RESEARCH ARTICLE

A Framework for Neuroplasticity Feedback Control

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ABSTRACT: Humans are complex organisms, people can think, learn, and develop new skills. The difference between humans and other organisms is the factor of neuroplasticity. By being able to alter the networks inside the brain to adapt to new tasks and environments, humans can become more advanced. This experiment used Electroencephalography (EEG) technology to record brain wave data from a total of 3 participants. The objective of the experiment was to explore the balance between exploration and exploitation type tasks to understand a participant's optimal range of learning. The experiment aims to apply the concepts of soft-wiring and hardwiring in the brain to high cognitive conscious activity and low innate unconscious activity respectively. A framework for neuroplasticity feedback control is proposed, where neuroplasticity is measured by the brain activity from the performance of each type of task, and task duration is used to generate the targeted neuroplasticity for the participants.

KEYWORDS: Physiology, Neuroplasticity; EEG; Exploration; Exploitation; Declarative Memory; Procedural Memory.

Introduction

In the animal kingdom, many organisms live simply to survive; therefore, many of the techniques exclusive to their species are hardwired into their brains once they are born, or only take a few days to develop and strengthen. However, humans are more complex, their early development of the brain allows learning of new tasks and mastery of skills. A variety of networks are constructed in a child's brain as they grow.

To learn something new and allow it to become automatic is the representation of neuroplasticity. This leads to resilience and a growth mindset which are continuously adapted into educational environments.[1] In this type of setting, a growth mindset drives a student's intrinsic motivation to explore their learning with curiosity thus improving their educational performance. During learning, when students come in contact with something new, their brains become active to absorb the rules and concepts to complete the task. As the task is done more times, the repetitiveness helps the task become more natural and eventually automatic to the student in the form of declarative memory (e.g., applying math formulas) and procedural memory (e.g., playing piano).[2]

Performing these tasks involves cognitive processing from two types of memory: Declarative and nondeclarative memory. Declarative or explicit memory is the conscious storage and recollection of information. Declarative memory is usually the primary process of thought when referencing memory. Non-declarative or implicit memory is the unconscious storage and recollection of information. An example of a non-declarative process would be the unconscious learning or retrieval of information by procedural memory. In David Eagleman's book "The Brain", he made the analogy of the conscious and unconscious as software and hardware to describe a cup stacking competition, which he did with a child expert. While Dr. Eagleman was "using a general-purpose cognitive software", the expert had already "transferred the skill into specialized cognitive hardware".[3-5] In David Eagleman's cup stacking experiment, procedural memory represents the stage that skills are hardwired into the brain or burned into the unconscious mind.[2] This, in turn, requires less brain energy to perform the task, compared to a new player, who uses a lot of cognitive power and effort in the conscious mind to perform the same task. Therefore, the degree of how much a skill has been hardwired (i.e., neuroplasticity) can be measured by comparing the brain activity of an experienced player with that of an amateur player.

The software and hardware of the human brain are constantly changing. This brings up the balance between exploration and exploitation. While exploration tasks "burn" new knowledge into our brain's neural networks, exploitation tasks reuse and consolidate our brain's existing network.[6] Both education systems and business organizations are promoting a balance between both activities so that the organization can be innovative and systematic in the long run.[7] These two activities are also commonly used in machine reinforcement learning to assist machines in completing cognitive tasks such as going through a maze, -where sometimes the machine performs in an exploration mode (to take more risks by trying possible paths). Other times, the machine performs in an exploitation mode by trying the best path based on current information.[8]

Many studies that observe the changes of the brain's software and hardware include recording brain wave activity using Electroencephalography (EEG) technology. EEG is a non-invasive measuring tool, where electrodes are placed on the scalp in designated positions concerning different sections of the brain. The brain waves that are recorded are separated into 5 frequency ranges: delta, theta, alpha, beta, and gamma.[9,10] Beta and gamma waves reside at the top with 13-30Hz and 30-44Hz, respectively. Alpha waves reside in the middle with 7.5-13Hz. Delta and theta are at the bottom with 1-4Hz and 4-8Hz respectively. High-frequency brain waves are dominant during the use of the conscious mind or the brain's software, while low-frequency brain waves are dominant during the use of the unconscious mind or the brain's hardware.[11] EEG headsets are

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commercially available such as the Muse headband used in this experiment.

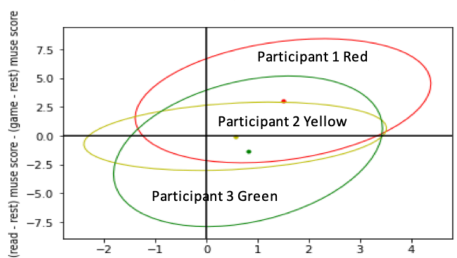
In this paper, a framework for neuroplasticity feedback control is proposed, where neuroplasticity is measured as the difference between the Muse EEG signals from the exploration task and the exploitation task, and task duration is used to achieve targeted neuroplasticity. A total of three participants performed an exploration task (reading) and an exploitation task (gaming). Each experiment had increasing duration intervals for the task and rest periods in between intervals. The Muse EEG headband was used to collect brain wave data during these experiments.

Results and Discussion

Part 1: EEG Measurements of Neuroplasticity:

A total of three participants participated in this experiment. The control for the experiment was a simple race car game task, which was assumed all subjects had experienced the same skills by using the unconscious mind. The control is used to compare the subject performing the reading task to measure the degree of neuroplasticity of their reading skills. Through this comparison, we can identify how much procedural memory for reading has been hardwired into the brain (see Figure 1).

Part 2: The Dynamics of Live-wiring:



	Active	Rest	Recovery
Exploitation (Ei)	A Ei	R Ei	S Ei = A Ei – R Ei
Exploration (Er)	A Er	R Er	S Er = A Er – R Er
	A Ei – A Er		S Ei – S Er

Figure 1: The correspondence between brain activity and recollection of exploration and exploitation activities.

Instead of studying a large number of subjects, we focus on three subjects and study the dynamics of each subject in terms of how EEG changes with time. For subjects still relying a lot on conscious cognitive effort, as reading activity time increases, EEG activity decreases, showing that subjects are transferring cognitive power into the unconscious mind as it becomes more adapted to reading material (see Figure 2). The concept of live-wiring represents the adaptive ability the brain has to new stimuli from the environment and experiences.[11] The repeated experiments of reading tasks (with increasing task durations) showed a steady decreasing trend in the work to read the novel, which shows the acceptance of the task and the beginning of the hardwiring process.

Part 3: A Framework for Neuroplasticity Feedback Control:

A framework for a neuroplasticity feedback control algorithm is proposed as the time control of a reference activity that is no longer needed, because the comparison is no longer interpersonal, the control is the initial state of the person.

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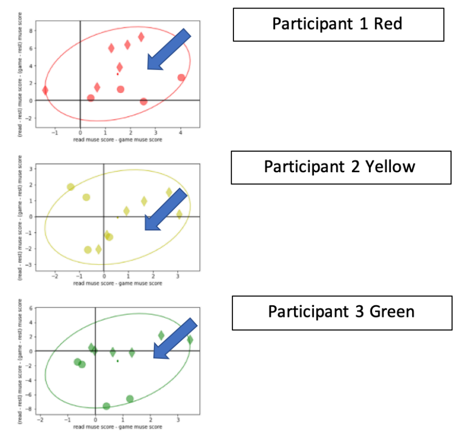

Figure 2: Separated graphs of each participant, circles represent experiments with thirty-minute intervals, and diamonds represent 5,10, and 15- minute intervals. As time increases, the cognitive activity is transferred to the unconscious mind as shown with the graphs.

1. Initially, measure neuroplasticity of a task from the Muse score at the skill, with a fixed duration of rest
2. Select a setpoint for the Muse score.
3. Increase task duration with a fixed duration of rest (if the Muse score is more than the setpoint)
4. Decrease task duration with a fixed duration of rest (if the Muse score is less than the setpoint)

A practical application for students is to reduce studying anxiety. For example, if the student wants to finish his study in a short amount of time, he may feel anxious and under pressure, requiring high brain activity; the plan is to increase task duration such that the student has time for the necessary cognitive processes. Alternatively, if the student already feels relaxed and calm, he/she may plan to decrease task duration to explore other challenging cognitive tasks.

An embodiment of the feedback control algorithm is the balance between exploration and exploitation portions of a task.

1. Initially, measure neuroplasticity of a task from the Muse score at the skill, then a fixed duration of rest
2. Select a setpoint for the Muse score.
3. Increase the exploitation (decrease the exploration) portion of the task duration with a fixed duration of rest (if the Muse score is greater than the setpoint)
4. Increase the exploration (decrease the exploitation) portion of the task duration with a fixed duration of rest (if the Muse score is less than the setpoint)

4s shown above, for a student to reduce study anxiety, he/she can also increase the exploitation portion of the task duration, which requires less brain cognitive activity. Conversely, if the student already feels relaxed and calm, he/she may plan to increase the exploration portion of the task duration such that the student explores more challenging tasks with higher brain cognitive activity.

Conclusion

In this experiment, we tried to show the existence of hardwiring in the brain when completing similar tasks repeatedly over some time. Through experimentation, the data showed

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how as time increased, the activity in the brain decreased. This means that the brain has adapted to the task and the cognitive work that corresponds to the task. By the time the brain is performing the task for the fourth or fifth time, activity in the brain is clustered towards the 3rd quadrant of the coordinate plane figure. With this in mind, the feedback control algorithm is applied by finding the optimal range where activities begin to become hardwired in specific participants.

Methods

The Muse headband contains seven electrodes, two on the forehead (prefrontal cortex), one behind each ear (temporal lobes), and three more electrodes as references (see Figure 3). The brain waves recorded with this device are combined into one signal moving between 3 mental states of calm, neutral and active.

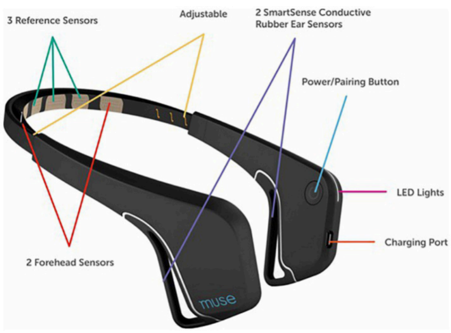

Figure 3: The Muse Headband.

In this experiment, 2 male middle school students and 1 adult male were tested for this change from soft-wiring to hardwiring by using a reading task (i.e. reading "Lord of the Rings, which all participants are unfamiliar with) and a gaming task (i.e. playing simple race car game, which all participants are familiar with) in the same environment (i.e. same room on the same recliner chair at the same time after 4 pm when the brain is most effective in learning[12]). The gaming task was used as a control, representing the hardwired mindset, a basic understanding of the controls was all that was needed. The participants would drive in a limited environment, much like how the brain continues to fire its neurons in a specific pattern for a task. The reading task was the task that was used to measure the change in the neural activity from soft-wired to hardwired. The reading task was tested in intervals of 5,10, and 15 minutes, with a 5-minute rest in between, then it was tested again for 30 minutes still including the 5-minute rests. Both experiments were repeated twice on the same day. Then for four days, this process was repeated, to gather all of the data. The data was processed using DataPlotDigitizer to convert Muse brainwave data into data points and used Python to create the clustered histograms.

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Charley Wan is a 10th-grade student who attends Central Bucks East High School. Along with his scientific interests in both physics and chemistry, social sciences have piqued his curiosity in delving into the complexity of human brains and their interaction with the world. He aims to study computational neuroscience.