Using Eye Tracking and Electroencephalography to assess and evaluate students' cognitive dimensions

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Abstract. Field dependence-independence (FD/FI) is an important dimension of cognitive styles. The current thesis seeks to identify individuals' level of field independence during visual stimulus tasks processing. It intends to examine brain signals with the use of the EEG neuroimaging method and the eye tracking device. Specifically, it aims to value the relationship between the Hidden Figure Test (HFT) scores, the Eye Tracking metrics and the EEG brain signals device by examine whether and how humans' cognitive behaviour (cognitive abilities) can be identified and clarified through the two cutting edge technologies. Additionally, it seeks to investigate if differences exist among the cognitive groups on a sample of students retrieved from a Public University in Cyprus. The progress achieved so far is outlined and further agenda of the work-in-progress is addressed.

Keywords: FDI dimension; higher education; eye-tracking; EEG; cognitive abilities; visual stimuli; hidden figures test

1 Introduction

The field of the applied cognitive dimensions is complex and challenging. Researchers working in the context of cognitive load theory [1] [2] [3] have been concerned with analyzing the effects of cognitive load on learning and devising strategies and tools to help learners maintain an optimal level of load in various learning contexts. As a consequence, measurement of cognitive dimension plays a key role in CLT research [3].

The visual appearance of interactive systems, such as Web pages and e-learning environments, tends to convey more information than we imagine. With the use of eye tracking technology and electroencephalography (EEG) as measures of noticing users' cognitive ability during visual processing, we can further enrich our knowledge in e-learning and adaptive environments design, by understanding how learners of different cognitive types interact within the same tasks. Cognitive style data is being incorporated into adaptive e-learning systems for the development of personalized user models. The link between eye tracking and cognitive modeling is an extremely intuitive and fruitful area of research. It is important therefore to understand precisely what the eyes and the brain reveal in order to model human behaviour by designing suitable learning environments based on the assumption that individuals learn differently. In general, the research work seeks to examine how cognitive abilities can be identified through the implementation of cutting edge technologies such as EEG and Eye Tracking.

Additionally, a challenge of this arena is to conduct research that compares different metrics that will provide a more spherical understanding on the phenomenon under investigation. There is a need to develop a holistic model of learning that will integrate all the cognitive dimensions. Thus, the undertaken study intends to provide an in depth understanding of the relation between cognitive abilities and brain cognitive process.

2 Goal of the study

The study is an exploratory research that seeks to examine whether cognitive abilities can be identified, through the implementation of EEG and Eye Tracking technologies. This research study is of great importance as it will illustrate what happens to the human brain as it receives visual information.

The main focus of the proposed thesis is to evaluate user's cognitive abilities identification based on the Field Dependent-Independent classification and examine new possibilities for validating human cognitive behaviour. Therefore the overall goal is to examine how cognitive abilities can be identified through EEG and Eye tracking metrics.

Specifically, it seeks to investigate the FDI dimension on the achievement of different instructional objectives in a self-paced and computer-based setting for developing a learning profile model based on the brain signals (EEG) and the eye-movement behaviour of which HCI and BCI fields can put into practice. We assert that knowing how cognitive abilities can be detected through eye tracking technology we can lead to solutions that improve users' Web experiences.

The research study addresses the following key aspects:

1. Explore the potential of EEG and eye tracking in assessing learners cognitive dimensions as new proposed methods of measurement.
2. Develop a learning profile framework based on users’ cognitive dimensions
3. Explore and Compare the results revealed form the two different BCI and HCI devices.

Therefore, the research questions that shaped the PhD study are:

1. Do differences exist between the three cognitive groups FD, FN and FI with regard to tasks time completion?
2. Is there a significant correlation between the eye tracker metrics and the Hidden Figure Test scores?

3. Is there a significant correlation between the results revealed from the electroencephalography (EEG) measures regarding participants' cognitive dimensions and the eye tracking metrics?
4. Can the developed learning profile model handle the cognitive load based on the insights of the EEG and Eye-tracking tools?

3 Theoretical background

3.1 Cognitive abilities - Field dependence/ independence dimension

The field dependence-independence (FDI) is among the most broadly studied of the variety of cognitive style dimensions appearing in the literature and especially in the educational technology field [4]. FDI is one of those cognitive style theories which is acknowledged in a number of studies on instructional effectiveness (e.g. [5] [6] [7]). These dimensions are formed based on the individual's reliance on the context to extract specific meaning and describe two contrasting ways of processing information; the field-dependent (FD) and field-independent (FI) individuals' distinct approach. Specifically, some individuals are classified as Field Dependent (FD) and other individuals are categorized as Field Independent (FI). Individuals who fall in the middle of the continuum are determined as Field-Mixed (FM) or Field-Neutral. The key difference between FD and FI learners is visual perceptiveness [8]. FD learners, who are asked to identify a simple geometric figure [9] that is embedded in a complex figure, will take longer to detect the simple figure than FI learners, or they may not be able to find it at all. Researchers have concluded that there is something about the ways human brains function that leads to how people learn and process information [10]. Additionally, existing works indicate the importance in assessing the cognitive load during learning activities in the process of capturing the cognitive state of learners [11] [12] [13] [14] [15]. Another interested study [16] examined the learning process in relation to the brain. Much of the research on FD-I has focused on examining the effects of FD-I on learners' computer performance [16]. A study [17] demonstrated cognitive-style based differences in Web searching tasks. It is important to note that most studies rely heavily on the prior completion of questionnaires by system users. Since the completion of questionnaires can be time consuming for users, potentially improving the measurement methods of users' cognitive load is meaningful.

3.2 Eye Tracking device

Cognitive and semantic aspects of a stimulus play an important role in visual and scene perception [18]. Eye movements are driven by properties of the visual world and processes in a person's mind [18]. Eye tracking and usability evaluation studies try to investigate and understand user behavior [18] with an increasing interest to Web page behavior [19]. A general conclusion is that user interaction depends on the visual factors (nearby visual features) and scene semantics (general knowledge about the scene layout). Understanding how this in-formation and cognitive overload affects user perception and Web interaction can lead to solutions that improve users' Web experience. We believe that an initial step towards this goal is to understand Web page visual perception and relate a user's implicit understanding of Web page visual complexity with its layout. The eye tracking measures aid the enhancement of usability as they can give information on issues such as cognitive activity [20]. Moreover, Van Gog and Scheiter [21] mentioned that the findings of their study can contribute in multimedia research by using eye tracking to investigate how diverse design interventions (e.g., spoken vs. written text) affect processing of complex visual presentations. Yesilada et al. [22] used eye tracking to investigate users' evaluation style while they were searching different Web engines. In Germanakos et al. [23] eye tracking measurements revealed statistically significant differences between different types of learners, whereas imagers focus on visual content, verbalizers on text and intermediates placed in between the other two types. The idea that user' features such as cognitive abilities and personality are affecting the effectiveness of information visualization techniques is continuously growing. An eye tracking study conducted by Toker et al [24] investigated the relationship between such characteristics and fine-grained user attention patterns. Their findings revealed that user's cognitive abilities such as perceptual speed and verbal working memory have a significant impact on gaze behavior in terms of task difficulty and visualization type.

4 Design of the research

In pursuit of answering the aforementioned research questions of the thesis, three studies were designed and shape the structure of the proposed thesis. The data revealed from the two research instruments will be thereafter compared giving more reliable results of the phenomenon under investigation. It is of great importance that participants' input show similar reactivity pattern in the EEG, the Eye tracking and the reliable tool used; the Hidden Figures Test, in order for the findings to validate the importance of the research. The following sections shape the progress achieved so far and sketch the future research dimensions of the proposed study.

4.1 Study 1 - Using Eye tracking in assessing learners' cognitive dimensions

Experimental Set up**.**

Different visual-stimulus tasks were employed in the current experimental eye-tracking study. The cognitive processes engaged in the visual attention study included two visual-stimuli tasks; the embedded shapes and the hidden faces.

The target audience of the study was consisted of a number of normal and healthy students recruited from a department in a public University in Cyprus. The participants were initially categorized into FD, FI and FN/FM learners on their performances on the Hidden Figures Test, and were then assigned to the experiment. FDI was assessed using the Hidden Figures Test (HFT) from the Educational Testing Services kit for cognitive factors [25] designed by [26], that measures the level of an individual's field dependence. The HFT consists of 32 questions divided equally into two parts and scores ranged from 1 to 31 (max =32 points). It presents five simple figures were learners had to identify which one of these simple figures is embedded in a more complex figure. The cut-off scores were decided taking into consideration how other researchers determined the cut-off scores in their studies [27] [28], so that meaningful comparative studies could be made in the future. Individuals who scored 10 or lower were categorized as FD, those who scored from 11 to 17 were classified as FM or FN, and those who scored from 18 to 31 as FI. The current phase of the PhD study is divided into two sections: a) Hidden figures test (HFT) [29], in order to access individuals' level of field independence and b) eye movements' analysis through the use of the iViewX model of the eye-tracking device, in assessing their cognitive abilities. The second section was conducted in two parts: Visual Stimulus - Embedded shapes; and Visual Stimulus – Hidden Faces, in order to explore participants' visual attention and calculate the level of field independence. The design of the instrument was inspired by the Hidden Figures Test.

Preliminary Results.

The preliminary findings of the study are discussed with respect on how FD, FM, and FI learners interact with the affordances of the proposed tools in order to answer a given task and therefore come up with data that indicate their level of field independence as HFT did. The quantitative data were analyzed with the aid of the Be Gaze 3.1 Software and basically focused on heatmap and scan path analysis. The results of the study detected individuals' visual style preferences based on the FD/ FI cognitive dimension. Furthermore, the eye tracking and stimulated data also suggest that although learners engage in similar environments of viewing activity, they tend to demonstrate different cognitive traits. The results of the two different tools with regard to the participants' cognitive ability were significantly correlated ($p=0.002<0.01$ $p = .002$, Cramér's $V= .721$). Additionally, the findings suggest that cognitive ability classification may be predicted by the time completion of each task. During the first task of the visual stimuli condition – embedded shapes, the performance of individuals classified as FI was significantly faster in time completion, indicating more accurately the correct response compared to the FD group. A comparison of a set of hotspots demonstrates the difference between Field Independent and Field Dependent. The FD needed more time in finding the hidden face, than the FI did, and there were times that they could not detect it at all.

The results of the current PhD study stage revealed the effectiveness and the potential of the eye tracker technology and the designed stimulus in assessing learners' cognitive dimensions since HFT validated the data retrieved from the eye tracker results. The time tracking varies among the participants, thus time might play an important additional factor in detecting subjects' cognitive traits through a computer based environment. This result was statistically examined indicating significant differences between the FD and FI cognitive cohorts.

Currently we are analyzing data collected from running the same study with a wider population. We believe that these preliminary and promising results will be verified. The data will be analysed and presented by the time of the conference.

5 Future dimensions

5.1 Study 2 - Using EEG in assessing learners' cognitive dimensions

Based on the results of the previous study, this research will utilize EEG as a device in detecting users' cognitive dimensions. The most efficient and reliable designed visual tool in assessing participants' cognitive dimensions used in study 1 will be employed as the experimental environment of this study. This part of the research is also aiming to identify learners' level of field independence as a mean to verify and strengthen the preliminary results achieved so far.

5.2 Study 3-Comparison of the cutting-edge technologies findings in assessing learners' cognitive dimensions

The final stage of the thesis relies on a comparison study that seeks to triangulate the data that will be retrieved from the two technologies (Eye tracking and EEG devices). The objective of this comparison study is to suggest and develop a learning profiling model based on individuals' cognitive dimensions. Additionally, instructors, designers, researchers, educators' specialized in the Human Computer Interaction (HCI), Brain Computer Interfaces (BCI) Educational Technology and Neuroscience domains will gain a better understanding of the affordances of users' FDI cognitive dimensions. The ambition is to exploit the proposed model from a technical perspective and provide insights that will allow the development of different algorithm(s) that will better predict and stimulate human performance in assessing cognitive load and contribute in designing e-leaning and adaptive environments.

6 Significance of the study and research contribution

The suggested research will contribute in the theoretical practical levels to the enhanced understanding of the relations between human brain (EEG) and cognitive abilities. Since the purpose of this study is to have a glance into individuals' cognitive abilities, gaining understanding on how the user sees and thinks we gather unique insight into HCI with respect to interface design, and e-learning environments design. Moreover the experiment has been designed to provide help to instructors and specialists, and to pinpoint the cognitive ability of a student. Eventually, the findings of the study aim to propose a framework in understanding a person's preferred way to think and learn, flattening gaps in the international literature with respect to the nature of a learner cognitive process, neuroscience field, brain-computer interface (BCI) and human-computer interaction (HCI) sectors and will enhance the educational technology domain. The suggested research can bring new contributions to this field and important educational, theoretical and research significance. It will therefore contribute methodologically as it utilizes a combination of techniques that are not widely used together. Finally, an emerging trend within the domain of the examined topic is to explore the impact of these outcomes on personalized and adaptive learning understanding how these results can be exploited in the TEL systems. This is a challenge for other researchers to take into consideration as the implementation and the outcomes of such studies will contribute to our society's educational milieu.

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