The neurological effects of subgoal-based learning

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<u>**Table of Contents**</u>

Abstract……………………………………………………………………………..............3

Introduction……………………………………………………………………………....4

Literature Review………………………………………………………………………..6

Methods…………………………………………………………………………………..8

Expected Results…………………………………………………………………...…12

Discussion………………………………………………………………………….......12

Conclusion……………………………………………………………………….…...13

Future Directions…………………………………………………………………….……14

Citations…………………………………………………………………………......15

Abstract

The inclusion of subgoals in instructional materials has been shown to help learners be more successful solving novel problems. However, there are no studies on the neurological effects of this learning methodology. Cognition can be quantified as changes in alpha, beta, and theta waves in the frontal cortex on electroencephalogram (EEG) readings. This study is designed to determine whether subgoal learning leads to stronger neural engagement compared to a learner just memorizing steps. Fifty neurotypical college students from the Georgia Institute of Technology will be recruited to partake in this educational study. Participants will wear an EEG throughout the entirety of the experiment. Each participant will be given a set of instructions on how to complete physics problems dealing with motion and Rubik's cube conceptual learning tasks. Participants will be given step by step instructions; half of the participants will have those instructions enhanced with subgoals that provide the purpose for groups of steps. These conditions will be randomly assigned. After being given time to learn the concepts, participants in both conditions will be asked to complete identical sets of motion and Rubik's cube tasks while verbally explaining their thought process. EEG readings will be observed and analyzed to determine whether there was a greater increase in power of alpha, beta, and theta waves throughout the learning and problem-solving portions for participants in the Subgoal Condition relative to the No-Subgoal condition. It is hypothesized that the Subgoal Condition will show greater increases in alpha, beta, and theta waves overall, and that theta waves will show a particularly strong increase at the moment of subgoal completion. Data collection will begin once COVID safety measures are put in place.

Introduction

In learning conceptual skills, students tend to find it very challenging to solve novel problems when there are minor changes between training and test problems. This is largely due to the fact that in learning skills that require hierarchical organization, students often learn a list of steps that will aid them in solving problems just like the ones they study. However, when given a novel problem, these steps will not aid the learner because identical steps cannot always be used to solve conceptually similar problems (Catrambone, 1998). For students to be able to effectively learn, they need to be able to give context and meaning to the information at hand and feel as though the instruction they are given is relevant to a broader topic (Kitchel, 2007).

Subgoals are a form of hierarchical learning that has been demonstrated to help students form connections with conceptual information. Subgoals "represent a meaningful conceptual piece of an overall solution procedure" (Catrambone, 1998). Subgoals differ from sets of memorizable steps by having a cue that leads learners to group steps and self-explain why such groupings occur. This helps students understand the purpose of a set of steps, making them more likely to be able to solve novel problems with the same subgoals but different steps (Catrambone, 1998).

Subgoal methodology has shown significant positive behavioral results for learners; however there are no studies that explore the neurological impact of subgoal-based learning. This experiment will utilize an electroencephalograph, or EEG, to determine if there is a correlation between neural engagement and subgoal learning.

An EEG is a common neural monitoring method used to measure electrical activity in the brain by recording and amplifying microvolt electrical patterns on the scalp. EEGs are known for their strong temporal resolution because they are accurate to the millisecond in linking a stimulus with electrical activity change. There are five basic wavebands that can be viewed on EEG readings: alpha, beta, theta, delta, and gamma (Liu, Chiang, & Chu, 2013). Alpha, beta, and theta waves are most relevant to cognition and will be the focus of this experiment. Previous neuropsychological studies have found that during cognitive tasks, alpha waves have been found to be correlated with attention and learning of conceptual information, whereas beta waves have been found to be linked to cognitive processing (Berry, 2015; Bosel, 1992; Jaušovec, 2000; Liu et. al., 2013; Ray & Cole, 1985). Furthermore, theta waves in the frontal cortex have been linked to memory encoding and goal completion (Amin, Malik, Badruddin, & Chooi, 2014; Berry, 2015; Jang, Kim, Kim, & Lee, 2009). Therefore, an increase in the power of these wavelengths during an educational experience is correlated with an increase in cognition. This experiment will explore the power of these wavelengths using EEG throughout an educational experience to determine whether or not a Subgoal Condition leads to more active stimulation of the brain in comparison to a No-Subgoal Condition.

It is hypothesized that alpha, beta, and theta wave activity will be stronger throughout EEG readings for the Subgoal Condition, and theta waves will be particularly strong when subgoals are being completed, because these wavelengths have been found to be associated with cognitive processing, attention, memory encoding, and goal completion. Understanding if there is a positive neurological impact of subgoal-based learning will contribute to knowledge about the success of different learning methods.

Literature Review

Students are known to be able to better understand and apply information learned while their brains are actively stimulated (Jaušovec, 2000). For procedural tasks, previous research shows that novel problems are more effectively learned through the use of subgoals, which organize information into conceptual knowledge that can be applied, rather than by using a set of memorized steps (Catrambone, 1998). However, there is no neurological evidence that shows that this manner of learning is associated with increased brain stimulation, and to what extent it may be. This study examines whether a subgoal learning approach increases stimulation across the brain in students completing a procedural task.

Grouping conceptual tasks has been found to help learners more easily digest them. In a study where monkeys were taught to form groups of items, scientists noticed that when the monkeys were grouping novel items, their prefrontal cortex (PFC) activity increased (Antzoulatos & Miller, 2011). In a human EEG study in which prediction-error signals were observed in multi-step behavioral tasks, it was found that attention has a strong impact on the success of hierarchical learning task completion. The tasks were broken into subgoals and the EEG readings further found that the medial PFC processes information at the goal and subgoal level (Ribas-Fernandes, Shahnazian, Holroyd, & Botvinick, 2019). Other human imaging studies have further shown that there is prefrontal cortex activity during category learning (Reber, Stark, & Squire, 1998; Seger, Poldrack, Prabhakaran, Zhao, Glover, & Gabrieli, 2000; Vogels, Sary, Dupont, & Orban, 2002).

Higher levels of cognitive processing in the frontal cortex have been shown to correlate with increased EEG engagement. In an EEG learning study in which participants were asked to study human anatomy and physiology, all EEG frequency bands showed higher mean power during the learning portion of the experiment in comparison to the resting state, and EEG activity in the frontal cortex was associated with attention and working memory (Tyng, Amin, Saad, & Malik, 2017). In another EEG study that observed adults completing cognitive tasks such as multi-level digit spanning and mental addition, it was found that EEG engagement was correlated with integration of information and working memory load among other executive functions (Ray et. al., 1985).

Executive functions take place in the frontal lobe (Jaušovec, 2000). Activity in this frontal region correlates with changes in alpha, beta, and theta waves in EEG readings. Alpha waves, which range between 8 and 13 Hz in frequency and 30 and 50 μV in amplitude, are associated with consciousness (Liu et. al., 2013). Cognitive studies have also found that alpha activity can be correlated with attentional demand, conceptual learning, and semantic memory processes (Bösel, R. 1992; Ray et. al., 1985). Beta waves, which range from 14 to 30 Hz in frequency and 5 and 20 μV in amplitude, are associated with the frontal region and active thinking (Berry, 2015; Liu et. al., 2013). EEG studies have linked beta activity to cognitive processing (Ray et. al., 1985). Theta activity, which are bands ranging between 4 and 7 Hz in frequency with an amplitude of less than 30 μV, while typically associated with restfulness, have been found to be linked to memory encoding and goal completion in the frontal lobe (Amin, H.U. et. al., 2014; Berry, 2015; Jang et. al., 2009; Liu, N. H. et. al., 2013).

Subgoal learning is a form of hierarchical learning with positive behavioral results in problem solving. Because this education methodology is associated with effective executive functioning, attention, and cognitive processing, it can be expected that subgoal learning correlates with neurological engagement in the frontal cortex based on previous literature. If subgoal learning structures lead to a more engaging educational experience, as evidence suggests, alpha, beta, and theta wave activity will be stronger throughout the entirety of the instruction and problem-solving portions of experiments in comparison to a no-subgoal control group. Furthermore, because theta waves are associated with encoding of memory and completion of a goal, participants may show stronger power in theta waves when fulfilling a subgoal. Evaluating the impact of subgoal learning techniques in the frontal cortex with specific attention to alpha, beta, and theta waves can aid in the understanding of what helps learners succeed.

Methods

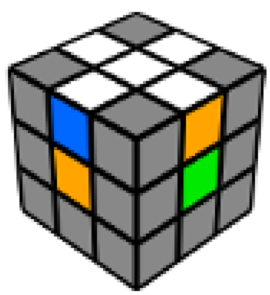
This study will recruit 50 students from the Georgia Institute of Technology to complete introductory physics problems and Rubik's cube tasks. The eligibility requirements will be as follows:

1) The participant must have taken at least one calculus course so that they could have the basic understanding needed to learn a preliminary calculus-based physics concept.
2) The participant must be at least 18 years of age because this is an adult study.
3) The participant must be proficient in English because all materials will only be provided only in English.
4) The participant has not taken a college-level (including AP) physics course. This is so that it can be ensured that the college-level physics concepts in the study are new to the participant and that they are only learning them through the Subgoal or No-Subgoal instructions provided.

Participants will be given instructions on how to approach a physics or Rubik's cube concept. Half of the participants will be given a set of instructions created using the subgoal model (Subgoal Condition) while another half of participants will be given a set of memorizable steps (No-Subgoal Condition). The conditions will be assigned to participants at random.

An example of how steps may differ between conditions follows:

Goal: Create a white cross on one face of the Rubik's cube as pictured:



Definitions Provided

Face= the 3x3 grid on any given side of the Rubik's cube

Top face= the 3x3 grid facing the ceiling at any given time

Center piece: the singular center of any given face

Edge piece= pieces that are directly adjacent to the north, south, east, or west of the center piece on any given face (these pieces create the cross around the center piece)

Corner piece= pieces at the four corners of any given face

Subgoal Condition:

1. Visualize a cross on the top face as shown in the picture.
2. Move edge pieces that only require one rotation to be put in their proper place on the cross.

a. If you want to rotate an edge piece to the cross but it would distort the current edge pieces that are in their proper position, move the top face so that you are creating an opening.
b. If a white edge piece is not one rotation away from being in its proper place on the white cross, you will want to move edge pieces so that they are one rotation away from being placed.
c. Ignore corner pieces and pieces of other colors during this process.

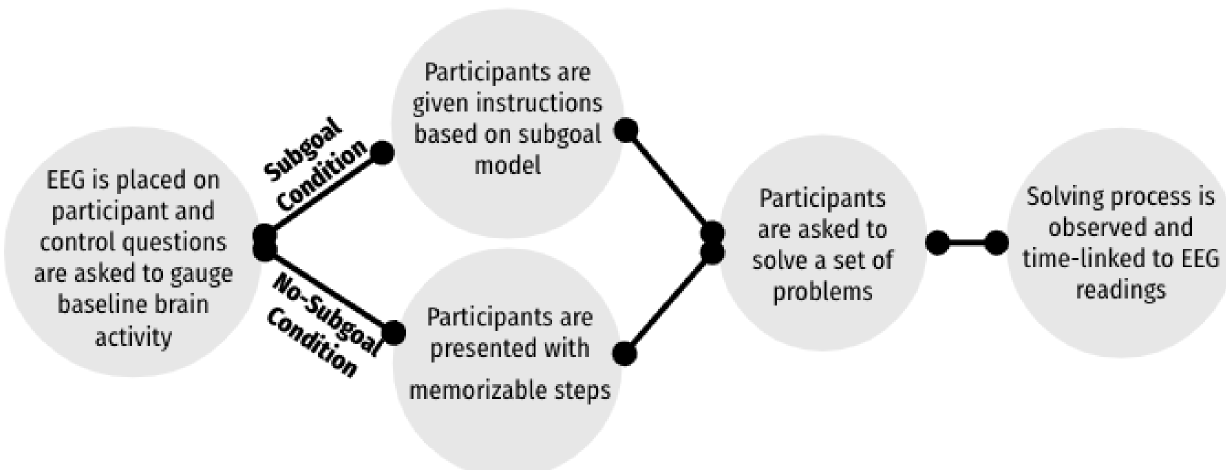
No Subgoal Condition:

1. Visualize a cross on the top face as shown in the picture.
2. If you want to rotate an edge piece to the cross but it would distort the current edge pieces that are in their proper position, move the top face so that you are creating an opening.
3. If a white edge piece is not one rotation away from being in its proper place on the white cross, you will want to move edge pieces so that they are one rotation away from being placed.
4. Ignore corner pieces and pieces of other colors during this process.

While the steps in the second condition are correct and may make sense to an expert, a novice may have trouble successfully completing novel problems without the guidance of defined subgoals.

After being given time to learn the material, participants in both conditions will be asked to solve a set of physics problems (which will be identical across groups) on a white board while verbally explaining their thought process, so that it is explicit when certain steps are being taken. Participants will be given three questions of increasing difficulty about solving for velocity using vector addition. The participants will then be given a Rubik's cube task and will be asked to complete it while explaining their steps aloud. An EEG will be placed on the participant's head throughout both the learning and problem-solving portion of the experiment and a video recording will be taken as the participant progresses through the tasks. The EEG readings will then be run through EEGLab in MATLAB to remove changes in the EEG readings that are insignificant and likely due to eye blinks and outside noise. The EEGLab readings will then be time-linked with the video and observed to determine which wavelengths changed throughout the experiment and at which instants they did. A two-way ANOVA test will then be performed to determine if there is a significant difference between readings in both conditions.

Figure 1. Flow chart depicting overall experimental procedure



Expected Results

In comparing participants under the Subgoal Condition to those in the No-Subgoal Condition, it is hypothesized that alpha, beta, and theta activity will be stronger in the frontal cortex throughout EEG readings for the Subgoal Condition, and that theta waves will be particularly strong when subgoals are being completed, because these wavelengths have been found to be associated with cognitive processing, attention, memory encoding, and goal completion.

Discussion

The neurological objective of this study is to determine whether participants show stronger power in alpha, theta, and beta waves in the Subgoal Condition to indicate increased cognitive processing. Additionally, the temporal resolution of EEG will be utilized to determine whether or not there are increases in power of theta bands at the time that a subgoal is being completed. These neurological results will be analyzed in congruence with the level of success on novel problems in both conditions. Due to the COVID-19 pandemic, data are yet to be collected.

Grouping tasks, similar to subgoal learning, have been found to increase prefrontal cortex activity according to several neurological imaging studies (Antzoulatos & Miller, 2011; Reber, Stark, & Squire, 1998; Seger, Poldrack, Prabhakaran, Zhao, Glover, & Gabrieli, 2000; Vogels, Sary, Dupont, & Orban, 2002). Activity in the frontal cortex can be associated with attention, working memory, and integration of information (Ray et. al., 1985; Tyng, Amin, Saad, & Malik, 2017). These executive functions, among others, are quantified neurologically as EEG engagement in alpha, beta, and theta waves in the frontal lobe (Ray et. al., 1985). Alpha and beta waves have a known association with attention and cognitive processing (Berry, 2015; Bösel, R. 1992; Liu et. al., 2013; Ray et. al., 1985), while theta wave activity has been linked to memory encoding and goal completion in the frontal lobe (Amin, H.U. et. al., 2014; Berry, 2015; Jang et. al., 2009; Liu, N. H. et. al., 2013). Building upon existing literature, it is expected that the power of alpha, beta, and theta waves in the frontal cortex will be stronger throughout the Subgoal Condition. Additionally, it is expected that theta waves will be particularly strong at the time when subgoals are being fulfilled. Lastly, it can be predicted that participants in the Subgoal Condition will perform more successfully on novel problems.

If subgoal learning correlates with stronger stimulation of the brain as well as higher success rates on problems, it may encourage educators and learners to adopt more effective teaching paradigms that have proven effects on neural activity, such as categorical learning methods. Educators may find this information particularly useful to structure their teaching in a way that more actively engages their students and produces higher success rates on novel problems. Learners may also use this information to self-teach and improve upon metacognitive skills.

Conclusion

Cognition is correlated with higher power in alpha, beta, and theta waves shown using electroencephalography. Because subgoal learning has led to higher success rates on novel problems, it is hypothesized that there will also be a higher power of alpha, beta, and theta waves in a Subgoal Condition versus a No-Subgoal Condition. Furthermore, it could be expected that the power of theta wavelengths will be markedly higher at the moment that a participant in the Subgoal Condition completes a subgoal.

Future Directions

This study will be properly conducted following the pandemic and depending upon the safety of running in-person participants. The methodology used will be identical to those outlined in the methods section, with the addition of the following:

1. To avoid transmission of the COVID-19 virus, both the researcher and participant will be required to do a COVID pre-screening and temperature check before entering the lab.

2. The participant and researcher will both be required to wear masks and gloves.

3. Any materials that are being used during this study will be disinfected before and after the participant leaves the lab.

4. The researcher will wear a face shield and get tested for COVID weekly as a precaution.

Once 50 or more participants have completed the study, the data will be analyzed. Depending on the results, follow-up studies will be conducted. Should consistent data show that subgoal learning structures lead to more neural engagement and higher success rates on novel problems, this information would be disseminated to school systems and learners to improve education.

Citations

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