Analyzing Neuroplasticity Due to Meditation as a Plausible ADHD Treatment with Statistical and Machine Learning Tools

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***Abstract*—Physical exercises can keep the body in shape, similarly many believe meditation could do the same for the mental fitness. Long term meditators after years of practice are thought to be capable of producing high gamma-waves and other brain waves, simply from the thoughts alone. To measure the changes in the brain waves EEG (Electroencephalography) and fMRI (functional Magnetic Resonance Imaging) are the two prominent techniques to collect data for various analytical purposes. Statistical tools can be used to find the existence of correlations between meditation and its neurophysiological effect and Machine Learning algorithms can be useful to classify the brain images. Many claim practices of meditation have neuroplasticity effect by boosting the memory muscle which can be a potential treatment for ADHD (Attention Deficit Hyperactivity Disorder). This paper takes a bottom-up research approach by scouring through the scientific progresses for the existence of neuroplasticity due to meditation and make an educated judgement on the applicability for the treatment of ADHD.**

***Index Terms*—EEG, fMRI, Gamma wave, Gamma-wave, meditation, ADHD, Machine Learning**

I. Introduction

In general, little is known about how the human brain works. Physical exercises can keep the body in shape, similarly many believe meditation could do the same for the mental fitness. Many claim practices of meditation are useful in relieving stress, anxiety and depression, and could also help in treating ADHD (Attention Deficit Hyperactivity Disorder) [1]. All these claims have to be proven scientifically. Long term meditators after years of practice are thought to be capable of producing high gamma-wave and other brain waves simply from the thoughts alone. Such neurophysicological activities need to be analyzed scientifically.

It is a daunting task to study how the human brains actually work let alone how meditation bring changes to the brain. Although the practice of meditation has been prevalent in the eastern part of the world for several centuries, the western countries have started showing interests only for the last 40 years [1]. The early scientific researches on the mediation has dated as far as 1956 [2]. In the year 2020 alone, hundreds of research papers have been published on the subject.

The definition of meditation itself can be elusive as the workings of it mostly unknown. However, meditation practitioners claim there are tangible effects to the fitness of the brain [1]. The researches done so far observed positive correlation between the long-term mediation and the recordings of high gamma-band frequency in the EEG [4, 7, 8]. The observations shown gamma synchrony which is a phase locking and frequency entrainment of the neural oscillations among groups of neurons [12]. These phenomena are proven by various statistical and computational techniques. Despite the structural networks of the human cerebral cortex have not yet been comprehensively mapped [13] the scientific communities have carried out various researches in the field of meditation in the last few decades.

Meditation in general is a method or exercise of maintaining focus on a single object, thought or activity to achieve a clear and stable state of the mind [6]. It is an acquired trait from long practices [4]. A seasoned practitioner could take as long as ten to fifteen years to be proficient at it [4]. This high clarity of focus could be channelled to distinguish between healthy and harmful mind which is intricately tied to the health of both body and the mind. However, there are many different types of meditations depending on one's cultural background which further opens gates for more researches. To have a healthy physical body is a necessity, while maintaining a healthy mind is mostly overlooked. The effect of the meditation to the mind or brain has been scientifically studied over the past 50 years. Many papers posit, meditation affects the neuroplasticity of the brain [11] bringing positive changes to the mind or the brain. The challenge in the field is to properly quantify meditation, and the proof of the actual sources of the brain waves.

The human brain signals generally consists of five major brain waves, namely: delta, theta, alpha, beta and gamma waves. Brain Computer Interface (BCI) is a device that allows to read the brain signals or activities with help of an Electroencephalogram (EEG) [3]. BCI serves as an interface between the human brain and a machine or a computer. It is a non-invasive motif by placing electrodes on the surface of the head scalp while invasive technique would involve placing the electrodes inside the human skull.

EEG and fMRI are the two prominent approaches for data acquisition to study the neurophysiological study of the brain. EEG records the brain activities by measuring voltage fluctuation and fMRI captures images of the current state of brain activity by detecting the changes associated with the blood flow [5]. This technique is based on the differences in the various magnetic fields of the blood flow, while EEG measure the electrical activity of the brain [3]. EEG is good at capturing the dynamic time resolution and fMRI gives high spatial resolution that compliments each other. There are other techniques such as PET (Positron Emission Tomography), MEG (Magnetoencephalography), NIRS (Near Infra Ray Spectroscopy).

The objective goal of this paper is initially to take a bottom-up approach by scouring through the landscape of the various scientific journals to gauge the progresses made so far and eventually narrow down into a niche to find out whether the application of neuroplasticity due to meditation is a plausible treatment for ADHD inductively. Along the way, using inclusion/exclusion protocol the paper lays a foundation on a handful of reputable scientific journals. Various statistical and machine learning tools can be applied for the analytical purposes.

Our brains are constantly changing for better or for worse. From the everyday learnings, trainings, social adaptations, physical exercises and from the diets we eat. The changes in the brain either by active training or from the day-to-day learning is called neuroplasticity. These changes can come either from the behavioural changes or the structural changes. The behavioral changes can occur when the same neurons learn new tricks or by losing the old tricks, and the structural changes are due to the formation of new networks either due to new axodendritic connections or a birth of whole new neuron. Poldrak [23] states the mental training is similar to training a piano or any other physically demanding trainings, thus the neuroplasticity in the mental training like meditation can be treated the same way a piano training brings changes to the brain. Meditation usually causes changes or enlargement of the prefrontal cortex, which is the chief executive part of the brain where logical decisions are made with reasonings as opposed to impulsive behaviours that happens in amygdala.

Functional Magnetic Resonance Imaging (fMRI) technique is forefront in observing the changes in the brain by capturing the images of the Blood Oxygenation Level Dependent (BOLD). However, fMRI does poorly in capturing the temporal information. EEG on the other hand records good temporal changes of the brain within few microseconds, while fMRI take couple of minutes to observe the changes. While on the other hand, fMRI does an excellent job in recording the spatial information activities via hemodynamic activities. Within a span of few seconds fMRI takes multiple images of a brain sweeping from left to right (sagittal), from the top (axial) and from front to back (coronal). These slices of images can be reconstructed back into a 3D model and with voxel-based analysis on the final result inferences can be made. Voxel is the unit volume in a 3D image processing approach equivalent to a pixel unit in 2D image processing.

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II. Literature reviews

Out of the five main types of the brain waves, based on the EEG brainwave patterns, the neurophysiological activities from meditation correlates to theta, alpha and gamma waves [4, 7, 8]. Dr. Richard J. Davidson and his colleagues published a paper [7] in year 2004, carried out an experiment on long-term Buddhist meditators using EEG. They observed self-induce sustained electroencephalographic high-amplitude gamma-band oscillation and phase-synchrony during meditation. A neuronal synchrony measure is a number that quantifies the level of synchrony of a large population of neurons within a network [22]. This can happen within a same lobe (intralobe; neighbouring electrodes) of a brain or among different (interlobe; long distance electrodes) lobes during the neural synchrony [7]. From the previous work, conscious perception is closely related to the neural synchrony of gamma-band frequencies (25-70 Hz) in EEG [14 - 18]. Observation of the ratio of gamma-band (25-42 Hz) to slow oscillatory activity (4-13 Hz) and neural synchrony are the core ideas of their experimental design. Statistical method Region of Interest (ROI) is used for inclusion/exclusion of electrical rods and ANOVA was used to find the correlation between the longevity of meditation and the presence of gamma-band frequencies in EEG. The analyses were done on the individual performances and the group performances. Neural synchrony was analyzed with the six neighbouring electrodes using the same statistical methods. The difference in the electrophysiological characterized by higher gamma-band oscillatory rhythms for the long-term meditator over the controls was observed. The analysis showed that the gamma activity was 30-fold greater in the practitioners compared with the controls even after adjusting the spectral power conservatively due to the muscle artifacts. The paper suggested neuroplasticity for future work.

In continuation from the paper [4], Davidson et al. carried out an experiment of gamma activity in NREM sleep of experienced mindfulness meditators for neuroplasticity [19,20]. In paper [7] meditators from Theravada tradition was included in addition to the Tibetan Buddhist practitioners only in paper [4]. Sleep is a spontaneous brain activity [21], the gamma-band thus generated is spontaneous given the sleep analysis. The objective goal of [7] is similar to paper [4], which is to find correlation between increased gamma power during sleep instead of active meditation in [4]. In paper [4], gamma-power was produced intentionally by actively practicing meditation, but here [7] it is produced spontaneously during sleep. Such spontaneity is due to the neuroplasticity or neurogenesis occurred during long-term practice of meditation according to [4]. There is significant change in the experimental design from participant screening, the inclusion/exclusion process, more devices and the statistical methods. In paper [4] the baseline is normal activity during awake state while in paper [7] is sleep state. Paper [7] included more devices due to the screening process; polysomnography, electrooculogram, electromyogram, plethysmogrpahy, pulse oximetry and position sensor. T-test was used to analyze sleep quality distribution and Independent Component Analysis (ICA) was used to filter the eye or muscle artifacts. Paper [7] has positively shown long-term meditators had higher NREM sleep gamma power compared to control in a parietal-occipital brain region. Now, how can this generalized over other traditions of meditations?

Papers [8] looked into various types of meditation practices (Vipassana, Himalayan Yoga and Isha Shoonya). It also observed higher 7-11 alpha activity in Vipassana group and lower 10-11 Hz activity in Himalayan yoga practitioners. The objective goals in [4][7][8], as presented, are all same in finding a positive correlation in the EEG gamma frequency range to the long-term meditation practitioners. To assess the significance of EEG spectral power across group or within subjects Analysis of Variance (ANOVA) was used. Their work showed the meditators from all three traditions exhibited higher parieto-occipital 60-110 Hz gamma amplitude than their control subjects as hypothesized.

Paper [24] makes the connection that the mental training of meditation is fundamentally no different than other forms of skill acquisition that can induce plastic changes in the brain. This makes the argument that meditation may be capable of the same way a pianist induces changes to the brain. The fMRI results from the paper showed less association with amygdala in the long-term meditators as opposed to the controls; suggesting the thought process of the meditators occurred in prefrontal cortex (PFC) which is the source of higher judgement with less impulsive behaviours. The reactive or impulsive behaviours usually stems from the limbic system specifically from amygdala which is the source of fear, anger and aggression. This shift of the allocation of the tasks to the prefrontal cortex is a clear indication of behavioral neuroplasticity. The findings from the paper showed neuroplasticity in both the subjects and the controls despite the differences in the active sites. In a similar active-controlled longitudinal experiment conducted by Chau et al. [25] also observed enlargement of the prefrontal cortex (PFC) just after eight weeks in the older people who never had prior meditation training. Such changes were not observed in the controls of similar age group. Paper [3] claims enlargement of the PFC has positive correlation to the positive valence perception in the subjects.

III. PROBLEM DESCRIPTION AND FORMULATION

EEG dataset and the fMRI images are acquired from the reputable sources. The dataset chosen carry information from both the subjects and the controls pertaining to the objective goal that the contemplative practice like meditation can possibly promote neuroplasticity and enhance focused attention. The EEG datasets from the subjects could be analyzed to show correlation between the meditation and affective brain sites through the observation of neural synchrony. Such neural synchrony could possibly promote neuroplasticity. fMRI images taken during the meditative task is hypothesized to help reveal the enlargement and efficiency of the brain activity.

IV. SYSTEM OVERVIEW

The proposed system is a two a two-pronged approach as shown in Figure 1, EEG dataset analysis and fMRI dataset analysis. Each approach takes independent route to establish the results. The results from these two different approaches can be clubbed together for interpretations.

EEG data requires signal processing capabilities to recognize the artifacts to filter out the signals blending with the signals of interests. These artifacts can be removed either by using software like MATLAB TOOLBOX or removing manually. The preprocessed dataset can be further pruned for Region of Interest (ROI) by Independent Component Analysis (ICA). On the final dataset, the correlation can be established by statistical tool like ANOVA. Most of the EEG dataset analyses of the review papers follow similar approaches.

The fMRI analysis on the other hand can be varying amongst the researchers where one way is depicted in Figure 2. The preprocessing of the brain images generally involves slice-time correction, realignment, coregistration (structural to functional), spatial normalization and spatial smoothing. General Linear Model (GLM) is a widely used approach on the preprocessed 3D brain images to calculate the unknown weights that can be used to find out the linear contrast thresholds.

GLM gives the output of each BOLD (Brain Oxygen Level Deference) signal with respect to the neighbor voxels, where each voxel is the individual three-dimensional input vector [X].

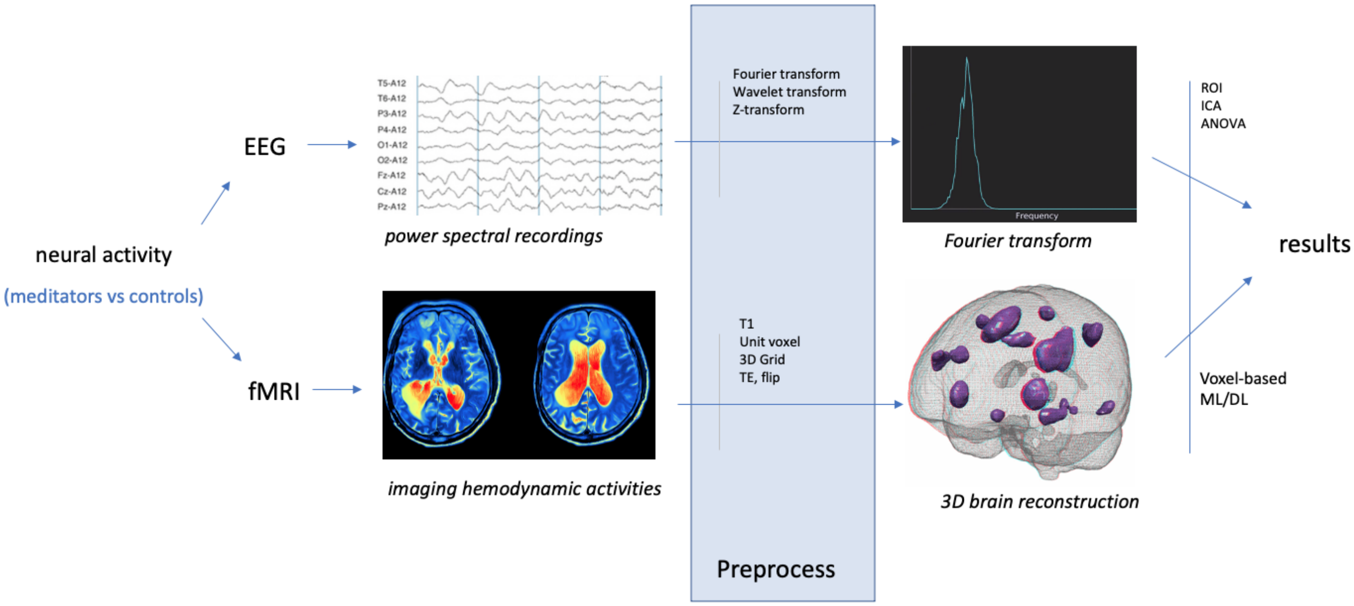

Fig. 1. A two-pronged data analysis of EEG dataset and fMRI images converging to a common result that require interpretation based on the logic inferred by the result

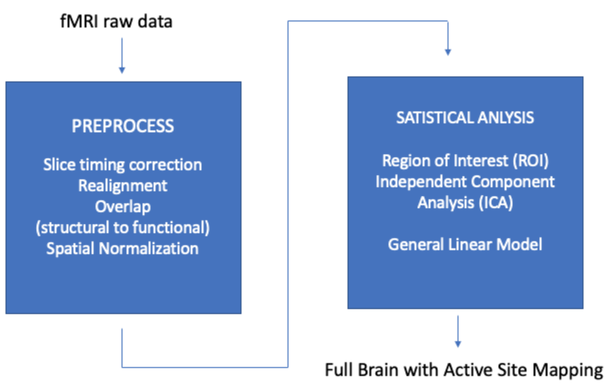

Fig. 2. Flow-chart depicting the architecture of fRMI raw data processing steps and the statistical analysis with GLM

The regressor from MATLAB ToolBox automatically finds the known weight vector [w] which contains a set of continuous values that optimizes highest discriminating power by lowering the error (SSE) against background noise. The baseline vector is established from the image taken when the subject is not actively performing the task (meditation).

$$[BOLDsignal] = [X] * [W] + [baseline]$$

where SSE is optimally minimized

V. Proposed Solutions and Comparison to the Literature

The proposed solutions are designed to match with the methods used in the literature reviews as there is not metadata generated from this project. This paper uses an existing data that is published for research purposes. As the preprocessing techniques and the analytical methods are also borrowed from the literature reviews, the results from this paper are expected to be same along with those that are published.

VI. Discussion and Conclusion

There seems to be a decent scientific progress made in the field of meditation after 50 years mainly due to potential application for mental health treatment and fitness. The fact that the concept of meditation is relatively new in the western culture may hinder its application in the clinical field any time soon. There are more than 12 different types of meditations to choose from which only adds to the confusion.

The upside is, among several types of meditations, the scientific finds so far observed clear correlation between the longevity of the practice of meditation and high gamma wave presence that are not present in the controls. Some papers even claim, there is correlation in the change of neuroplasticity and meditation. So far from the different types of brain waves, the meditation research seems to revolve around theta, alpha and gamma waves, excluding delta and beta waves. The gamma-wave seems to be the standard trait to establish the experimental designs for the scientific findings.

Signal processing continuous to pose challenges in the brain signal analysis. The signal potentials generated from the brain are very small compared to the signals generated by eye movement and other muscle twitches. Such low signal-to-power ratio pose challenges to the device sensitivity, data acquisition, signal filtration, data preprocessing thus spilling over to the data analytics. Other challenges could be, among various civilizations, religions, belief system, nations, cultures, way of living, diets, etc. all play role in shaping up the workings of their brains. A study in one set of community many be able to generalized over other groups of communities. The study of the neurophysiological activities appears to remain challenging for many more years to come.

In the eastern part of the world, their culture is mostly based on the “mind over matter” concept, which implies that the physical health of the body is very dependent on the mental well-being. Some even claim the healing power from the mind. If such statement is true, the scientific research in the field of meditation should be at the highest priority from the public health prospective.

Our brains are constantly changing for better or for worse. One should obviously strive for the better, and more importantly so in the knowledge of how-to. The long-term meditators are believed to have better control over their mental dispositions, their well-beings, their emotional controls and their focus regulations. There could be a few transferable knowledges into the non-pharmacological application for the treatments of the mental health disorders. The cost of the pharmaceutical products is perpetually going up while the knowledge of meditation is available free of cost. There are varieties of traits of meditations that may suit to the personal choice. One can even come up anew on their own based on the existing ones.

As a recurrent theme in all the researches, signal processing during the data accusation pose continuous challenges due the artifacts from the muscles and other involuntary physiological activities like breathing and eye blinks. The brain computer interface technologies such as EEG and fMRI techniques are also evolving as there is always need for a better of capturing the brain activities. At this point, fMRI suffers in recording the temporal information and EEG lacks spatial information. In many of the experimental settings, both of these modalities are used due the shortfalls in their respective measuring devices. New technologies that can capture both the spatial and temporal information can open new doors in the upcoming researches.

Various interpretations can be drawn based on the inferences made on the results generated from the statistical analyses. The inferences made here can be an area of hotly debated topics as understanding of our brains is at the early stage. Yet, it sets another point of reference which either proven true or false at the latter stage. Based on the researchers’ cultural backgrounds and upbringing there could be many ways biases find their way into the interpretation of the results.

The author believes at this point, proper sleep patterns, healthy relationships, physical exercises, kind and caring hearts takes precedence over meditation for a healthy mind. But when it comes to a time to delve deeper into meditation, the scientific findings will help guide one into making a proper decision, whether at the individual level or for the clinical applications. The author believes that the success in this field could bring a measurable impact in the mental health community.

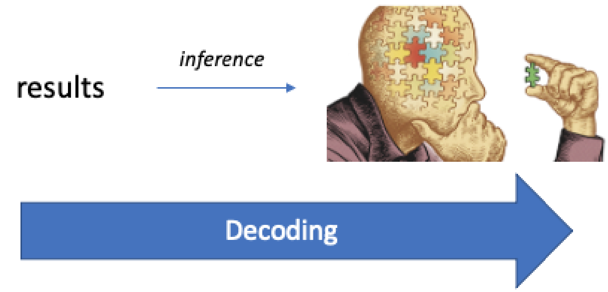

Fig. 3. The results generated by the statistical analysis from the encoding process on the EEG and fMRI datasets could lead to different interpretations by the inferences made on the results. The inferences part is treated as decoding of the brain signals.

Conflict of Interest:

The author declares that there is no conflict of interest regarding the publication of this work as there is no funding for this project.

Acknowledgement:

Immense thanks for the unwavering support and guidance from the project supervisor Dr. Thiago E. A. de Oliveira of Lakehead University, Computer Science Department.

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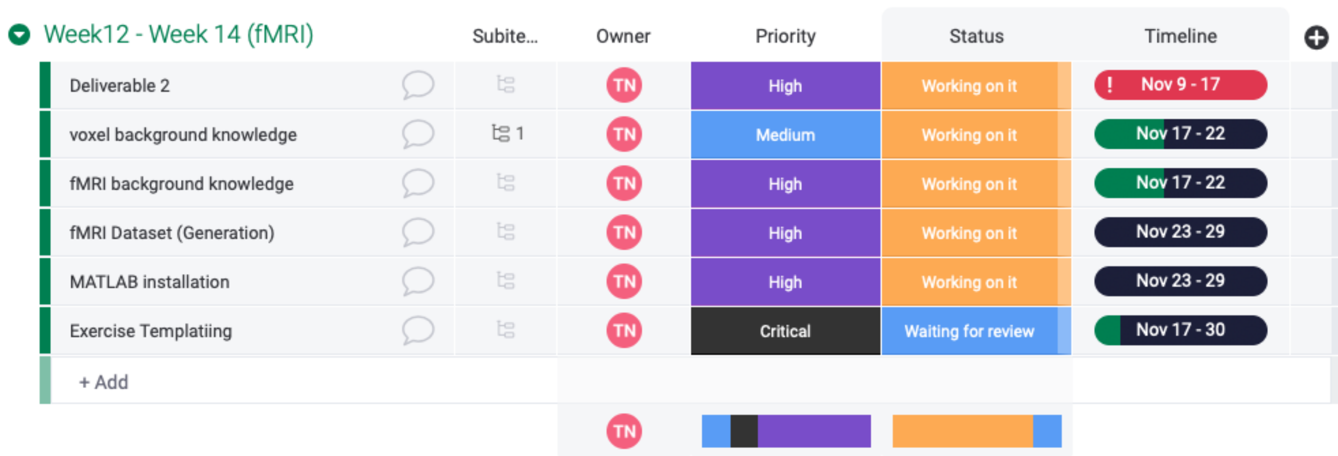

Fig. 4. Appendix1: Using the online project management app Monday.com, the screenshot capturing the table-view of the task allocation

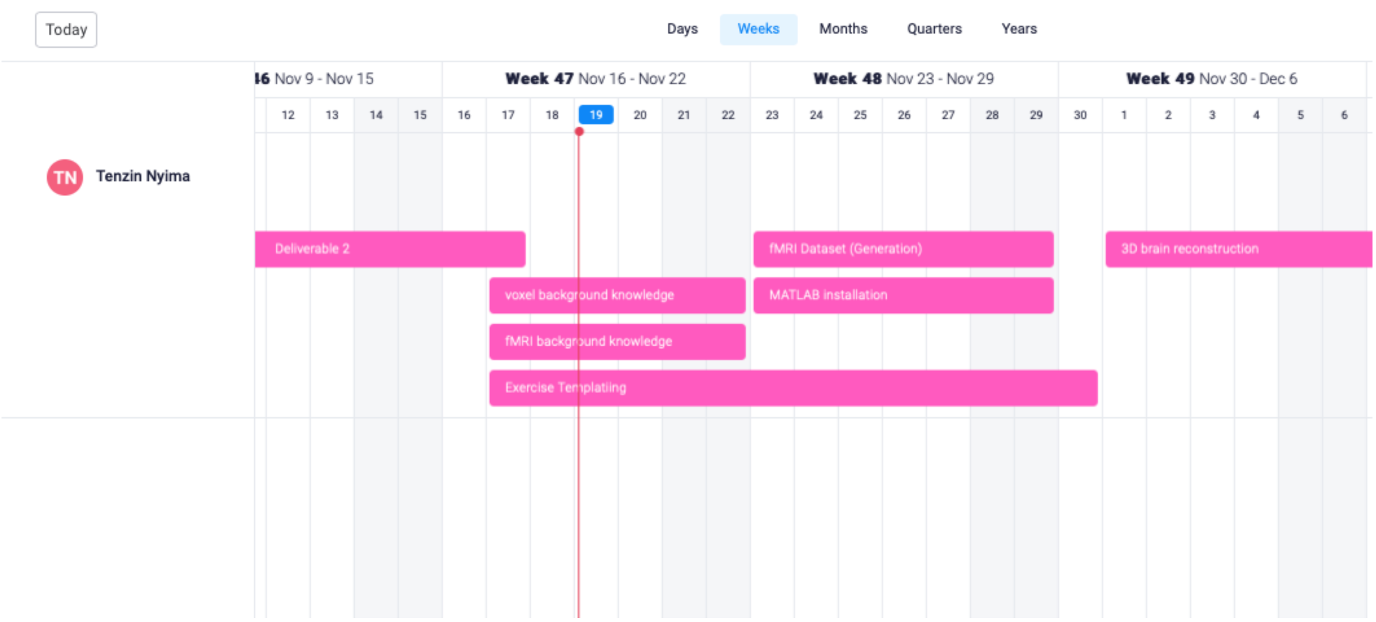

Fig. 5. Appendix2: Using the online project management app Monday.com, the screenshot capturing the timeline-view of the task allocation

Timeline

Task	Development mode	Timeline (Fall 2020)	Remarks
EEG data accusation	sprint	Oct 19 – Dec 31	paused
EEG data preprocess	sprint	Oct 19 – Dec 31	Paused
Deliverable 2	--	Nov 17	submission
Voxel foundation	--	Nov 17 – Nov 20	Lecture videos
MATLAB installation	--	Nov 17 – Nov 20	Google search
fMRI data accusation	sprint	Nov 20 – Nov 30	dataset to be generated
Exercise dataset (templating)	sprint	Nov 17 – Nov 30	base template code
demo dataset preprocess	sprint	Dec 1 – Dec 7	MATLAB* && python
Voxel (ML/Deep Learning)	sprint	Dec 8 – Dec 15	MATLAB* && python
3D brain reconstruction	sprint	Dec 15 – Dec 31	MATLAB* && python

Fig. 6. Appendix3: The timeline depicting the project dateline targets from Nov 17 till Dec 31