“The Thinking Cap 2.0”: Preliminary Study on Fostering Growth Mindset of Children by means of Electroencephalography and Perceived Magic using Artifacts from Fictional Sci-Fi Universes

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ABSTRACT

Interventions aimed at promoting a growth mindset in children range from teaching about the brain’s ability to change to playing computer games. In this work, we explore a novel approach to foster a growth mindset by means of interaction with a "magic hat” system which consists of using objects from sci-fi and pop-cultural references like *Avengers* or *Star Wars*. The artifacts are “enhanced” with embedded Electroencephalography (EEG) electrodes. In an initialization phase, the “magic hat” uses established Brain-Computer Interface algorithms to recognize certain mental processes of the child and the child is then able to use their brain signals to control a robot. We report on an experiment that validates the system with children who were asked to solve math problems. We evaluated their mindset before and after use of the system. In comparison with a control group, the children who used the system self-reported having a stronger growth mindset.

Author Keywords

Mindset, Brain-Computer Interfaces, Magic; Pop-culture; EEG

CSS Concepts

Human-centered computing → Human computer interaction (HCI) → User studies; Social and professional topics → Children

INTRODUCTION

Several research experiments have shown the power of psychological interventions to meaningfully improve the academic performance of school children and students [12, 51]. Most of these interventions are based on providing the students with a workshop/lectures about the structure, function and plasticity of the brain. Such neuroscientific information is particularly effective when applied to explain a so-called “incremental theory” effect or growth mindset – which explains intellectual ability to students as something that can be grown and developed over time in contrast with “entity theory” or fixed mindset, where intellectual ability is seen as something fixed and unchangeable over time (terms introduced by Dweck in 1988, [13]). Example of how students can vary in their implicit theories, from more of a fixed or entity theory of intelligence or personality to more of a malleable or incremental theory is shown in Table 1 [50].

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Although social-psychological or academic-mindset interventions show improvements in academic performance of students over time, they pose several challenges in practice [16]. First of all, almost all of these interventions require extensive training of participating faculty, and careful context and timing of intervention delivery. Currently these interventions are still mostly performed in-person, which limits their scalability and means the success of the intervention is highly dependent on the knowledge and experience of the person delivering it. For example, parents and teachers may believe that when their child/student struggles in a subject it is best to acknowledge that it is not his/her fault—that it simply is not his/her “strength”—and to encourage them to focus on their successes in other domains/subjects [34]. However, research shows that this strategy grows out of an *adult’s* entity theory: the adult’s belief that a struggling student has low ability in that area and will never do well in it. This, in turn, can create low confidence and poor resilience in students.

In order to overcome these challenges, we focus in our work on building a system that offers psychological interventions, thereby addressing the problem of “demotivating” messages from adults as well as scaling constraints. This paper builds on the “Magic Hat” system [21], a wearable system that communicates a combination of effort and ability praise in order to foster growth mindset of the student wearing it and thus, have positive consequences for their motivation. The Magic Hat is designed after the Sorting Hat from *Harry Potter* fantasy story series [37,38], which is equipped with an embedded Electroencephalography (EEG) headset and a Bluetooth speaker (Figure 1, top left and Figure 3, left). In an initialization phase of the experiment, the Hat uses established Brain-Computer Interface (BCI) algorithms to recognize and report on certain mental processes to the child. In the usage phase, the Hat provides verbal praise for a combination of effort and ability to improve the child's resilience. The authors reported on an experiment that tests the system with children that were asked to solve math problems as compared to: the same system which does not have any EEG headset inside and a system which only has EEG headset but no *Sorting Hat* component in addition to a control group, which did not include any EEG or *Hat*. The authors evaluated the mindset of children before and after use of the system. In comparison with a control group, the children who used the system self-reported having a stronger growth mindset and showed increased persistence on problems.

However, there are several limitations to be acknowledged in this work. Firstly, the authors picked up one magic universe and they did not propose any personalization options. Second limitation is the BCI system the authors used, in particular the hardware, an EEG headset, which is not very cheap ($800) and a bit bulky. These limitations lead to a bigger discussion around the fact that children were primed when performing this study and perceived it as cool. It is interesting to try to further address this issue and to better understand the dimension which influences each participant mostly, by comparing different form-factors of the system coming from different sci-fi and magical universes where the choice of the preferred universe comes from the child themselves, as well as different BCI headsets, which are cheaper and more lightweight than the one used in the initial study.

We thus hypothesize that using such customized system can thus lead to fostering growth mindset even further than a pre-defined system, like the initial version of “Magic Hat”. We present a “Magic Hat 2.0” which: 1. Uses different artifacts coming from different universes (e.g., tiara from Wonder Woman); 2. The choice of the universe and artifact is based on the child’s preference only; 3. A very lightweight, flexible EEG band is used in this study. In this paper, we report on experiment that tests the use of such system with children.

RELATED WORK

We define the main components of our contribution which we use as:

- **Magic familiarity.** Using an object or representation of a favorite hero associated with magic and fantasy – the Sorting Hat from *Harry Potter*; magic tiara from *Wonder Woman*; a Master Yoda mask from *Star Wars*, etc;
- **Pop-cultural reference.** Addressing very popular fantasy story series, comics, books or movies – *Harry Potter*; *Avengers*, *Star Wars*, etc;
- **Neuroscience.** Using a technology which provides access to brain activity of the user – non-invasive Brain-Computer Interfaces in the form of an electroencephalograph (EEG) headset.

	Entity Theory	**Incremental Theory**
Goals	Look smart	Learn
Value of effort, help and strategies?	Higher	Lower
Response to challenge	Tendency to give up	Work harder and smarter
Changes in grades during times of adversity	Decrease or remain low	Increase

Table 1. Summary of academic mindsets, for those with more of an entity versus incremental implicit theory of intelligence. Adapted from Yeager and Dweck [50].

Perceiving Magic and Mindset Interventions

Perceiving magic is considered to be a valuable tool to enhance children’s mental and physical wellbeing in a wide range of areas including motivation, engagement in treatment of disorders [17], therapy for addictions and maladaptive behavior [18]. Several programs like Healing Magic, Project Magic, Hocus Focus and Breathe Magic use magic for therapy purposes [2, 40].

A study of Subbotsky *et al.* [43] provides evidence that experiencing magic encourages children to be more creative. Children watched movie clips from a *Harry Potter* film that either did or did not contain strong magical content. Those who had watched the clips with the magical content were significantly more creative than those who had not.

Another interesting contribution is a Harry Potter Growth Mindset Study Kit for US teachers [42]. Though it does not report any actual results, it suggests a lot of textual evidence from the *Harry Potter* series to illustrate the heroes with both fixed and growth mindsets. For example, Hermione (one of the heroes from *Harry Potter*) shows multiple qualities of having a growth mindset, because she values learning, practices her spells, and seeks answers. This study includes several other examples, and then asks students to find quotes and heroes from the series which illustrate both growth and fixed mindsets, as well as how a growth mindset helps a character or how a fixed mindset hinders him/her.

We refer the reader to the paper of Bagienski and Kuhn [2] which presents a framework of using magic to enhance wellbeing from both empirical and theoretical perspectives.

Fiction, Personality Traits and Mindset

Books, movies, video games and other mediums have a strong effect and influence on social attitudes, personal and inter-personal relations as well as the perception of self. It is believed that spectators and readers tend to identify with those elements from the stories and movies they watch that are closer to one’s personal character [7, 45], such identification can also lead to changes in one’s perception of the self and environment. These identification processes can influence individual psychological states such as self-esteem [45], well-being [5], as well as an individual’s personality characteristics [10] values [7] and emotions [9]. For example, participants' Big Five personality trait scores — extraversion, agreeableness, conscientiousness, neuroticism, and openness — changed more after reading a piece of fiction than after reading a documentary-style text [11]. In another study, participants temporarily absorbed traits portrayed by film characters into their own self-concepts [39]. Crysel *et al.* [8] hypothesized that readers and viewers of *Harry Potter* identify themselves with House-specific personality traits that are congruent with their own personality traits. Ultimately, House assignment can provide its members with a feeling of belonging [35]. Dablander *et al.* [10] in part replicated the results from Crystel *et al.* [8] presenting evidence for the association between respondents' personality and the House they identified with.

Neurosciences and Mindset

Most of the interventions which promote the growth mindset are focused around the notion of neuroplasticity and explaining it to children or students in different ways. Examples include: talking about the brain; sharing new facts about it; building a brain model; creating a brain poster; reading about neuroplasticity as well as watching videos; discussing how neuroplasticity had helped in someone's life [28]. A lot of lessons on fostering the growth mindset happen during after school activities or workshops. The neuroscientific information about the brain provided during these lessons is particularly effective when applied to explain a growth mindset. The information on neuroscience is not only intrinsically interesting [29] but numerous experiments show that psychological arguments are more effective when they are accompanied by neuroscientific data [3]. Blackwell et al. taught a group of seventh grade students that intelligence is malleable [3]. Before the intervention, students' math grades had been decreasing, but after the intervention students' grades improved significantly.

Although these interventions are strongly based on neuroscientific findings, they do not provide any hands-on ways to integrate or replicate the neuroscientific studies and experiments within this mindset syllabus.

SYSTEM DESCRIPTION

The "Magic Hat" system is composed of the following hardware, software and feedback elements:

1. The "artifact": either the "Hat" which represents a Sorting Hat replica from Harry Potter series (Figure 1), or masks of sci-fi heroes like Captain Marvel, Captain America, Thor, Iron Man, Magneto, Darth Vader, Kylo Ren, Black Panther, Minnie Mouse, Wonder Woman's tiara and Master Yoda; all acquired from Amazon [1, 4, 49].
2. Two EEG headsets: an EEG Emotiv Epoc headset [15]. This headset was used exclusively with the Sorting Hat. Two Velcro stripes were added to the hat to hold the headset inside (Figure 2, top). Muse research edition, flexible band [6] (Figure 2, bottom). The band was used with all the masks and a tiara. One to two velcro stripes were added to the masks to hold the band inside.
3. a Macbook Air computer which runs a BCI algorithm to enable the detection of the brain signals as well as their classification in two classes. The computer is connected to the BCI headsets via a Bluetooth dongle.
4. a small rolling open-source robot from Sphero [41], which is used in the "intervention" phase of the study: the children can move it or to stop its movement (Figure 1, left). The robot connects to the computer via Bluetooth module as well. The computer issues commands to the robot to move it to stop. We call this control feedback.

In our study, we have 5 main conditions based on different combinations of the system's components:

1. **Hero.Active** or **Hero.A** condition uses the Muse band + any of the hero masks. The feedback e.g., the way the robot is moving, is based on the brain activity of the child.
2. **Hat.Active** or **Hat.A** condition uses hat and the Emotiv EEG headset. The feedback e.g., the way the robot is moving, is based on the brain activity of the child.
3. **Hat.Random** or **Hat.R** condition is the same as Hat.A condition except the feedback e.g., the way the robot is moving, is random and is not based on the brain activity of the child (previously recorded session from another child is used).
4. **Hero.Random** or **Hero.R** condition is the same as Hero.A condition except the feedback is randomized in a similar manner as for Hat.R condition.
5. **NEUTRAL** or **CONTROL** condition does not incorporate any of the aforementioned components of the "magic hat" system, such as EEG headsets, masks or hats.

Figure 1: "Artifacts" used in this study: Sorting Hat; Captain Marvel, Captain America, Thor, Iron Man, Magneto, Darth Vader, Kylo Ren, Master Yoda, Black Panther, Minnie Mouse, Wonder Woman's tiara.

More formally we summarize all the conditions in Table 2.

Cond.	Hat	EEG headset	Muse band	Hero mask	Feedback
Hero.A	N	N	Y	Y	Active
Hat.A	Y	Y	N	N	Active
Hero.R	N	N	Y	Y	Random
Hat.R	Y	Y	N	N	Random
Neutral	N	N	N	N	No

Table 2. Summary of all 5 conditions and their components used in this study.

Hypotheses

The main hypothesis is that interacting with a "magic hat" system will have a positive impact on fostering children's growth mindset as "magic hat" system incorporates all three notions of magic (hat/hero mask), pop-cultural reference (*Harry Potter, Avengers, Wonder Woman, Star Wars, etc*) and neuroscientific tool (EEG) that prove themselves effective in other mindset interventions. We also hypothesize that using the preferred hero mask with a light EEG band and a feedback component will be more effective than using a *Sorting Hat* + active feedback component. As previous study has already shown, a presence of the EEG headset itself as well as the presence of a hat will not be sufficient to make a significant difference on fostering a growth mindset.

More formally, we hypothesize condition dependent effects:

- **H1:** Participants in both Hero.A and Hat.A conditions will score higher on the post mindset assessment questions compared to the control condition (NEUTRAL).
- **H2:** Participants in the Hero.A condition will score higher on the post mindset assessment questions compared to four other conditions (Hero.R, Hat.A, Hat.R and NEUTRAL).

With respect to any other gains (learning, academic performance) from this short, single-shot encounter, we do not expect to see any condition dependent effects, since the impact of having a growth mindset associated on learning gains is typically a longitudinal effect.

We also hypothesize that participants in Hero.A condition will show more task enjoyment, more task persistence than children in four other conditions (**H3**).

Ultimately, we hypothesize that participants in Hero.A and Hero.R will score their experience with the masks higher regardless of the correctness of the feedback compared to Hat.A and Hat.R condition (**H4**).

Finally, we expect children in the control condition to hold pre- and post- mindset assessment scores in approximately equivalent numbers (**H5**).

Figure 2: Top: Emotiv Epoc headset; Bottom: Muse headband, flexible research edition.

EXPERIMENTAL DESIGN

Participants

Twenty-four children between the ages of 8 to 12 years old (age M = 11.67, SD = 1.09; 12 females) participated in the study. Participants were randomly assigned and counter-balanced across the three following groups with respect to their age and gender (8 children/4 females per group):

- **ACTIVE group**: children in this condition performed both Hat.A and Hero.A conditions;
- **RANDOM group**: children in this condition performed both Hat.R and Hero R. conditions;
- **CONTROL group**: children in this condition performed only Control condition.

The protocol was approved by the IRB of the institution where the study took place. Each caregiver and child received a $15 check as a thank-you for their time. 1 week prior the study took place, the experimenter sent an email to the parent/caregiver to collect the following information: age of the child; which grade the child was in as well as his/her most/least favorite subjects at school and their favorite sci-fi/magical universes and heroes if any. The list of all the universes and heroes was compiled and is present in Figure 1. with one exception: *The Sorting Hat,* was included by default.

Figure 3: Examples of assembled "Magic Hat" system. Left: The Sorting Hat from Harry Potter with Emotiv Epoc headset inside as well as a Sphero robotic ball next to it. Right: a tiara from Wonder Woman with a Muse headband inside.

Protocol

The experimental protocol followed seven stages: 1) welcome, briefing and pre-assessment questionnaires, 2) solving a math exercise sheet of medium difficulty, 3) intervention, 4) post-assessment questionnaires and debriefing.

Stage 1: Welcome, Briefing and Pre-assessment questionnaires

At the beginning of each session, the experimenter explained in great details the EEG and the BCIs, as we did not want to leave the children and their parent(s) with the impression of a "mind-reading device", as these technologies are sometimes perceived in the general literature and on TV. Both an Emotiv headset and a Muse band were presented to the children and their functioning and differences were explained.

Once consent forms were signed, the child filled a mindset assessment questionnaire. It probes children's beliefs about their own mindset through introducing two statements at a time and asking the child which statement they agree with more. The statements used in the questionnaire are based on Dwerk's mindset questionnaires from [12] as well as [21, 30]. In total, ten pairs of statements were presented to the child, one sentence representing a fixed mindset and the other representing a growth mindset. For example, one of the statements is a fixed mindset one: "*I like school because I'm really good at the things we do there*", and the other statement is a growth mindset one "*I like school because I learn to be better at things we do there*". Participants used the same questionnaire in both pre/post assessment parts of different experimental stages of the protocol, and thus, the questions were presented in randomized order and slightly rephrased.

Total time to complete stage 1 of the experiment was approximately 15 minutes.

Stage 2: Solving Math Problem-1

All the children were asked to work on a set of math problems, containing 24 expressions with multiplication, division operations or fractions. We asked them to solve all problems if possible. The set of math problems was strictly built based on the corresponding notions of grade the children were in. We compiled the problems from one source, a series of workbooks for grades 3 till 7 [48]. Dweck and her co-authors in their studies on mindset experimentally induced performance or learning goals in order to examine the patterns of cognition, affect, and behavior that followed from the goals [12, 13, 29]. They used achievement situations like solving different sets of problems, and in our study we decided in part to replicate their setup by using math problems as well.

After the children completed the set of problems, they were asked to respond to a series of questions that probed their desire to persist on the problems, their enjoyment of the problems, their perception of the quality of their performance, and their attributions for poor performance if any. Children rated their task persistence, task enjoyment, and performance quality on a scale from 1 (not at all) to 6 (very much). Task persistence was indexed by children's responses to the question "*How much would you like to take these problems home to work on*?". Task enjoyment was indexed by children's responses to the questions "*How much did you like working on this set of problems?*" and "*How much fun were the problems?"* Finally, children's judgements about the quality of their task performance were assessed by their responses to the question "*How well did you do on the problems overall?*" All the aforementioned measures were taken from Dwerk's studies [29]. After children responded to the measures described above, the experimenter additionally asked them about their most and least favorite subjects at school and why did they like/dislike them. As we did not want to bias or to prime them, we did not ask these questions in the beginning of the study but once this part was over.

Total time to complete stage 2 was approximately 10-15 minutes.

Stage 3: Intervention

Stages 1 and 2 were the same for all three groups, but stage 3 was different for each of the groups.

ACTIVE group

Hat.A condition

Once stage 2 was over, the experimenter brought the *Sorting Hat* equipped with the Emotiv headset as well as a computer and a robot. On the computer the experimenter had launched a BCI system from [24, 25] to control a robot using three mental commands: imagining a soccer ball, imagining a red card and staying in resting state (no imagination). These mental commands were associated to issue two corresponding commands to a robot: move and stop moving, resting state was not associated with any command for the robot. Due to the nature of BCI, the system requires the training/calibration to be done for each participant individually (brain activity varies across people, for a given person across several sessions and within the single session over time); thus we needed to perform a training for each child separately. The duration of the training is typically around 3 minutes. We will provide the details on the BCI system used in this study in the end of this section.

Once the training was over, the child performed a task for the duration of 5 minutes, where he/she tried to move the robot using his/her brain signals.

Once this intervention was over, the hat as well as the computer were taken away from the child's desk and he/she was proposed to evaluate the performance of the hat as well as their own. Children rated their task persistence, task enjoyment, and performance quality on a scale from 1 (not at all) to 6 (very much). The questions included: *"Would you like to take the hat home with you?" "Did you like playing with it? "How much fun was it?" "Would you like to bring it to school?" "Was the session, when you were moving the robot, accurate?"*. The other questions were more open-ended and included: *"What is your favorite universe (sci-fi/magic/anime/anything of your choice) if you have any?"; "Would you like to use the headset separately from the hat? Why?"*; "*How well do you know Harry Potter universe?"*; "*Can we call you a fan of Harry Potter universe? If yes, what do you like the most about it?"*.

Once the participant answered the questions, we had three tasks that we proposed children to pick up from, adapted to their grade and age group. One task represented a math sheet, very similar in difficulty and exercises to what they have been solving during *Stage 2* of the experiment. Sheet 2 represented another math sheet, but of high difficulty. And finally, sheet 3 represented a reading task of medium difficulty. Children were proposed to pick up any of the three tasks and to solve it. After the children completed the set of problems they have chosen, they were asked to respond to a series of questions that probed their desire to persist on the problems, their enjoyment of the problems, their perception of the quality of their performance, and their attributions for poor performance if any. This was the same set of questions as was the one administered during *Stage 2* of the experiment. The only small difference was that we added one question, "*Could you explain why did you choose the set of the problems among the three?"*

We then administrated the mindset assessment questionnaire which we described in *Stage 1* section. As discussed previously, this test slightly varied from the pre-test version.

Hero.A condition

The experimenter suggested a 5 minutes break, and then he brought a set of 12 A4 pages, each containing an image of all the artifacts and masks (including the hat) from Figure 1. The experimenter showed the images one by one to the child and the child was asked to evaluate how much they like the hero which is depicted on the image. Then the experimenter asked the child if he/she would want to try any of the artifacts, and if yes – to choose the artifact. If the child made a choice, the experimenter went to another room and brought back the chosen artifact with the attached Muse band to it (or the *Sorting Hat* with Emotiv headset, if the Hat was chosen). The experimenter also brought a computer and a robot. On the computer the experimenter had launched a BCI system to control a robot using two mental commands: being in engaged, focused state (e.g., performing mental calculus) and staying in resting state (no imagination). These mental commands were associated to issue two corresponding commands to a robot: move (engaged state) and stop moving (resting state). These mental commands were different than in the case of the Hat.A condition, as the Muse band only has electrodes on the pre-frontal cortex and no electrodes on visual cortex or motor cortex, thus performing mental imagery task is not possible with this form-factor. We performed a training of BCI system for each child separately. The duration of the training is typically around 3 minutes. We will provide the details on the BCI system used in this part of the study in the end of this section, as it is different from Hat.A condition.

Once the training was over, the child performed a task for the duration of 5 minutes, where he/she tried to move the robot using his/her brain signals.

Once this intervention was over, the artifact as well as the computer were taken away from the child's desk and he/she was proposed to evaluate the performance of the artifact as well as their own in a similar manner to condition Hat.A. We additionally included the questions of preference between Hat.A and Hero.A versions of the system and asked to explain their choices.

Once the participant answered the questions, we had three tasks that we proposed children to pick up from, adapted to their grade and age group, similar to Hat.A condition.

We then administrated the mindset assessment questionnaire which we described in *Stage 1* section. As discussed previously, this test slightly varied from the pre-test version.

RANDOM group

In this group the children performed Hat.R and Hero.R conditions. This group and the conditions were exactly the same as in ACTIVE group, except the feedback administrated to the children, was not based on their brain activity, but was randomized (a recording from another child from another session was used).

CONTROL group

Finally, CONTROL condition did not include any hat, BCI system or artifacts (Table 1). The experimenter took a copy of the child's math task he/she just solved during *Stage 2*, looked through it for 1 minute and then said "*You seem to work hard! Looks like you are going to be great in math today!*". A modified version of the questionnaire similar to other conditions was administered to children, but no questions about the EEG headset, or hat/artifacts were present in the questionnaire. The questions mostly included questions about favorite universes, as we still needed those answers for our statistical assessment of results. This condition though called CONTROL, was actually close to a "classic" growth mindset intervention, when the praise for effort would come from a parent or a teacher.

Once the participant answered the questions, we had three tasks that we proposed children to pick up from, adapted to their grade and age group, similar to two other groups.

Total time to complete stage 3 was approximately 25-30 minutes.

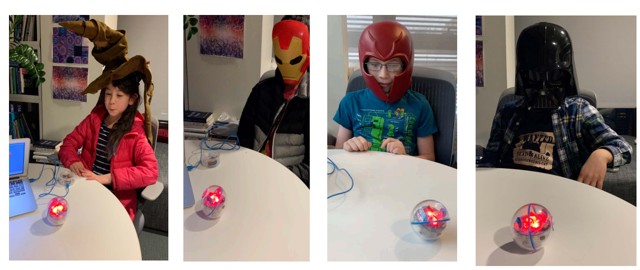

Figure 4: Participants trying to control a robotic ball while wearing different versions of the "Magic Hat" system; from left to right: the Sorting Hat, the Iron Man, the Darth Vader and the Magneto artifacts.

BCI System Used During Stage 3, Hat.A condition

We used an architecture from [25] as it is a real-time BCI system that only needs a small amount of data (1 trial) to be functional. The BCI system is based on a minimum distance classifier. The distance measure used is Spearman.

For EEG acquisition in this condition we used the Emotiv EPOC which has 14 electrodes [15]. The main motivation behind this choice was related to the fact that this headset is relatively compact and could be fitted easily inside the hat unlike some current EEG devices that have a form-factor of a cap, which might be harder to set up for our study. EPOC was also shown to be used in different mental imagery scenarios with children and adults [51].

For more details about the implementation, artifact removal and limitations of the proposed system, please refer to [24, 25], and we refer the reader to paper from Kosmyna *et al.* [23] to know more about the underlying mental imagery processes.

Training step was standard for BCI systems. For each of the BCI commands, the training trials were captured. A computer screen shows the images representing the commands for the robot. The images are successively enlarged in order to indicate to users what is the current class to train. Users have to imagine the associated image so that we can capture training signal for each of the classes. We instructed the participants to avoid moving unnecessarily during the training step.

Once the training was over, the participants had an opportunity to control a robot with their brain signals as described in Stage 3 of the protocol for Hat.A condition.

BCI System Used During Stage 3, Hero.A condition

We followed the signal processing pipeline proposed and presented in [19, 22].

We used engagement index E to calculate focused and relaxed states. This index E is modeled from Pope et al. [32], in which we input the averaged power of alpha, beta, and theta frequency components obtained from the Power Spectral Density (PSD) over 5-second sliding windows. We refer the reader to [22] for a full review of the engagement index, and its extensive usage with EEG bands of 1 to 6 channels. Next, we smooth E using an Exponentially Weighted Moving Average. This outputs a smoothed engagement index per 15 seconds E_{smooth} sent to the application.

Participants first went through a calibration phase. The calibration session determined the distribution of E from E_{min} to E_{max}, where E_{min} is low engagement (e.g., relaxation, eyes closed) and E_{max} is high engagement (e.g., solving arithmetic problems) [19]. Based on the minimum E_{min} and maximum E_{max} engagement scores collected from the calibration for each participant, we calculated a normalized engagement score for each participant between 0 and 100 as:

$$E_{norm} = (E_{smooth} - E_{min})/(E_{max} - E_{min}) \times 100$$

in a similar fashion to [19,32,46].

We divided the engagement index into low, medium, and high levels of engagement in a similar fashion to [19,32,46]. An engagement score of 0–30 is considered as low, 31–70 as medium, and 71–100 as high. The robot is activated (e.g., starts/stops moving) only when engagement index is high/low for at least 15 s (empirically determined duration accounting for the possible false positives in the classification output).

Stage 4: Post-assessment Questionnaires and Debriefing

Once *Stage 3* was completed, participants completed a mindset assessment questionnaire which we described in *Stage 1* section. As discussed previously, this test slightly varied from the pre-test version.

We then debriefed them shortly to 1. make sure that they will not leave the lab with any misconceptions about the scientific theories which underlined this study and study goals; 2. answer any additional questions that might have raised; 3. collect any additional feedback and comments from the children they wanted to express; 4. assure that all children left the lab proud of their performance.

Total time to complete stage 4 was approximately 10 minutes.

Total duration of the experiment was around 80-90 minutes.

To counterbalance our study, as there were two different conditions each participant underwent when assigned to one of three groups, 4 participants in each group started the experiment with the hat condition (regardless -.A or .R) and other 4 participants started with hero condition (regardless -.A or .R).

RESULTS

Let us first compare the distribution of mindset scores, both before and after feedback from each of the conditions. Our hypothesis is that before intervention, there shouldn't be any statistically significant differences in the mindset score distributions. In the post intervention setting, we expect that some conditions (specifically Hero.Active and Hat.Active) to lead to statistically significant differences in mindset scores. In both the pre-setting and the post-setting, the distributions are not normally distributed (Shapiro-Wilk significant: $p<0.01$). We cannot apply the standard linear model with a normal distribution and instead use a generalized linear model (from lmer in R) Analysis of variance with a Gamma distribution (suitable for strictly positive values, which is always the case here) and with the favorite subject, least favorite subject and subject chosen as random effects. The fixed effect was the condition. For the pre distribution, we have AIC= 98.6 and BIC=114,0 with a non-significant ANOVA (df=4, Chi.2=5.77, p=0.22), meaning that all group differences are non-significant, as hypothesized. In the post setting we have AIC=101.8 and BIC=117.2 with a significant ANOVA (Chi.2=20.28, df=4, p<0.0001). A post-hoc tests finds that there are significant differences between the following pairs: NEUTRAL - Hat.Active ($p<0.05$); Hero.Random - Hero.Active ($p<0.001$); NEUTRAL - Hero.Active ($p<0.01$). There were no significant differences between Hero.Random, Hat.Random and NEUTRAL. Thus, we can validate our first hypothesis (H1), see Figure 5.

The differences between Hero.Active and Hat.Active were not significant ($p=0.09$), however, we hypothesize that given more samples the difference would be likely to be significant. Moreover, the average effect size difference is of about 1 score point and the distribution of Hero.Active score points is much more compact (stdev=0.5) that for Hat.Active (stdev=1.06). As such, given current levels of evidence we must reject hypothesis 2 (H2).

In order to test for hypothesis 3 (H3), we now compare the distributions of Task 1, 2, 3 enjoyment and persistence scores for each condition. First let us examine persistence. For all the following tests, we will use the same generalized linear model: with the favorite subject, least favorite subject and subject chosen as random effects. The fixed effect was the condition. For ANOVA tests there were four (4) degrees of freedom. Before estimating the generalized linear model, we check for normality (non-significant Shapiro-Wilk test) and for homogeneity of variances (non-significant Flinger-Killeen test). We then perform a Tukey post-hoc analysis when ANOVA is significant. See Table 3 below for the details of the parameters.

For Task 1 and 2 persistence, we have a non-normal but homogeneous distributions. We obtain a non-significant ANOVA (no significant group differences). For Task 3 persistence, we have a non-normal distributions with homogeneous variances.

We obtain a significant ANOVA A Tuckey post-hoc analysis reveals that significant pairs are: Hero.Active - Hat.active, Hero.Active - Hat.Random, Hero.Active - Neural. For Task 1 and 2 enjoyment, we have a non-normal but homogeneous distributions. We obtain a non-significant ANOVA (no significant group differences). For Task 3 enjoyment, we have a non-normal distributions with homogeneous variances. We obtain a significant ANOVA A Tuckey post-hoc analysis reveals that significant pairs are: Hero.Active - Hat.Active, Hero.Active - Neural. There isn't sufficient statistical evidence to conclude that Hero.Active leads to more persistence or enjoyment. Hypothesis 3 must therefore be rejected given current evidence and will require additional higher-powered studies to prove or disprove.

To check for H4, we compare Scores against Conditions. We follow the same statistical validation process: we will use the same generalized linear model: with the favorite subject, least favorite subject and subject chosen as random effects. The fixed effect was the condition. For ANOVA tests there were four (4) degrees of freedom. Before estimating the generalized linear model, we check for normality (non-significant Shapiro-Wilk test) and for homogeneity of variances (non-significant Flinger-Killeen test). We then perform a Tukey post-hoc analysis when ANOVA is significant. The parameters are summarized in the Table 4.

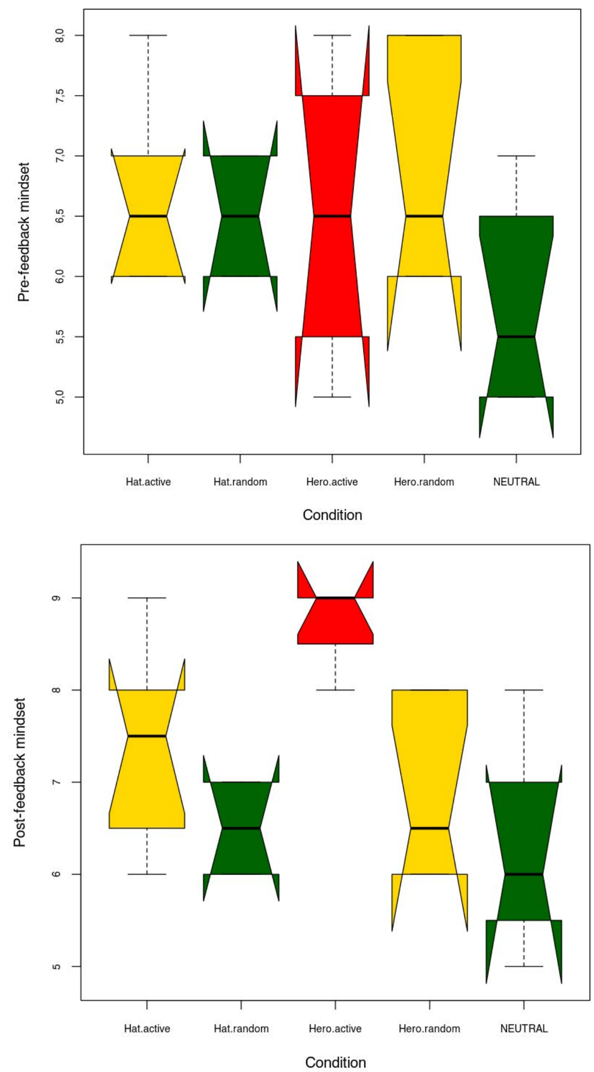

Figure 5: Pre- (top) and post- (bottom) mindset scores for all 5 conditions.

Here we have non normal distributions that do not have homogeneous variances. ANOVA on the generalized model is significant and post-hoc analysis reveals that the Score distributions for all non-Hero conditions are not significantly different from each other and average between 3.5 and 4 points of score. Where the Hero conditions regardless of the effectiveness of the feedback (no significant difference between Hero.A and Hero.R) score around 6, with very little variability. This observation very precisely matches the prediction in H4, which can therefore be validated given the level of evidence shown here, see Figure 6.

To evaluate H5, we keep only individuals in the NEUTRAL condition and compare Pre-mindset and Post-mindset scores.

We have a significant Shapiro-Wilk test for Pre-mindset (W=782, **), and a non-significant one (W=0.917) for Post-mindset. Thus only the first distribution is normal. The Fligner-Killeen test between the distributions is non-significant, meaning variances are homogeneous. To compare the significance between the two distributions given that one is non-normal, we use the Mann-Whitney-Wilkoxon test, which is non-significant (W=23, p=0.45). This observation validates H5, see Figure 7.

Subjective Comments of Children

Overall, children commented a lot on all conditions which involved the hat and the artifacts from different universes. We can regroup all the comments in three main categories: 1. Customization - use with other universes that do not always match the "superpower" of "mind control"; 2. Controlling other objects; 3. BCI headsets.

Children who were in ACTIVE and RANDOM groups commented on customizations. Though 19/24 children evaluated artifacts from other universes higher in likeness than the hat, 6 children commented on having a mismatch between the superpowers of some heroes and the "mind control" ability of the System: *"I actually like the Hat more, because it is what it is supposed to do in the book as well,* […] *to know about your thoughts*". The overall excitement came from the fact that each child had a strong preference towards a given hero. Two participants reported not watching and not having any preference for any sci-fi and/or other stories; two other children preferred the Hat as is, and one child reported not knowing what the *Sorting Hat* was.

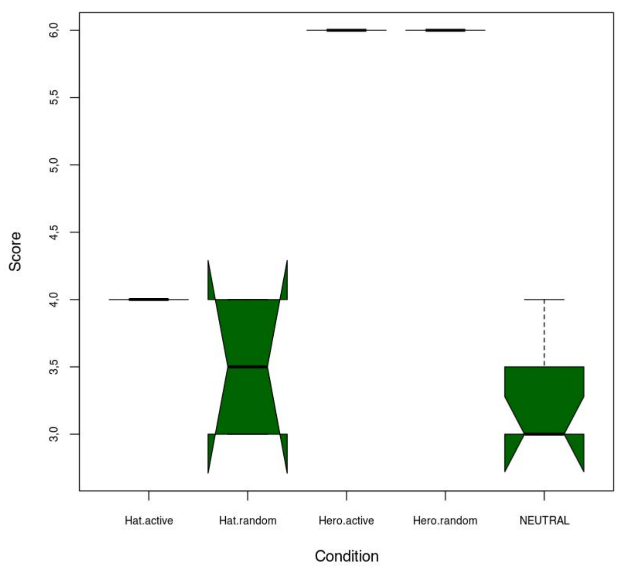

Figure 6: Scores of experience provided by the participants themselves in all the conditions.

DISCUSSION, LIMITATIONS AND FUTURE WORK

Given the growing accessibility and potential of wearable systems, in particular, the BCIs as well as everlasting effect of movies and books reported in previous works, we

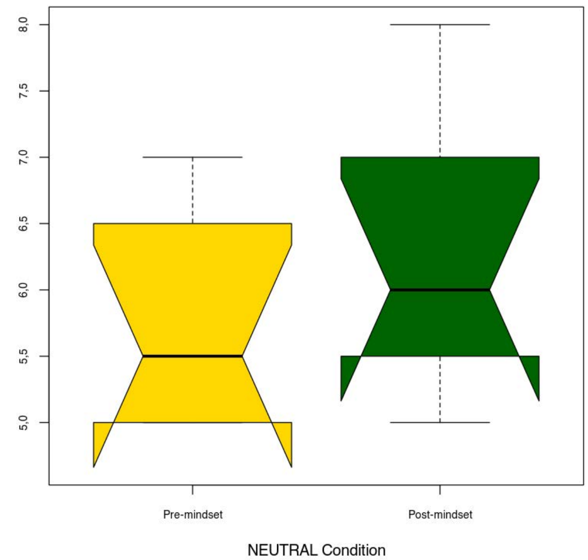

Figure 7: Pre-mindset and Post-mindset scores of NEUTRAL group.

investigated the new mechanisms and techniques we can leverage using the technology that by definition promotes and gives more direct access to the brain but also the fantasy worlds by which children sometimes learn from or take as examples for their lives to follow and be inspired from.

To summarize the results from the previous section, Participants in the Hero.Active condition scored higher on the post mindset assessment questions compared to other conditions, thus our H1 is not rejected. Participants in Hero.A and Hero.R scored their experience with the masks much higher regardless of the correctness of the feedback compared to Hat.A and Hat.R condition, thus our H4 is not rejected. Finally, as we expected, children in the control condition hold pre- and post- mindset assessment scores in approximately equivalent numbers (H5). However, our H2 and H3, though looked promising, were not significant: participants in the Hero.A condition did not score significantly higher on the post mindset assessment questions compared to four other conditions (Hero.R, Hat.A, Hat.R and CONTROL) and they did not show significantly more task enjoyment, more task persistence than children in four other conditions.

Thus, all these results, though interesting, should be taken and interpreted as preliminary.

First of all, these results can be in part explained by the element of magic (using an object that is perceived as magical) which was a part of the intervention itself that the participants experienced. In our study, we might have enhanced this magical intervention by embedding a neuroscientific tool, which explains the intervention itself but ultimately, intensifies the result.

Additionally, though the BCI algorithms used in this work are not a part of the contribution per se, the accuracy and more controlled measures should be performed in follow-up studies. Another limitation is the number of participants in each group that still remains on a lower side (8 children per group). The forth limitation is the duration of the intervention. Though several works in the community also performed very short and "pin-pointed" interventions like Brain Points [33] – 3 minutes or when using a robot [30], it is to be tested if such intervention makes a difference on a longer time scale and more importantly, if this intervention brings any improvements to the academic performance.

All the limitations lead to a bigger discussion around the fact that children were primed when performing this study and perceived it as cool. Ultimately, it might be almost inevitable that the object which is looking like a Sorting Hat or one of the favorite artifacts from the favorite movie or comics will provoke engagement and curiosity within the group of participants who know what this object is. However, engagement and curiosity in the context of the growth mindset are actually welcomed [14]. We believe that this priming itself might have been one of the reasons of the obtained results. We thus plan to conduct more studies to try to further address this issue and to better understand the dimension which influences each participant mostly.

CONCLUSIONS

In this work we suggested to harness the power of knowledge-seeking positive experiences, engagement and curiosity the objects perceived as magical carry in themselves by combining them with pop-cultural reference and neuroscience in order to derive a novel intervention to foster a growth mindset in children of 8-12 years old. We created "Magic Hat 2.0", a wearable system in the form-factor of different masks, artifacts and objects from sci-fi and pop-cultural references like *Avengers* or *Star Wars*. All the artifacts were fitted with a commercially available EEG headband. We designed and conducted a study to investigate the effect of using a "Magic Hat 2.0" to foster children's mindset. Our results suggest that interacting with a "Magic Hat 2.0" (limited by classification accuracy and recording factors) has a positive impact on children's mindset as expressed through their communicated beliefs and task-based behaviors. Though our study should be considered and treated as a preliminary proof-of-concept, the results suggest a possibly provocative new kind of relationship and interaction paradigm between children and a wearable EEG system, enhanced by perceived magic and cultural references.

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SELECTION AND PARTICIPATION OF CHILDREN

Twenty-four children (8-12 years old) participated in the study. A consent form, which mentioned the outline of the experimental protocol and explained the terms in simplified language, was presented to a child. We also asked for explicit consent from the child as for being audio/video-recorded, and their data published and presented in scientific venues. Once the study was over, we debriefed the children to 1. make sure that they will not leave the lab with any misconceptions about the scientific theories which underlined this study and study goals; 2. answer any additional questions that might have raised; 3. assure that all children left the experimental setting proud of their performance.

Comparison	Shapiro-Wilk	Flinger-Killeen	GLM	Anova	Post-hoc
T1 Persistance wrt. Condition	W=0.718 *** (NN)	χ^2=3.44, H	AIC=72.4, BIC=87.8	χ^2=4.11, NS	∅
T2 Persistance wrt. Condition	W=0.863 *** (NN)	χ^2=0.349, H	AIC=55.9, BIC=71.3	χ^2=3.66, NS	∅
T3 Persistance wrt. Condition	W=0.874 ** (N)	χ^2=5.44, H	AIC=92.8, BIC=108.3	χ^2=19.30, S ***	Hero.A/Hat.A ** ; Hero.A/Hat.R * ; Neutral/H.A ***
T1 Enjoyment wrt. Condition	W=0.839 *** (N)	χ^2=1.95*, NH	AIC=83.0, BIC=98.4	χ^2=5.98, NS	∅
T2 Enjoyment wrt. Condition	W=0.881 ** (N)	χ^2=0.85, H	AIC=67.1, BIC=82.5	χ^2=7.12, NS	∅
T3 Enjoyment wrt. Condition	W=0.915 * (N)	χ^2=12.07, H	AIC=101.8, BIC=117.2	χ^2=16.00 **, S	Hero.A/Hat.A * ; Neutral/Hero.A **

Table 3. All the parameters regarding task persistence and enjoyment.

Comparison	Shapiro-Wilk	Flinger-Killeen	GLM	Anova	Post-hoc
Score wrt. Condition	W=0.773 *** (NN)	χ^2=15.62, NH, **	AIC=43.1, BIC=58.5	χ^2=341.14, S ***	All pairs *** , **EXCEPT:** Hat.R/Hat.A; Neutral~Hat.R; Hero.A/Hero.R

Table 4. The parameters regarding scores and conditions.

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