Design and Evaluation of Surprise Effects in Simulation - A Framework

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ABSTRACT

While a certain level of surprise is required for nearly any type of learning, it is a challenge to provide for surprises in an effective way. Simulation enables the training designer with powerful options to provide for surprising experiences, either to engage students, to stimulate thinking, or to learn to deal with them. Dealing with emergencies or replanning for example are explicit training objectives in many simulator sessions – although the students often already expect the surprising events. Alternatively, surprises in simulation sessions can be instrumental to achieve a context in which other training objectives can be achieved, such as leadership, decision making, and coordination. This study explores the nature of surprises and provides suggestions for designing surprises in training and subsequently for assessing its effectiveness. The framework for designing and evaluating surprises relates to the capabilities that cause the surprise (this may be cue based, narrative based or personal-based) as well as a human (surprise) information processing model. Assessing the effects of surprises is relevant during the design of the training scenario to tailor the effects to the target audience, and may also have the potential to guide the instructor during the training to inject weaker or stronger events. The use of electro encephalogram (EEG) is a promising technique for assessing mental state levels of relaxation, attention, or agitation/confusion. In this study EEG is applied to analyze brainwave patterns and investigate the potential for assessing the effects of a variety of surprise types in a VBS training scenario. Preliminary results indicate that EEG is sufficiently sensitive to measure mental state effects of surprising events. More study is required to determine the validity of the measurements and whether it can be used as the single technique or that a toolkit using a variety of techniques are needed.

ABOUT THE AUTHORS

Jelke van der Pal is Senior Scientist at the Dutch National Aerospace Laboratory NLR. He has earned a Ph.D. in 1995 from the University of Twente in the Netherlands) on the effectiveness of interactive graphics for education in Formal Logic. Since 1996 he is active in the aviation training R&D, which includes training analysis for the proposed pan-European military pilot school (Eurotraining), and for NATO-level networked simulator mission training. Jelke has co-ordinated the European ADAPT-IT project, producing a instructional design tool that provides competency-based support for several phases of the ISD cycle and has been responsible for the training concepts in other EU projects, for example the CRISIS project aiming to enhance crisis management training for airports using gaming technology. Currently, he is trying to understand the principles behind effective simulation and gaming for learning processes and how to determine effectiveness.

Konstantinos Georgiadis has a BSc in Industrial Informatics at the Kavala Institute of Technology, Greece. Currently he is working towards his MSc in Game & Media Technology at the Utrecht University, NL, as a trainee at the National Aerospace Laboratory in Amsterdam. In his work, he applies a multidisciplinary approach that combines both Informatics and Cognitive Psychology in the context of serious gaming.

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INTRODUCTION

Surprise is complex phenomenon with physiological and psychological elements and relates considerably on situational meaning and therefore the personal background of the surprised person. What counts as a surprise, often defined as inconsistency between predicted and observed outcome (e.g., Ranasinghe & Shen, 2008), differs between individuals. What is considered to be a surprise for one person, does not need to be a surprise for another person, or it may differ in experienced intensity (ranging from insignificant to huge or even life threatening), depending on the persons experience and sensitivity to external input. A surprise can have valences such as positive, neutral, or negative; and pleasant or unpleasant (Frijda 1986).

The surprising event can trigger a variety of responses such as startle, surprise, confusion, stress, panic, shock, and trauma. Startle is physiological response to a sudden event and usually last for a couple of seconds. Startle may result in biological reflexes such as eye blinks, body movements, increased heart rate, goose bumps, and biochemical changes. Startle and surprise do not always concur. A well-known startle reaction without surprise comes with seeing a balloon being pricked. The loud noise does not happen unexpectedly, and yet the observer will blink the eyes. Surprise can also come without a startle effect. Receiving a call from your car dealer informing you that your broken car is repaired two days earlier than planned, may surprise you, but is not likely to induce a startle effect. Surprise therefore involves interpretation, a cognitive process in which the event is compared to memory. This process is mostly automatic and may last a few seconds. Finding explanations and possibly solutions for the surprise could last from a split second to lifelong, depending on the valence and relevance the surprise has on a person, and on the competence of the person to deal with the surprise. When the surprise is intense, the immediate phase of finding explanations will go together with feeling confused or even stress or panic when under time pressure or in danger. When the surprise event includes extreme violence, danger, injury, or loss of life, it may result in shock and grow into a trauma. We focus on the first three response types in this paper: startle, surprise, and confusion and suggest an approach to design scenarios with a potential to induce these responses. This approach can be used to enable the following training functions: 1) learn to deal with specific types of events; 2) provide conditions for learning complex competencies in whole tasks situations; 3) enhance the learning effects.

Learning to deal with Surprises

Certain operational situations require immediate action to ensure safety of vehicle and crew or to ensure the mission goals can still be met. Emergency situations in aircraft are obvious examples, as well as unforeseen enemy behavior or other hazards to a mission plan. The training goal is to ensure that effects of startle, surprise, and confusion are known, recognized, and dealt with in such a way that these phases are as short as possible and do not lead to extreme reactions such as shock or panic, while practicing to analyze the situation and take appropriate actions (according to procedures or contingency plans).

Enable whole task training

Surprising events are useful in providing a context for acquiring complex competencies such as (tactical) decision making, prioritizing, maintaining situational awareness, and coordination under time pressure, threat or novel situations. These competencies need to be flexible and adaptive to a wide variety of new situations. Surprise here may be life threatening, but can and will often be more subtle, disturbing task execution only slightly. Most learning theories, such as associative learning and connectionist learning models, state that an unforeseen, unpredicted outcome is the basis for learning. With more experiences, the new association is strengthened and gets more stable. Providing the same event in the same environment time and again, may lead to fast learning, but will not generate the desired far transfer of the learning product into the real and less predictable professional world. The very nature of whole task training, provided in a rich environment that contains realistic elements of objects, human behavior, and processes, therefore depends on the surprise and variation quality of events or features.

Enhance learning

Conditions in which learning takes place (light, music, drug use, etc) may effect learning positively, in particular when the performance in a test or operational situation is taken under the same conditions. A surprising event, not related to the learning task, can also provide for a learning enhancing condition (Van der Spek, 2013; Ranganath & Reiner, 2003)

The need to improve simulated surprises

With these three vital functions of surprising events in training, it is remarkable that the majority of training, including simulation and serious gaming, provide for highly predictable training setups and scenarios (cf. Burki-Cohen, 2010). Improvement of scenarios is expected to benefit by applying a training perspective on when and how to use surprises and variation. This perspective depends on understanding which elements (in simulation and gaming) can induce surprise as well as an understanding of how surprises work for individuals or groups with the same level of experience. Because surprise effects are related to the personal background and experience of the trainee, a generic theory of surprise effects may not be sufficient to realize the required improvement. A framework for optimal use of surprises will have to measure the effects either a) during the scenario design phase in which prototype test results are used to increase or decrease the surprising effect of the event or variation, or b) during the scenario run, using real time feedback of scenario effects on trainees to change the scenario events or settings either automatically or by advising instructors. The next section provides for a concept framework for using surprise effects in this way. The framework intents to support the practitioner (instructor, scenario designer), not necessarily the research community.

FRAMEWORK FOR DESIGNING AND MEASURING SURPRISE EFFECTS

Enhancing the design for surprises can be achieved by following design principles and by adapting the scenario based on knowing the effects the surprise has on trainees. The latter requires application of techniques to measure surprise effects. Therefore, we describe a toolset for measuring the effects of surprises first and subsequently the design principles.

Measure Surprise effects

The effects of surprises can be measured in several ways by using various means. Recent progress in biofeedback technology promises measurement of different physiological responses concurrently and then correlate them in a unified analysis frame in order to reach robust conclusions about the surprising effects (Murugappan et al., 2010). For example, the physiological responses of a trainee in a serious gaming context can be measured by using electroencephalogram (EEG), galvanic skin response (GSR), eye blinks, eye-tracking, facial expressions, heart-rate, etc (Chanel et al., 2006). In addition, the trainee’s behavior can be evaluated by comparing his/her in-game task performance (response times, game scores) before and after the surprising events. Additionally, trainees can provide self-ratings on perceived impact of surprising events by using questionnaires.

For practical training purposes, not all these measures can be taken simultaneously. An optimal and practical selection is yet to be found. Furthermore, the use of easy to apply, inexpensive measurement tools are critical for application on a wide scale. In the last decade, several commercial products for measuring heart rate, eye gaze, and EEG seem to comply with these requirements.

EEG probably provides for the most rich measurement of mental state and therefore the first to explore in the framework. The human brain generates electricity that can be measured on the scalp surface in microvolts. Electric output can be found in wavelengths from 0.1 to 100 Hz. This brainwave spectrum is categorized into meaningful bandwidths or brainwave types. Each type has been found to indicate certain psychological states. Table 1 illustrates example bandwidths (from NeuroSky Inc., 2009; Hondrou & Caridakis, 2012)

Table 1. Brainwave types and mental state indications

Brainwave Types		
Brainwave Type	**Frequency Range**	**Mental States and conditions**
Delta	0.1 Hz to 3 Hz	Deep, dreamless sleep, non-REM sleep, daydreaming
Theta	4 Hz to 7 Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8 Hz to 12 Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12 Hz to 15 Hz	Relaxed yet focused, sensorimotor response
Mid-range Beta	16 Hz to 20 Hz	Thinking, aware of self and surroundings
High Beta	21 Hz to 30 Hz	Alertness, agitation
Gamma	30 Hz to 100 Hz	Higher mental activity, motor function

The power in these bandwidths tend to differ over the scalp, reflecting the specialized parts of the brain that are active while processing e.g. visual input, motoric actions, problem solving, making calculations, maintaining SA, etc. Depending on the hardware used, one, four, or more positions on the scalp can be measured, limiting or extending the scope of measurement and potential use. Measuring more positions is attractive, but comes with a price. It will increase the level of complexity in analyzing data, and may also lead to more intrusive measurement to the trainee. For a practitioner oriented framework, this is a high price to pay. We will focus on one channel EEG equipment, with an electrode on the prefrontal scalp (therefore, the higher cognitive functions of the prefrontal lobe are measured best) and embedded algorithms for artifact correction (from eye movements).

Design for surprises

Designing surprising events can be done in a variety of ways. We distinguish four design approaches:

1. Initial design with bottom up surprises, using sensory elements
2. Initial design with top down surprises, using cognitive, narrative elements
3. Revised design, using mental state measurements post-hoc
4. Adaptive design, using mental state measurements real-time

The bottom up and top down surprises relate to the general information processing model (Newell & Simon 1972) of receiving information through senses – processing information in working memory – retrieving information from long term memory (and integrating new information to existing knowledge structures) – generate actions by motoric actions (for an information processing model dedicated to game development, see Van der Spek, Van Oostendorp & Wouters, 2011). A bottom up surprise is generated by providing unexpected sensory input; a top down surprise is generated by providing cognitive inconsistencies (to long term memory) or narrative surprises.

Bottom up surprises

Visual and auditory cues in the virtual environment can be used in order to create a bottom-up surprise. In the case of visual cues, the surprise of visual stimuli can be more or less salient, determined by features like the local luminance contrast, the color contrast, the orientation and direction of motion. Moreover, the flickering of a color (especially red) in some parts of an image where it used to be stationary black can also be surprising and trigger the player’s attention (Itti & Baldi, 2005). Beside the visual cues that can be used in order to generate bottom-up surprises from the virtual environment, a scenario or game developer can also use auditory cues. Any sudden and unexpected change of tonality, loudness, pitch etc. of voices, music, sounds and noises can cause surprise to the player. Table 2 summarizes some of the basic visual and auditory surprising factors:

Top down surprises

Top-down surprises can be created by building surprises from a narrative or by addressing the personal (lack of) knowledge base of the trainee(s). For example, assume reading a book in which the main character starts dating a person. The information related to this event becomes surprising when it is coupled to the reader’s knowledge in the long-term memory, for example that the person dated is the sister of the person’s wife. As result, the surprise may trigger a physiological reaction such as facial expressions or to give a cry.

Table 2. Overview of visual and auditorial cues which stimulate surprises

Bottom-up surprises		
Visual cues	Unexpected and sudden changes in • local luminance contrast, • color contrast (red/green, blue/yellow - chromatic channels), • orientation of motion • direction of motion, • flickering	Example: An unexpected explosion
Auditorial cues	Unexpected and sudden changes in • pitch, • loudness, • tonality, • rhythm, • timbre/melody of voices, • music, • sounds and noises	Example: A sudden scream

A well-known example of how a designer can create a surprising narrative is provided by Brewer & Lichtenstein (1981), a narrative in four sentences:

Butler puts poison in wine.
Butler carries wine to lord Higginbotham.
Lord Higginbotham drinks wine.
Lord Higginbotham dies.

There is no surprise in this narrative, but if the first sentence is removed, the death of Lord Higginbotham comes as a surprise because the reader will be ignorant of the poison.

A narrative in a (game)scenario can either be light or heavy. In the case of a light narrative, there will be a strong environmental storytelling (Jenkins, 2004) from which the surprise events may potentially pop-up by destabilizing the player's visual prediction over the observed outcome. In the case of a heavy narrative (McQuiggan et. al, 2008) there will be a rich plot/story, in which, by leaving out important information or an important event, a subsequent event may become unexpected and thus surprising. See table 3 for examples of surprises from light and heavy game narratives.

Table 3. Overview of narrative types that stimulate surprises

Top-down surprises	
Light narrative (background storyline)	Changes of: • weather, • indicators, • items, • characters, • environment, etc.
Heavy narrative	Leaving out an important event or information related to the game objectives or the characters participating in the storyline.

To sum up, surprises can be elicited from the narrative, from cues or from a combination of narrative and cues (i.e. mixed surprises). Together they form a surprise capacity of a game or scenario. The personal knowledge base can also be considered as a surprise capacity. People do not have the same surprise capacity and ability to regain or maintain an optimal state capacity for surprises in long-term. The range of surprise capacity differs between people for various reasons, primarily related to demographic characteristics such as education, previous experiences, age, gender etc. Also, the current physiological and psychological state in which someone is when being surprised is a factor. For example, someone is more prone to surprise while daydreaming.

Game or scenario developers aiming for a high surprise impact should design the events preceding the surprises in such a way, that the trainee gets into a relaxed state before being exposed to the surprise event. The surprising events must be genuine and unprecedented; while trainees do not have prior knowledge about it. For example, our three sentence Higginbotham narrative would come less as a surprise when it was announced as an Agatha Christie story.

Lastly, the surprising event can either be related to a task or a procedure that is being executed by the trainee at the moment or not. In other word, a surprise event can be either task-dependent or task-independent. It is expected that these surprise types will have different impact on and meaning for trainees.

It is assumed that the impact of surprise event, either task dependent or task independent, is a function of a) the surprise capacity range of individuals, b) the surprise capacity range of cues, and c) the surprise capacity range of the narrative.

As a result, we distinguish six different categories of surprises a game or scenario designer can create surprises:

1) task-independent cue based surprises (e.g. while the player is about to perform a task, he/she suddenly hears a Non-Playing Character (NPC), in a nearby dark alley, screaming loudly out of pain),
2) task-independent narrative based surprises (e.g. while the player is heading towards a target location to complete a task, he suddenly receives a call that his house has been robbed),
3) task-independent mixed surprises (e.g. while the player is trying to gather some supplies for his mission, a nearby fellow NPC which was supposed to aid him/her on the task, suddenly gets on fire and starts screaming),
4) task-dependent cue based surprises (e.g. while a player opens a chest to reveal its treasure, a fire trap disarms and causes an explosion which destroys all the content),
5) task-dependent narrative based surprises (e.g. while the player is heading to a certain location in order to complete a task, he/she gets informed that this location has changed) and
6) task-dependent mixed surprises. (e.g. by the time a player reaches a mission target, the target gets destroyed by a sudden explosion caused by a bomb that a fellow NPC set; whom until this point of the mission was considered to be a friend or ally)

Revised design

By measuring the impact of the surprise events on the mental state of the trainee during prototype testing or during training evaluation it can be determined whether the effects are sufficiently strong. If not, the events or the overall scenario/narrative should be replaced or redesigned.

Adaptive design

The same type of measurement could also be used during the training itself. The mental state measurements would feedback in the scenario where software can change the narrative or cues accordingly (i.e., make subsequent events less surprising or more). This is known as a passive-BCI (brain computer interface) technique (e.g., George & Lécuyer, 2010). This could be achieved automatically or by means of an instructor support system.

USABILITY OF EEG FOR MEASURING SURPRISE EFFECTS

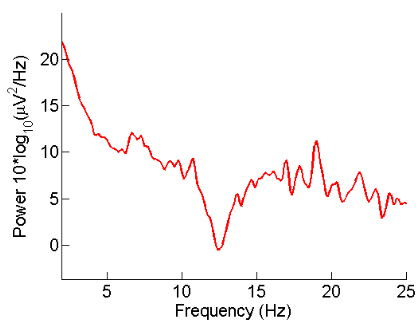
The framework presented above requires considerable work to ensure it is usable and valid. We have started this by exploring the potential of measuring mental states during a simple VBS2 based scenario containing a variety of surprising events. Mental state was measured by EEG equipment for the consumer market, the Mindwave Mobile, a non-intrusive EEG headset from NeuroSky. The main reason for choosing this specific device was its simplistic configuration; since it only uses one single dry electrode on the left frontal scalp plus a reference point to the left earlobe. Data transfer is wireless. Hence, this allows non-EEG experts to use it in training applications, without having the constrictions and complexities that an expensive and advanced intrusive EEG device would pose.

Method

A game mission with an undercover agent narrative was created to provide the six categories of surprises described above by using the VBS2 editor from Bohemia Interactive. The gameplay was set as single player, action-based in a non-military setting using a linear, simple scenario that was playable even for participants unexperienced to first person shooter games. In total ten surprising events where strategically placed in certain parts of the mission in order to measure the participants' reactions towards them. The assessment of the surprise effects was done by measuring mental states as well as by means of a Likert-scale post-game questionnaire and in-game indicators for players' time and scores.

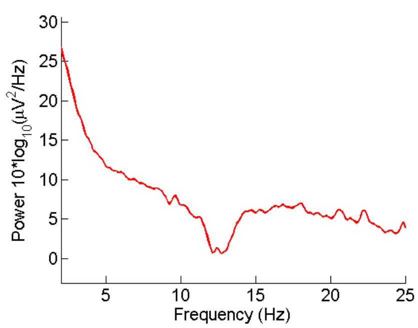
After fitting NeuroSky's Mindwave Mobile to the participants head, they were asked to wait while remaining calm and inactive for a period of time in order to perform a 5 minute baseline recording. EEG data was collected with a sampling rate of 128 Hz. Data was recorded by using NeuroSkyLab. The start of surprising events were manually time-stamped by using key-strokes. After collecting the EEG data, EEGLAB was used in order to plot the power spectra and the mean power of each individual frequency bandwidth for all the time-stamped events of the game missions. The EEG data recorded directly after the surprising events was analyzed in three time periods: three, five and eight seconds after the time stamp. This may reveal differences between startle, surprise and confusion.

The game was introduced to the players by a tutorial to use the controls and by presenting the tasking to the players. Playing the game took about 25 minutes. The total session lasted about 45 minutes.



Band	Mean Power
Delta (1-4)	89.5463
Theta (4-8)	12.9659
Alpha (8-13)	4.1960
Beta (13-30)	2.9846
Gamma (30-80)	0.0311

Figure 1. Baseline EEG power spectrum and mean band power for one male participant



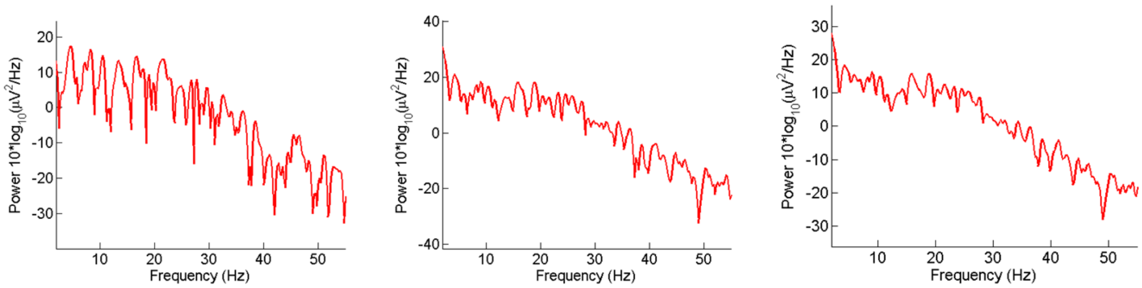
Band	Mean Power
Delta (1-4)	228.0988
Theta (4-8)	12.7558
Alpha (8-13)	3.5643
Beta (13-30)	2.5425
Gamma (30-80)	0.0310

Figure 2. Baseline EEG power spectrum and mean band power for one female participant

Preliminary results

While data collection is still ongoing, results from two participants (one female, one male) were analyzed. First, the baseline EEG recordings (see figures 1 and 2) revealed that the female participant was in a more relaxed, even dreamy state since the mean power of the delta frequency band is much higher than the male's. The male seems to be more alert and active, which is also reflected in the less smooth power spectra curve. We will use the mean power in the each band to compare it with the surprise effects.

Concerning the first surprising event (task dependent cue-based surprise), the female participant was in extremely "wake" state for the first three seconds (see Figure 3), since (compared to the baseline) she had very low mean power value at the delta frequency band, while she was also more attentive. At five seconds (see Figure 4), the levels of relaxation rapidly return back to a relatively normal state, but in the same time her attention/agitation is boosted. At eight seconds (see Figure 5), the mean power values of almost all the frequency bands fall a bit; however the higher frequency bands remain higher in mean power value compared to the baseline recording. The power spectra curves display an intense turbulence in her brain state even after eight seconds. Most of the surprises follow the trends over time of the first surprise event.



Band	Power
Delta (1-4)	5.7248
Theta (4-8)	9.6554
Alpha (8-13)	4.0179
Beta (13-30)	3.5263
Gamma (30-80)	0.0222

Band	Power
Delta (1-4)	276.0796
Theta (4-8)	25.2095
Alpha (8-13)	17.9432
Beta (13-30)	11.6063
Gamma (30-80)	0.0471

Band	Power
Delta (1-4)	154.8989
Theta (4-8)	27.5414
Alpha (8-13)	12.2922
Beta (13-30)	8.7905
Gamma (30-80)	0.0457

Figures 3 (left), 4 (middle) 5 (right). EEG power spectrum and mean band power for the female participant in the 3 seconds (left), 5 seconds (middle), and 8 second (right) after the first surprise event

For the male participant for example, the alpha band reveal the time pattern (averaged over the event) of lowering of power immediate after the event, followed by increasing power until 8 seconds (see Figure 6).

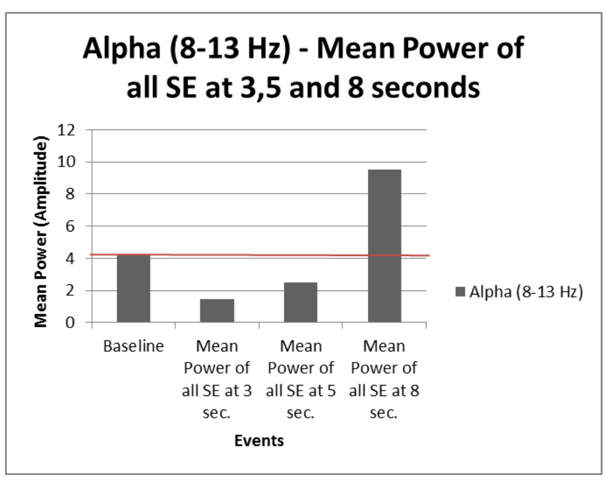


Figure 6. Mean EEG Alpha band power for one female participant for three time frames after the surprise events, compared to the baseline

When comparing between the surprise events, for example over 8 seconds after the event, we see differences in band power between the events and between the bands (two examples are provided in figures 7 and 8). Also, several events do not differ much from the baseline, indicating that the event is not generating a specific effect of any kind.

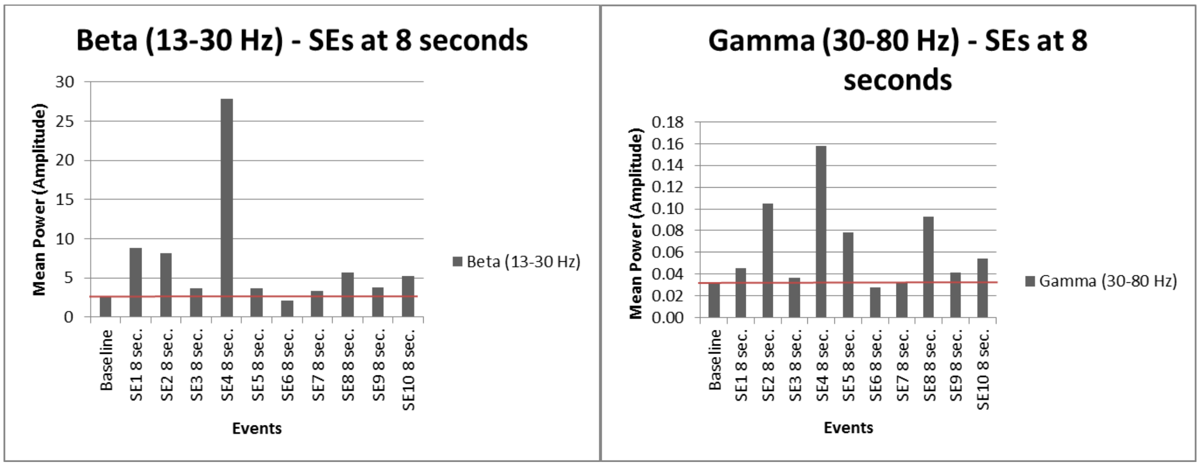


Figure 7 and 8. Mean EEG Beta and Gamma band power for one male participant in the 8 seconds time frame, comparing 10 surprise events and the baseline

When comparing between the types of surprises (figures 9-14) it shows that task-dependent surprises generate higher more effects (participant is more active, thinking) than after task-independent surprises. Cue-based surprises generate somewhat less and slower effects on mental state. The mixed surprises do not seem to generate mental effects above the baseline.

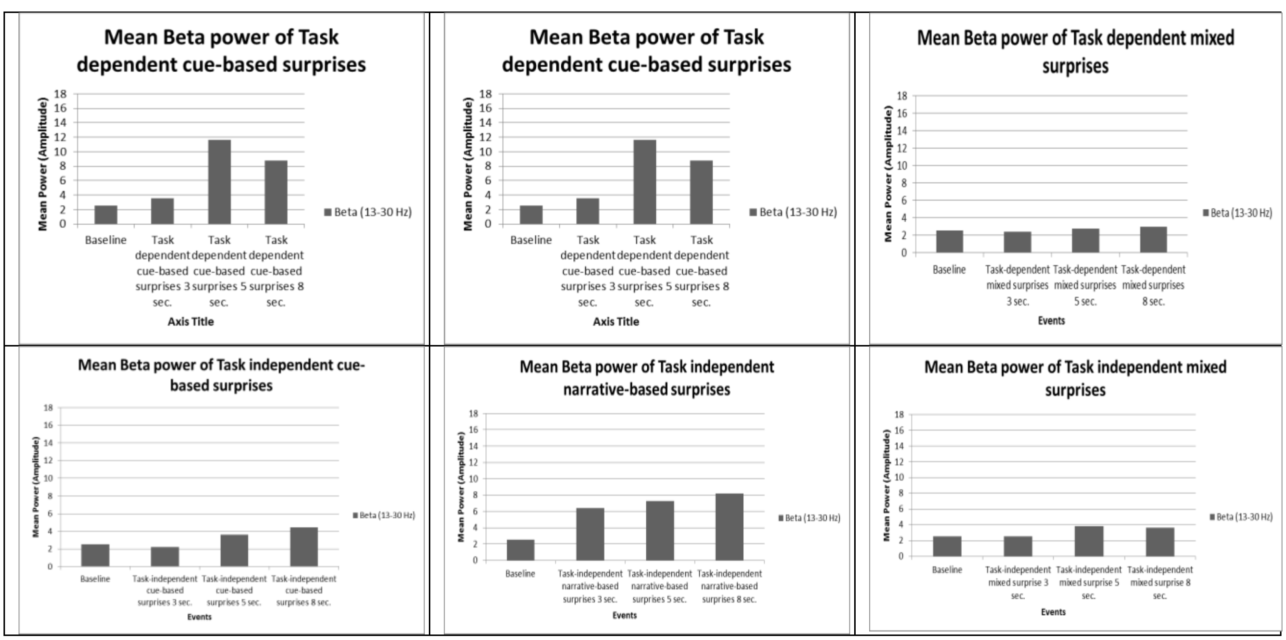


Figure 9-14. Mean EEG Beta band power for one male participant in three time frames after the surprise events and the baseline for the six surprise categories

Discussion

The results from the two game cases obviously are limited and idiosyncratic. No general conclusions should be derived for game design from these results. What is does reveal is that mental state measurement can be sensitive to differences in surprises in game or simulation settings and that such differences can be used to determine the surprising quality of events. Whether a surprise event generated startle or confusion may be reflected by differences in the time frame effects. Clear interpretation of the mental states (time frame effects, bandwidth differences) is still difficult. The size of the mental state change after surprise events can be assessed, but it does not provide a clear perspective on the exact feeling of the person. Interpretation depends on the content of the event and may be validated to some extent by interviewing the person.

CONCLUSION

This paper presented an outline for a framework of techniques to optimize scenario design for training that requires trainees to deal with new situations with a desired and highly personal level of impact to the trainee's mental state. The framework consists of three major parts: 1) bottom up techniques that stimulate the senses such that information is presented in such a way that it generates or enhances a surprising effect, 2) top down techniques that generate surprise and confusion by presenting unexpected or inconsistent information either from the narrative or from the knowledge base of the trainee, and 3) techniques to measure the surprise effect and feedback into the design to ensure the effects are optimal for the learning process.

The study focused on testing the usability of one technique in the framework that has powerful potential in measuring mental states: EEG. The preliminary results indicate that a simple, commercial of the shelf tool that is easy to use in standard training situations, is sensitive to differences between surprising events, time effects, and individuals. However, interpretation of band power is not easy as several mental states are known to generate power in a particular band. Also, using the data recording and analysis software is at present not a simple task, and limited information is provided by the manufacturer. Usability for instructors and scenario designers of the post hoc analysis therefore is currently low. The passive BCI function for adaptive scenario design has not been applied in the current study. More study is needed to determine the full potential of the technique and the validity of measuring the intended mental states.

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