Optimal Affective Conditions for Subconscious Learning in a 3D Intelligent Tutoring System

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Abstract. In this paper we take a closer and in-depth look at initial results obtained from a previous novel experiment conducted with a 3D subliminal teaching Intelligent Tutoring System. Subliminal priming is a technique used to project information to a learner outside of his perceptual field. Initial results showed great promise by illustrating the positive impact of the subliminal module on the overall emotional state of the learners as well as their learning performances. Indeed, since emotion monitoring is critical in any learning context, we monitored the physiological reactions of the user while they learned and while they answered questions. We present a detailed and precise look at the optimal affective conditions that set the best learners apart. We will also explain a most surprising finding: the positive long term impact of subliminal priming on the entire learning process.

Keywords: optimal affective conditions, HCI, subconscious learning, 3D ITS.

1 Introduction

In recent years, researchers in human-computer interfaces (HCI) as well as in various fields such as Intelligent Tutoring Systems (ITS) have taken advantage of adaptive and customizable HCI to record and analyze emotions [1]. This is not surprising since emotions, especially motivation and engagement, are widely related in various cognitive tasks [2]. Moreover, the importance of measuring emotions as well as consider them has become the focus of much growing research. The availability, ease of use and affordability of physiological devices helped in their integration into the tutoring systems. That data is then used to model the learner's emotional and physiological profile in order to better adjust and adapt learning accordingly [3]. Learning in virtual worlds has taken a very important part in the HCI community for recent evidence has shown the relevance of using such virtual ITS for affective feedback and adaptation [3, 4].

Nevertheless, the current learning strategies have a limitation when it comes to processing complex information. Indeed, cognitive learning theories base mostly their intervention on attention to the specified task at hand. Complex information is broken down into pieces to gradually enable the learner to concentrate on one small part of the puzzle at a time. However, a large body of work in neuroscience and other fields lead us to believe that learning simple to complex information can be done without

J.A. Jacko (Ed.): Human-Computer Interaction, Part IV, HCII 2009, LNCS 5613, pp. 39–48, 2009.

perception or complete awareness to the task at hand [5-8]. In fact, the existence of perceptual learning without perception has been neurologically proven and accepted [9]. Furthermore, recent work has put forth the performance increase in performance when using a subliminally teaching Intelligent Tutoring System [10]. Yet, subconscious learning systems are still widely absent in the HCI community.

We intend to investigate in this paper the optimal emotional state of learners when using a subliminal teaching ITS by stating two research questions. First, in learning to solve a problem in a 3D virtual system, is there a significant emotional state in which the best learners are that sets them apart from the rest? Second, in answering questions following a learning session, what significant relationship can we establish between learners' emotional state and subliminal projections?

The organization of this paper is as follow: In the next section, we will present and discuss the previous work related to various aspects of our research. The following section describes the experiment setup and depicts the various aspects related to subliminal stimuli in a virtual 3D tutoring system. The obtained results will follow the experiment section leading to the last section where we conclude and present future work.

2 Related Work

To the best of our knowledge, only a handful of papers in various fields have claimed the use of subliminal priming as a support for memory in the HCI community. The first and most referred to is Wallace's text editor program [11]. In this experiment, Wallace and colleagues put forward two important findings: (1) the projected stimuli must take into account the specifications of the computer such as screen resolution and refresh rate (2) that the frequency at which subjects requested help was much lower when the requested information was projected subliminally. The Memory Glasses by [5] used wearable glasses that projects subliminal cues as a strategy for just-in time memory support. The objective was to investigate the effect of various subliminal cues (correct and misleading) on retention in a word-face learning paradigm and compare recall performance. Another use of priming for memory support can be found in the thesis of [12] where the author assesses the effects of brief subliminal priming on memory retention during an interference task. Finally, our most recent work showed the positive impact of subliminal stimuli on the learner's performance [10].

Besides seeming to impact memory, subliminal priming can also have an emotional consequence on learners. Indeed, subliminal priming can have an emotional impact on the self-attribution of authorship of events [13]. Subjects were asked to compete against a computer in removing non words such as "gewxs" from a computer screen in the fastest time possible. However, after a determined amount of time, the computer would remove the word. Subliminal primes of self-associated words like "I" and "me" before an action increased the personal feeling that it was the participant that eliminated the non word and not the computer, thus increasing the feeling of self-authorship of events. Furthermore, visual subliminal stimulus has been neurologically proven to have an impact in many physiological signals, namely the galvanic skin response (correlated to arousal) [14].

Since we also use physiological sensors to monitor the emotional reactions of the learner, it would be relevant to sum some of the work related to using physiological sensors to record and analyze emotions that can occur in a learning environment. Physiological signals are generally correlated with emotions by associating specific signals, such as skin conductance and heart rate, to valance and/or arousal [15]. Indeed, the Empathic Companion is a good example where multiple physiological sensors, namely galvanic skin response (also referred to as skin conductance), heart rate and respiration were taken in real-time to analyze and adapt the tutor to the emotional reactions of the learner in a virtual 3D ITS [16]. Further research has analyzed a more detailed and relevant emotional significance of physiological signals, either in complex learning or gaming [17-19].

3 Experiment

The current experiment uses precise and timed subliminal projections in a 3D intelligent tutoring system while monitoring the physiological reactions of the learner. In the same time we record the actions on the screen as well as the facial movements of the learners. Those visual recording are crucial to remove noise and identify events of special interest. Moreover, we constructed the subliminal cues in a way which would accelerate the learning process by triggering and enhancing an already possessed knowledge.

3.1 Design of the Experiment

Indeed, the focus of the experiment is to visually teach, in a virtual 3D environment, the construction of an odd magic square of any order with the use of neither a calculator nor one mental arithmetic operation. A magic square of order n is a square containing n^2 distinct integers disposed in a way such as all the n numbers contained in all rows, columns or diagonals sum to the same constant. The first part of Fig. 1. below depicts such a square.

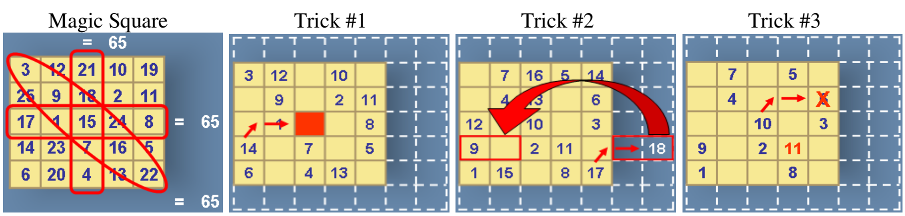

Fig. 1. Experiment design : Magic square and the three tricks taught

To construct the following square, one must successively apply three simple tricks. These tricks are illustrated in Fig. 1 and labelled trick 1 to 3 respectively. We decided to show the learners multiple examples of each trick without explaining how the trick works. As an example, the first trick to construct any magic square is to place the following number one square above and two squares to the right of the previous one (exactly like a knight's move in chess). If we look at the second picture of Fig. 1, we notice that number 15 is placed one square above and two squares to the right of number 14. The same logic applies to numbers 1 and 2, 4 and 5 and so forth. Instead of giving away the answer to the first trick, we ask the subjects to deduce the rule by themselves. This is where the subliminal stimulus comes into play. We will have two groups, one group will take part of the experiment without subliminal stimuli (control group) and the tutor will subliminally send the answer to the other group. We will then compare performances, trick completion time, question completion time as well as physiological signal variations. The teaching material is separated into parts, or PowerPoint-like slides, and displayed at a slow rate to give every learner an equal chance at fully reading each "slide".

The subliminal stimuli and threshold were carefully chosen following the neural bases of subliminal priming [9]. Each stimulus was preceded by a 271 ms pre-mask of random geometrical figures, a 29 ms prime and a 271 post-mask of random geometrical figures. The subliminal stimuli that will be presented to one of the two groups will be displayed at significant places before and after specific slides. The experiment intends to "boost" learning by priming the answer before showing the corresponding slide. Fig. 2. shows a diagram of the way subliminal priming will take place between slide 1 and slide 2 when learning to deduce the inner working of the first trick.

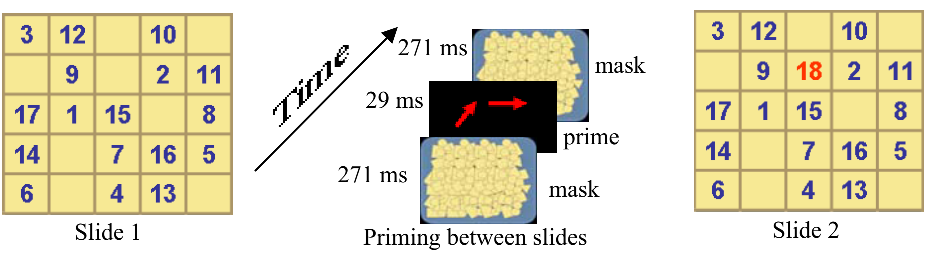

Fig. 2. Subliminal priming of the solution between 2 slides

The learners were instructed to answer a series of two to three questions following each learned trick to test their knowledge. The learners were instructed to finish the experiment as quickly and efficiently as possible. No time limit was imposed. A base line for the physiological signals preceded all monitored activities. A questionnaire preceded the experiment aiming at collecting demographical data as well as the gaming experience of the subjects. Another series of questions were asked at the end of the experiment to evaluate the learner's appreciation and more importantly their overall appreciation of the system.

3.2 The 3D Virtual Environment

Learning takes place in a game-like environment called MOCAS [20] as show in Fig. 3. The experiment has three rooms like the one illustrated on Fig. 3. Each room teaches one trick. MOCAS takes place in full-screen mode for a better immersion and less window distracting events. Furthermore, the system clock is hidden so users don't get distracted by continuously monitoring the time they have spent on each lesson. The interactions between the avatar's learner and the pedagogical agents are done via mouse clicks. This interaction is important because learners have a time window of 30 seconds to answer each question. If they feel that time was not enough, they can simply re-click on the agent and the question restarts. This re-click factor was important in distinguishing good from bad learners.

The learners are instructed to continue once they are convinced they have discovered the inner working of each trick. They are then asked to answer a series of questions (two to three) by another set of visually different pedagogical avatars. Each question is related to the last trick learned. The agent asks the user to correctly place a number in a magic square. The learner responds by choosing the path that correctly answers the question.

Physiological signals of the learners were also monitored in real-time and saved for further analysis. The used signals were heart rate, galvanic skin response, respiration rate and skin temperature. The signals are managed by the ProComp Infinity encoder [21].

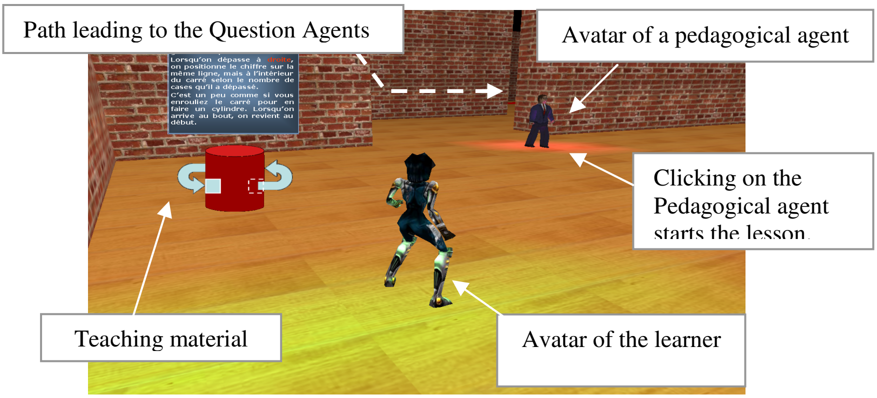

Fig. 3. 3D virtual learning environment

3.3 Learners Tested

A total of 31 healthy volunteers, 16 men and 15 women, took part of the experiment. One participant had to be removed because of a major recording issue in the video-signal synchronisation module. The sample's mean age was 26 (SD = 4.51). Only two volunteers had extensive video gaming experience. All the others gaming experience ranged equally anywhere from weak to moderate high. A repartition of the learners can be found in table 1.

Table 1. Participants' distribution

	Men	Women
Group A : no subliminal stimuli	8	7
Group B : primed with subliminal stimuli	7	8
	15	15
Total	30	

4 Results

The first aspect we wanted to examine was the existence, if any, of a relationship between affective variations and subliminal projections while learning the tricks. Fig. 4 shows the average quantitative affective variations of learners with regards to valence and arousal when learning all three tricks with and without the subliminal module. The signal used and correlated with valence is the heart's inter-beat interval (IBI) and galvanic skin response was used and correlated with arousal (GSR) [15].

These signal values are normalized by mean-shifting, that is subtracting each signal's value from the signal's baseline mean then dividing the result by the signal's standard deviation. This widely accepted technique enables us to compare learners' results for it solves the problem of extra-individual physiological differences. Fig. 4 shows the average affective values for a period of 4 second following every subliminal stimulus. The full brown bars represent the average value of the signal for all subliminal stimuli at the precise moment the stimulus was projected (t=0s, s is for seconds). The horizontal dashed bars represent the same averaged value except for it's computed for the 4 seconds following that projected stimulus (T=t + 4s). Since group A was not primed with subliminal stimuli, we placed markers for each learner at the precise moment where subliminal cues would have been projected if these learners would have been taking the course with the subliminal module.

For example, the first four numbers from the left (-0.7, -0.7, 0.3 and 0.6) represent the following situation: on average, all learners in the experiment have had a normalized valence change of zero (-0.7 at moment t=0 and -0.7 after 4 seconds) when learning without the subliminal module compared to a normalized valence increase of +0.3 (0.3 at moment t=0 and 0.6 after 4 seconds) when learning with the subliminal module.

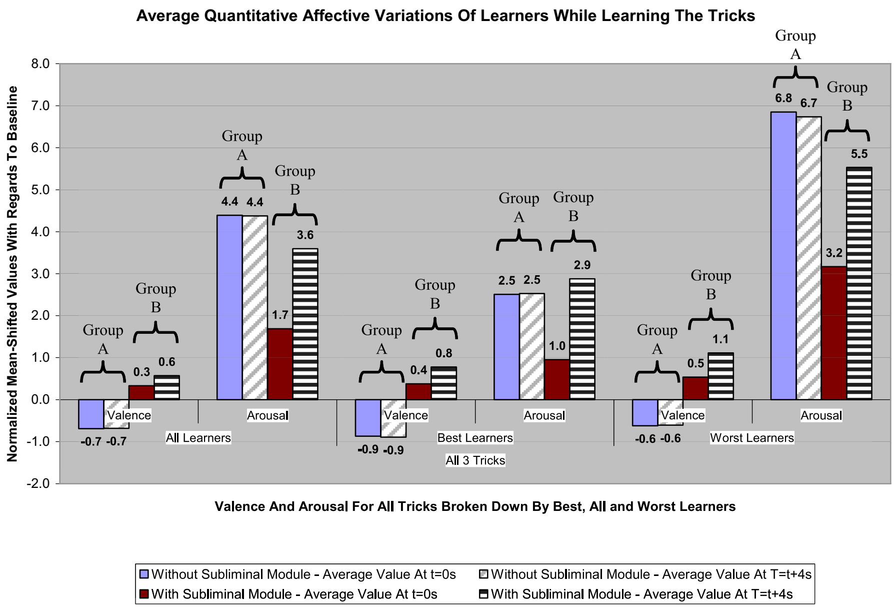

Fig. 4. Quantitative affective variations when subjected to subliminal stimuli while learning

The results shown in Fig. 4 are not only statistically significant ($p<0.001$, $\alpha=0.05$) but very important for they enable us to distinguish between the best and worst learners in terms of valence and arousal but also in terms of how much variation is considered optimal for success. In this case, having an average positive valence variation increase of about 0.8 and arousal increase between 2.5 and 2.9 is what our system should be looking for. In fact, we can clearly see at the far right part of Fig. 4 that the worst learners, those who made the most mistakes, were the ones who had a negative valence variation. Checking the results with Lang's two dimensional space [15] informs us that a negative valence leads to a negative emotional state and thus not optimal for learning. Since subliminal projections increase valence variations, our system could then detect this negative emotional state and start projecting more stimuli until an optimal state is reached.

The second aspect we wanted to investigate was the affective state of learners when answering questions. It is important to mention that no subliminal priming took place when answering questions. Group A and group B can then be compared without bias. Fig. 5 displays the quantitative affective variations when answering questions grouped by trick. The horizontal dashed bars represent the values for group B, that is the group projected to subliminal stimuli during learning. The results are surprising and the difference showed here is more than statistically significant for alpha is equal to 0.01 ($p<0.001$, $\alpha=0.01$). Not only does the subliminal module help increase valence and arousal variations to optimal levels as discussed previously, but the effect seems to last throughout the experiment. Indeed, we can see that the best learners from group B are twice less stressed when answering all the questions and much less aroused than the best learners from group A.

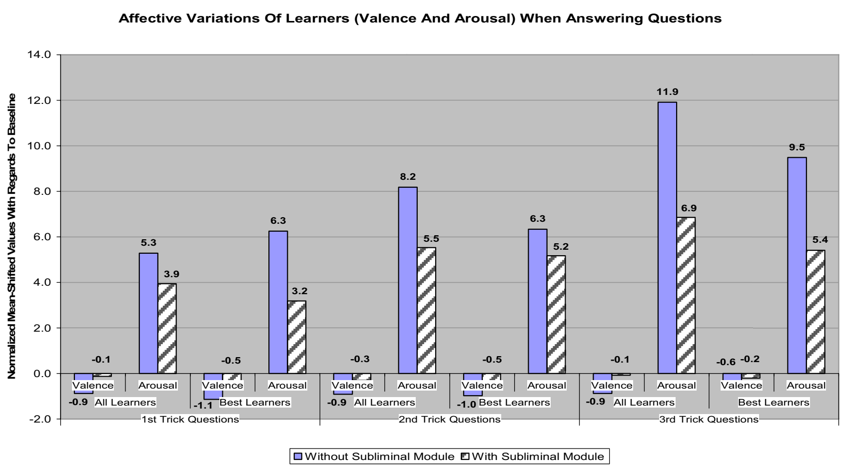

Fig. 5. Affective variations of learners while answering questions

The results of the two previous figures give us an insight into the complex inner-workings of unconscious perception. It seems that positive arousal variations (between 2.5 and 2.9) and positive valence variations (between 0.6 and 0.8) seem to yield the best results when answering questions. Furthermore, subliminal projections seem to produce a cumulative positive effect because of the observed results for the third trick. Indeed, the last trick is the most difficult because it requires the use of the first two, henceforth the very high arousal variations for group A. We demonstrated in [10] that the subliminal module helped reduce dramatically the number of mistakes made. Fig. 5. has just explained why in terms of valence and arousal.

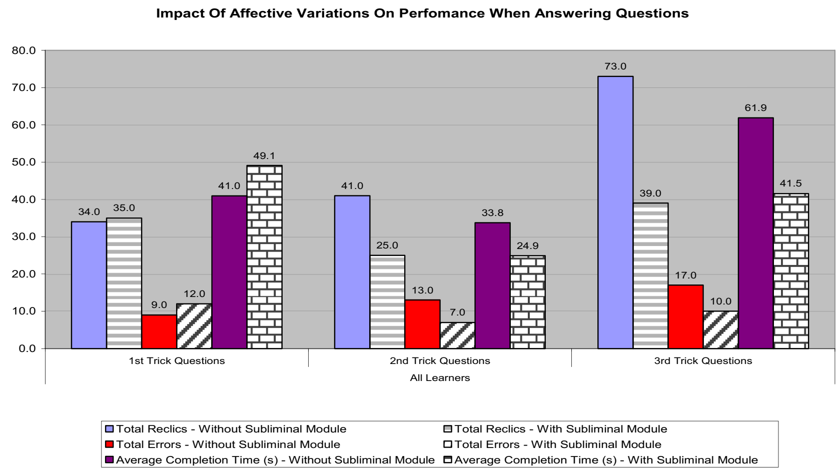

Fig. 6. Impact of the affective variations on results, broken down by trick

The affective variations examined throughout this section lead us to carefully examine the effect on performance when answering questions of the third trick. Indeed, we can surmise that a learner can correctly construct a magic square if he successfully answers all questions but more specifically the third trick questions. Fig. 6. displays the results of our analysis by comparing group A's results with group B's with regards to total re-clicks (number of times learners asked to restart the question), total errors and more importantly completion times.

The results present another argument for the combination effect of subliminal stimuli. Indeed, we can see that the total re-clicks for group B is almost the same as group A's for the first trick but dramatically decreases as the subliminal projections increase throughout the experiment. The same phenomena can be observed with errors and completion times. The last aspect, completion times, is very important because it represents the foundation of what we are aiming at: faster and more efficient learning. We are very pleased with the results because they clearly show the significant contribution of the subliminal module ($p<0.001$, $\alpha=0.05$) to the dimension of performance as well as emotions.

5 Conclusion

We presented in this paper the optimal affective conditions for subconscious learning in a 3D virtual ITS. Subconscious learning is done with the use of carefully engineered subliminal projections aiming to accelerate and enhance learning. We also illustrated the importance that subliminal stimuli can have on the long term process of learning and pattern recognition. In contrast to the previous work regarding the use of subliminal priming and emotions, our work differs in three ways. First, the subliminal priming was used in an HCI to teach a more complex lesson than simply face recognition or item association. Second, in contrast with the vast majority of researchers, we discussed and placed forward the use of quantitative, and not just qualitative, affective variations in building an effective HCI to detect the best learners from the rest. Third, we placed forward the long-term impact that subliminal cues can have on the entire learning process and not just simply on simple tasks such as face memorizations or item pairing. As future work, we intend to use these results to construct an intelligent real-time HCI system that detects the emotional variations of the learner and adjusts the subliminal projections accordingly.

Acknowledgments. We acknowledge the support for this work from the Fond Québecois pour la Recherche sur la Société et la Culture (FQRSC).

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