Effect of Light Priming and Encouraging Feedback on the Behavioral and Neural Responses in a General Knowledge Task

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Abstract. The increase of cognitive demands in society nowadays requires new ways to deal with problems, such as burnout and mental fatigue. Lately, more and more scientifically-based rigorous research in the area of brain-computer interfaces has been done in the quest for restoring and augmenting cognition. The current research work investigates light-based priming and positive reinforcement as possible mediators of cognitive enhancement.

Keywords: priming with light, cognitive enhancement, positive feedback.

1 Introduction

Priming refers to an increased sensitivity to a stimulus due to prior experience. Because priming is believed to occur outside of conscious awareness, it is different from memory that relies on the direct retrieval of information [1]. Priming is an effect of implicit memory. The effects of light-based priming have been widely shown in both humans and animals [2, 3].

Significant research exists on the influence of color on human perception, cognition, and behavior. In [4, 5], blue and green colors are presented as leading to higher cognitive performance than red color, [6, 7] however report the opposite. In [8], it is shown that the red color enhances performance on a detail-oriented task; whereas blue enhances performance on a creative task. These findings together with the ones from [9, 10], suggest that warm colors as being more effective modulators of cognitive performance in a memory related task than cold colors.

The influence of sensory stimuli on cognitive performance in a school context was shown in [11], where exposing underachieving children to olfactory stimulation elicited an increase in performance in a new test by using a scent which was previously associated with high performance in a prior test.

Increased cognitive performance can also result from stereotype priming where people are primed to think about a particular person or profession (the stereotype) exhibiting high cognitive ability, prior to engage in a task requiring cognitive ability. In [12] it is shown that the performance in a general knowledge task of participants

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primed with the stereotype of a professor is higher than the performance of participants primed with the stereotype of a hooligan.

Feedback and reinforcement can be used in a positive manner to enhance peoples' feelings of competence, which then increases intrinsic motivation. This area, called behavior modification, assumes that behaviors are strengthened when they are rewarded and weakened when they are punished or unrewarded. The stronger the perceived self-efficacy is, the more challenging the goals that people set for themselves become [13].

In a previous study [15], we investigated the influence of light conditioning on cognitive performance. This work can be summarized in three steps: 1) detect (or create) events where a person performs particularly well, 2) apply the targeted light setting with the goal of creating an association between high performance and the light setting, and 3) at a later stage use the light setting to predispose the person for high performance. Three experimental conditions were considered: 1) a control condition, 2) a congruent condition (the association and the test phases had the same light setting) and 3) an incongruent condition (the association and the test phases had different light settings). The cognitive performance associated with each condition was evaluated and positive results were obtained for the congruent condition.

In this study we aim at investigating the behavioral and neural responses as characterized by the electroencephalogram (EEG) of light-based priming and encouraging feedback on a general knowledge cognitive task.

2 Materials and Methods

Twenty healthy volunteers (10 female and 10 male, Mean age = 27.1 and SD = 5.1) participated in the study. All of them had at least a BSc degree. They were randomly assigned to one out of three experimental conditions: a control condition, a congruent-first condition or an incongruent-first condition (see Table 1). All participants signed an informed consent before starting with the experiment. This experiment was approved by the Philips internal ethics commission.

The task of the experiment was a four-choice answer Trivia test which consisted of 4 sets of 25 questions each. There were general knowledge questions belonging to seven different knowledge domains and distributed over three levels of difficulty. All the questions were taken from a Trivia quiz [16]. An example of a question and suggested answers is: "If you suffer from daltonism, you are: a. Color blind, b. Schizophrenic, c. Mute, d. Deaf."

The participants had half a minute to answer to each question. The sets of questions were randomized over the task. EPrimeTM software (from Psychology Software Tools Inc) was used for the presentation of the task [17].

The participants were looking at a 20 inch LCD screen from a distance of 70 cm. Following a short practice session in which no priming was involved, the actual Trivia test started. The light settings (see Fig. 2) were randomly chosen for each participant. After each phase of the experiment the participants were asked to complete a computer-based intrinsic motivation inventory questionnaire [18].

In this study we distinguish three types of feedback which were supposed to modify further performance. True positive feedback – all the questions that were correctly responded received positive feedback. True negative feedback – with a probability of 70%, the questions that were incorrectly responded received negative feedback. Positively biased feedback – incorrectly answered questions could receive positive feedback with a 30% probability. We use the term "encouraging feedback" to refer to the sum of true positive feedback and positively biased feedback.

The feedback was presented on the screen for 3 seconds, starting immediately after the participant's answer or after 30 seconds (time out). For both true positive and positively biased feedback the message displayed on the screen was: "Good job!" followed by the accumulated performance in percentage. For the true negative feedback the message was: "Incorrect answer" followed by the accumulated performance in percentage. In the case of a time-out, the message was: "No response detected".

The study consisted of 4 phases (baseline, association, test1 and test2) each of them lasted for 10 to 15 minutes (see Fig. 1). "P" represents the initial practice phase and "Q" stands for the questionnaire that followed after each phase.

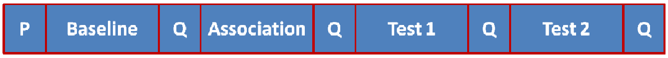

Fig. 1. Timeline of the experiment

The illumination conditions were rendered using 4 Philips LivingColor lamps [20]. The light was projected on the walls. The estimated maximum illumination level was below 100 lux. The colors for this experiment were chosen to be different from each other; complementary colors and not disturbing for the eyes. We distinguish 3 types of light conditions (illumination settings): white light, lightA, lightB.

Fig. 2. Illumination settings (white light, lightA, lightB)

In the baseline phase, the participants performed the task under white light for all conditions. In the association phase, the participants were divided in two groups, one performing the task under lightA and the second under lightB. In the last two phases (testing), each group was further divided into two groups, in which the participants were stimulated with both illumination settings, depending on the condition. Positively biased feedback was given to the participants only during the association phase (see Table 1).

EEG signals were recorded with Biosemi™ Active2 signal acquisition system [19]. The location of the electrodes in the experiment was according to the 10-20 system. Data was recorded from 32 channels (Fp1, AF3, F7, F3, FC1, FC5, T7, C3, CP1, CP5, P7, P3, Pz, PO3, O1, Oz, O2, PO4, P4, P8, CP6, CP2, C4, T8, FC6, FC2, F4, F8, AF4, Fp2, Fz, Cz). The sampling frequency was 2048 Hz. The EEG signals were first, filtered to remove the 50 Hz power-line noise using a FIR band-stop filter (stop band: 49.9-50.1 Hz). The signals were then subsampled at 256 Hz. Ocular artifact correction was done using the well-known independent component analysis (ICA) based approach [21]. The signals were then re-referenced to the signal average (common average referencing). The resulting signals were band-pass filtered in the 2-25Hz band. This filter permits to attenuate both: DC shifts (low frequencies) and muscle artifacts (high frequencies).

Table 1. The design of the experiment

Phase / Condition	Baseline	Association	Test1	Test2
Control condition	White light, with no positively biased feedback.			
Congruent first condition	White light, with no positively biased feedback.	lightA or lightB positively biased feedback; true positive and true negative feedback.	lightA true positive and true negative feedback lightB	lightB true positive and true negative feedback lightA
Incongruent first condition		lightA or lightB	lightB true positive and true negative feedback lightA	lightA true positive and true negative feedback lightB

The EEG was segmented in epochs lasting from 500 ms before the onset of the stimulus to 1000 ms after the onset of the stimulus. The EEG signal segments where the energy was not within twice the standard deviation were rejected as they were likely to be movement artifacts.

3 Results and Discussion

The overall performance was measured as a percentage of correct answers. Failing to provide an answer, which happened in 0.2% of the cases, was considered as a wrong answer.

Fig. 3 shows the performance during all the phases, baseline, association, test1 and test2. One should take into account that test1 and test2 are half shared by congruent-first and incongruent-first conditions. On average, the participants answered 47.3% (SD=11.6) of the questions correctly. In the baseline condition the average performance across participants was 48.2% (SD=13.8). In the association condition the average performance was 48.3% (SD=10.8). In the test1 and test 2 conditions, the average performance as 43.7% (SD=7.9) and 48.8% (SD=13.1) respectively (see Fig.3). A t-test revealed no significant difference in the performance between conditions. The third phase presented a smaller variance, having values between 32% and 60% - which might be due to the higher scores in performance displayed on the screen, during association, as a result of the encouraging feedback.

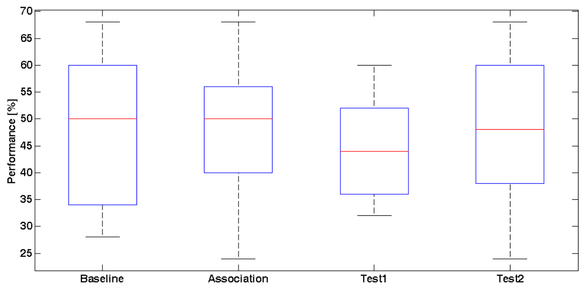

Fig. 3. Overall performance during the experiment

Fig. 4 presents the results of the previous experiment, in which it can be seen that the median performance during the baseline was similar in all the conditions (43%), which means that the participants were equally distributed in terms of proficiency across the three groups. The performance during the association phase of the control condition was very similar to the one of the incongruent condition. The performance in the third phase has lower values in the control (43%) and incongruent conditions (39%), compared to the same phase during congruent condition. The performance during the test phase of the congruent group is higher than the one in the incongruent and control groups, which indicates the effects of light priming. By comparing these results with the control condition, we can also say that, the improvement in the congruent group is caused by both the effects of light and positively biased feedback.

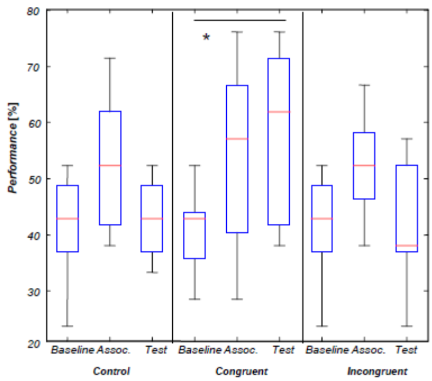

Fig. 4. Overall performance during the first experiment

The average performance level was 48.7% (SD=11.8). The last phase from the control condition had the same average score as the baseline. In the congruent condition, the performance score during association had a larger variance (SD=16.7), average score was 56.3%, higher than in the other conditions. In the congruent condition the test phase had large variance, with an average score of 56% (SD=12.1). During the last phase of the incongruent condition, the average performance score was 39.8% (SD=11.9). The average level of performance decreased as compared to the same phase during the congruent condition.

The participants in the congruent condition had a higher performance than the ones in the incongruent condition. This suggests that the increase is affected by the illumination setting. Furthermore, one of the illumination settings yielded a higher performance improvement, which suggests that the color of light may also play a role.

The experiment design does not permit to distinguish between the effect of light conditioning and that of encouraging feedback. Their combination enhances the performance over all conditions and this may be mediated by an increase in the motivation to perform better.

The analysis of the questionnaire responses yields significant results on the Effort/Importance scale showing that a higher amount of effort was put while performing the last phase of the task in the congruent condition. This also means that performing better during this phase was more important for the participants. The scores of the same scale under control and incongruent conditions had a similar trend, showing that there was no difference in performance in the control and in the incongruent conditions.

To better assess the effect of the intervention (light and encouraging feedback), the last two phases were split according to the corresponding conditions, congruent-first and incongruent-first (see Fig.5).

During the control condition the variance of the performance was large for all phases, except the third one. In the baseline, the average performance was 46% (SD=14). During association, the scores slightly decrease, the average performance is 40.5% (SD=15). During the third phase, the scores decrease even further and the variance of the scores was significantly smaller; the average score was 38% (SD=2.3). In the last phase, most of the participants increased their levels of performance, the average performance was 51% (SD=14.4), which is the highest level of performance over all phases of the control condition.

The congruent-first condition presented a "zig-zag" trend in the levels of performance over phases, with both positive and negative slopes. During the first phase, the average performance score was 45.5% (SD=12.5). Then, the association presented a slight increase in performance, with an average score of 52% (SD=8.8). The third phase, congruent, had the average performance, 46.8% (SD=8) a bit higher than the baseline. The fourth phase presented higher levels of performance, average score was 53% (SD=7.9) of correct answers. There was no significant difference between the phases of the congruent-first condition.

The incongruent-first condition presented a continuous decrease in performance over the phases. The baseline phase presented the average score of performance of 52% (SD=15.7). This is the highest averaged value from all the phases of this condition, but is not significantly higher than the rest. The variance is also very large. During the association, the variance of the performance scores was smaller compared to the baseline, the average score of performance was 48.5% (SD=9.7). The third phase, incongruent, presented the average performance score of 43.5% (SD=8.7). The last phase, congruent, has the largest variance in performance levels, the average level of performance was the same (43.5% (SD=16.1)) as during the previous phase, incongruent, but the variance was larger.

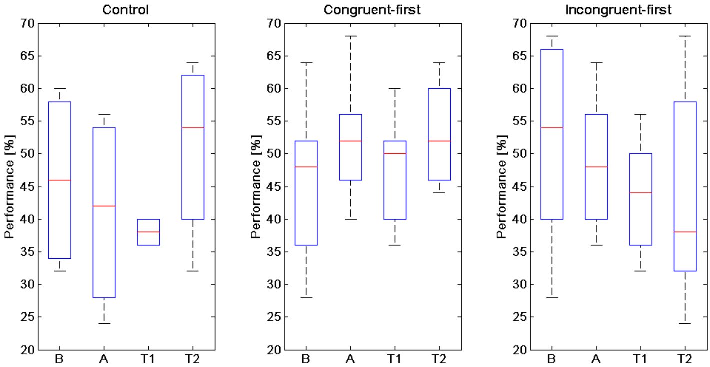

Fig. 5. Box-plots of the performance scores during all the conditions

To compare these results (see Fig. 3) with the ones of the previous experiments (see Fig. 4), the current association phase was split in two parts (see Fig.6).

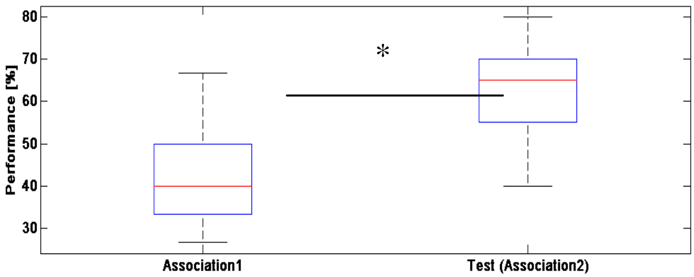

Fig. 6. Splitting the association phase in order to compare the performance results

We assume that in the first part we establish the association and the second part represents the testing. The average performance score of the newly obtained association was 41.7% (SD=11.5), while the new testing phase had a very high the average score of 63.1% (SD=13), compared to the other phase.

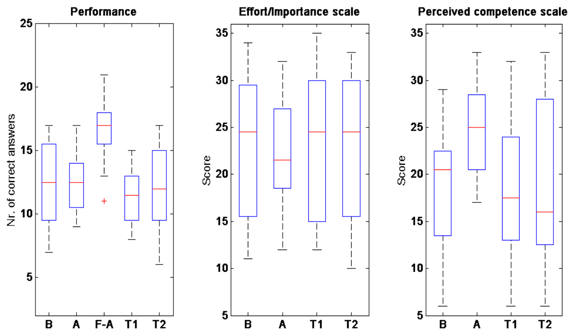

Fig. 7. The number of correct answers in the intervention conditions and the corresponding scores for the Effort/Importance scale and Perceived competence scale

This difference was significant (ttest, t=1, p<0.001) and presented similar trend compared to the congruent condition of the previous experiment. This suggests that a prolonged association is required in order to establish higher performance or that the participant needs to be motivated also during the test phase. Because of the experimental design, we however cannot replicate the incongruent condition of the previous experiment.

The results of the questionnaire together with the performance results during congruent-first and incongruent-first are presented in Fig. 7. The label "F-A" from the performance subplot represents the false (biased) association.

One observation is represented by the correlation between performance and perceived competence. The average performance score over the phases was 50% (SD=11.2), while the positively biased level of performance was 70% (SD=8.9). The Effort/Importance scale presented score in a very large variance and with a similar average value. The Perceived competence scale presented a significant difference between the second and the third phase's scores. A similar decreasing trend was presented in the performance subplot.

Brain activity monitoring is frequently used to gain a better understanding of behavioral results. Here we present the results according to the event related potentials (ERPs) investigation.

Fig. 8 presents the grand average for ERPs 500 milliseconds before the onset of the feedback and 1000 milliseconds after the onset of the feedback. The grand average is presented for the Fz channel. The figure presents 3 different signals corresponding to the type of feedback. The difference between the correctly and incorrectly answered trials Fig. 8 presents a clear peak, around 250-300 milliseconds. This peak is also known as feedback negativity (see [21]). The vertical dashed line at 0 represents the onset of the feedback.

As potential factors that could influence our results, we considered the population knowledge level and the difficulty of the sets. The populations for each experiment have comparable knowledge level. The questions were equally distributed over the sets in terms of difficulty.

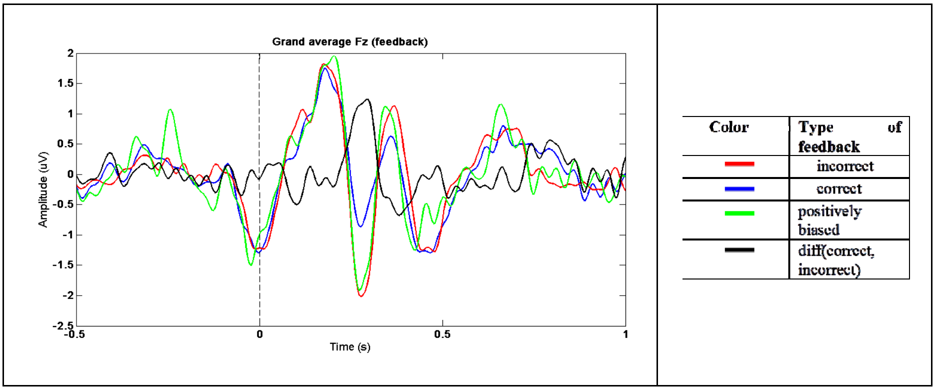

Fig. 8. Grand average across all participants in a [-0.5, 1] second window showing the onset of the feedback for channel Fz

Summarizing all the results that we have so far, brings us to the conclusion that there is no clear influence of light, but the encouraging feedback induces important effects.

The feedback gradually becomes the most salient factor in the process of modulating cognitive performance.

4 Conclusions

The performance of the participants was not strongly influenced by the light intervention. According to the questionnaire results their perceived competence was influenced by positive reinforcement, which played the role of a mediator, leading to a higher performance during that phase. The absence of the encouraging feedback during the next phase led to a decrease in performance and perceived competence.

Regardless of the illumination setting or condition, the feedback seemed to be the most important factor when analyzing the performance scores.

The feedback negativity is a component of the event-related brain potential that is elicited by feedback stimuli associated with unfavorable outcomes. We detected this feature, represented as the difference between correctly and incorrectly answered trials, at 250-300ms after the onset of the feedback. According to the grand average, this feature has the highest magnitude on the frontal cortex, as it is also presented in [14].

The order of the phases had a great impact on performance levels. We observed that regardless of the illumination setting, after association, when the positively biased feedback was introduced, the performance dropped, during the third phase. The order of the congruent phase before or after incongruent, had an impact on performance.

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