Learning and Performance Increase Observed In a Distant 3D Virtual Intelligent Tutoring System When Using Efficient Subliminal Priming

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Abstract. In this paper we discuss the use of efficient, well thought, subliminal priming in a novel way in the context of a 3D virtual tutoring system. Subliminal priming is a technique used to project information to a learner outside of his perceptual field. Various field claimed using subliminal projections but never in the domain of 3D Intelligent Tutoring Systems. Emotion monitoring is critical in any learning context and thus we monitored the physiological reactions of the user while they learn. We will present the virtual environment and the subliminal module used. The results of this study show that learners enjoy the experience even if they hardly have any video gaming experience at all. Furthermore, subliminal priming, even though not consciously perceived by a learner, seems to elicit strong positive physiological reactions as well as positively impacts performance and overall learning.

Introduction

For more than twenty years now, the aim of intelligent Tutoring Systems (ITS) has been to properly adapt learning sessions and material to the learner. The systems evolved from Intelligent Computer-Aided Instruction to intelligent tutoring. Nowadays, ITS comprise of multiple goal-specific modules to aid the learner. One of these modules, the tutor, can possess and make use of one or more pedagogical strategies during a learning session depending on the learner's needs and evolution. However these strategies were mainly based on cognitive learning and teaching theories where emotions did not, at first, have an important role to play. Nevertheless, the importance of incorporating emotions into those strategies has been getting a lot of attention in recent years. Indeed, researchers have proven that emotions, especially motivation and engagement, are widely related in various cognitive tasks (Damasio 1994). 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. This interesting collaboration between ITS and physiological devices supplied the student model with affective data. That data is then used to model the learner's emotional and physiological profile in order to better adjust and adapt learning accordingly. Another step forward was taken when emotions and physiological signals were combined with virtual reality. Indeed, this new partnership is very important to consider for recent evidence has shown the relevance of using such virtual ITS for affective feedback and adaptation (Blanchard et al. 2007, McQuiggan & Lester 2006).

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 perception or complete awareness to the task at hand (DeVaul et al. 2003, Dijksterhuis & Nordgren 2006, Nunez & Vincente 2004, Watanabe et al. 2001). The idea that any information projected too fast to be consciously perceived by a learner (called subliminal projection), has been the focus of much research in neuroscience but hardly any attention has been directed to it in the ITS community. Indeed, the existence of perceptual learning without perception has been proven (Watanabe et al. 2001) and we believe that subliminal stimulus, which is stimulus below the threshold of conscious perception, can help and increase learning in various situations if carefully constructed and projected.

The approach of combining emotion detection and subliminal projections aiming at faster and better learning in a virtual learning ITS is unique in our field and has, to our knowledge, never been put forward before. We intend to investigate in this paper the impact of such a novel learning strategy in a 3D virtual system on learning by stating three research questions. First, in solving a problem in a 3D virtual system is there a positive emotional impact on learning? Second, is it possible to enhance the transmission of classic information using a subliminal technique? and third, what relevant links can we establish between the physiological signals, thus the emotional state of the learner, and the successive suggestions that we will project subliminally ?.

The organization of this paper is as follow: In the first section, we explain the grounds upon which this novel research is based since it is the first of its genre in the ITS and E-Learning community. The second section will present and discuss the previous work related to various aspects of our research. The third section describes the experiment setup and depicts the various aspects related to subliminal stimulus in a virtual 3D tutoring system. Section four will present the obtained results which will be discussed in section five leading to the last section where we conclude and present future work.

Subliminal Priming in a Distant Virtual Environment

As mentioned before, this research focuses on subliminal stimulus in a 3D virtual system to enhance learning. Before going further, we need to clearly establish the terminology that will be used in this paper. Indeed, the simple mention of the word subliminal can lead to discord and confusion. We establish a stimulus as being subliminal when it is projected too fast for a user to consciously report its existence. Conscious perception is well established in neuroscience and its properties are well known (Del Cul et al. 2007). One of those properties is the existence of a threshold for conscious access. It is precisely this threshold that we accept as being the “line” between conscious and subconscious perception (a term also referred to as unconscious perception). The technique used to send a given stimulus *below* this threshold of awareness is what’s known as a subliminal stimulus as opposed to a paraliminal stimulus that can be consciously perceived *above* the threshold.

Moreover, subliminal information must therefore be presented for a very short time and can vary in intensity, duration and frequency. It has however been established that subliminally projected information can bias behavior and even yield better results under specific experimental situations (Dijksterhuis et al. 2008, Kunde et al. 2003, Watanabe et al. 2001). Indeed, simply projecting subliminal messages without caring for context nor desired goals and emotions can prove to be inefficient or simply useless (Karremansa et al. 2005, Schutte 2005, Strahan et al. 2002). The cognitive process that takes place when the stimulus, either vocal or visual, is either unattended or subliminally projected is a stage we call subconscious processing. Contrary to popular belief, high-level semantic and even emotional processing has been observed during this stage (Govier & Pitts 1982, Treisman 1964). Another fascinating experiment placed forward the long-term effect of subliminal projection, or priming, on the visual system (Watanabe et al. 2001). In this experiment, subjects learned a task without actually realizing it. Participants were asked to focus their attention at random letters appearing on a computer screen while at the same time imperceptible moving dots in different directions were appearing outside their visual field. After a month’s training, the participants subconsciously learned to recognize and better identify the dots movements even if their attention was concentrated on the letters appearing in their visual field on the screen.

Thus, we believe possible, with our carefully designed subliminal stimulus, to enhance learning without consciously alerting the learner. We also believe that this new form of learning can trigger a set of positive emotional conditions in the learner, such as motivation and engagement, and thus enhance learning, problem solving and even decision making.

Related Work

Subconscious learning in a virtual 3D tutoring system is a novel approach. Thus, to the best of our knowledge, no existent work related to this specific research has been found neither in the ITS community nor in the Human Computer Interaction (HCI) community. However, a handful of papers in various fields have claimed the use of subliminal priming as a support for memory in the HCI community.

One of the early work regarding the implementation of subliminal cues for task-supported operation within a software was the text editor program of (Wallace et al. 1991). In this experiment, Wallace and colleagues investigated the response of subjects when requiring help from a text editor. They found that the frequency at which subjects requested help was much lower when the requested information was projected subliminally. Another very important finding explains why all previous subliminal studies did not have the intended results: the projected stimulus did not take into account the specifications of the computer such as screen resolution and refresh rate. The Memory

Glasses by (DeVaul et al. 2003) 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 (Schutte 2005) where the author assesses the effects of brief subliminal priming on memory retention during an interference task. The thesis examined in detail multiple parameters of subliminal projections such as duration, relevance and contract. Although the results of these priming seemed very encouraging, the author cautions HCI designers that misusing subliminal priming can lead to critical disruptions of ongoing tasks. Further work from (Mitchell et al. 2002) have stated that recognition performance in a standard item-based forgetting paradigm may be altered by subliminal cues. These authors believe that these cues can automatically activate different mnemonic strategies thus enhancing memory retention and recall. The results have shown that item-based words primed with the word "remember" seem to be better retained than "forgot" by a very slim difference however. Besides seeming to impact memory, subliminal priming can also have an emotional consequence on learners. Very recent work from (Dijksterhuis et al. 2008) put forward an interesting effect that subliminal priming can have on the self-attribution of authorship of events. 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.

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 (Lang 1995). 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 (Prendinger & Ishizuka 2005). Further research has analyzed a more detailed and relevant emotional significance of physiological signals, either in complex learning or gaming (Conati 2002, DiMello et al. 2007, Picard et al. 2001).

Experiment

Our research incorporated and combines all of the many different aspects of the presented related work. It uses subliminal priming in a 3D intelligent tutoring system while monitoring the physiological reactions on the learner. Moreover, we constructed the subliminal cues in a way which would accelerate the learning process by triggering and enhancing an already possessed knowledge.

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. Figure 1 below depicts such a square.

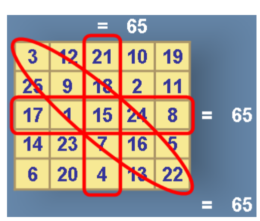

Figure 1. Magic square of order 5 that sums to 65.

To construct the following square, one must successively apply three simple tricks. We decided to show the learners the end result of each trick without explaining how. 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 figure 1, we notice that number 10 is placed one square above and two squares to the right of number 9. The same logic applies to numbers 1 and 2, 23 and 24 and so forth. Instead of giving away the answer to the first trick, we ask the subjects to deduce this 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 stimulus (control group) and the tutor will subliminally send the answer to the other group. We will then compare performances, time to complete and answer questions as well as physiological signals. 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 stimulus and threshold were carefully chosen following the neural bases of subliminal priming (Del Cul et al. 2007). 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 stimulus 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. Figure 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.

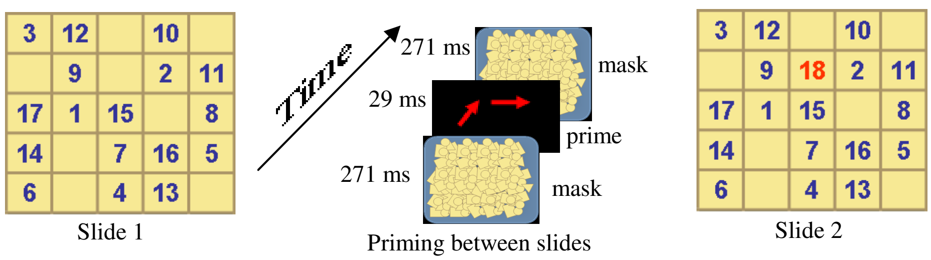

Figure 2 – Subliminal priming of the solution between 2 slides

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.

MOCAS and material used

Learning takes place in a game-like environment called MOCAS (Blanchard & Frasson 2006) as show in Figure 3. The experiment has three rooms like the one illustrated on the left part of figure 3. Each room teaches one trick. The lessons and examples are presented in the virtual world. MOCAS takes place in full screen for a more complete immersion and less window distracting events. Furthermore, the system clock is hidden to 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.

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. In the right part screen shot of figure 3, the learner can choose to follow either the yellow, blue or red path. Two of these paths will lead to dead-ends where he will be instructed to turn back and try again by another visually different pedagogical avatar.

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 (Thought_Technology 2008).

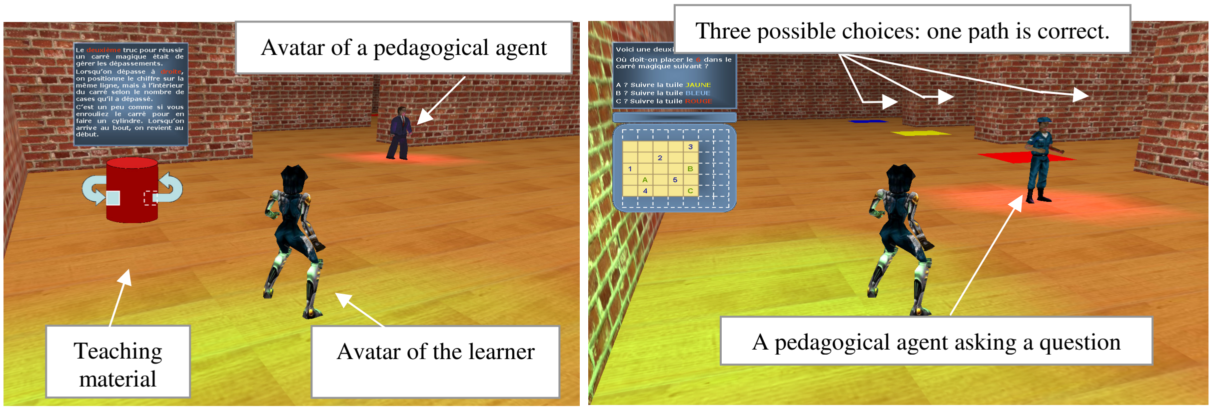

Figure 3 – 3D virtual learning environment

Learners tested

A total of 31 healthy volunteers, 16 men and 15 women, took part of the experiment. The sample's mean age was 28 (SD = 4.81). 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.

	Men	Women
Group A : primed with subliminal stimulus	8	7
Group B : no subliminal stimulus	8	8
	16	*15*
Total	**31**	

Table 1. Participants' distribution.

Results and discussion

The first aspect we wanted to investigate in this experiment was the presence, if any, of a positive emotional impact of problem solving in a 3D virtual system. Table 2 highlights some very interesting results regarding the degree of enjoyment when using our system. It seems that the learners having the least video game experience are the ones that seemed to enjoy it the most. Measuring the degree of enjoyment was also important because positive emotions are exactly where we want the learner to be for optimal learning. However, only 5 learners showed moderate enjoyment while using the system. Nonetheless, we wanted to be thorough and asked them to justify their answers. All five answers converged to the same result: the system was not flexible enough to their needs. They would have loved to be able to manipulate the material taught, to rotate it or spin it in a different direction/angle. The score they gave had nothing to do with the material learned. It had to do with the fact that they expected the environment to be very much like a game, extremely flexible and all components moveable and playable.

Video gaming experience	*How enjoyable was it to learn in this 3D environment?*	
	Moderately	*Highly*
Low		16
Moderate	2	6
Moderate to high		4
High	3	
	5	*26*
Total	**31**	

Table 2. Participants' enjoyment with regards to their video gaming experience.

The second research question was to investigate the possibility of enhancing the transmission of classic information by means of a subliminal technique. The results we obtained are surprising to that regard. Indeed, Figure 4 clearly shows that overall performance with the presence of the subliminal module was 2.6 times more efficient on average than without the module (44% less mistakes overall with the presence of the subliminal module on average).

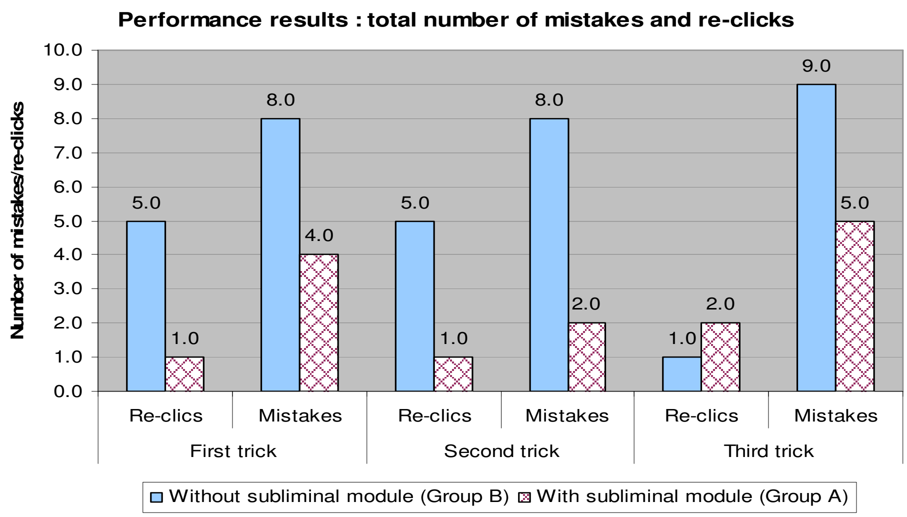

Figure 4 – The overall number of mistakes made for every trick

Furthermore, the number of re-clicks is also an important indicator as to the efficiency of the subliminal module. This number represents the number of times learners asked to restart the lesson. A number of 5 re-clicks for the first trick means that this specific lesson was repeated 5 times. We can clearly see on those results that there is a significant difference in the amount of re-clicks when using the subliminal module, except for the last lesson ($p = 0.03$, $\alpha = 0.05$). That tends to show that users tend to repeat every lesson three times less on average. This result is surprising and very encouraging. In our efforts to better understand the reasons behind these results, we decided to analyze the time subliminally primed learners took before answering each question and compare it with the time it took to our control group. Figure 5 presents the obtained results.

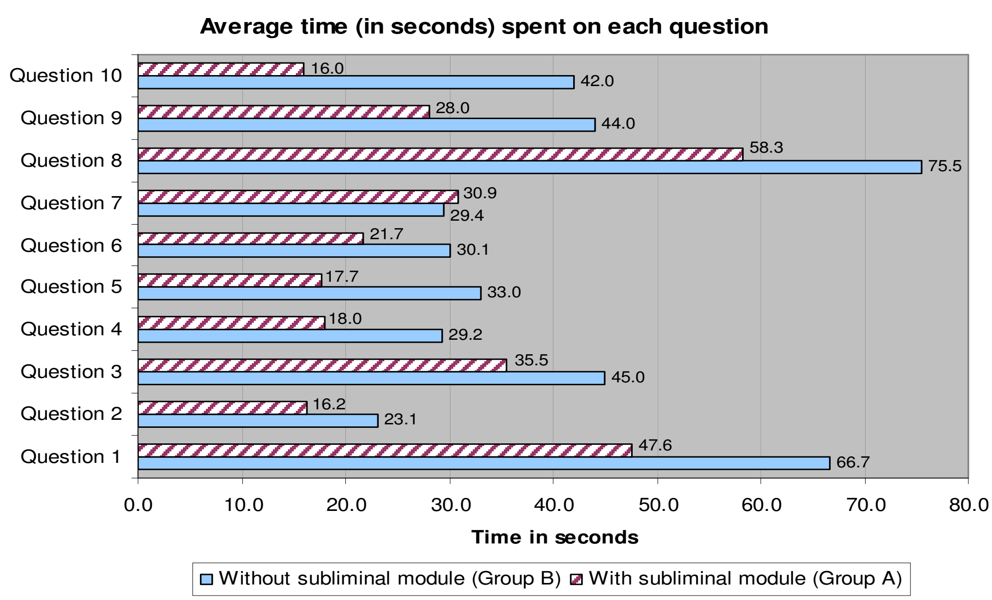

Figure 5 – Average time spent on each question

The results tend to confirm what we have been observing all along. Subliminal priming at specific and well timed intervals during the lesson seem to significantly reduce the time later spend on each question. Not only does the performance of primed learners is enhanced but the time they spent on each question is reduced as well by an overall factor of 1.3 (Single factor ANOVA $p = 0.023$, $r = 0.858$, $r\text{-}square = 0.736$, $\alpha = 0.05$). It is important to note that NO subliminal priming is done during the questions. All the priming is done during the lesson taught. The answer to the questions is not projected subliminally when the question is asked. Two factors in our opinion explain those results. First and foremost, the subliminal priming seems to act as an accelerator on learning because some of the primed learners did not read the entire lessons. Four of them skipped right in the middle and clearly stated that they understood the lesson before the end. None of the learners in the control group interrupted the lessons. Second, the fact that the subliminal priming is goal-relevant to the cognitive task at hand might accelerate links between already present knowledge and quickly converse to a solution as observed by three previous studies presented here (Strahan et al. 2002).

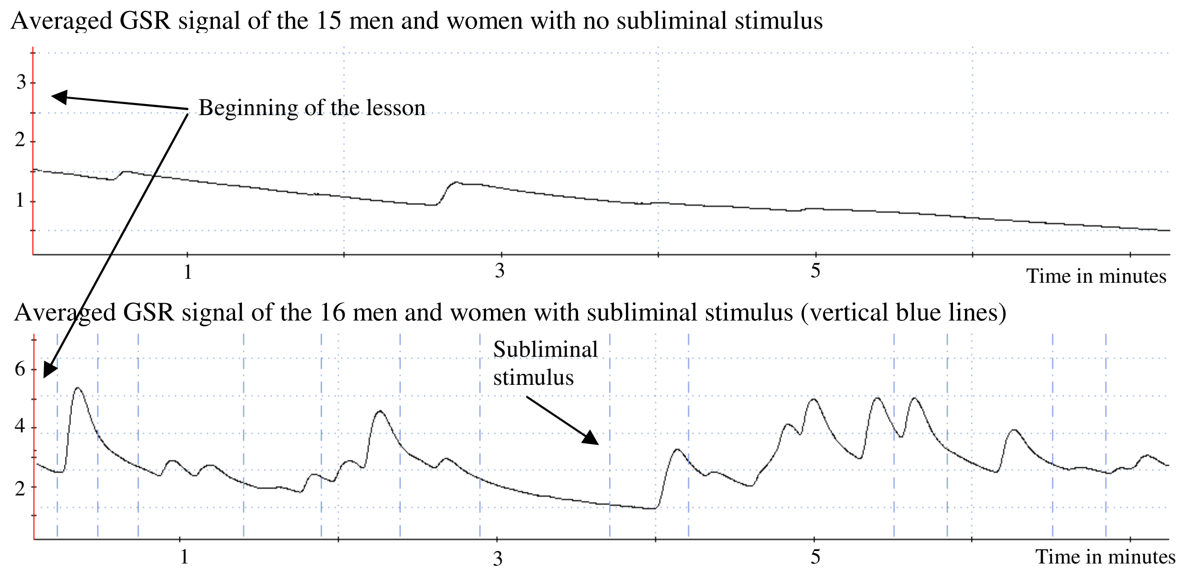

Figure 6 – Mean GSR signals for the subjects while learning the second trick

The last aspect we wanted to investigate was the relevant links between the physiological signals and subliminal primes. We used Matlab to smooth and average all galvanic skin responses. Figure 6 above presents the levels of arousal when learning the second lesson, thus trying to deduce the second trick. The vertical blue dotted lines represent the moment in time when priming is projected on the screen. The GSR signal value is presented in black. The red line denotes the beginning of the lesson. As we can clearly see, a learner's emotional reaction significantly differs when viewing a lesson without the subliminal primes. The differences represent an increase ranging from 10% to 150% from the averaged baselines. Since there is an accepted positive linear correlation of GSR with arousal (Lang 1995) we can state with confidence that not only subliminal stimulus is subconsciously perceived but produces significantly high arousal levels in the learners.

Nevertheless, high arousal levels alone are not indicative enough of positive emotional impact of subliminal primes. Indeed, emotions are defined in two dimensions: arousal and valence (Lang 1995). Arousal is basically the intensity of an emotion, ranging from low to high, while valence is the degree of expression, ranging from positive to negative. Hence, it is important to measure both dimensions to have a precise idea of what emotion has been expressed or identified. Basing our results on Lang's widely accepted two dimensional affective space (Lang 1995), we can determine that our observed arousal levels put us anywhere between joyful and excited. To complete the emotional state of the learners, we normalized in Matlab the Heart Rate signals of the participants. We used the widely accepted median shifting technique which relates all data to their specific standard deviation. Figure 7 shows the obtained results. A value of 1.5 represents a heart rate signal that's one time and half higher than its standard base line value. More importantly, a negative value means that the learner is actually calmer and more relaxed than its positive counterpart.

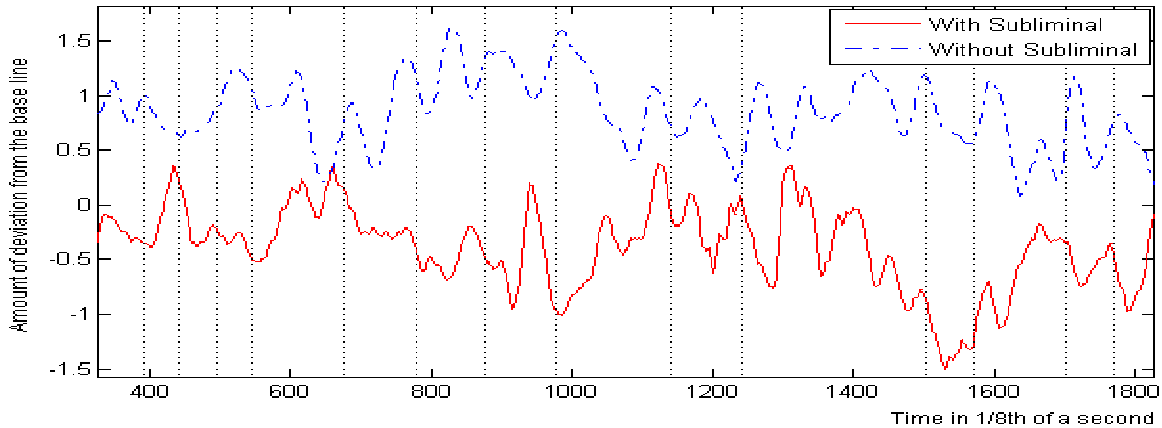

Figure 7 – Normalized HR signals for the subjects while learning the second trick

A very high positive value means that the learner's valence level is too high thus leading towards excitation which is a bad indicator for learning. The same could be said of negative values that tend to place the learners in a state of frustration. Overall, we can see that the valence levels range from 0.5 to -1.5 when using the subliminal module. When combined with the arousal levels observed, we can confidently state that the learners who used the emotional module have an emotional state ranging from relaxed to joyful.

Conclusion

We presented in this paper the use of subliminal priming in a novel way in the context of a 3D virtual tutoring system. In contrast to the previous work regarding the use of subliminal priming, our work differs in three ways. First, the subliminal priming was used to try to elicit an already possessed knowledge to get a better and faster understanding of the problem at hand. We showed that not only the overall performance was enhanced but the time learners took to answer questions was also shortened by the presence of the subliminal priming module. Second, the integration of 3D gaming-like environment, physiological sensors and subliminal stimulus is novel in itself and as the results have shown seem to yield very promising results as well as also showing motivation and enjoyment. Third, we presented physiological evidence supporting the emotional response in terms of arousal of subliminal priming in the context of learning in a virtual environment. In the light of the encouraging results, we plan as future work to determine and validate in more details the various correlations between the subliminal primes and the other physiological signals and try to link them to performance if possible in the hopes of establishing solid correlations. We also would like to examine the pertinence of projecting a more complex series of stimulus in a situation where the solution is a succession of steps. We would like to see and test the different sorts of priming that we could use in specific situations: do we send all of the parts of the solutions or do we subliminally prime certain parts. Finally we would also like to study the various aspects of real-time adaptation and subliminal priming with regards to the emotional state of the learner.

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