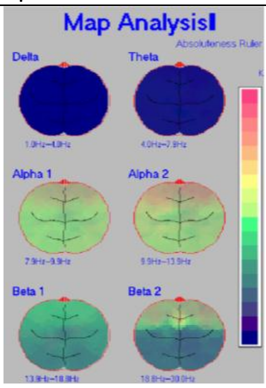
<td>
Speed 3</td></tr>
<tr><td>Group B (Females)</td>
<td>
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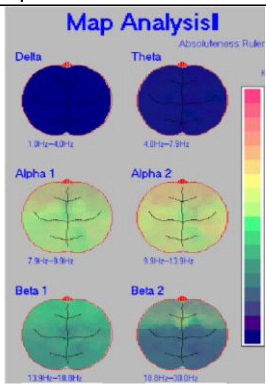
<td>
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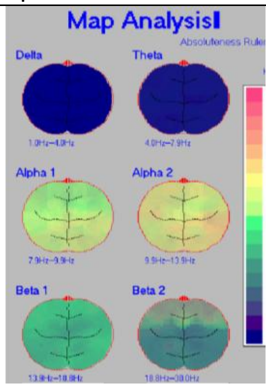
<td>
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<table>
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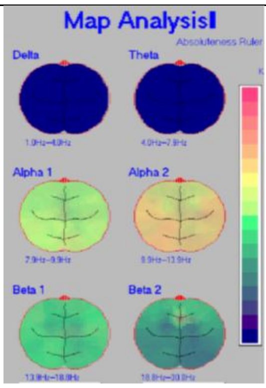
<td>
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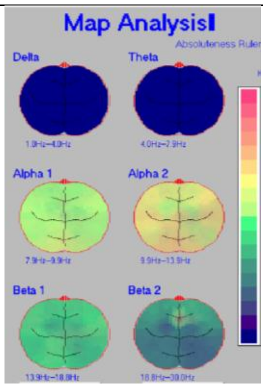
<td>
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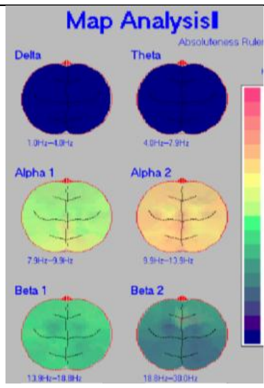
<td>
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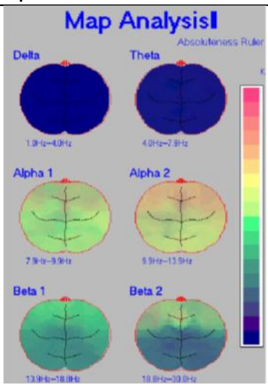
<tr><td>Group B (Females)</td>
<td>
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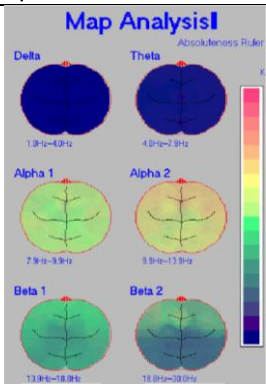
<td>
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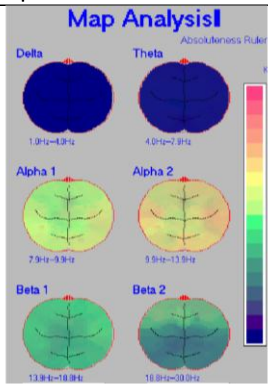
<td>
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</table>

Table 1: Motion Test – Brain Maps

From these results one can clearly discern which materials were found to be the most comfortable for each group. High alpha brain wave activity indicates that the user is calm and content. When the brain shows increased activity, especially in the medial frontopolar cortex and the posterior cingulate/precuneus, this shows that the user is making an unconscious preference:

> "…regions of medial frontopolar cortex and posterior cingulate/precuneus encode freely chosen abstract intentions before the decisions have been consciously made."[1]

The brain wave activity demonstrates how the test subjects would have been analysing the comfort of the different materials and making an unconscious choice – that is, without being aware of the choice being made.

The results of these tests during motion demonstrate the following sequential differences in male and female material preferences:

Preference	Males	Females
1st	Material 2	Material 1
2nd	Material 4	Material 4
3rd	Material 3	Material 2
4th	Material 1	Material 3

Males showed a preference for Material 2 which has a high percentage of cotton element while females showed a preference for Material 1 which is 100% cotton. Clearly natural cotton is considered to contribute to comfort during exercise. However, Material 1 scored the least with males. This is probably due to the discrepancy in fit, and manufacturing quality of the shirts provided for the test, that did not allow for the material testing to be unbiased.

[1] Chun Siong Soon, Anna Hanxi He, Stefan Bode and John-Dylan Haynes, 'Predicting free choices for abstract intentions,' in *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110 no. 15, 6217–6222, doi: 10.1073/pnas.1212218110, Edited by Marcus E. Raichle, Washington University in St. Louis, MO, and approved February 22, 2013 (received for review July 19, 2012)

The following are the experiment results of the Sleep Test divided in two groups, males and females.

<table>
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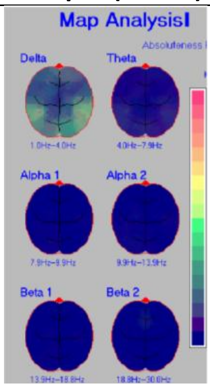
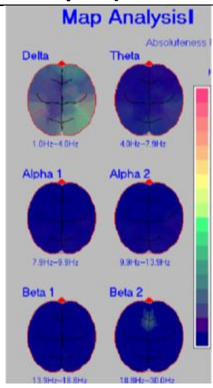
<tr><td>Material 1</td><td>
</td><td>
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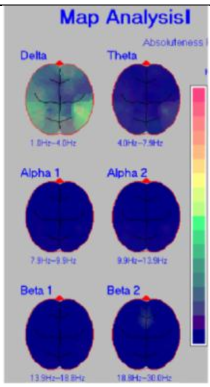
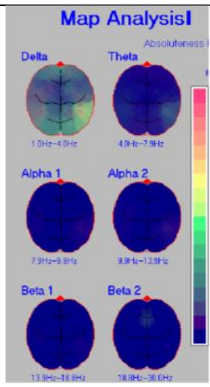
<tr><td>Material 2</td><td>
</td><td>
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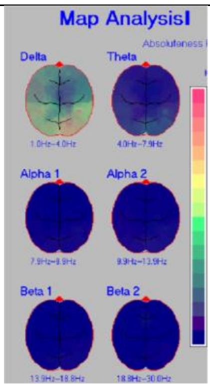
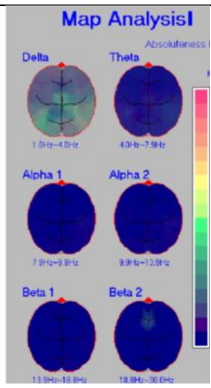
<tr><td>Material 3</td><td>
</td><td>
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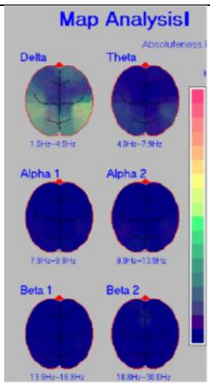
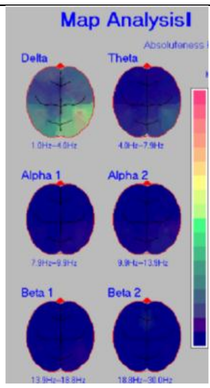
<tr><td>Material 4</td><td>
</td><td>
</td></tr>
</table>

Table 2: Sleep Test Brain Maps

In this experiment, our subjects went through the full first and second stage of NREM sleep. Sleep Stage 2 is usually linked to the loss of self-conscious awareness and encroaching deep sleep. During this stage, brain activity decreases in a number of brain regions-thalamic and hypothalamic regions, the cingulate cortex, the right insula and adjacent regions of the temporal lobe, the inferior parietal lobule and the inferior/middle frontal gyri.

From the results we can see that in general, material 1 shows the least brain activity in both males and females. This means that the brain is losing consciousness and moving towards deep sleep, indicating higher degree of sleep comfort.[2]

5 |Thermal Imagery Analysis

An essential role of clothing is to maintain temperature and provide an additional layer of insulation to the body. Clothing should allow heat transfer from the skin (body) through the same fabrics. This is generally done through convection, conduction and sometimes even vaporization of sweat. If the clothing material would not allow enough heat transfer, the underlying skin would absorb the heat. This means that while the body is trying to cool off by transferring heat to the outside environment through the skin, heat is re absorbed by the body since not enough heat transfer is taking place: this results in discomfort and may have even injury implications. [3]

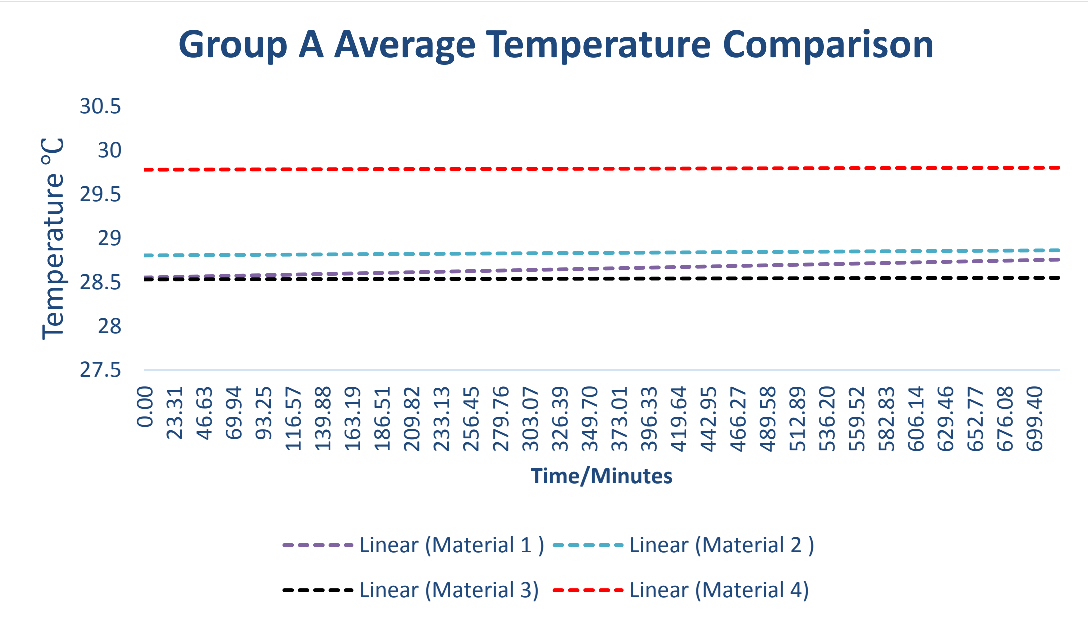


Figure 17: Linear representation of the Average Temperature variance for the four materials within the male group during the motion test

[2] C. Kaufmann, et al., Brain Activation and hypothalamic functional connectivity during human non-rapid eye movement sleep: an EEG/fMRI study, Brain (2006), 129, 655–667
[3] Stoll, A. M. and Chianta, M. A. (1971), Heat Transfer Through Fabrics As Related To Thermal Injury. Transactions of the New York Academy of Sciences, 33: 649–670.

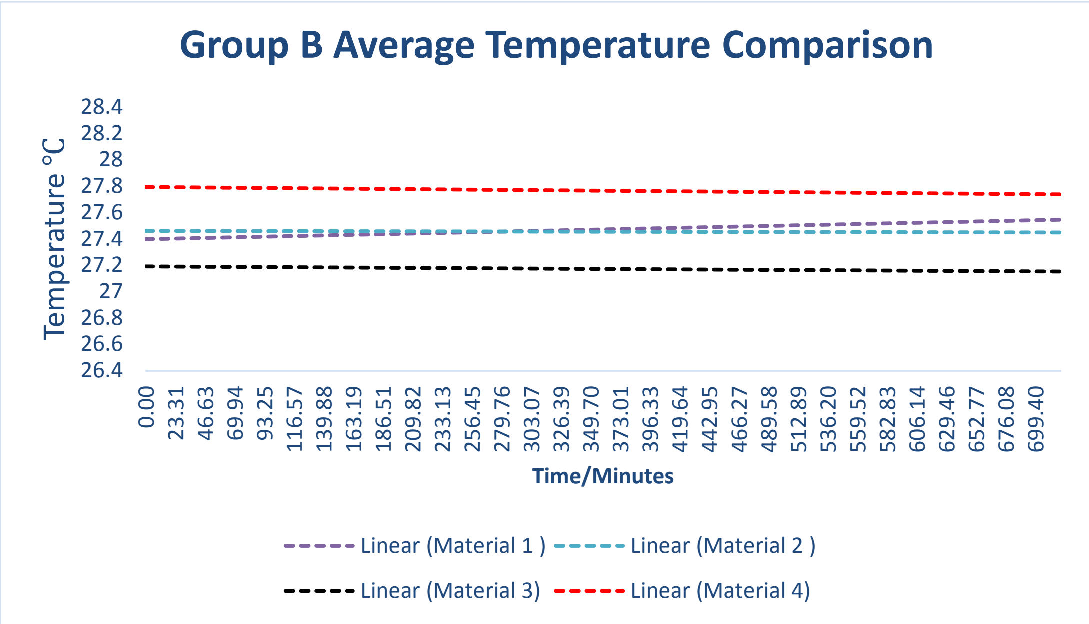


Figure 18: Linear representation of the Average Temperature variance for the four materials within the female group during the motion test

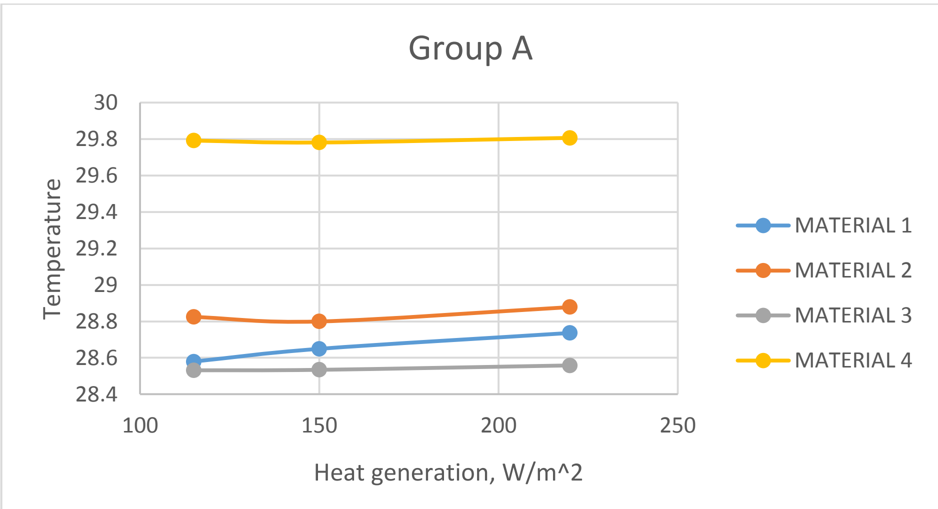


Figure 19: A representation of how temperature varied per material while performing the motion test at 3 different speeds for the male group. Each speed is represented by its associated relative heat generation (metabolic rate): Speed 1: 0.89 m/s – 115 W/m^2; Speed 2: 1.34 m/s – 150 W/m^2; Speed 3: 1.79 m/s – 220 W/m^2

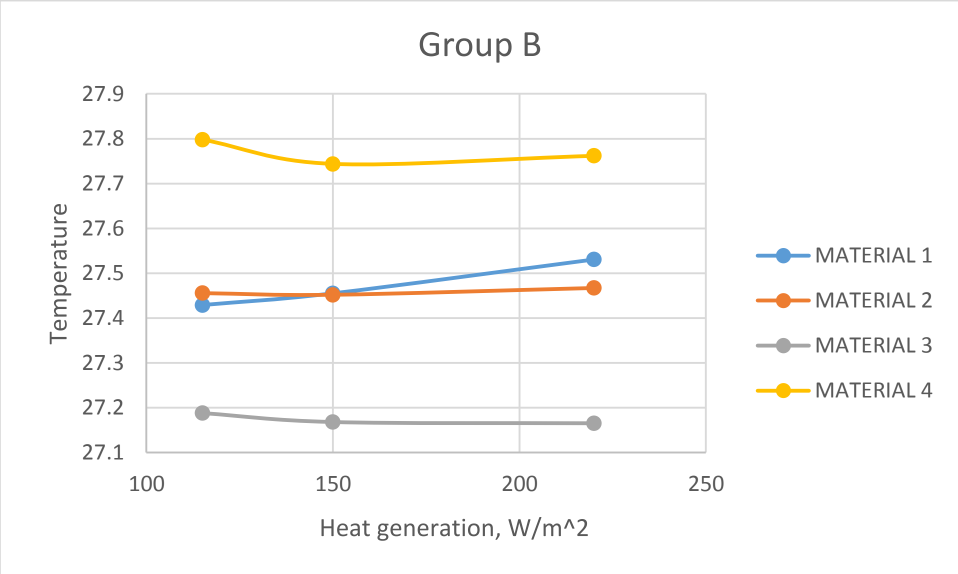


Figure 20: A representation of how temperature varied per material while performing the motion test at 3 different speeds for the female group. Each speed is represented by its associated relative heat generation (metabolic rate): Speed 1: 0.89 m/s – 115 W/m²; Speed 2: 1.34 m/s – 150 W/m²; Speed 3: 1.79 m/s – 220 W/m²

A person's body and skin temperature change according to the level of activity he or she is undertaking. The heat produced by the body is transferred from the body's skin to the environment. In a steady-state heat balance, the heat energy produced by the metabolism equals the rate of heat transferred from the body (W/m^2) by conduction, convection, radiation, evaporation and respiration. Therefore, clothing is needed to protect the body against climatic influence and to assist its own thermal control functions under various combinations of environmental conditions and physical activities. The heat loss from the body and the feeling of individual comfort in a given environment and during a given activity is much affected by the clothing worn.[4]

Different activities generate different levels of heat in the body, according to the amount of metabolism needed, meaning how much food needs to be converted into enough energy, to perform the activity. As the metabolic rate increases, the clothing surface temperature and the temperature of the body skin must decrease. This is because high metabolism increases core body temperature. The body's natural homeostasis mechanism reduces the skin temperature so as to achieve thermal comfort.[5]

The skin temperature values resulting from changes in levels of metabolism for different activities are not the same for men and women. This is because thermoregulation (the ability to keep body temperature within certain boundaries) in men and women is effected by

[4] R. Tuğrul Oğulata, The Effect of Thermal Insulation of Clothing on Human Thermal Comfort, FIBRES & TEXTILES in Eastern Europe April / June 2007, Vol. 15, No. 2 (61)#'
[5] Oğulata, 2007

a number of factors mainly pertaining to the properties of female physiology such as sex hormones, body mass and size, muscle and body fat content and exercise capacity.[6]

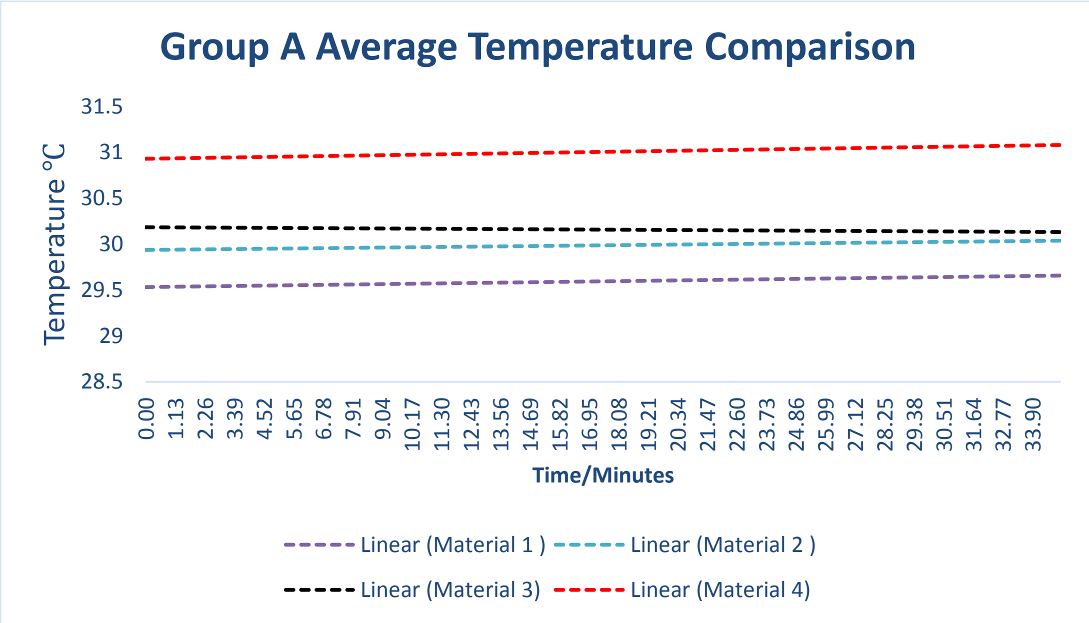


Figure 21: Linear representation of the Average Temperature variance for the four materials within the male group during the sleep test

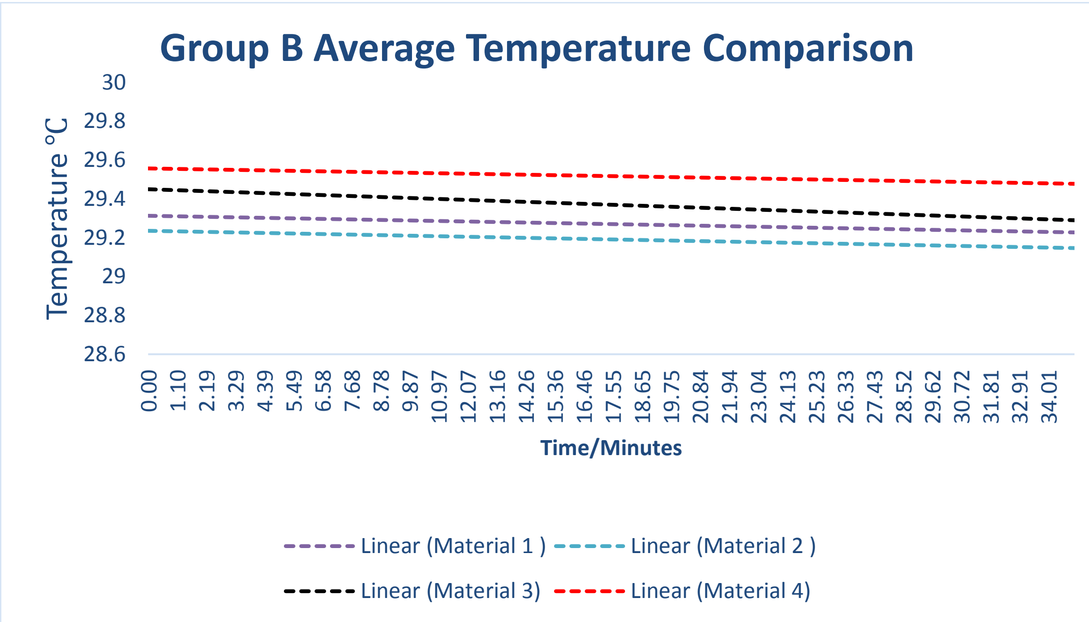


Figure 22: Linear representation of the Average Temperature variance for the four materials within the female group during the sleep test

[6] Hanna Kaciuba-Uscilko and Ryszard Grucza, Gender differences in thermoregulation, Current Opinion in Clinical Nutrition and Metabolic Care 2001, 4:533-536

When people go to sleep, their body temperature usually decreases drastically and reaches a minimum point. Once the minimum is reached, the body temperature will start to increase until it reaches a somewhat constant temperature. A by-product of this tendency is that we are at our deepest sleep mostly after about two hours of sleep onset. [7]

Increasing the skin temperature facilitates sleep onset. This is because by increasing the skin temperature, we are promoting to reach the target temperature for deep sleep. Subsequently this skin temperature increase affects the process of falling asleep and sleep quality. For the optimal sleep experience, one would have to have the ideal surroundings, such as comfortable bedding and clothing, all of which would help create a micro-climate 34℃ – 36℃ (body temperature). The ideal clothing would be able to increase the skin temperature slightly so as to promote sleep onset and then be able to maintain the increase temperature during the sleep. [8]

Skin temperature varies with time and according to the state of the body performing specific functions. Skin temperature changes are very important in keeping homeostasis within the body. A high presence of hormones within female body (particularly but not just during the menstruation phase) makes the skin temperature change rapidly. In fact, higher levels of oestrogen and progestin will lead to higher body temperature for females during the day and/or just before sleeping. Therefore, females have higher temperatures than males do at sleep onset, however, once hormonal activity slows down as they prepare to sleep, their respective temperature decreases drastically.[9]

From the results of these experiments, it is evident that material 4 is not an ideal material to wear during sleep for either males or females. Material 4 recorded a consistently higher temperature than other materials which is not ideal since it would cause discomfort. In females, it is evident that materials 1 and 2 show the best response to sleeping since they gradually decrease the temperature while material 3 has a higher gradient of decrease in temperature. A gradual decrease in temperature is preferable rather than a higher decrease in order to reach deep sleep at an earlier stage. Males, on the other hand showed that materials 1 and 2 promote a slight increase in temperature which would encourage deep sleeping at an earlier stage. On a general note, material 1 and 2 have the best characteristics for someone to sleep without getting too cold before deep sleep.

[7] Patricia J. Murphy and Scott S. Campbell, Sleep Onset Nighttime Drop in Body Temperature: A Physiological Trigger for Sleep Onset?, Laboratory of Human Chronobiology, Department of Psychiatry, Cornell University Medical College, White Plains, New York, U,S,A, 2007 Sleep, 20(7):505-511.

[8] Roy J.E.M. Raymann, Dick F. Swaab, Eus J.W. Van Someren, Skin temperature and sleep-onset latency: Changes with age and insomnia, Physiology & Behavior 90 (2007) 257–266.

[9] F. C. Barker et al., Sleep and 24 hour body temperatures: a comparison in young men, naturally cycling women and women taking hormonal contraceptives young men, naturally cycling women and women taking hormonal contraceptives, Wits Sleep Laboratory, Brain Function Research Unit, Department of Physiology, University of the Witwatersrand, Johannesburg, South Africa, Journal of Physiology (2001), 530.3, pp.565—574.

6 Claims

1. Cotton is the ideal material to sleep in since it registered the least activity in the brain, indicating deeper sleep.
2. Cotton-based materials were preferred by both males and females during motion.
3. Cotton scored favourably against thermal discomfort due to its ability to transfer excessive heat from the skin to the outside environment.
4. Cotton-based materials scored best for sleeping with, since they have the ability to maintain the decrease of temperature after sleep onset and thus promoting deep sleep.
5. Sleeping garments made of cotton should be encouraged for females since a decrease in hormonal levels when preparing for sleep decrease drastically their temperature and cotton showed that it is the most suitable material to maintain this decrease in temperature at a stable rate.
6. Cotton has proved itself to be the best thermo-regulating material both during sleep and motion.