Eye-tracking Users' Behavior in Relation to Cognitive Style within an E-Learning Environment

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Abstract

Eye-tracking measurements may be used as a method of identifying users' actual behavior in a hypermedia setting. In this research, an eye-tracking experiment was conducted in order to validate the construct of cognitive style as a personalization parameter in adaptive e-Learning systems. The main research question was whether the verbalizer/ imager axis of the Cognitive Style Analysis theory reflects actual preferences in an e-learning environment and properly identifies learner types. The findings from a sample of 21 participants reveal statistically significant differences among types of learners; as hypothesized, imagers concentrate on visual content, verbalizers on text, while intermediates are placed in between.

1. Introduction

Adaptive e-learning systems continuously proliferate, due to the potential benefits of personalized tutoring in a diverse target population [1]. Identifying and addressing individual or user groups' needs, abilities and characteristics is a key factor in providing a personalized learning experience; thus, a corresponding learner model is required [2].

In this context, a learner model for adaptive e-learning environments and an adaptive e-learning system have been proposed and evaluated [3, 4]. In short, this approach is focused on individual differences at an intrinsic level, addressing cognitive and emotional characteristics (cognitive style, working memory, speed of processing, anxiety, emotional regulation).

The construct of style (both cognitive and learning) has also been taken into account into previous adaptive e-learning systems [5,6,7,8]. In spite of its popularity in this field, its importance is yet to be established in the field of traditional education [9]. Nevertheless, the abovementioned previous research by the authors demonstrated an increase of performance attributed to personalization on learners' cognitive style.

In order to externally validate this dimension of the proposed model, an eye-tracking experiment was designed and conducted. The aim was to correlate learners' actual behavior in the e-learning environment with their cognitive style preference, as previously identified by the corresponding psychometric tool in the profiling procedure.

2. Theoretical Background

As depicted in the introductory section, the research that is presented examines the relationship between cognitive style and eye-tracking patterns of users in an e-learning environment. Therefore, relevant work on eye-tracking measurements and the theory of cognitive style are discussed in this section.

2.1 Eye-tracking and Hypermedia

The examination of user behavior with the use of eye-tracking methods has been under the scope of HCI and e-learning research. According to Schiessl et al [10], "analyzing the gaze pattern can be very helpful in

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understanding how a user structures information, which provides a useful basis to create better layouts"; their results demonstrate that this measurement offers a better insight on users' behavior, thus allowing a more comprehensive interpretation of conventional (e.g. number of clicks) techniques.

In the field of e-learning, there are studies that support that on-line modeling of users through eye-tracking provides more accurate assessment of student self-explanation (meta-cognitive processes) [11] or self-assessment [12], that attention-aware systems may benefit the learning procedure through corresponding adaptation [13], or even propose an e-learning research framework based on real time eye tracking [14].

At the level of psychological research, differences in eye movement in information processing has already been supported at a cultural level [15], at the level of gender differences [16], and even in relation to cognitive style (verbal-analytic vs. spatial-holistic) [17]; the latter is quite relevant to our approach, though the specific research refers to reflective eye movements in verbal and visual thinking tasks.

The aforementioned studies generally indicate that a) eye-tracking provides a rather validated method for identifying users' behavior in a hypermedia setting and that b) there are individual differences in eye gaze patterns of individuals. Both these acknowledgements may support the use of an eye-tracker as a measurement of external validity of cognitive style, and that the identification of differences based on style is possible.

2.2 Cognitive Style

Cognitive style has been defined by Messick as consistent individual differences in preferred ways of organizing and processing information and experience, a construct that is different than learning style [18]. Cognitive styles represent an individual's typical or habitual mode of problem solving, thinking, perceiving or remembering, and "are considered to be trait-like, relatively stable characteristics of individuals, whereas learning strategies are more state-driven…" [19].

Amongst an impressive number of cognitive and learning style theories [20, 21], we have opted for Riding and Cheema's Cognitive Style Analysis (CSA). The CSA is actually derived from a factor analytic approach on previous cognitive style theories, summarizing a number of different yet highly correlated constructs into two distinct independent dimensions [22]. This covers a wide array of the former cognition based style typologies, without going into unnecessary depth- for the needs of web education that is.

Most importantly, the two independent scales of the CSA (verbal/imager and wholist/analyst) correspond ideally to the structure of web environments. A personalized environment that is supported by an automated mechanism can be altered mainly at the levels of content selection and hypermedia structure; the content is essentially either visual or verbal (or auditory), while the manipulation of links can lead to a more analytic and segmented structure, or to a more holistic and cohesive environment. These are actually the differences in the preferences of learners that belong to each dimension of the CSA scales [23]. Finally, the CSA has been also applied in other multimedia applications with significant results [24]. An online version of the test has been developed in the past and it was easily incorporated in our experiments.

2.3. Correlating Cognitive Style with Eye-tracking

As mentioned above, the CSA consists of two independent scales. In our environment, the personalization process involves both axes of style, in a distinct way: the structure/ navigation is defined by the wholist/ analyst preference, and the selection/ presentation of visual over verbal content is driven by the verbalizer/ imager preference. Consequently, the quantity and type of the presented learning objects are related to the latter dimension.

In this research we focused only on the verbalizer/ imager dimension, since it would far more feasible to measure the behavior of users in terms of preferred learning objects, through an eye-tracking experiment. The wholist/ analyst axis alters the way web-pages are linked and the degree of freedom of navigation, presumably not affecting the eye gaze patterns of users within each page.

According to this rationale, it is expected that verbalizers would focus more on text, while imagers would spent more time on visual representations of information. In a sense, this could be considered as a prerequisite for the effectiveness of our personalization approach. The CSA theory argues that this is indeed true, since actual cognitive processes are addressed, but a further validation of this assumption would significantly enhance the argument of using cognitive style as a personalization parameter in hypermedia.

To that direction, the construct of cognitive style was crosschecked with eye gaze patterns of users in a hypermedia environment. Personalization on cognitive style was found to improve the performance of learners in our previous work [3]. We should mention though that there has been some debate over the reliability and validity of the CSA [25].

Therefore, in order to validate the importance of cognitive style in educational hypermedia, in parallel to our initial experimental results on personalization, we designed an experiment that would provide data on whether the classification of users according to their style does indeed reflect their actual preferences and behavior over the visualized content of an e-learning environment.

3. Method

The experimental design was between participants. Each individual took the CSA test for the assessment of the imager/verbalizer axis of cognitive style, and afterwards participated in an e-learning course about algorithms in computer science. The number of participants was 21 (12 female and 9 male); they all were students from the University of Cyprus. Their mean age was 23, ranging from 20 to 26. It turned out that their distribution was almost equal among categories of cognitive style: 7 imagers, 8 verbalizers and 6 intermediates.

During the on-line course, an eye-tracker that was attached to the computer screen measured learners' eye fixations and tracking on the educational content. It should be noted that the learning content consisted of balanced, to the extent that is possible to convey the necessary information, visual (images) and textual (written text) objects. No personalization processes were employed in this experiment.

The dependent variables of our analysis were a) the calculated ratios of eye fixation and tracking (images to text ratio in a scale 1-10, with higher positioning on the scale implying focus on images), b) the number of fixations on the menu of the learning environments, and c) the duration (msec) of the experiment; users were free to allocate as much time as they wanted to each web-page of the lesson.

The component that gathers all eye-tracking data was developed from scratch, within the framework of the AdaptiveWeb[1] system. A visual representation of users' behavior was also available; though the differences between learners will be discussed in the results section of this paper, figure 1 illustrates how an imager differs in his eye-tracking patterns from a verbalizer.

[1] http://www3.cs.ucy.ac.cy/adaptiveweb/

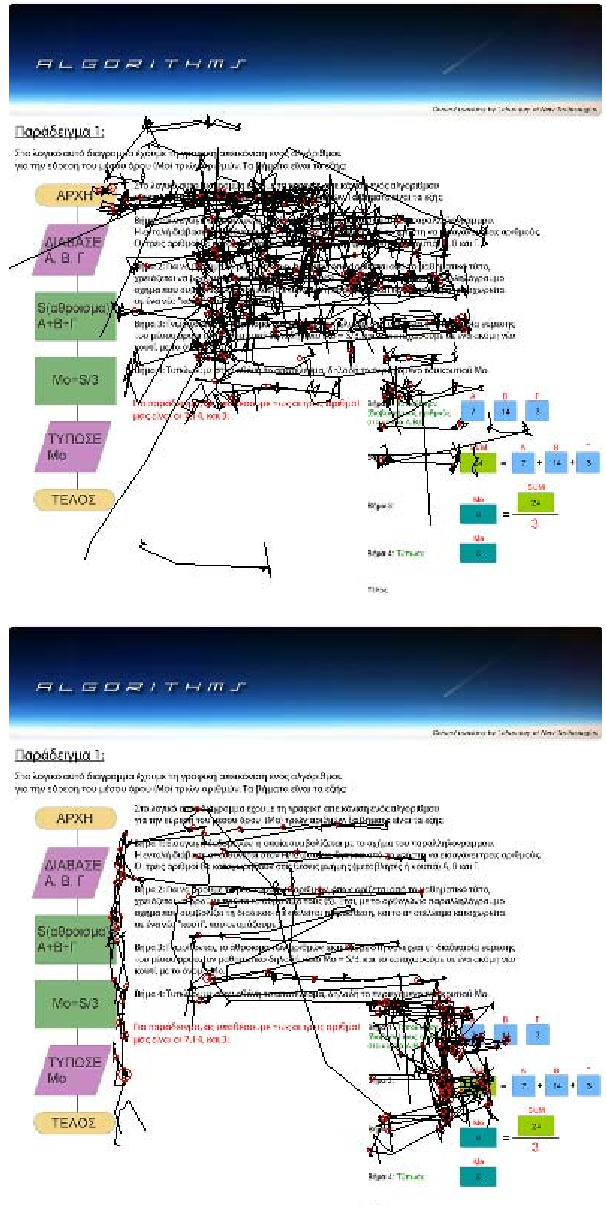

Figure 1. Differences in eye-tracking of a verbalizer (above) and an imager (below) within the same educational web-page.

4. Results

Since the variance of users' ratios of images to text fixations was homogeneous (Levene statistic$_{(2,17)}$=0.845, p.=0.446), one way analysis of variance was performed on the data. Indeed, there was a linear differentiation in users' fixations with respect to their cognitive style; imagers focused more on images, verbalizers on texts, and intermediates were placed in the middle. This difference is statistical significant: $F_{(2,18)}$=6.074, p.=0.01. The actual differences in the calculated images to text ratio are shown in figure 2.

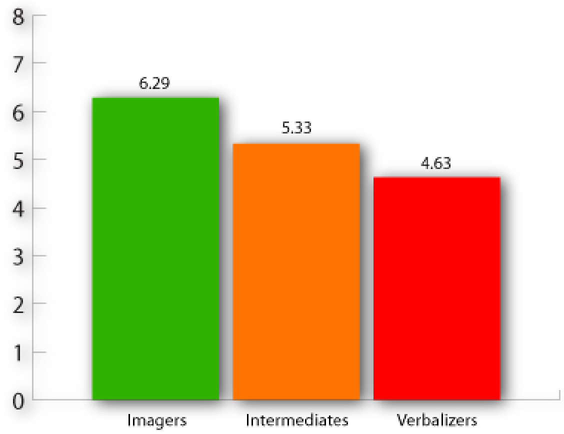

Figure 2. Calculated images to text ratio of eye fixations on a scale from 1-10 (textual to visual preference).

Exactly the same applies with the calculated ratio of images to text tracking (imagers: 5.82, intermediates: 4.80, verbalizers: 4.27), albeit with even greater statistical effect and significance: $F_{(2,18)}=10.411$, p.=0.001. Fixation and tracking on the menus of the web-interface is more or less the same among categories with no differences observed.

As it concerns the time that users allocated to the entire course, which was available for 12 out of 21 participants due to a technical error, there was also an effect of cognitive style: imagers and intermediates devoted about the same amount of time, while verbalizers spent considerably less amount of time. Post hoc analysis of variance has shown that this difference on behalf of verbalizers is statistical significant compared to both imagers and verbalizers (see table 1).

Table 1. Differences in participants' allocation of time to the on-line course.

Dependent Variable: duration (msec)

	(I) style	(J) style	Mean Difference (I-J)	Sig.
Tukey HSD	Verbalizer	Imager	-209285 (*)	**.030**
		Intermediate	-207172 (*)	**.021**
	Imager	Intermediate	2113	.978

The explanation of this finding is not as clear cut as with the aforementioned results. It could be argued that the processing of visual stimuli and the interpretation of the meanings that are conveyed is a more time consuming cognitive process; since verbalizers have a clear preference towards text, they allocate less time in the processing of text. However, according to Riding's theory, imagers also focus on textual resources, while the reverse is not observed; therefore, more time is consumed. With the case of intermediates on the other hand, it makes much sense that equal processing of all objects would require further allocation of time.

It should finally be mentioned that no gender differences were observed in any of the measurements.

Therefore, it is clearly indicated that the visual behavior of users in a web-environment, according to the eye-tracker measurements, depends on their cognitive style. These results also provide a form of validation for the effect of style in information processing within the context of e-learning hypermedia. This is of course a preliminary study conducted with a small number of participants, and it has to be replicated. Still, since the results are statistically robust, we believe that style could be considered as an important personalization factor in system design.

5. Discussion

The construct of cognitive style, as defined by the CSA theory, seems to be validated with the use of an eye-tracker, in terms of reflecting learners' actual behavior in an e-learning setting. This finding has two implications in the design of e-learning and hypermedia applications: a) the psychometric tool and theory are both suitable for identifying types of users and b) the CSA reveals differences in information processing and may be used as a personalization parameter.

It should be noted though that the setting of this experiment was educational, and it could be possible that users would exhibit differentiated behaviors in a commercial web-setting, or in a less challenging learning course. Additionally, eye fixations and tracking on images or text cannot be considered as an indicator of all cognitive processes. The preference for a specific type of learning objects has been shown, but in-depth information processing of this material cannot be revealed with an eye-tracking study.

Still, considering that our previous research has demonstrated that personalization on cognitive style is beneficial, the findings of the eye-tracking experiment validate the use of the CSA in educational hypermedia environments.

One of the main considerations in our future work, other than exploring the effect of the remaining dimensions of our aforementioned learner model [3] (especially working memory were current on-going work has produced very significant results), is the further external validation of the emotional processing dimension with physiological measurements. Specifically, the reported levels of anxiety of learners will be correlated to galvanic skin response and heart rate measurements (with the use of a modified computer mouse), in an effort to optimize the psychometrics of affect and to validate previous results [4].

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