Detecting Insight and Emotion in Visualization Applications with a Commercial EEG Headset

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Abstract

Insight represents a special element of knowledge building. From the beginning of their lives, humans experience moments of insight in which a certain idea or solution becomes as clear to them as never before. Especially in the field of visual representations, insight has the potential to be at the core of comprehension and pattern recognition. Still, one problem is that this moment of clarity is highly unpredictable and complex in nature, and many scientists have investigated different aspects of its generation process in the hope of capturing the essence of this eureka (Greek, for "I have found") moment.

In this paper, we look at insight from the spectrum of information visualization. In particular, we inspect the possible correlation between epiphanies and emotional responses subjects experience when having an insight. In order to check the existence of such a connection, we employ a set of initial tests involving the EPOC mobile electroencephalographic (EEG) headset for detecting emotional responses generated by insights. The insights are generated by open-ended tasks that take the form of visual riddles and visualization applications. Our results suggest that there is a strong connection between insight and emotions like frustration and excitement. Moreover, measuring emotional responses via EEG during an insight-related problem solving results in non-intrusive, nearly automatic detection of the major Aha! moments the user experiences. We argue that this indirect detection of insights opens the door for the objective evaluation and comparison of various visualizations techniques.

Categories and Subject Descriptors (according to ACM CCS): Information Systems [H.5.1]: Multimedia Information Systems—; User Interfaces [H.5.2]: Evaluation/methodology—.

1. Introduction

Insight, epiphany, eureka moment, Aha! effect [Leh08]—these are all names for one of the most intriguing and even mysterious process through which humans gain knowledge. But what is insight really and how does it enrich our capacity to gain and manage knowledge? There are many definitions, each capturing a slightly different aspect of the experience. The Merriam-Webster dictionary defines insight as "the act or result of apprehending the inner nature of things or of seeing intuitively". Encyclopedia Britannica exposes it as the "immediate and clear learning or understanding that takes place without overt trial-and-error testing". Whatever the definition, all suggest the presence of a moment of extreme clarity, a moment when a solution is found that satisfies all conditions for the problem that is inspected.

While this concept has been around for centuries, it has been only introduced in psychology at the beginning of the last century [Bue11], as the German term "Aha-Erlebnis". Since then, the process of insight has been investigated from the perspective of many fields, like medicine, cognitive neuroscience and computer science, to name just a few.

At the same time, some researchers dislike any reference to spontaneous Aha! moments because it suggests irrationality. Still, many of world's most famous discoveries have been achieved by people experiencing a moment of epiphany. Isaac Newton claimed having a moment of clarity when he observed an apple falling from a tree, insight that lead to the formulation of the theory of gravity. Similarly, Friedrich August Kekulé von Stradonitz experienced the ring-like structure of benzene in a daydream [MG90].

Besides the purely knowledge-related aspects of insight, particular experiences suggest that moments of epiphany are sometimes accompanied by extremely powerful emotions, like the joy of understanding a problem or the excitement of decoding a riddle after a timely process of analysis. These moments of triumph have in many instances shown their potential to shift the emotional states of a person. Still, "the shock of recognition" is not always a side effect of the Aha! experience [Par06], and further investigation is required to establish a possible correlation between insight and emotion on insight.

Furthermore, directly detecting moments of insight is difficult, and neuroscience has struggled to capture these events in real-time. While modern methods like fMRI scans support the identification of Aha! moments [CZGR09], these approaches are still very restrictive and even intrusive operations for the subjects. Nonetheless, adjacent processes like emotional reactions generated by the excitement and joy of insight might be more simply detected by mobile brain-computer interfaces (BCI) that do not influence the person's comfort and mobility to a large extent. These BCI devices can represent the key for a less intrusive, indirect identification and observation of periods of insight, as well as a migration of insight detection to wherever it takes place without limiting the environment of its existence, i.e., medical facility.

The following sections shortly highlight related work in the field of insight research as well as EEG-based detection of emotional states and corresponding brain activity. Next, a preliminary study is presented that involves the observation of brain signals by a commercial EEG headset and the translation of these signals into emotional reactions generated by moments of insight. We highlight the results of this study, as well as capture some advantages and limitations of indirect EEG-detection of insight-related patterns. Finally, we present possible future directions of this research and summarize our conclusions.

2. Insight and Visualization

Many scientific areas have taken it upon themselves to bring clarity to the concept of insight. As a result, various characteristics of insights have surfaced during the past years, some more relevant than others in comprehending the series of processes that converge to create an Aha! moment. Studies have found that insight can be seen as a two-phase process [QZ08]. During an initial step, a subject tries to systematically explore the space of possible solutions to the task. If this approach fails to give results in a certain timeframe, an impasse is achieved that can manifest itself in the form of frustration [SAM06]. People try to overcome this impasse in a subconscious manner that builds upon relaxing the constraints of the problem or approaching it in a non-conventional manner (thinking out of the box). If the change in the mental representation of the problem is successful, the second phase is reached, the impasse is overcome, and the subconscious process suddenly and unexpectedly provides the person with a piece of information—an insight.

Studies suggest that the presence of prior knowledge about the problem or tasks as well as knowledge of one or multiple possible solutions or patterns, can interfere with the unconscious processing that leads to an insight [AFS79, WSCT00]. The reduced prior knowledge only adds to the unpredictability of this concept, which is one of its essential characteristics derived from the complexity of mental activities. In [Mar90], insights are considered in terms of pattern matching, where the mind is trying to establish an approximate fit between the set of current patterns and previous experiences. Further, a categorization is highlighted involving the information content of the epiphany in terms of anticipation: to recognize (expected information) and to notice (unexpected information).

Besides the field of psychology, various studies from medicine and cognitive neuroscience have focused on pinning down the processes and brain activity in the moment of insight. Most of these employed brain-imaging technologies, like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) [BJBFK05], to observe the brain activation patterns of subjects while solving a wide range of insight-connected problems. Participants were asked to solve specific insight problems, visual and logical riddles [LN03], and anagrams [AZKI09]. Some of these problems, like anagrams, are used because their solution can be achieved in at least two ways: through a conscious, systematic search of the space of possible solution or through sudden insight that appears abruptly in the conscious mind [KFG*08, BJBFK05]. The experiments concluded that tasks that involve problem solving via insight activate certain parts of the human brain [JBBH*04, KFG*08], leading to the possibility of detecting when a subject experiences an Aha! moment, and distinguishing this from simply finding a solution based on a systematic search.

But what about fields like information visualization that have the concept of insight at their core? Over the years, researchers have focused on defining insight and its importance for visualization [SND05, Nor06, Pla04, CZGR09]. Most famously, insight is defined as the "purpose of visualization" [CMS99], the ultimate goal by which successful representations and interactions should be measured. But how can we measure something as unpredictable and multifaceted as insight?

Most approaches in the visualization community try to achieve this by including characterizations that are aimed at defining insight in an objective, quantitative manner [SND05, Nor06], with attributes like time, complexity, domain value, depth, uncertainty, unpredictability, correctness, expectedness, and others. Attention is sometimes focused to a particular topic, like cartography [MG90], to investigate the appearance of insight when working with a certain type of representation.

Still, in many publications, the focus quickly shifts towards the importance of insight for evaluating visualizations. If insight is the purpose of all visualization, then it should also be the measure by which the quality and functionality of visualizations is determined. Currently, this is achieved in most cases by performance and accuracy experiments on restrictive benchmark tasks. Sadly, such restrictive tasks often introduce bias or capture only the performance for a particular type of task without giving answers about the performance of another. While [SND05,Nor06] highlight viable alternatives to this by suggesting open-ended protocols together a set of quantitative measures for insight, such experiments could represent an intrusion in the analysis flow of the user by introducing interruptions or imposing the think aloud method.

In the following section, we highlight an approach that overcomes some limitations of the previously presented methods, by employing a mobile non-intrusive EEG-solution for detecting moments of insight during visual problem solving.

3. EEG Detection of Emotion and Insight

As moments of insight are accompanied by powerful emotions of joy and satisfaction on discovery or comprehension, the question arises if an objective connection can be established between the Aha! moment and the emotional explosion. In order to evaluate if insight generates emotional reactions that are detectable by means of EEG measurements, we devised a preliminary experiment that focuses on capturing the feelings of users while involved in visual problem solving.

This study is based on our previous work, where we investigated the capabilities of the Emotiv EPOC wireless neuroheadset to detect facial expressions and emotional states [COEK11]. After a validation of the EEG headsets functionality in simple tasks aimed at triggering certain emotional responses, the EPOC was used as a real-time evaluator of more complex applications, like spot-the-difference tasks and computer games. A set of emotions was considered during the tasks, including engagement, excitement, satisfaction and frustration. These emotions were computed by means of the Emotiv intelligent framework that interprets the signals from each electrode to offer a real-time summary of the user's feeling. The output of the EEG device was then compared to common evaluation methods, like video log analysis and post-task questionnaires. The results of this comparison are highlighted in Figure 1.

The average differences between the EPOC results and the questionnaire answers combined with the video log transcripts showed that the emotional states captured by the EEG headset were similar to the ones reported by the users themselves. On average, the distances between the responses were under one unit on a 5-point Likert scale (strongly agree, agree, neutral, disagree, and strongly disagree), with a standard deviation of again under a unit [COEK11]. Moreover, a

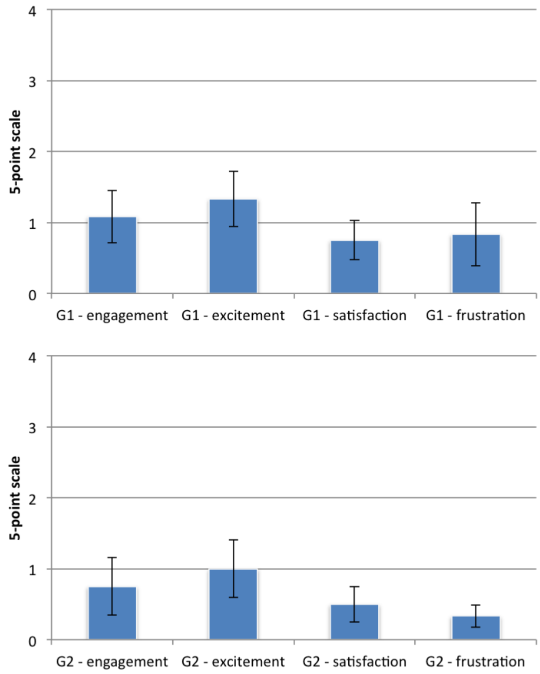

Figure 1: *Average difference between the EPOC device output and the questionnaire results for the two scenarios. Top figure, left to right: spot-the-difference task with engagement, excitement, satisfaction, frustration; Bottom figure, left to right: FPS game with engagement, excitement, satisfaction, and frustration. The distance of one unit in this 5-point scale is equivalent, for example, to the distance between "strongly agree" and "agree", or "disagree" and "neutral".*

paired sample t-test was computed in order to validate the results. Overall, the test suggested no significant difference between the subjectivity measurements and the questionnaire answer, except for one of the eight instances from Figure 1.

In this initial study, we built upon the validation of the EPOC device and its capacity to detect emotion states to explore the existence of a correlation between insight and emotion. More precisely, the spectrum of emotions that is considered in the following experiments involves only the excitement and frustration levels of the participants. The ultimate goal of this endeavor is the analysis of how well emotional states can reflect the presence of insight, and if capturing these states by EEG enables the detection of Aha! moments in information visualization techniques.

3.1. Pilot Study

The current study involved six participants with a good knowledge of visual representations and visualization techniques. The subjects were given a set of four tasks, two represented by visual insight problems and two information visualizations. For the visual riddles, the subjects had to find a unique solution, most likely resulting in a single fundamental insight. This allowed for a simple comparison of the moment of insight with the emotional states prior and during the discovery. At the same time, for the visualizations the participants were asked to find as many insights about the data as possible. For each tasks, every user had ten minutes to offer her/his insights.

Insights take time to process and clarify in the mind. Carl Friedrich Gauss said once after an epiphany: “I have the result, only I do not yet know how to get to it” [DGD04]. Therefore, once a user would report an insight, the EPOC output before this moment was inspected. More precisely, fluctuations in the level of frustration over a time period of two minutes before the insight, as well as changes in the excitement levels of the user ten seconds prior to the insight were explored.

3.1.1. Visual Insight Problems

For the visual riddles, all participants were initially subjected to a larger set of problems, of which only two were selected–Eight Coin Problem and Matchstick Arithmetic–that none of the subjects reported to know beforehand (Figure 2). For these two problems, only in 58% of all cases a solution was reached. In other words, the six participants reached an insight in 7 cases out of 12. Figure 3 highlights the correlation between insight and emotions in these cases.

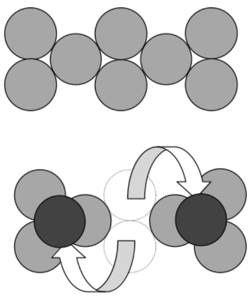

Figure 2: *Representation of the eight-coin problem. The top figure represents a possible initial configuration for the coins, while the bottom representation highlights the solution to the problem. The configuration of the coins has to be modified by moving only two coins, such that in the new grouping each coin touches exactly three others [OMC02].*

One can notice that over 80% of those who managed to solve the visual riddles have felt frustrated in the two minutes before the insights. This is also suggested by other publications, that cite frustration or deadlock as a prerequisite for the generation of an Aha! moment [MG90]. In a slightly lower percentage of cases, the subjects have also experienced excitement in the seconds prior to the insight.

While these results by themselves give us a reduced amount of information about the connection between insight and emotion, Figure 4 captures the percentage of emotional reactions for subjects that have not experienced insight at all. The lack of insight for these participants was suggested, on one hand, by their lack of a solution for the problems, but also by a post-task questionnaire that each of them filled out.

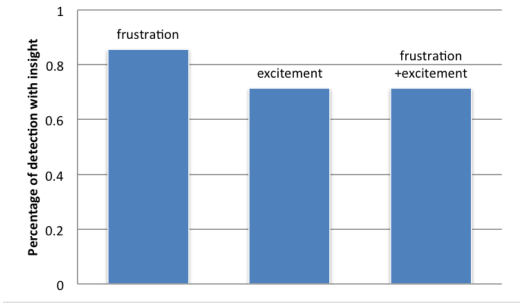

Figure 3: *Measured emotions with the EPOC headset in the presence of insight. The graph presents the average percentage of cases when frustration was detected before insight (Bar 1), excitement was detected during insight (Bar 2), and both frustration before and excitement during insight were measured (Bar 3).*

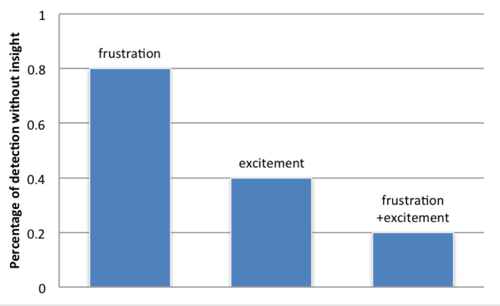

Figure 4: *Measured emotions with the EPOC headset in the absence of insight. The graph presents the average percentage of cases when frustration was detected and not followed by insight (Bar 1), excitement without insight (Bar 2) and the presence of both emotions when no insight was achieved (Bar 3).*

By inspecting both Figures 3 and 4, one notices that in both cases the frustration levels are around 80%, independent of the presence of an insight. But at the same time, the detection of excitement is much more likely in subjects that have experienced an insight. When looking at both of these emotional states, excitement and frustration were detected for 72% of the experienced insights. At the same time, the combination of excitement and frustration only appears in about 20% of the cases where no insight was gained by the subjects.

As frustration seems to be a recurring element in problem solving, the time of appearance for the feeling of frustration was analyzed. Our results suggest that states of frustration tend to be measured in participants more often during the later stages of an exploration process (second part of the ten minutes window). Also, emotional states of frustration that last longer (over one minute) are more likely to be followed by excitement, which we hypothesize might be correlated with insight. As this is a pilot study, further research involving more tasks and participants will be required to confirm these results.

The two visual problems (Figure 2) were followed by a questionnaires related to the emotional and mental states of the participants. After explaining what an Aha! moment is, we asked those that reported answers to the problems if they experienced an insight in this sense, or if it was a systematic search-and-find process that generated their answers. All the participants that experienced frustration and excitement, and that also reported the solution to the task, have confirmed that they experienced a moment of insight. On the other hand, in two instances, participants that supplied a solution and reported experiencing an epiphany were not reported by the EEG device as experiencing an increased frustration and excitement level.

3.1.2. ManyEyes Visualizations

For the information visualization tasks, we selected two visualizations from the ManyEyes website, as it harbors various datasets represented by widely accepted visualization techniques [VWvH*07]. More so, as the visualization are collaboratively explored and annotated, one can detect those that have a popular thematic and a high potential for revealing patterns and supporting hypotheses manipulation. The popularity of the visualizations was important in the selection process, as it could suggest the overall effort that users would invest in mining for insight in that representation. At the same time, a visualization that captures the tendencies of a topic that is highly relevant to the analyst has, in our view, a higher chance of generating an emotional reaction.

The two visualizations that were selected contained data about global demographics and social media, and were represented as a stacked graph and a cartographic visualization, respectively (Figure 5). The participants had an accommodation period with the ManyEyes website, during which the main supported interactions were highlighted to them. Before being the task, the participants were instructed to find all possible insights in the visualization. This approach is similar to the one in [Nor06], where insight was also observed by applying an open-ended protocol, without additional restrictions to the insights that were considered.

Furthermore, it was also suggested to the subjects to focus more towards deep insights that involve new hypotheses and multiple data types, to avoid noticing only simple facts about the data. Similarly to [SND05] and [Nor06], all spawned in-

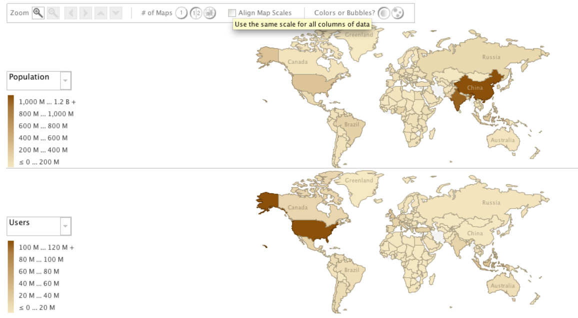

Figure 5: *Map visualization from the ManyEyes website employed in our experiments.*

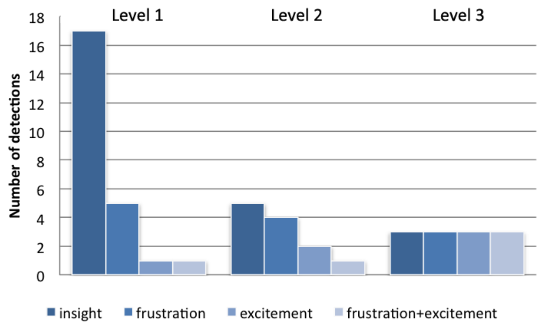

Figure 6: *Correlation between the number of insights and the instances where frustration, excitement and both frustration and excitement were detected. The results are grouped by depth of insight: the four leftmost bars represent the values for depth Level 1, the next four for depth Level 2, and the last four bar encode the number of insights and corresponding detected emotions for the deepest insights.*

sights were grouped by depth into three levels: the first level refers to trivial insights that include direct observations of one data type; Level 2 insights that are generated by a combination of multiple data types or insights about a process; and Level 3 insights that refers to new hypotheses about the underlying information. The EPOC EEG headset was used to inspect the levels of emotional frustration and excitement during the interaction of the users with the visualizations.

Figure 6 presents the correlation between the number of generated insights and the various emotional states the users experienced. The bar chart is divided into three sections, representing the different depths of the captured insights and their corresponding emotions. The number of simple insights seems to dominate the representation, as deeper insights were more rarely detected. This fact is even more visible in Figure 7, where every single eureka moment and emotional state was plotted along a time axis.

Although the number of deeper insights is lower than the one of trivial observations, one notices the fact that deeper insights have a higher probability of generating an emotional response, especially a higher probability for excitement during the Aha! moment. This culminates in our tests for the deepest insights with a detection accuracy of 100%, via the EEG measurements of emotions, when considering both the prior experience of frustration and the excitement on discovery. Note that in Figures 6 and 7 the results of the two visualizations are convoluted, as no significant differences could be detected between the results for the two visualizations.

By using the temporal dimension, we also notice in Figure 7 that users more quickly detect the simpler insights than deep ones, and that the deep ones take more time and are less likely to be detected. Moreover, Level 3 insights are more probable to generate an emotional reaction that combines frustration and excitement, while easily noticeable facts are less likely to be accompanied by excitement. Therefore, the probability of accurately capturing an insight by measuring the emotional response of a subject via EEG seems higher when the insight is deeper, more complex, and it occurs later in the analysis process.

As previously, the participants have been asked to complete a questionnaire after employing the visualizations. Questions that were posed involved the interaction and visualizations, as well as the relevance and accessibility of the data presented in them. Many participants suggested that they did not experience the Aha! effect. Reasons given for this included the fact that the information they discovered had a low complexity and was "easy to find". Furthermore, while they were interested in the presented topic, they were not involved with it to the extent that any newly discovered insight would influence their way of thinking ("I don't think this can surprise me"). When inquired about the moments of insight, participants mentioned that they reached some answers by a simple search process. As suggested by [AZKI09], logical search for new information is a process different for gathering knowledge than the one of epiphany. Based on the questionnaire results, an even stronger correlation was noticed between the instantaneous insights that would not involve a systematic search process and the emotional responses; but as these investigations were subjective–based on open-end questions and the verbal narration of the participants' insights during the task–no quantitative values are currently available.

These answers, together with the unpredictability of insights, could represent a partial explanation for the limited number of deep insights generated by the participants. Our hope is that further experiments can generate a larger set of insights in diverse visualizations, and thus offer a more complete view of the possibilities and limitations of mobile EEG detection of insight.

Another relevant aspect for the validation of EEG measurements for detecting insight moments is given by the false positives. In our scenario, false positives are represented by moments in time when no insight is generated, but the emotional states of frustration and excitement are detected inside the time-frame described at the beginning of this section. In the second row of visualization tasks, only nine such instances were recorded by the EEG system. As the possibility exists that these were generated by elements external to the software system (real-world or mental distractions of the user), further investigation is required to deduce their impact on a larger scale. Note that an insight is implicitly considered true by the issuer, at least in the initial stager of the Aha! moment. Usually, in knowledge tasks a generated insight later undergoes a validation process that implies the systematic analysis of all facts and the insight information. This can result in an erosion of confidence, but even insights that contain false information will most likely have the potential to generate an emotional response. As a result, the EEG measurement of emotional states generated by insights should not be considered as a validation of the provided information, but as a sign of for the presence of insight.

4. Future Work

One can hypothesize about the potential of EEG measurements—and in a wider sense of emotion detection—to accurately capture the presence of moments of epiphany or insight in subjects during various tasks, like problem solving, pattern recognition and extraction, concept manipulation, etc. Although the nature of insight and emotion is clearly subjective, the presence of a mechanism for connecting these elements and reliably detecting one of them through mobile brain-imaging [COEK11] opens an entire set of possible research directions for the future.

A major opportunity in this sense is represented by the quantitative detection of insights in the process of evaluating visual applications and information visualization techniques. Especially for information visualization methods, the capacity to generate insights is the essence of a powerful representation [Nor06]. While emotional response does not quantify the power of an insight, it is capable of suggesting the presence of a reaction generated on insight. Additionally, this can suggest the relative value of the insight to the person, as our tests revealed that insights generate a detectable emotional reaction mostly if they are sufficiently deep, take a longer amount of time and effort to achieve and the topic of the problem is relevant to the subject. Therefore, in the future we plan to further investigate non-intrusive, mobile detection of emotional states of users during interaction and analysis of visualizations. Our hope is the development of new EEG-based tests for evaluating and comparing different visualization techniques, by simply looking at the number of insights that they enable. Such an approach could enable the detection of good visualization techniques and even foresee how easily users with a particular background would adopt these visualizations.

Besides evaluation of visualization techniques, the capacity to detect the moment of insight can be used for automatic

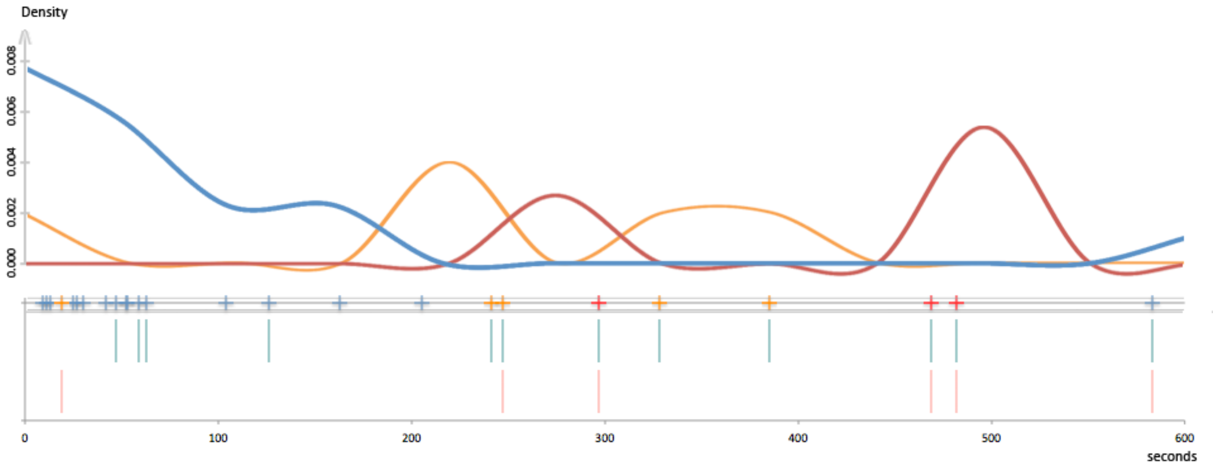

Figure 7: *Correlation between the insights generated by the participants and the emotional responses detected by the EEG headset. The insight moments are marked by 25 plus (+) signs and are plotted along the horizontal timeline. Note that all + signs are visible and there is no perfect overlap between two moments of insight. The colors of the insights represent the depth of the generated insight: blue is Level 1 (simple), orange is Level 2, and red is Level 3 (deepest). The green and red vertical lines beneath the insight + signs indicate the presence of an emotional response. A green line under a certain + sign indicates the presence of frustration previously to the insight generation. Similarly, the red line under a particular plus sign indicated the presence of excitement in the moment of insight generation. The three colored lines above the + signs represent the kernel density estimates for individual Gaussian kernels constructed around the three types of data points from the horizontal axis.*

operations like data tagging and binding based on the interactions the user executed shortly prior and during the moment of insight, highlighting of information involved in the Aha! moment and capturing layout screenshots that are relevant to a particular insight. Certainly, these methods would have to be implemented in a visualization solution that is more flexible, offering a wide range of closely coupled interaction possibilities (e.g., focus+context, InfoVis dashboards, etc.) and including a dataset that is more complex than the one highlighted in the previous section of this paper.

5. Conclusions

Insight plays a vital role in knowledge and understanding, especially in the field of visual applications. In the paper at hand, we narrowed our attention to the field of information visualization in the hope of exploring if insights in visual tasks have the potential of generating emotional responses. We measured the emotional responses of a set of subjects with the mobile EPOC EEG headset while trying to complete visual tasks: solve visual riddles and extract insight from visualizations. The obtained results have suggested not only a strong correlation between insights and feelings like frustration and excitement, but also that EEG measurements have the potential of detecting emotions corresponding to Aha! moments in an non-intrusive way. Further, it seems that the most accurate detection can be achieved if the generated insights required more thinking time, had already generated frustration in the subject, and contained potentially complex and unexpected information.

References

[AFS79] AUBLE P., FRANKS J., SORACI S.: Effort toward comprehension: Elaboration or aha!? *Memory & Cognition 7* (1979), 426–434. 2

[AZKI09] AZIZ-ZADEH L., KAPLAN J., IACOBONI M.: "aha!": The neural correlates of verbal insight solutions. *Hum Brain Mapp, 30(3)* (2009), 908–916. 2, 6

[BJBFK05] BOWDEN E., JUNG-BEEMAN M., FLECK J., KOUNIOS J.: New approaches to demystifying insight. *Trends in Cognitive Sciences, 9(7)* (2005), 322–328. 2

[Bue11] BUEHLER K.: Tatsachen und probleme zu einer psychologie der denkvorgänge. über gedanken. *Archiv für Psychologie, 9* (2011), 297–365. 1

[CMS99] CARD S., MACKINLAY J., SHNEIDERMAN B.: Readings in information visualization - using visualization to think. *San Francisco: Morgan Kaufmann* (1999). 2

[COEK11] CERNEA D., OLECH P., EBERT A., KERREN A.: Eeg-based measurement of subjective parameters in evaluations. *Proc. of the 14th International Conference on Human-Computer Interaction (HCII)* (2011). 3, 6

[CZGR09] CHANG R., ZIEMKIEWICZ C., GREEN T., RIBARSKY W.: Defining insight for visual analytics. *IEEE Comput. Graph. Appl. 29, 2* (2009), 14–17. 2

[DGD04] DUNNINGTON G., GRAY J., DOHSE F.: Carl friedrich gauss: Titan of science. *The Mathematical Association of America* (2004), 418. 4

[JBBH*04] JUNG-BEEMAN M., BOWDEN E., HABERMAN J., FRYMIARE J., ARAMBEL-LIU S., GREENBLATT R., REBER P., KOUNIOS J.: Neural activity when people solve verbal problems with insight. *PLoS Biol 2(4): e97* (2004). 2

[KFG*08] KOUNIOS J., FLECK J., GREEN D., PAYNE L., STEVENSON J., BOWDEN E., JUNG-BEEMAN M.: The origins of insight in resting-state brain activity. *Neuropsychologia. 46* (2008), 281–291. 2

[Leh08] LEHRER J.: The eureka hunt: Why do good ideas come to us when they do? *The New Yorker* (July 28, 2008), 40–45. 1

[LN03] LUO J., NIKI K.: Function of hippocampus in "insight" of problem solving. *Hippocampus 13* (2003), 316–323. 2

[Mar90] MARGOLIS H.: Patterns, thinking, and cognition: A theory of judgment. *University Of Chicago Press; 1st Edition* (1990). 2

[MG90] MACEACHREN A., GANTER J.: A pattern identification approach to cartographic visualization. *Cartographica: The International Journal for Geographic Information and Geovisualization, Volume 27, Number 2* (1990), 64–81. 1, 2, 4

[Nor06] NORTH C.: Toward measuring visualization insight. *IEEE Comput. Graph. Appl. 26, 3* (2006), 6–9. 2, 3, 5, 6

[OMC02] ORMEROD T., MACGREGOR J., CHRONICLE E.: Dynamics and constraints in insight problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 28* (2002), 791–799. 4

[Par06] PARKER B.: Aha! *Trafford Publishing* (2006). 2

[Pla04] PLAISANT C.: The challenge of information visualization evaluation. *Proc. Working Conf. Advanced Visual Interfaces (AVI), ACM Press* (2004), 109–116. 2

[QZ08] QUI J., ZHANG Q.: Aha! effects in a guessing chinese logogriph task: An event-related potential study. *Chinese Science Bulletin. 53(3)* (2008), 384–391. 2

[SAM06] SAM: Scientific american mind, 2006. Oct. 2

[SND05] SARAIYA P., NORTH C., DUCA K.: An insight-based methodology for evaluating bioinformatics visualizations. *IEEE Trans. Visualizations and Computer Graphics, Volume 11, No. 4* (2005), 443–456. 2, 3, 5

[VWvH*07] VIEGAS F., WATTENBERG M., VAN HAM F., KRISS J., MCKEON M.: Manyeyes: a site for visualization at internet scale. *IEEE Transactions on Visualization and Computer Graphics* (2007), 1121–1128. 5

[WSCT00] WILLS T., SORACI S., CHECHILE R., TAYLOR H.: "aha" effects in the generation of pictures. *Memory & Cognition 28 (6)* (2000), 939–948. 2