Using Eye Tracking to Identify Cognitive Differences: A Brief Literature Review

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ABSTRACT

Being the windows to the soul, eyes reveal information about individuals' feelings, emotions and behaviour, affecting various cognitive tasks, such as focus of attention, spatial cognition and navigation, cognitive load, etc. With the increased use of computer systems, complex information is visualized and communicated through visual interfaces as a mean of information presentation to and processing by the users. However, people differ regarding the way they seek, retrieve, process, comprehend, organize and recall information, based on their individual perceptual characteristics, cognitive skills, abilities and styles. Therefore, the point and the motion of the eye gaze could reveal behavioural patterns related to individual cognitive differences; patterns that are extracted using eye tracking tools which quantify and provide compelling data regarding eye gaze movement. In this paper we review the current literature regarding the effect between the FD-I cognitive style of users in visual exploration and search activities and to correlate these with objective measures gathered through eye-tracking.

CCS Concepts

•Human-centered computing → HCI theory, concepts and models; •Computing methodologies → Cognitive science;

Keywords

Cognitive styles; Eye tracking; Visual perception; Cognitive differences; Literature review

1. INTRODUCTION

Several studies [11] have indicated that people with different iris features, gazing patterns, and eye characteristics tend to develop along different personality and cognition lines, reflecting on their individual differences and their cognitive styles. The evolutionary technological era has enabled the development of highly accurate eye tracking tools which collect and analyse data regarding eye movement reflecting on visual perception abilities. Elaborating such tools allows for identifying individual cognitive differences and enables researchers to further understand user visual behaviour.

1.1 Cognitive Styles

Cognitive styles refer to "*people's characteristics and typically preferred modes of processing information*"[26]. There is a number of related terms that describe characteristics similar to cognitive styles, including learning, thinking and information processing styles. Lying at the junction between cognition and personality, cognitive styles describe individual differences in how people use their cognitive skills and abilities to solve problems and process information in their preferred way.

A number of cognitive styles have been proposed [1, 10, 23, 32], modelling the individuals' preferred way of information processing, based on their cognitive differences. One of the most well established, credible and validated [2, 5] cognitive styles is the *Field Dependence-Independence (FD-I)* style [32]. It is a single dimension model having the field dependence on the one side and the field independence on the other. According to this model, the individuals are classified either as field dependent (FD) or as field independent (FI). However, several studies on FD-I style have introduced a third cognitive group: the field neutral (FN) or field mixed (FM), which reflects on individuals who do not have a clear orientation towards FD or FI [12, 25]. FD individuals tend to prefer a more holistic way when processing information, have difficulties in identifying details from information in complex schemes and perform better on inductive tasks [32]. On the other hand, FI individuals tend to prefer impersonal orientation, follow a more analytical way when processing information, pay attention to details and easily separate simple elements and structures from the surrounding composite context [32]. Several cognitive style elicitation tools have been developed to classify individuals as FI or FD. The most credible, validated and widely used tools are based on traditional techniques, like "paper-and-pencil" and they include the tools:

- Hidden Figures Test (HFT) [7];
- Group Embedded Figures Test (GEFT) [19];
- Children Embedded Figures Test (CEFT) [31];
- Embedded Figures Test (EFT) [31].

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1.2 Visual Perception

FD-I cognitive style is closely related to visual perception, i.e. the ability to organise, identify and interpret the surrounding environment by processing visually displayed information [32]. One of the fundamental approaches regarding the visual perception is the *Gestalt* theory and its derived principles on how people acquire and maintain meaningful perceptions in a chaotic world. The cognitive elicitation tools discussed in the previous section are greatly influenced by the Gestalt framework. The first stage of the visual perception process comprehends the phases of exploration and search. These stages differ in great extent, and they influence people's behaviour when they are looking for information in chaotic environments [20]. During the visual exploration, people get an overview of the data and they interactively browse through different portions of the data, as they have only vague hypotheses about the nature of the data. In this sense, visual exploration can be understood as an undirected search for relevant information within the data [28]. To support users in the search process, a high degree of interactivity must be a key feature of visual exploration techniques. On the other hand, visual search requires high degree of attention, which typically involves an active scan of the visual environment, seeking for a particular object, i.e. target, within a cluttered visual set of other objects, i.e. distractors [29].

1.3 Eye Tracking

Measures of eye movements and visual perception are highly correlated, especially in visually complex scenes, where many important details cannot be easily resolved [33]. Furthermore, since eye movements can be observed directly, unlike shifts of covert attention, they provide a rich dataset to improve our understanding of visual search and exploration [33]. A very popular technique on analysing visual perception is the eye-tracking, which is used to investigate the approach an individual follows to solve a problem visually, identify where attention is drawn and understand the required effort and the cognitive workload of the users when solving the problem [22]. The recent technological advances had a major impact on the eye tracking industry, which provides accurate solutions of high standards to researchers, helping them understand the users' behaviour while interacting with computer systems.

An eye tracker mechanism captures gaze information in terms of fixations and saccades. Fixations occur when a person focuses their vision on a particular point over a period of time, while quick changes in eye position are referred as saccades. These two parameters along with fixation duration, i.e. the amount of time the eye fixate within an area of interest (AOI), are the fundamental features of the analyses used in the literature in order to derive viewers' attention patterns. A number of more complex high-level eye tracking metrics have been built on the aforementioned fundamental features, which are widely used in eye tracking studies [27]. Such metrics include:

- Fixation count, rate, and duration;
- Relative and absolute saccade angle;
- Heat maps and scan paths;
- Fixation proportionate in AOIs;
- Fixation transitions in AOIs.

2. EFFECTS OF FD-I IN VISUAL SEARCH AND VISUAL EXPLORATION

2.1 Effect on Visual Exploration

Visual exploration occurs when people do not search for specific information within a complex environment, but they visually browse the given data [20, 28]. Being the initial stage of the visual perception, many researchers have studied the effect of FD-I style on visual exploratory tasks. In 1978, Shinar [24] studied the driving behaviour differences between FD and FI individuals with the use of eye tracking mechanisms. The results of his study indicated that FD individuals spent more on the focus of expansion; an overall good approach when driving on straight road, but inefficient while negotiating curves. Moreover, FD drivers were more concentrated on their fixations, and thus they did not easily adapt themselves to changing environments, thus they had slower visual search process than FI drivers. Therefore, FD drivers tend to be less adaptive and efficient in curve negotiating environments where the perceptual load is drastically increased and the target area, i.e. the road, changes iteratively within their visual field.

Yekan and Cagiltay [34] investigated the effects of FD-I style on students' interaction with a computer-based instructional interface through eye-tracking measures. They examined whether there are differences between FD and FI individuals in terms of fixation count and duration when exploring an instructional website. The website was built by the researchers and was divided into ten AOIs. Their findings revealed no statistically significant differences, as none of the AOIs was preferred by one or the other group; however, the FD individuals tended to fixate in the AOIs for longer time periods than FI students. This could imply that FD individuals have lower performance in hypermedia-based activities; no statistically significant differences were identified though. The fact that the instructional website was used for the very first time by the study participants could have an impact on the study findings, as the learning curve was not taken into account by the researchers.

Mawad et al. [14] investigated the effect of FD-I style on information processing and selection of food product labels. The study participants had to choose a yoghurt to consume, after looking the labels of two different products. The analysis revealed that FD and FI individuals had different visual approach on information seeking in order to decide which product they would choose. FI consumers had longer fixation durations and spent more time evaluating the two product labels and they tended to seek information more exhaustively, having greater fixation ratios in specific areas of the yoghurt labels such as nutrition facts. This finding suggests that FI consumers tended to sustain their attention on the product labels and performed a deeper evaluation of the presented information before choosing a product.

Raptis et al. [21] investigated how visual attention on interactive game elements is distributed among players with different cognitive styles. The study participants were asked to play a video game, in which they had to explore an ancient civilisation, and their eye movements were analysed based on fixation count and duration. The eye tracking analysis revealed significant differences between the game-playing approaches of FD and FI individuals. FI gamers had greater fixation count and fixation duration than FD gamers; a finding that could be explained by the analytical nature of FIs.

However, the game had different types of elements: items that their acquisition was compulsory in order for the players to proceed in the level, and optional items that would help players to enrich their knowledge about the ancient civilisation. No significant differences was found regarding the fixation count and fixation duration towards compulsory objects; whereas a significant effect regarding the fixation count and fixation impact toward bonus items was revealed. Overall, FD players observed less times and for shorter time periods the game items, as they followed a more intrinsic approach and were less inclined in detecting details, whereas FI players were more analytical, and thus they observed bonus items more often and for longer time periods.

In a recent study Katsini et al. investigated the effect of FD-I style on a graphical authentication mechanism. The study participants were asked to create an image based password by choosing five different images of a set of 199 images. The primary finding of their study was that FD individuals fixated on a smaller subset of the image grid than FIs. FDs visually explored about 30% less images, which reflected on the security level of their passwords, with FDs being more vulnerable. Moreover, FD and FI individuals tended to follow different visual approaches, with FDs being more holistic and FIs more analytical, as it was shown through heatmaps.

Apart from adults, studies have performed on children as well. Baron [3] investigated whether FI individuals exhibit more proficient scanning strategies than do FD individuals, when watching a television program. The study participants were 85 third-grade pupils who undertook CEFT [31] to be classified as FD or FI. The participants then watched the Children's Television Workshop program "The Electric Company", and the researcher was freezing the moving segments at specific intervals, which were chosen for their individual stimulus qualities such as electronic bridges, animation, etc. The analysis of fixation count and duration revealed that there were no major differences in eye movement patterns between FD and FI individuals. However, FIs showed more proficient scanning strategies as indicated by significant differences in percentage of fixations on target and fixation duration for specific segments. This finding raises questions about the reason why high-level cognitive differences have an impact on the way individuals scan, but it was not further examined in Baron's paper.

2.2 Effect on Visual Search

In contrast to visual exploration, visual search requires high degree of attention, which typically involves an active scan of the visual environment, seeking for a particular object (target) within a cluttered visual set of other objects (distractors) [29]. In 1968, Conklin et al. [6] investigated the eye-movement patterns of high and low scorers on EFT elicitation tool. Thirty-two first-year university students took part in the study, and a series of EFT problems were presented to them. When each subject felt that he had solved the task in a time frame of 20 seconds, he was asked to close his eyes. The dependent variables of their study were: the mean fixation durations and the mean track lengths. Moreover the Informative Search Score (ISS) [13] was determined for each subject. Inspection of the track-length variable revealed that the observed differences in track length are associated with the degree of structure in the stimulus. The greatest difference in track length between FDs and FIs was observed on the very unstructured figures. The figures of medium level of structure complexity yielded a marginal difference on track length. This finding suggests that FI individuals tend to have longer and more random eye movements than FDs as the structure complexity increases. While no differences between the samples were found for fixation duration, there was a tendency for study participants to fixate longer on less structured figures. An interesting finding is the highly reliable difference found on the ISS variable. This result suggests that FI individuals are capable of attending to the more relevant information more precisely and can quickly solve such tasks as the EFT.

Wijnen and Groot developed the software system *EMAS* [30], to analyse eye movement data recorded during figural tasks. The study participants undertook the HFT [7] and the EFT [31] tools, and the collected eye movement data were examined through EMAS functions. It was revealed that FI individuals scanned systematically, for longer time periods at specific sectors, and had a greater overall fixation count. In the contrast, FD individuals scanned unsystematically in an "unarticulated" way with many short fixations nearly all sectors during the two tests. Despite the fact that the scan paths followed by FD and FI individuals were different, the researchers did not perform exhaustive analysis on them, to gain more insights on the way FDs and FIs scan an area when seeking for a particular visual clue. Nevalainen and Sajaniemi [15] investigated the short-term effects of graphical versus textual visualisation of variables on program perception. The participants studied four simple Pascal programs using two different tools, PlanAni programming animator and Turbo Pascal programming environment; a graphical and textual environment respectively. Then they had to write a brief description of each program they studied. During the eye–tracking study the screen was divided into three areas: the code area, the variables area and the rest area. The variables area was viewed more times in PlanAni than Turbo Pascal in general, and FD individuals paid more attention than FI individuals on it. Turbo Pascal is a textual visualisation environment, and it does not require the users to be able to separate meaningful items from structured perceptual field like in PlanAni, which provides a rich colourful graphical interface. Therefore, the level of field-independence had an effect on the visual attention and perception which would had an impact on the constructed mental models of the programmers. However, we should mention that due to nature of the programming environments, the variables areas had different size, with PlanAni having a larger variables area, which could contribute to the overall fixation count of each area.

Nisiforou et al. [18] investigated the impact of cognitive abilities on visual search tasks. The study participants were classified as FD or FI and then each of them undertook a set of nine fact-finding tasks, with the information being sought placed on a particular location of the webpage. They examined both the completion time needed for each task and the visual search behaviour of the study participants. The visual search behaviour was analysed qualitatively through gaze plots, focus maps and heat maps. The analysis revealed that the behavioural patterns among each cognitive group were highly related to the complexity of the scanned webpage. For webpages of low complexity the visual search strategies were similar. However, the scan paths of FD individuals appeared to be more disoriented and scattered on webpages of medium and high complexity, in contrast to FI individuals,

Study	Elicitation tool	Participants	Apparatus	ET metrics	Results
Baron [3]	CEFT [31]	– 85 third-grade pupils – 42 boys and 43 girls – CEFT: 3-24 (m=15.3) – CS: 36 FDs and 49 FIs	Polymetrics eye movement recorder (V-1164-1)	Fixation count, duration and ratio	The analysis of fixation count and fixation duration revealed that there were no major differences in eye movement patterns between FD and FI individuals. However, FIs showed more proficient scanning strategies as indicated by significant differences in percentage of fixations on target and fixation duration for specific segments.
Conklin et al. [6]	EFT [31]	– 32 UG students – Gender: 16 F, 16 M	Polymetrics eye movement recorder (V-1164-1)	Fixation duration; track length; Informative Search Score (ISS)	The observed differences in track length were related with the degree of structure in the stimulus. The greatest difference in track length between FDs and FIs was observed on the very unstructured figures. FDs tended to have longer and more random eye movements than FIs as the structure complexity increased. The difference found on the ISS variable suggests that FIs are capable of attending to the more relevant information more precisely and can quickly solve such tasks as the EFT.
Jia et al. [8]	EFT [31]	– 30 UG students – Gender: 24 F, 6 M – CS: 15 FDs, 15 FIs	n/a	Fixation count and duration	FIs could focus their attention to cue-pointed objects relying on internal references, while FDs tended to scan both the targets and distractors without the cue using external references. The study results indicated that FIs could remove irrelevant information more efficiently than FDs.
Katsini et al. [9]	GEFT [19]	– 51 adults – Gender: 16 F, 35 M – Age: 18-40 (29.3±5.8) – GEFT: 3-18 – CS: 25 FDs and 26 FIs	Tobii Pro Glasses 2	Fixation count and duration; heat maps	In order to create their graphical password, FDs fixated on a smaller subset of the image grid than FIs. FDs visually explored about 30% less images, which reflected on the security level of their password, with FDs being more vulnerable. Moreover, FDs and FIs followed different visual approaches, with FDs being more holistic and FIs more analytical, as it was revealed through heatmaps.
Mawad et al. [14]	GEFT [19]	– 133 adults; – Gender: 88 F, 45 M – Age: 18-46 (23.3±5.1) – GEFT: 2-18 (m=8.7) – CS: 77 FDs and 56 FIs	Tobii T60 Eye Tracker	Fixation count, duration and ratio	FI consumers had more fixations and spent more time evaluating the food products before choosing one. They sought information more exhaustively than FDs, having greater fixation ratios in specific AOIs, such as the nutrition facts label. FI consumers sustained their attention on the product labels and performed a deeper evaluation of the presented information before choosing a product.
Nevalainen and Sajaniemi [15]	GEFT [19]	– 12 UG students – Gender: 5 F, 7 M – GEFT: 7-18 (14.75±3.22)	n/a	Fixation count and duration	The level of field-independence had an effect on the visual attention and perception which could had an impact on the constructed mental models of the programmers.
Nisiforou and Laghos [16]	HFT [7]	– 16 PhD students – CS: 5 FDs 5 FIs 5FNs	SMI iViewX; BeGaze 3.1	Fixation count; heat maps; scan paths	FDs and FIs followed different visual search strategies in order to identify a given pattern. FD users scanned different points of the given shape, as they could not recognise the hidden figure. On the other hand, FI individuals could easily recognise the hidden shape, and thus their quest was more organised and their fixations more precise.
Nisiforou and Laghos [17]	HFT [7]	– 54 UG/PG students – Age: 18-35 – CS: 24 FDs 14 FIs 16 FNs	SMI iViewX, BeGaze 3.1	Fixation count; saccades count; heat maps; scan paths	FD individuals could not identify the correct shape as they were looking at different areas than the shape of interest and they spent more time in fixating into incorrect shapes. On the other hand, FIs could easily and quickly recognise the simple shape hidden in the complex pattern. The scan paths of the FI revealed a more oriented eye movement behaviour producing less number of fixations and saccades than FDs. FDs generated double fixations than FNs and quadruple fixations than FIs. These findings suggest that FD-I cognitive style affects the eye movement patterns, revealing a more inefficient visual search behaviour as the field dependence level increases.
Nisiforou, Michailidou and Laghos [18]	HFT [7]	– 16 adults – Age: 18-28 – CS: 7 FDs 6 FIs 3 FNs	SMI iViewX; BeGaze 3.1	Scan paths; heat maps; focus maps.	The visual search behaviour depends on the environment complexity. For webpages of low complexity the visual search strategies of FD and FI individuals were similar. However, the scan paths of FD individuals appeared to be more disoriented and scattered on webpages of medium and high complexity, in contrast to FI individuals, who displayed more oriented and organised scan paths.
Raptis et al. [21]	GEFT [19]	– 14 UG/PG students – Gender: 2 F , 12 M – Age: 18-23 (20.5±1.8) – GEFT: 11.7±2.9 – CS: 8 FDs and 6 FIs	Tobii T60 Eye Tracker	Fixation count and duration	FD players observed less times and for shorter time periods the game items, as they followed a more intrinsic approach and were less inclined in detecting details. On the other hand FI players followed a more analytical approach, and they observed the game items more often and for longer time periods.
Shinar [24]	EFT [31]	– 5 UG students; – Gender: 2 F, 3 M	Shinar's et al. built eye-tracking mechanism	Fixation count and duration	FD drivers were more concentrated on their fixations, being less adaptive efficient in changing environment, such as curve negotiating, where the perceptual load is drastically increased and the target area (the road), changes iteratively within their visual field.
Wijnen and Groot [30]	EFT [31] HFT [7]	n/a	EMAS software system	Fixation count and duration; scan paths	FD and FI individuals followed different visual approaches (e.g. scan paths) to solve hidden figure problems. I individuals scanned systematically, for longer time periods at specific sectors, and had a greater overall fixation count. In the contrast, FD individuals scanned unsystematically in an "unarticulated" way with many short fixations nearly all sectors during the two tests.
Yekan and Cagiltay [34]	GEFT [19]	– UG students – GEFT: 14.82±2.87	Tobii Eye-Tracker device	Fixation count and duration	FD individuals had longer fixation duration on hypermedia areas of interest, but no statistically significant differences were revealed.

Table 1: Reviewed eye tracking studies

who displayed a more oriented and organised scan paths. In another study, Nisiforou and Laghos [16] examined the relationship between HFT [7] scores and various eye tracking metrics. Sixteen participants undertook the HFT test, while their eye movements were recorded. The researchers studied the heat maps and scan paths of the two cognitive groups, which differed greatly, and it was revealed that FD and FI individuals follow different visual search strategies in order to identify a given pattern. FD users scanned different points of a given shape, as they could not recognise the hidden figure. On the other hand, FI individuals could easily recognise the hidden shape, and thus their quest was more organised and their fixations more precise. The researchers also found that there is a high correlation between the task performance, in terms of time, and fixations on each given figure, with FD individuals being slower. They also designed an instrument based on the collected eye-tracking data, inspired by HFT, to measure the level of field-independence. The comparison of the findings derived from their tool and HFT declared that the patterns developed using two tools were similar and that there is a correlation between the two tools. However, no further analysis was performed to measure the effectiveness and the reliability of their tool.

In a later study, Nisiforou and Laghos [17] extended their previous study [16] by studying differences in visual search patterns between three cognitive groups: FD, FI and FM individuals. Fifty-four students were engaged in visual exploration tasks, proposed in researchers' previous study [16]. Each time, a complex figure with embedded simple shapes was displayed to each participant, who had to identify which simple figure of a given set was correctly hidden into the complex one.Their analysis was based on the comparison of heat maps and scan paths (qualitative analysis) and the comparison of the fixations and saccades (quantitative analysis). Regarding the heat maps and the scan paths, the eye movement patterns demonstrated that FDs could not identify the correct shape as they were looking at different areas than the area containing the correct simple form. Additionally, they spent more time in fixating into incorrect shapes. On the other hand, FIs could easily and quickly recognise the simple shape hidden in the complex pattern. The scan paths of the FI revealed a more oriented eye movement behaviour producing less number of fixations and saccades than FDs. In particular FDs generated almost double fixations than FNs and quadruple fixations than FIs. These findings suggest that FD-I cognitive style affects the eye movement patterns, revealing a more inefficient visual search behaviour as the field dependence level increases.

Jia et al. [8] investigated the effect of FD-I style on the performance in a visual working memory task. The results showed that FD and FI individuals performed differently, especially in distraction condition. The correct response rates and contralateral delay activity (CDA) amplitudes in 2-item and 2-item-2-distractor conditions were comparable for FI participants. FD participants performed worse, and the CDA amplitude was enhanced when distractors appeared. FIs could focus their attention to cue-pointed objects even through the items had disappeared in the memory stage because they could rely on internal references, while FDs were more likely to scan both the targets and distractors without the cue because they mainly tended to use external references. The study results indicated that FIs could remove irrelevant information more efficiently than FDs.

3. DISCUSSION

In this paper we reviewed 12 studies which use eye tracking tools to investigate the effect of Field Dependent - Independent cognitive style in various application domains, and we provided a summary of them in Table 1. The findings of the studies indicated that eye tracking provides valuable and credible information about the individual cognitive differences in visual perception tasks, including both exploration and search of information. Motivated by the need of designing better models of human performance and behaviour and the importance of understanding cognitive processes at the highest possible level of elaboration, we argue that eye tracking tools could be used as elicitation mechanisms, replacing the tools used today, which are based either on "pen-and-paper" techniques or computerised tests, demanding high amount of resources, such as time, cost, test subjects, etc. The elaboration of eye-tracking techniques provides a more natural environment for the identification of individual cognitive styles, and thus tools based on eye-tracking could be used in order to implicitly classify the individuals based on their cognitive styles, providing them with a personalised experience, both in design and run-time stages. However, only a few attempts have been made towards this direction, such as AdELE [4], EMAS [30] and ET tool [16, 17, 18], but no such framework has been proposed yet. Therefore, further research is required in order to provide an eye tracking implicit classification mechanism of individuals based on their cognitive preferences.

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