Field Dependence–Independence and Eye Movement Patterns: Investigating Users' Differences Through an Eye Tracking Study

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The notion that users' characteristics such as the cognitive ability affect their visual information processing is continuously increasing. This eye tracking user study investigated the association between adults' ($N = 54$) cognitive style and eye movement (EM) patterns while interacting with a set of visual tasks. Users' cognitive type was measured with the use of the Hidden Figures Test (HFT), which classifies them into field dependent (FD), field neutral (FN) and field independent (FI) individuals. Overall, the psychometric measures and the eye tracking-derived data were statistically examined revealing significant differences and large effect sizes among the two variables tested. Particularly, the findings demonstrated that the field dependence group exemplifies a more disoriented and disorganized EM activity. Hence, greater numbers of fixations and saccades are generated, contrary to the FN or FI users'. This research study adds further to the evidence and theory base of human–computer interaction for applications in the user-centred design by identifying how users' differences in cognitive style can be manifested in eye gaze patterns.

RESEARCH HIGHLIGHTS

- Field dependence–independence (FD-I) cognitive style affects eye movement (EM) behaviour.
- EM behaviour differs significantly between different cognitive groups.
- Field dependence (FD) group produces a disoriented EM activity.
- FD group generates the greatest numbers of fixations and saccades.
- FD-I style can be used as a prospective component of user-centred design.

1. INTRODUCTION

Eye movements (EMs) are an integral and essential part of our visual perception. Visual exploration 'consists of the succession of saccades that depend on both external visual or "bottom-up" stimuli and cognitive "top-down" control' (Liman and Zangemeister, 2012, p.1). There are over 10 types of EMs, of which the most known ones are the fixations and saccades. Fixations are produced by cause of users' EM stops in order to focus on a certain area, and the extremely fast movements between these fixations are called saccades. When the eye fixates, during this stop the brain starts to process the visual information received from the eyes (Rayner, 1998).

Visual perception encompasses complex cognitive processes involved in other forms of conceptualization and learning (Workman, 2004). Individuals' cognitive characteristics and visual complex environments have been gaining ground in

the literature. Cognitive style describes the tendencies of the modes in which students approach, acquire, organize, process and interpret information (Miron *et al.*, 2004) and how these interpretations are used to guide their actions (Hayes and Allinson, 1998). Furthermore, cognitive style refers to relatively stable patterns of information processing that are displayed by an individual (Dillon and Watson 1996, p. 627) such as the field dependence–independence (FD-I) cognitive style (Witkin *et al.*, 1975).

Scholars have recently started investigating users' responses to visual stimuli using psychometric measures. They rely on these tests as a medium to identify the impact of visual complexity on user subjective ratings and other individual differences in cognitive characteristics (Goldberg, 2012, 2014; Nisiforou *et al.*, 2014). Complexity can be defined as 'the degree of difficulty in providing a verbal description of an image' (Oliva *et al.*, 2004; Harper *et al.*, 2009, p. 5). A visual pattern is also defined as 'complex if its parts are difficult to identify and separate from each other' (Oliva *et al.*, 2004; Harper *et al.*, 2013, p. 2).

Cognitive style data are being integrated into adaptive systems for the development of personalized user models (Mehigan *et al.*, 2011). Studies confirm that cognitive skills such as spatial and verbal ability influence the interaction and particularly, the navigation performance of the user (Zhang and Salvendy, 2001; Juvina and van Oostendorp, 2006). Subsequently, user navigation preferences reflect their cognitive styles (Nakić and Granić, 2009). Moreover, Kinley and Tjondronegoro (2010) demonstrated that the cognitive style is related to differences in the Web searching tasks.

Since the cognitive style has been explained in diverse context, there is a need to understand the performance of the FD-I cognitive style on users' visual attention tasks so that the differences in cognitive processing can be sufficiently delineated. The FD-I cognitive style lies among the most broadly studied out of a variety of cognitive styles appearing in the literature and mainly in the educational technology domain (Dragon, 2009). FD-I cognitive style is formed based on the individual's reliance on the context to extract particular meaning. This cognitive type describes three contrasting ways of processing information; the field dependence (FD), the field mixed (FM) or known as field neutral (FN) and the field independence (FI) distinct approach.

The use of EM inputs is recently attracting even more attention to the increasing demand for user interfaces and adaptive environments based on users' cognitive behaviour. Previous studies have indirectly used EMs to gather useful information regarding users' cognitive characteristics (Toker *et al.*, 2013). Since EM behaviour can reflect individuals' complex mental state (Sugano *et al.*, 2014) the investigation of what the eye patterns can further infer, remains a challenge. The interaction between the user and the computer may be enhanced if these psychological traits are taken into account for the design of the user interface and the design of introductory courses (Van der Veer, 1989).

Earlier studies found that user perceptual speed and visual/verbal memory have a significant impact on both user gaze behaviour and user performance in terms of task difficulty within a given visualization (Toker *et al.*, 2012, 2013). In addition, eye tracking measures aid the enhancement of usability as they can provide information on issues such as cognitive activity (Boksem *et al.*, 2005).

The scope of this research work is broader, since user cognitive characteristics are investigated and compared with user eye gaze patterns as a medium to identify the link within field dependent (FD), field neutral, FI, in relation to the EM components (e.g., fixations, saccades). The findings will provide insights as to how these different cognitive groups of individuals' interact with visual stimuli and how this interaction impacts their eye gaze patterns.

1.1. Objectives of the study

The study presented in this paper has a two-fold objective:

1. Determine whether and how features in user EM behaviour are affected by a user's cognitive style.
2. Explore individual similarities and dissimilarities in EM patterns during visual images tasks processing between the three cognitive groups of users (i.e. FD, FN and FI).

1.2. Research questions

Specifically the study seeks to address the following research questions:

Q1. Does users' FD-I cognitive type affect their EM behaviour while interacting with visual tasks and how?
Q2. What are the differences between the three cognitive groups (FD, FN and FI) and users' EM behaviour?

It is hypothesized that users of different cognitive style groups might exhibit different EM patterns. Specifically, it is assumed that the FD participants will be less task-oriented and disorganized in their images viewing processing, producing higher values of fixations and saccades, compared with the FN and FI ones. Addressing these questions can provide a better understanding of how the FD-I cognitive dimension impacts the processing of users' EM patterns (i.e. fixations and saccades). Notably, by using eye tracking to demonstrate how user cognitive style influences a user's eye gaze behaviour, one can consider to explore eye tracking as a technique to capture real-time information of a user in relation to the FD-I cognitive type. These results will enable instructional designers and system developers to provide adaptive interfaces and learning environments that will reveal users' individual characteristics.

The use of eye tracking technology as a measure of noticing users' cognitive type during visual processing gives insights

into how this information and cognitive overload affects user ability to interact. This raises an important question as to whether eye gaze components such as the number of fixations and the number of saccades can suggest users' FD-I cognitive style.

A variety of studies uses the Hidden Figures Test (HFT) which was developed by Ekstrom *et al.* (1976) as a medium to categorize individuals into their FD-I cognitive style. Palmquist and Kim (2000) suggest that Websites should include different kinds of navigational options and eliminate visual complexity. Therefore, this study seeks to examine whether differences in navigation patterns in terms of EM behaviour exist between FD, field neutral and FI individuals. Subsequent to the concerns of this article, the terms 'cognitive characteristic', 'cognitive dimension', 'cognitive style' and 'cognitive type' are used interchangeably and treated as synonyms.

2. RELATED WORK

2.1. User cognitive characteristics, visual complexity and human-computer interaction (HCI)

'With the rapid and constant advancement of technology, new ways are continually being introduced to present information that leads to visually complex online environments' (Harper *et al.*, 2013, p. 1) Westerman (1997) stated that instructional designers should understand the interaction between user characteristics and interface styles.

Browne *et al.* (1990) provided one of the first classifications of candidate dimensions of user differences that may impact computer usage, including diversities in cognitive styles (i.e., FD/I, impulsivity/reflectivity etc.) (Nakić and Granić, 2009). Based on this suggestion, a previous study argues that the amount of usability difficulties evaluators' face varies across their FD psychological construct (Clemmensen *et al.*, 2009).

The link between eye tracking and cognitive modelling is an extremely intuitive and potentially fruitful area of research based on the assumption that individuals interact differently. According to Dillon and Watson (1996) recommendations, psychological measures of individual differences are in need to raise potentials for the generalization of HCI outcomes. Since the perception of complexity is correlated with the variety in the visual stimulus a visual pattern may also look complex if its parts are difficult to identify and separate from each other (DaSilva *et al.*, 2011). Therefore, cognitive psychological theories and methods should be further applied to human-computer interaction to interpret users' individual needs and cognitive traits.

2.2. FD-I style in HCI

The cognitive construct style of FD-I refers to several phenomena, one of which mentions that few people find it

much easier than other to identify parts of a figure as being separate from a whole (Galotti, 2013). Individuals who are located towards the FD style face difficulties in distributing incoming information from its contextual surroundings. This group of people are more likely to be influenced by external cues and to be non-selective in their data uptake (Guisande *et al.*, 2007).

Field independent users, on the other hand, are more likely to be determined by internal than external cues. Therefore, they are selective in their information input and global in their behaviour (Zhang, 2004; Guisande *et al.*, 2007). Further, FD people can explain individual performance differences on a broad variety of visual perception tasks and capture the relative influence of whole visual fields (Witkin, 1950). Mainly, they can separate a part from the complex whole in which that part was embedded. Besides FD experience greater difficulty in focusing on and processing objects embedded in a context (Orth and Crouch, 2014). People who are more FD face difficulties in perceiving a part separately from the complex whole in which was embedded (Goodenough, 1987).

Field dependent captures the degree to which perception is affected by the dominant structure of a visual field (Witkin, 1950). As a consequence, they find it more difficult to distinguish between relevant and irrelevant information (Arthur and Day, 1991). In contrast, FI learners have greater cognitive disembedding skills and encounter fewer problems in discriminating relevant from irrelevant information (Goodenough, 1987). Conversely, people who are more FI have more excellent disembedding skills and meet fewer problems discriminating relevant from irrelevant information. A number of instruments such as the 'Hidden Figures' Test (HFT), the 'Body Adjustment' Test, the 'Rod and Frame' Test and the 'Embedded Figures' Test have been designed to measure cognitive styles and specifically the FD–independent construct style. The concept of FD/I was developed by Witkin (1950), and it is used to classify individuals as FD and FI. It is concerned with the strategy used to separate parts of aspects from the whole in which they occur. The approach a person employs when faced with a complex task depends on the characteristics of the individual (Aykin and Aykin, 1991).

Much of the research on FD-I cognitive dimension has focused on examining the effects of FD-I on learners' computer performance (Hercegfi, 2011). A study by Ford *et al.* (2005) demonstrated individual cognitive style differences in Web searching tasks. In addition, Józsa and Hámornik (2012) stressed out the necessity for further studies to use new grouping variables such as the cognitive style as a means to identify users' information seeking behaviour. The growing number of online learning environments is instructive and calls instructional designers to understand cognitive individual differences during navigation processing.

The ability to capture process differences in learners has been cited as one of the major uses of computer-based assessment (Baker and Mayer, 1999). Additionally, it is mentioned that hypermedia evaluation needs to take into account both structure and content, thus field dependency needs to be considered since some users quickly distinguish structure from content (Paterson *et al.*, 2011). Moreover, research confirms that response readiness forms a user visual characteristic component and constitutes one of the critical usability issues that can influence users' response to visual stimuli (Lim *et al.*, 2014).

2.3. EM behaviour and eye tracking

Nowadays the rapid changes in technology and the increased use of the Internet have changed the way in which information about users is collected, stored, accessed and distributed. These changes require people to disclose personal information online (Shih *et al.*, 2012) and will assist the development of personalized learning environments based on individuals' needs. One of the main goals of the eye tracker studies was to comprehend the human visual system, as well as the visual process itself. Such measures offer information on issues such as cognitive activity (Boksem *et al.*, 2005). "EMs are driven by characteristics of the visual world and processes in a person's mind" (Rayner, 1998; Nisiforou and Laghos, 2013, p. 5). Understanding how this information and cognitive overload affects user perception and Web interaction can lead to solutions that improve users' Web experience (Michailidou, 2009; Khan and Sekharaiah, 2013).

Eye tracking and usability evaluation studies try to investigate and understand user behaviour (Jacob, 1995; Rayner, 1998) with an increasing interest in Web page behaviour and visual images interaction. The idea that user characteristics such as the cognitive styles and personality are affecting the effectiveness of information visualization techniques is continuously growing. The use of eye tracking has long been established in psychology as a technique for analysing user attention patterns in information processing tasks (Tuch *et al.*, 2009; Steichen *et al.*, 2013). Research in this field has also examined the impact of individual user differences on reading and search tasks (Witkin *et al.*, 1975, 1977).

A previous study examined the potential of eye tracker as a tool for detecting users' cognitive dimensions with respect to the FD-I classification and identified differences between the three cognitive styles and tasks time completion (Nisiforou and Laghos, 2013). Moreover, an earlier study by Michailidou (2009) found that visually complex pages generate users' disoriented navigation while, visually simple pages produce the opposite result. Researchers in human–computer interaction and data visualization have also begun to use eye tracking technology to examine tendencies

and dissimilarities in user attention patterns and decision processing (Toker *et al.*, 2013). Although the studies mentioned so far in this section provide valuable insights on how different tasks and/or activities affect a user's gaze behaviours, they have traditionally neglected individual differences among study participants. This research has focused on identifying differences in gaze patterns for different cognitive groups within complex tasks and on explaining these differences in terms of user FD-I cognitive style.

Previous work has empirically determined relationships between eye gaze and individual user differences in attention-related tasks (Kruschke *et al.*, 2005; Toker *et al.*, 2013), which is not directly relevant to the focus of the current study. This research adds to this body of empirical work by providing detailed evidence of how individual cognitive differences affect a user's engagement patterns during visually complex stimuli. Work by Tang *et al.* (2012) was 'focused on a single, domain-specific user trait (task-domain expertise), showing that domain experts and novices display different gaze behaviours' (Toker *et al.*, 2013, p. 2). Besides, eye tracking and usability evaluation studies exist aiming to investigate and understand user behaviour (Jacob, 1995; Rayner, 1998). An eye tracking study conducted by Toker *et al.* (2013) investigated the relationship between such characteristics and fine-grained user attention patterns. Their findings revealed that user's perceptual speed and verbal working memory have an effect on gaze behaviour (Toker *et al.*, 2013).

Additionally, the eye tracking method has become practical for studies of visual user interfaces (Grier *et al.*, 2007) and usability studies. A study conducted by Michailidou *et al.* (2008) found that visually complex pages generate users' disoriented navigation, while, visually simple pages produce the opposite perspective (Michailidou *et al.*, 2008; Nisiforou *et al.*, 2014). Additionally, Tsianos *et al.* (2009) have shown that users' cognitive and emotional characteristics have a significant impact on the personalization and adaptation process of online environments that increase user usability and satisfaction during the navigation and learning procedure.

Moreover, van Gog and Scheiter (2010) claimed that the findings of their study can contribute to multimedia research by using eye tracking to examine how diverse design interventions (e.g., spoken vs. written text) affect processing of complex visual presentations. Visual perception depends on the stimulus and the user's characteristics (Lavie and Tractinsky, 2004). Additionally, cognitive measures such as perceptual speed and visual memory have been shown to affect a user's ability to complete a task effectively (Conati and Maclaren, 2008). Even though data mining methods can quickly identify clusters of similar attention patterns during visual tasks (Goldber, 2014), it is unsupervised how user gaze behaviour relates to user cognitive type.
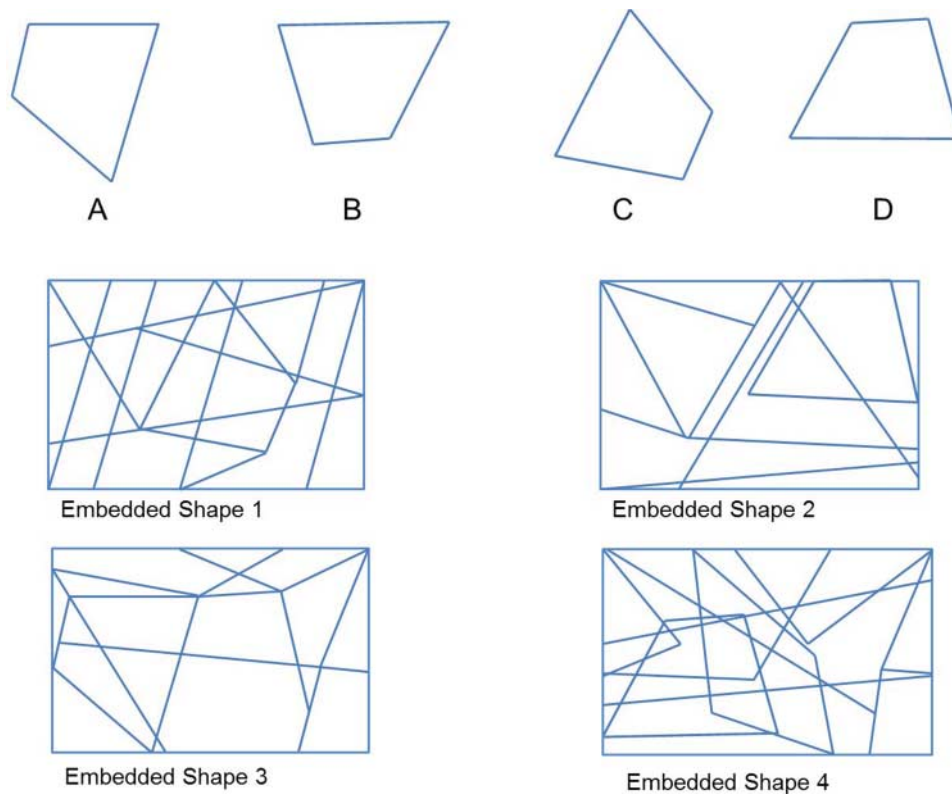
Figure 1. The visual stimuli displayed in the eye tracker study.

3. METHOD

3.1. Participants and materials

This section describes the study that was conducted to investigate the association between users cognitive group and gaze patterns. Visual images were displayed on a monitor and users' performance was measured with the use of the eye tracker. The eye tracking technique was used as a method of identifying users' EM differences with respect to their FD-I cognitive type classification during visual processing tasks as a medium to address the objectives of the study.

The population of the study was recruited from a Public University in Cyprus. A total of 54 students (aged 18–35 years) participated voluntarily in the experiments. The participants were initially categorized into their current FD-I cognitive occupation (FD, field neutral and FI) on their performance on the HFT (Ekstrom *et al.*, 1976). The HFT is a psychometric tool that measures the level of an individual's field dependency. It consists of 32 questions divided equally into two parts and scores ranged from 1 to 31 (max=32 points). The test presents five simple figures and asks learners to identify one of the five simple figures embedded in a more complex pattern. Participants' who scored 10 or lower were defined as FD, those who scored of 11–17 as FM or FN, and those who scored from 18 to 31 were categorized as FI. An SMI iViewX eye tracker

device was used to record participants' EMs while completing the tasks.

3.2. Apparatus, tasks and stimuli

The study was conducted in two phases.

Phase A. HFT: cognitive styles–users' level of FD was measured with the use of the HFT developed by Ekstrom *et al.* (1976). Participants were asked to complete the paper-based HFT for classification to one of the three cognitive measures with a duration limit of 24 min (12 min each part).

Phase B. User study: EM behaviour–users' were engaged in visual exploration tasks and were placed in front of an eye tracker and were engaged in a visual exploration task. The environment of the study was inspired by the HFT, and four complex shapes were designed to serve as the stimuli of the experiment (see Fig. 1). Four lettered shapes were embedded within each one of the four main shapes. Participants were placed in front of an eye tracker and asked to complete a visual task on four complex shapes that were designed for the purposes of the study. Subjects had to identify one of the four lettered shapes that were embedded within the main complex shape and report their response, both verbally and by clicking on the finding answer. Once participants clicked on the correct answer, the next stimulus appeared on screen. Calibration was

performed prior to each recording session. While reviewing the embedded shapes users' eye activity was recorded with the use of the eye tracking system. The embedded images were presented with no time limits as to elucidate continuous, objective measurements of human–system interactions.

3.3. Data analysis

The results are based on the eye gaze derived data in the pre-defined four visual stimuli tasks and were analysed with the aid of the BeGaze analysis software provided by SMI. For the analysis participants' visual behaviour was measured, analysed and evaluated, subject to the number of fixations, number of saccades, scan path and heat maps eye gaze analysis, for each individual stimulus. Consequently, the total number of fixations of each cognitive style group was computed on every stimulus, and the average total number of all four stimuli was calculated. The same procedure was followed for the number of saccades.

The eye tracking-derived metrics were statistically analysed with the use of the SPSS software. One-way ANOVA (Post hoc analysis using Fisher's LSD criterion) tests were conducted as a means to examine the effect of the FD–independent cognitive style on users' EM behaviour in relation to fixations and saccades.

In the subsequent section, the findings are discussed with respect to the research questions of the study for each cognitive group. It was hypothesized that FD users will yield a more disoriented and disorganized eye patterns while performing the visually embedded shapes tasks, and hence produce greater numbers of fixations and saccades. On the other hand, FI learners will generate less number of fixations and saccades. Thus, a more organized behaviour will occur.

4. RESULTS

4.1. FD-I cognitive style

The findings of the study are discussed in terms of the association between FD, FN and FI users and the number of fixations and saccades they generate during a search task process. As previously mentioned, the HFT was used to define users' FD-I current cognitive type (e.g. FD, FN/FM and FI). Participants' score on the test was calculated as the difference between the numbers of questions answered correctly minus the number answered incorrectly. Taking into account how other researchers determined the cut-off scores of the test in their studies (e.g. French *et al.*, 1963; Chen and Macredie, 2004; Angeli, 2013) the participants were classified into their cognitive type. In line with this classification framework, participants in the current study were classified as follows: 24 field dependent, 16 field neutral and 14 field independent.

The testing activity involved in the HFT is a reliable and widely used approach for determining FD-I cognitive dimension. Rittschof (2010) and the Kuder–Richardson

reliability coefficient of the HFT reflects the degree of 0.76 (Study, 2012).

4.2. EM features

Eye tracking data were analysed using data mining techniques, such as scan path clustering (Goldberg, 2014). An eye tracker captures gaze data in terms of fixations (i.e. keeping gaze at one area on the screen) and saccades (i.e. quick movement of gaze from one fixation point to another) (Toker *et al.*, 2013). These can be analysed to give a viewer's attention patterns. These features are built by calculating statistics upon the fundamental eye tracking metrics such as the number of fixations and saccades. To facilitate the presentation of the results, this section is discussed in terms of users' cognitive type and the EM data they produce. The eye tracking metrics that were used for the purposes of this work include the following:

– Heat maps/scan paths analysis in association with the FD/I cognitive style.
– Fixations/saccades analysis in association with the FD/I cognitive style.

4.2.1. Comparisons of heat maps and scan paths EM analyses

Figure 2 demonstrates the heat maps of the FD subjects by virtue of their interaction in the four embedded shapes of the study. The eye tracking heat maps reflect the users' EM patterns while performing the visually embedded shapes tasks. These EM patterns demonstrate that the FD could not identify the correct shape as they were looking at different areas than the shape of interest. Additionally, we can see that the FD participants devoted more time in the incorrect lettered shapes rather than the correct ones indicated by a circle. In contrast, Fig. 3 determines the heat maps produced by the FI. Specifically, their eye gaze patterns exemplify their correct responses or their oriented behaviour while searching for the task. It was observed that FI could recognize the hidden lettered shape within the complex pattern as the green heat maps overlapped on the correct answers given by the users. The correct response to each corresponding complex stimulus is circled.

A study by Oliva *et al.* (2004) found that the textures that contain oriented patterns are less complicated than the disorganized ones. The outcome above suggests that the more disorganized a pattern, the more complex is and opposed, the more organized; the less complex is. However, what happens when different cognitive groups of individuals interact with the same visual patterns? Do they all generate fewer complex or more complex EM patterns? A comparison of a set of scan paths between FD and FI users demonstrated the differences in their EM patterns (Fig. 4). The scan paths of the FI revealed a more oriented EM behaviour producing less number of fixations and saccades than the FD participants. The latter group tends to generate more fixations and saccades and, as a result, exemplifies a more disoriented and disorganized gaze
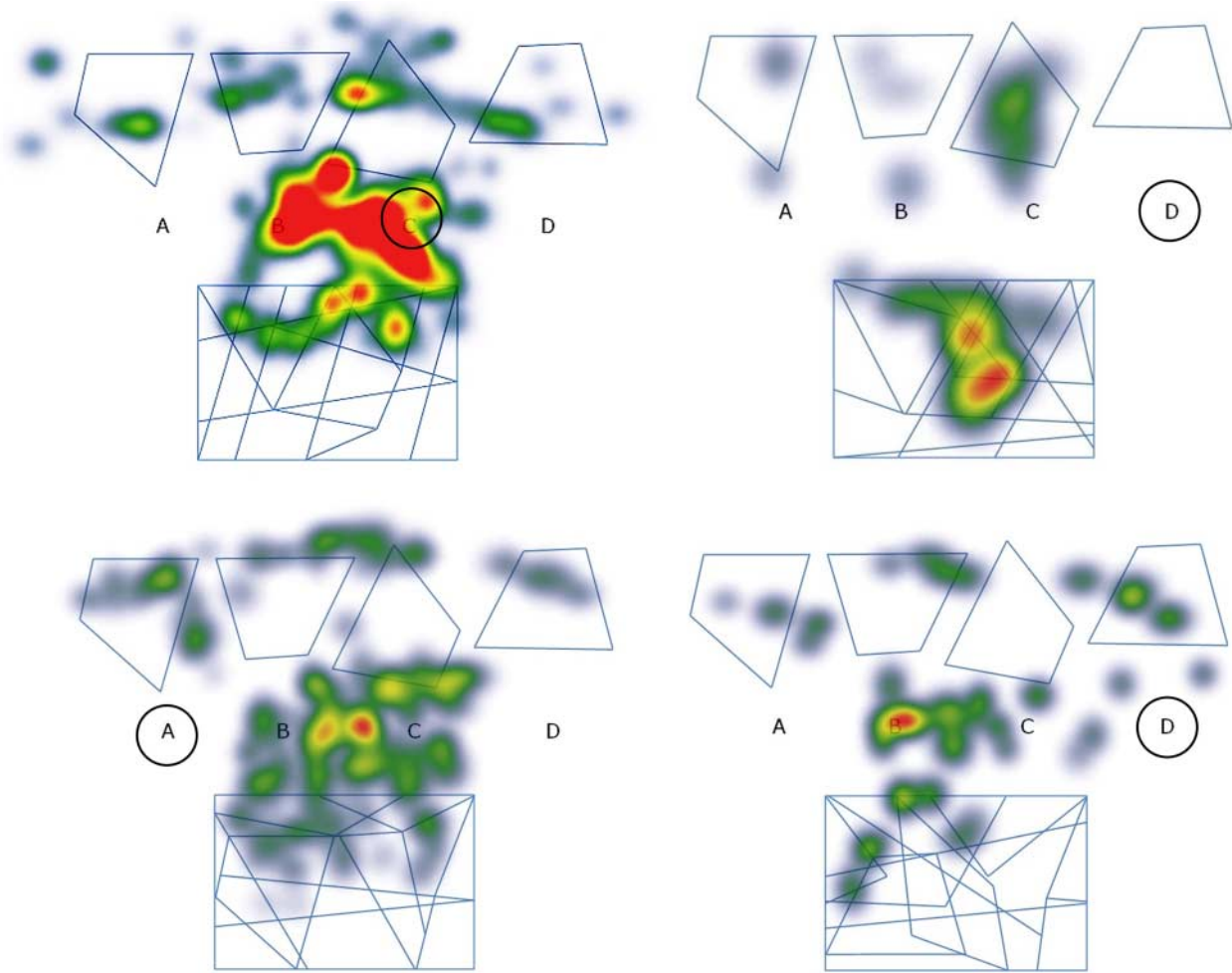
Figure 2. Heat maps of the four embedded shapes reflecting the FD subjects.

behaviour. This finding suggests that users' cognitive style in terms of the field-dependence/independence dimension affects their EM patterns when the same visual patterns are produced. Therefore, although oriented patterns are considered to be less complex, this emerging result suggests that the EM behaviour a user generates, rely upon his/her FD-I cognitive type.

Users were categorized into their FD-I cognitive style based on their performance on the paper–pencil HFT. In consideration of the existing cut-off scores classification, Table 1 summarizes the range of the number of fixations and saccades each cognitive group produced after the interaction with the visual stimuli of the study. Looking at the values it is plain that FD users who revealed disoriented eye gaze patterns tend to produce on average greater or equal to 100 of fixations and saccades. On the other hand, FN fall between 60 and 100 number and finally, equal or beyond the range of 60 found to be associated with FI classification. It is worth mentioning that the aforesaid outcome needs to be further considered since this is an initial assumption of introducing new ways to measure

and identify a user's FD-I cognitive dimension based on eye gaze features.

4.2.2. Fixations and saccades analyses

All participants' EMs differ significantly between the three cognitive groups. Number of fixations and saccades were compared in relation to the FD-I cognitive dimension. Table 2 demonstrates a comparison of the total average number of fixations and saccades between FD, FN and FI users during their interaction with the visual environment of the study. A significant variation in the total average number of both EM derived metrics between the subjects of the three different cognitive groups was identified. Specifically, the total average number of fixations of the FD participants was nearly double than the overall mean average of the FN learners and closely four times higher than the values generated by the FI group. Additionally, the FN users' doubled the average number of fixations and saccades produced by the FI ones. The result of more overall fixations reflects inefficient search by the user
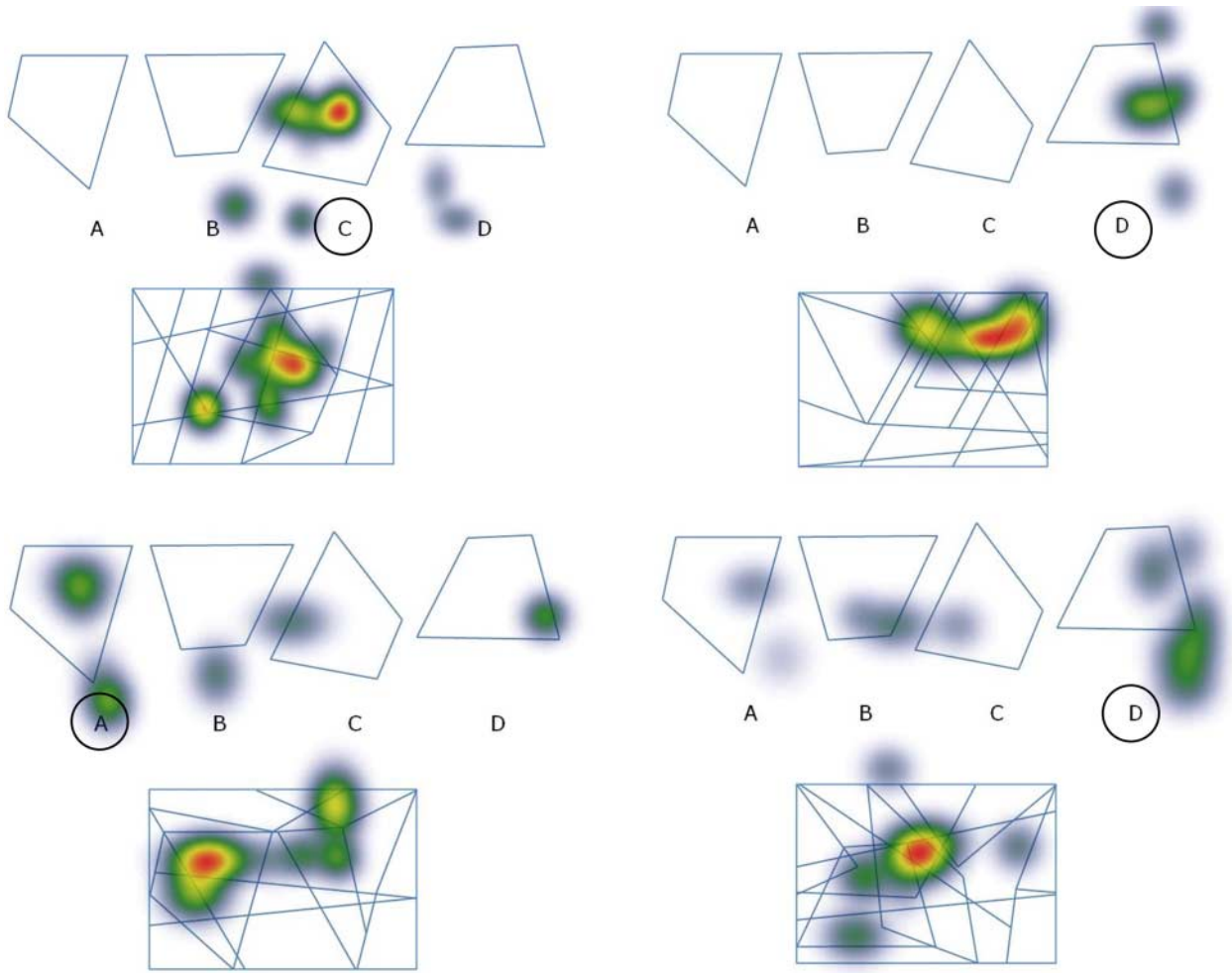
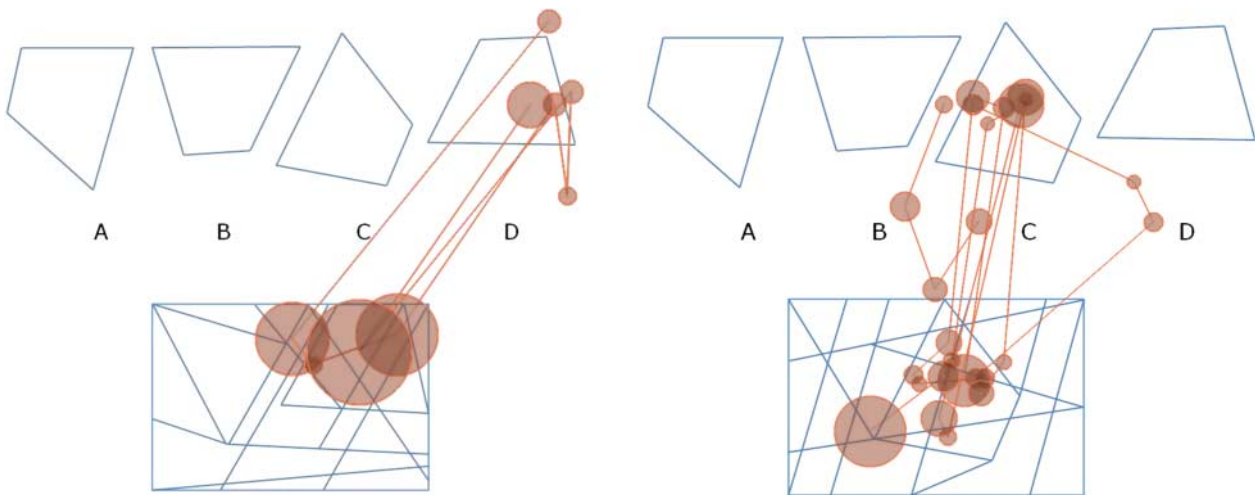**Figure 3.** Heat maps of the four embedded shapes reflecting the FI subjects.

Figure 4. Scan paths comparisons between FI (left) and FD (right) users.

Table 1. Participants eye movement behaviour and number of fixations and saccades per cognitive group.

Cognitive abilities	Eye gaze patterns	Eye movement components	
		Fixations	Saccades
FD	Disoriented	≥ 100	≥ 100
FN	Mixed	$60 < NF < 100$	$60 < NS < 100$
FI	Oriented	≤ 60	≤ 60

NF, number of fixations; NS, number of saccades.

Table 2. Average total number of fixations and saccades per cognitive group.

Cognitive group		Visual stimuli: embedded shapes				
		A	B	C	D	Total average
FD	Fixations	251.63	159.33	103.13	114.96	157.26
	Saccades	238.00	164.25	100.83	111.88	153.74
FN	Fixations	116.25	97.81	45.36	73.38	83.20
	Saccades	130.25	85.88	46.88	75.19	84.55
FI	Fixations	59.93	38.29	36.79	38.21	43.30
	Saccades	58.64	37.21	35.14	37.57	42.14

Table 3. Descriptive statistics for cognitive group $\times$ number of fixations; $\times$ number of saccades.

Cognitive group	N	Mean		SD	
		Fixations	Saccades	Fixations	Saccades
FD	24	157.26	153.74	49.87	50.90
FN	16	83.20	84.55	9.76	18.00
FI	14	43.30	42.14	14.52	13.50
Total	54	105.77	104.31	59.52	59.20

while more saccades exemplify more searching (Goldberg and Kotval, 1999).

Consequently, FD learners yielded more fixations and saccades in their attempt to complete the visual image tasks than the FI and FN did. In additon to this, there were times that they could not detect the correct response and, as a result, provide a wrong answer. Besides it is a notable effect that the FN learners occasionally behave as FD or FI relative to the learning condition. This eye activity is verified and illustrated in Table 2 as the total average number of the FN learners falls between the values performed by the FD and the FI cognitive groups.

Field dependence-independence and fixation effects. Most central to the purpose of this study was the observation of a statistically significant interaction between cognitive type and fixations. The descriptive statistics associated with EMs across the three cognitive groups are reported in tabular form in Table 3. It can be observed that FD group of users was associated with the numerically highest mean value of fixations ($M = 157.26$) during the visual images tasks, compared with the FN and the FI participants. To test the hypothesis that

Table 4. One-way ANOVA between the three cognitive groups $\times$ number of fixations; $\times$ number of saccades.

		SS	df	MS	F
Between groups	Fixations	126407.30	2	63203.65	52.52**
	Saccades	118994.66		59497.33	45.46**
Within groups	Fixations	61377.86	51	1203.49	
	Saccades	66745.30		1308.73	
Total	Fixations	187785.16	53		
	Saccades	185739.96			

**$P < 0.001$.

individuals' FD-I cognitive style had an effect on their EM behaviour in relation to the number of fixations they produce, a one-way analysis of variance (ANOVA) was performed (see Table 4).

The independent variable was the cognitive style factor, divided into three groups: (i) FD, (ii) FN and (iii) FI. The dependent variable was the difference in the number of fixations as a result of the user EM activity. The findings

Table 5. Fisher LSD post-hoc comparisons between the three cognitive groups × fixations; × number of saccades.

Cognitive groups		Fixations Mean	Saccades Mean
FD	FN	74.06*	69.19*
	FI	113.96*	111.59*
FN	FD	−74.06*	−69.19*
	FI	39.90	42.40**
FI	FD	−113.96*	−111.59*
	FN	−39.90*	−42.40**

*$P < 0.01$; **$P < 0.001$.

yielded a statistically significant effect at the level $P < 0.001$ within the three cognitive groups, $F(2, 51) = 52.52$, $P < 0.001$, $\eta^2 = 0.67$. Thus, the null hypothesis of no differences between the means was rejected. The strength of the relationship was medium to high ($\eta^2 = 0.67$) with the cognitive-type factor accounting for 67% of the variance of the dependent variable (number of fixations). As a medium to evaluate the nature of the differences between the three means, further comparisons were followed-up, with the use of Fisher's LSD post hoc test (Hayter, 1986). The Fisher LSD is 8% more powerful than Tukey's HSD (Seaman *et al.*, 1991) and therefore selected as the most appropriate post hoc criterion. The LSD test revealed statistically significant differences between all the three different cognitive pairs (see Table 5). The differences between the FD and FI ($M = 113.96$), FD and FN ($M = 74.06$) and the FI and FN groups ($M = 39.90$) were statistically significant. Additionally, the statistically significant differences between the means were associated with large effect sizes ($d = −2.47$; $d = −2.48$ and $d = −2.45$, respectively) based on Cohen's (1992) guidelines.

FD-I and saccades effects. A visual depiction of the descriptive statistics of users' EMs in relation to the three cognitive groups is presented in Table 3. It can be observed that FD participants generated a greater number of saccades ($M = 153.74$) in contrast to the FN and the FI users'. A one-way ANOVA was computed to compare the effect of the FD-I cognitive construct style on users' EMs with refer to the number of saccades they produce (see Table 4).

The independent variable remained the same (cognitive-type factor), and the dependent variable was the change in the number of saccades in consequence to user's eye patterns. The results showed that the effect of cognitive style on users' EM behaviour was significantly different across the three cognitive groups $F(2, 51) = 45.46$, $P < 0.001$, $\eta^2 = 0.64$ at the $P < 0.001$ level (see Table 4). With a view to understanding how much the independent variable (cognitive type) has affected the dependent variable (average number of saccades) the effect size was calculated with the use of the eta squared (η^2). The effect size related to the statistically significant effects is interpreted as moderate to high ($\eta^2 = 0.64$) and shows the strength of association between the variables. Therefore,

the null hypothesis of no differences between the means was rejected, and the 64% of the change in the number of saccades was accounted for by the FD-I cognitive dimension.

In furtherance of better interpreting the data and be able to measure the degree of association between the variables, post hoc analyses using Fisher's LSD criterion for significance were conducted to evaluate pairwise difference between the means. The test revealed statistically significant differences between all the three different cognitive pairs (see Table 5). Significant differences in the means of the FD and FI ($M = 111.60$), FD and FN ($M = 69.19$) and the FI and FN groups ($M = 42.40$) were observed. Furthermore, the statistically significant differences between the means of the three cognitive groups were associated with large effect sizes ($d = −2.45$; $d = −2.46$ and $d = −2.43$, respectively) based on Cohen's (1992) guidelines.

These results exemplified that the FD-I cognitive style factor influenced users' EM activity. Notably, the findings declare that the average number of saccades was significantly higher in the FD group than the two other groups (FN and FI). This outcome is in line with a previous study where the effect of FD-I cognitive dimension on Websites complexity was examined. The findings demonstrated that the FD participants needed more time to complete a task within a visually complex Website in relation to the FN and FI users' (Nisiforou *et al.*, 2014).

5. DISCUSSION

The effect of the FD-I cognitive style on users' EM patterns was examined using eye tracking analysis and statistical tests (one-way ANOVA). The objective of the study was to investigate (i) whether users' cognitive style affects their EM patterns and how, and (ii) explore the relationship between the three cognitive groups (FD, FN, FI) and the EM features (fixations and saccades). The following sections are discussed in terms of the two objectives of the study.

5.1. Objective 1: determine whether and how features in user EM behaviour are affected by a user's cognitive style

The eye tracking study revealed some implicit knowledge of users' cognitive characteristics and gaze patterns and exemplified that user navigation preferences do reflect their cognitive styles (Nakić and Granić, 2009). Earlier studies found that user cognitive abilities such as perceptual speed affect user gaze behaviour and user performance (Toker *et al.*, 2012, 2014).

Specifically, in this study EM patterns are influenced by users' FD-I cognitive type and were analysed through the eye tracking gaze plots (scan path) and attention maps (heat maps) analysis. The results revealed that although participants

were engaged in the same computer-based viewing stimuli, they tended to demonstrate different visual behaviour patterns. The emerged findings were discussed in view of common and different navigation patterns in relation to the three cognitive style categories.

The gaze data exemplified that the three cognitive groups of individuals (FD, FN, FI) affect their EM patterns in a different way. As a case in point, the FD users' gaze plots analysis revealed that their scan paths during the visual images search tasks process were more disoriented and disorganized in contrast to FI subjects that displayed a more oriented and organized scan paths. These findings are in accordance with the results of a recent study that examined the online behaviour of FD, FI and FN in visually complex Web pages with the use of the eye tracker device. The authors stated that the FD users' scan paths appeared to be more disoriented and scattered within visually complex pages in contrast to the FI subjects that revealed a more oriented and organized gaze plots (Nisiforou et al., 2014). Besides, Michailidou (2009) found that visually complex pages generate users' disoriented navigation while, visually simple pages produce the opposite perspective. Similar results were also reported in a work conducted by Harper et al. (2009). Additionally, the FD group heat maps indicated users' difficulty in detecting the correct response. This outcome reflects what was said by Goodenough (1987) that the people who are more FD, they experience difficulties perceiving a part separately from the complex whole in which it is embedded. On the contrary, the heat maps presented by the FI individuals illustrated that they could recognize the correct shape within the complex pattern as the green heat maps overlapped on the correct responses given by the users. This result is supported by Zhang's work (2004) that FI individuals face less difficulty in separating an essential information from its context than FD subjects do.

5.2. Objective 2: explore individual similarities and dissimilarities in EM patterns during visual images tasks processing between the three cognitive groups of users

The majority of the existing studies examine the FD-I cognitive style in terms of time taken to respond to a problem-solving and performance. The findings of the current study are discussed with respect to how FD, FN and FI groups interact while performing visual images tasks and how this interaction differs in terms of the EM features (fixations and saccades) they produce. The number of fixations and saccades were compared in relation with the FD-I cognitive dimension. The results showed that the EMs produced by the three cognitive groups differed significantly. In summary, the highest number of fixations and saccades were detected from the FD group, in contrast to the FN and FI ones that produced fewer values of fixations and saccades.

Furthermore, the eye tracking and simulated data also suggest that although users were processing the same visual stimuli, they tend to demonstrate different cognitive traits. The effects of the two variables about the participants' FD-I cognitive type and EM features were significantly correlated. This fact reflects the findings of previous work were users' level of FD validated the data retrieved and found a large variation in task completion time among the FD-I cognitive groups (Nisiforou and Laghos, 2013). In line with these results, Tinajero and Paramo (1997) found that FI students perform better than FD students. Isaak-Ploegman and Chinien (2009) mentioned in their study that FI learners outperform FD learners in terms of their scores on the HFT.

Additionally, the results of previous work (Burnett, 2010) hypothesized that FI learners will outperform FD learners with respect to time taken to response correctly to the problem-solving task. An earlier study (Nisiforou and Laghos, 2013) found that the groups of FD and FI exemplified differences in their EM features in terms of task time completion, with the first group outperforming the latter. The results of the current study revealed that users' cognitive style has a significant impact on user gaze behaviour and that this influence is detectable through eye tracking metrics. This outcome was discussed in a previous study (Józsa and Hámornik, 2012) where cognitive style was related to differences in the online searching tasks.

6. IMPLICATIONS FOR PRACTICE

Caveats need to be considered and are subject to three limitations. The number of the visual shapes used to serve as the environment of the experiment. Therefore, future research should be conducted using a larger number of visual stimuli, so the findings and the method used can be tested for reliability and validity. Additionally, more user characteristics such as age, gender, culture and different academic disciplines should be taken into consideration. Notwithstanding other eye tracking measures could be included in future studies, to give deeper illumination of how individuals' cognitive characteristics affect their EM patterns.

Currently, there is an escalation of studies that examine individuals' cognitive components in correlation to visual perception. Visual appeal is an essential element in the design of online learning environments (Orth and Wirtz, 2014). Adaptive and personalized learning environments are becoming even more important in today's technological era. This statement alerts the necessity to provide implications for designing interfaces that scaffold learners' online experience on the cognitive demands of the task (e.g. time task completion, task context) based on their cognitive needs and characteristics.

Since the influence of cognitive abilities on HCI implications becomes critically important, the findings of the study

suggest potentially fruitful lines of further research. The results of the study enrich our understanding regarding user cognitive characteristics and HCI, finding out valuable ways to improve users' online experience and performance. Instructional designers should identify and consider the nature of the user population related to their cognitive differences and be able to tolerate how individual characteristics relate to interface design. Therefore analysing individual differences in cognitive terms could become significantly beneficial for users, instructors and designers.

Furthermore, instructional designers and developers can design environments that will be accessible to all users by matching the visual design of their online environments with the users' cognitive characteristics and interaction type. Understanding, therefore, how individual differences in the FD-I cognitive style affects users' online interaction will betterment their online experience.

The findings provide insights that enable the development of models that better predict and simulate human performance in evaluating cognitive characteristics. Besides, implications can be applied in terms of designing computer systems that scaffold users' complex problem solving by counting the cognitive demands of the task. This framework could be used in designing new environments that can predict a user's cognitive style.

In addition, further research is under progress that will take the above study on its next stage combining behavioural and electrophysiological methods. The forthcoming study aims to gain insights into the classification of the FD–independent cognitive style through the use of ambiguous figures (images with more than one meanings). Finally, the upcoming study seeks to investigate the mechanisms that underlie the association between FD-I cognitive style, eye gaze patterns and creative thinking.

7. CONCLUSION

Overall the novel findings indicated that the greater number of fixations and saccades is generated when individuals fall within the FD cognitive group while FN and FI produce fewer values of the same EM features.

Specifically, the combination of these factors and measures (FD-I cognitive style and EM components/fixations-saccades) used in this study identified that: (i) the eye tracking metrics revealed useful information regarding users' cognitive activity related to their level of field dependency, (ii) the developed visual stimuli could be used as an additional objective measurement battery to classify users' FD-I cognitive style, (iii) it demonstrates the significance in designing interfaces that can reflect user's FD-I cognitive type. In addition, the effects of cognitive style FD/independent on users' EM patterns provide several implications for practice and theory that can be beneficial to learners.

These results contribute to the long term vision of designing personalized environments that can reflect users' cognitive needs and characteristics. In the case of the forthcoming integrative FD/FI cognitive framework, this can act as a rudder that will potentially provide research paradigms on how to improve Web experience of different cognitive groups of individuals'. As a final point, studies should examine the potential of introducing FD-I cognitive dimension as a prospective component of user-centred design.

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