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The Relation of Visual-Digital Literacy in User Interaction with Mobile Devices

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Abstract. The rapid pace of technological innovation highlights the issues of users' relation with the digital sphere, and, in regards to graphical interfaces, shows the existence of a Visual-Digital Literacy. This paper proposes as an overall intention to investigate the impact of Visual Literacy in users' access to smartphones. To that effect, we hypothesize that a limited visual repertoire is a direct cause of users' deficiency in Digital Literacy skills. We defined two evaluation techniques: an Iconographic Comprehension Test and an experiment. The convergence of both sought to answer the following research question: how does Visual Literacy relate to users' digital proficiency? First, we applied the Comprehension Test to detect the proper understanding of symbols, i.e., to measure users' ability to interpret visual elements. The test proposed the classification of 48 subjects, ranging from 18 to 65 years old, in two extremes of Visual Literacy. Afterward, using extreme case sampling, we recruited 12 of said subjects to our experiment, seeking to assess the impact that Visual Literacy has on Digital Literacy, while users performed tasks on a smartphone. We used three methods of qualitative and quantitative data analysis to measure users' performance: Student's t-test and Pearson Correlation Coefficient, followed by Retrospective Think Aloud (RTA) protocol. The results showed that Visual Literacy does influence users' performance in the interaction with devices, proving that Digital Literacy relates to people's visual repertoires.

Keywords: Digital Literacy · Visual Literacy · Human-Computer Interaction

1 Introduction

Personal use technologies are everywhere, intertwined in the various aspects of everyday life. Mobile devices such as smartphones have been promoting massive transformations in society, starting from the accomplishment of daily tasks and the socialization between people to the acquisition of knowledge and the attenuation of geographical barriers. Although manifesting through a variety of senses, these technologies highlight the human tendency to visual stimuli, since device screens and their Graphical User Interfaces (GUIs) certify the presence of visual rhetoric [1].

In the digital sphere, visual information acts as active parts of the electronic text interaction process [2], which relies heavily on graphic symbols to inform the user of navigational paths. The user needs to understand the structure of the graphical interface, the meaning of an icon, feedback or other alerts and visual elements. This

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understanding of *visual reading* configures in a Visual Literacy. In this paper, we argue that this form of literacy, a sum of visual repertoires, is a skill inherent to digital users' fluency. Visual repertoires are a set of terms developed historically as parts of the common sense of culture [3]. Considering a mobile device's GUI, these terms, or elements, when interpreted by users, help them in the performance of tasks, and that is when we have the concept of *affordance*. We often use the notion of affordance to describe something that aids a user to do something. Thus, we can understand it as the relation established between an object and an organism that acts on the object.

For this study, we consider it relevant to argue about what constitutes the meaning of a visual element, stipulated through *cognitive affordance* [4]. For the affordance relation to occur, it is necessary that people, either in a designer (author) and user (reader) relationship, or by constructions and conventions within a social sphere, share the attribution of meaning to an object. If in the context of digital technologies the user demands unique visual abilities, therefore, we find it congruent to draw a parallel between Visual Literacy and the concept of Digital Literacy. Several studies on Human-Computer Interaction (HCI) fall within the scope of Digital Literacy, with researchers using cross-disciplinary approaches. In prior research, the conflict of generations in HCI, e.g., was a path deeply paved by the dichotomy of the Native and the Digital Immigrant [5]. Inequality in access to digital devices based on the age gap was also discussed in specific cases concerning the elderly [6] and children [7]. Moreover, other characteristics and social conditions were considered variables that intervene in the relation of users with devices. Amongst them, Verbal Literacy [8] and the different contexts, or cognitive and cultural backgrounds [9].

In short, there is a logical progression of the most fundamental properties of Digital Literacy, which starts from the basic access to devices to the comprehensibility of the paths of interaction through GUIs, for example. In this paper, we chose to relate the phenomenon of Digital Literacy, in the context of mobile devices – since mobile internet usage exceeds desktop worldwide [10] –, with that of Visual Literacy. We work with the hypothesis that a limited visual repertoire is a direct cause of users' deficiency in Digital Literacy skills. Here, we propose as an overall goal to research the impact of Visual Literacy, through the acquisition of repertoires, in the experience of users in accessing mobile devices such as smartphones.

2 Methodology

This descriptive research sought to establish the relationship between the variables Visual Literacy and Digital Literacy. In addition to being descriptive, this study assumes the characteristics of a *quasi*-experiment, considering the impracticability of total control of the sample, or even of the external influences on the dependent variables. This paper presents the analysis of a hypothetic-deductive model, and, in this section, we specify the techniques and procedures applied to the hypothesis testing. To understand how Digital Literacy relates to Visual Literacy, the convergence of two techniques was necessary. The first, called the Iconographic Comprehension Test, sought to evaluate how subjects interpret visual elements, more specifically icons, of graphical interfaces. With the results of the Comprehension Test, we evaluated the performance of our research subjects in an experiment.

2.1 Iconographic Comprehension Test

The Comprehension Test aims to detect the correct understanding of symbols, being an indispensable procedure in the development of images for public information [11]. Here, however, our goal was to measure the visual repertoire levels of subjects rather than the variants of a particular referent, as is usually the case. Thus, we chose not to spend the same rigidity of the tests of the genre, despite following the basic rules of application of this technique for the data collection and analysis. We developed this test plan to cover the following specific objectives: to measure the correctness and errors of the research subjects as to the meaning of commonly used icons; and to classify such individuals into two extremes of Visual Literacy. At one end, we expected to find the participants with high visual repertoire, and in another, those with a more limited repertoire. This segmentation, known as extreme or deviant case sampling, would be crucial to the recruitment of subjects for our experiment.

Participant Characteristics. To evaluate the levels of Visual Literacy, we stipulated some criteria for the selection of the participants. First, everyone should be smartphone users, since the subsequent experiment would occur by using that sort of device. Also, the subjects should either have or be pursuing a degree in higher education, so that very different degrees of schooling would not interfere in the control of the sample and, consequently, in the final results of the study. Self-selection bias is a well-documented research challenge, and, although we sought to balance the number of subjects in a total of approximately 40, distributed in a balanced way between male and female subjects and among six age groups, we do not claim that our sample accurately represents the whole population. We chose an estimated number of participants to guarantee a minimum population for a statistical treatment of the data.

Method (Test Design). The test consisted of presenting 40 images of digital icons for each test participant. Tests of this nature require around three to six variants for each referent [11], however, in the survey we chose to work only with icons commonly used in digital technologies, more specifically those present on operating systems for desktop computers of two popular platforms, Apple and Microsoft. For this reason, we selected only two variants for each referent, one representative of each platform. We chose Mac OS (from Apple) and Windows (from Microsoft) as our operating systems for icons selection since these are the most used platforms worldwide [12].

Icons Selection. For selecting the icons, we decided on a pre-selection of variants from 1984 to 2005 – due to the first operating systems of Apple, from 1984, and Microsoft, from 1985. The last variants observed were present in Windows XP (from 2001) and Mac OS X 10.4 Tiger (from 2005). The final year determined in this pre-selection is because the following versions of both systems were only released in 2007, when equivalent smartphone software began to circulate, influencing the visual repertoires of individuals. We had several icon referents fit for selection, but they were not all in balanced amounts between Apple and Microsoft's systems. Therefore, we chose only

20 of them, present on both platforms, as we matched each of the referents to two icons, tallying 40 icons. We based our choice of one icon variant per referent and platform according to the following Pre-Selection Method [11]: from each referent, we select the disparate graphic elements and, among them, those with better legibility.

Procedure. Before each icon, participants should conjecture as to the affordances of the element presented, i.e., indicate the icon's path of interaction when touched in a finger-operated UI or by a mouse cursor. As a result, we evaluated subjects' performance for visual comprehensibility; assigned them a score and then rated them about their inferred Visual Literacy. We sought to segregate the subjects' sample into two control groups: the participants with above average scores and those with below average scores. For this analysis, we scored the answers as *hits*, counting 2 points; *near hits*, 1 point; *errors*; and no answer, both without punctuation (no point, or zero). The maximum possible score achieved by each subject was 80 points. We computed the data in a spreadsheet in Microsoft Office Excel 2016 software, and we made five pilots for adjustments before conducting the test sessions.

Test Results – Selecting the Experiment Participants. We applied the Iconographic Comprehension Test remotely, via an online questionnaire, as a recruitment process to the experiment participants. We evaluated the visual repertoires of 48 subjects, being 24 male and 24 female, from six different age groups, ranging from 18 to 65 years old and above. Everyone claimed to be smartphone users and have or be pursuing a higher education degree in any field.

We selected the experiment participants based on the test scores. To do so, we performed a statistical analysis using a histogram and the Kolmogorov-Smirnov test (K–S), a test designed to assess normality, i.e., to verify the normal distribution of our histogram data. The result of this test showed normality distribution, allowing, therefore, parametric statistical inferences. After statistical analysis, we were able to highlight the extremes[1] of our sample. The subjects grouped at the ends of the sample were those that, from the mean, are at a standard deviation below or above. To facilitate the mention of these two groups in the course of this paper, we have chosen to name them as participants with *low* and *high visual comprehensibility*.

We identified 11 participants with low performance and 7 with high. For our experiment, we expected to evaluate the performance of 24 participants, among pilots, regulars, and backups. The decision to recruit backup participants started from the need to ensure that at the end of the study, approximately 14 of these subjects' performance were feasible for analysis. From 14, half should be ones with low visual comprehensibility and half with high. We defined this number since only seven subjects fit the high-comprehensibility group, and the final analysis would require two symmetric samples. To confirm the validity of the backups, we applied Student t-tests, which allowed determining which subjects outside our deviant sample we could consider, within a 95% confidence interval, as with values within the limits of one of the two

[1] By extremes, we mean the limits that are at or above standard deviation. They equate to the inflection point of a Normal [15].

extremities (low or high). Thus, we verified the existence of three potential backups for the low-comprehensibility group and nine for the high.

2.2 Experiment

We elaborated the plan of our experiment based on a format similar to that of a Usability Test [14], to collect empirical data on participants' behaviors and to continue the confirmation or refutation of our hypothesis. The purpose of this experiment was to explore how individuals use their respective visual repertoires in interacting with graphical user interfaces. To that effect, we targeted on evaluating only subjects' from our extreme case sampling (low or high-comprehensibility) while performing tasks on a smartphone. The confluence of the Iconographic Comprehension Test with the experiment resulted in the following questions:

- Do the different (deviant) visual repertoires interfere with tasks completion rates?
- Do the different (deviant) visual repertoires interfere with the number of touch-screen gestures during task performance?
- Do the different (deviant) visual repertoires interfere with how users navigate the interface and use shortcuts?

Method (Experiment Design). The experiment had as its essential goal to express the relations between two phenomena, in this case, Visual and Digital Literacy. Therefore, we work with some variables, being: the score of the participants in the Iconographic Comprehension Test, as an independent variable; and the task completion rates, the number of touchscreen gestures and users' overall interaction strategies – through qualitative analysis – as dependent variables. We decided to conduct the experiment sessions with the aid of an Eye-Tracking device since the use of this technology provides the monitoring of the subjects' visual attention. The experiment consisted of five tasks, presented to participants in a Nokia Lumia 820 smartphone with a Windows Phone operating system. The decision to work with this particular operating system was because it is a platform of low popularity in the market, in contrast to the Android and iOS devices [12]. For this reason, when performing the tasks using the Nokia Lumia 820 smartphone, the possibility of the users having prior knowledge of the system interface would be smaller, not influencing the experiment results. However, to ensure control of this variable, we asked the participants about any experience with Windows Phone devices and discarded participants whose response was positive.

Procedure. We gave the participants a summary of all crucial points of the survey – including purpose, type of data collected and procedures – and asked them to sign a term expressing Free, Prior and Informed Consent (FPIC). Due to the use of the Eye-Tracking device, we found necessary to have two moderators in the experiment room, one lead moderator, and one technical moderator. We defined as an introductory stage to explain the role of these moderators, as well as to point out and describe the equipment (see Fig. 1 – *left*); the participant's expected conduct; and the processes for performing the tasks, which we presented in the same order to all of the subjects. We compiled the experiment task list and presented the explanatory text of each task through the OneNote application. The five tasks were: (1) Add contact number;

(2) Disable mobile data; (3) Set a screen lock; (4) Save calendar appointment; and (5) Change system font size. As with the Iconographic Comprehension Test, we conducted pilots to determine the validity of our experiment's design. We recorded all sessions in both video and audio during the execution of the tasks, and audio only at the time of the RTA.

Regarding the smartphone device used, a Nokia Lumia 820, we made interface adaptations to the home screen (see Fig. 1 – *right*). The Windows Phone operating system has a UI based on Microsoft's "Metro" design project, whose home screen is made of live tiles. These dynamic tiles work as shortcuts, and can be added, rearranged or even removed by users. For this experiment, we chose to place all the shortcuts arranged on the initial screen to observe how the participants reacted to the visual organization of the tiles and its icons. The arrangement of the home screen shortcuts was the same for all subjects. Still, participants could have access to the features of the device in any way, at their discretion, and not only by selecting the icons of the home screen.

Fig. 1. *Left:* Experiment room equipped with a notebook, an external microphone, and the Tobii Pro X2–60 screen-based eye tracker. *Right:* Reordering of the Nokia Lumia 820 home screen shortcuts. We purposely enlarged the OneNote application icon to make it easier to access the tasks list.

Data Collection Methods and Analysis. To analyze our collected data, we considered necessary to manipulate the levels of the independent variable – the score of the participants in the Iconographic Comprehension Test – and to observe the result produced on the dependent variables. These variables were the users' performance in the experiment, as well as the interaction strategies in the course of the tasks. Performance data is based on user action metrics. We selected two metrics of a primarily quantitative nature and a qualitative one. Once we statistically validated the answers, we expected to crosscheck these data with the qualitative data obtained through the verbal protocol. Defining measurable issues was crucial for the data analysis planning since we needed to guarantee necessary conditions for inferring a causal relationship.

Task completion. As a criterion of analysis, we made use of the binary (or base-2) system, in which the participant received a score of zero, in case of failure in the completeness of the task, or one, if the subject completed it successfully. To determine completion, we instruct participants to announce during the session as soon as they believe they have reached the goal of the task. In a dropout situation, the subject would receive the score concerning the failure to completeness.

Touchscreen Gestures Count. Regarding touchscreen counting, we performed the convergence data analysis between the Iconographic Comprehension Test and the experiment following a mixed factorial model [15], which includes both between and within-subjects variables. To validate if there is the influence of the independent variable (Comprehension Test scoring) on the dependent (number of screen touches), we performed a Student's t parametric hypothesis test, with α of 5%[2]. With Student's t, we glimpsed to see if there was a statistically significant difference between the performances of the participants of the two groups analyzed within the experiment.

After verifying the existence of influence among the variables, we would apply another test to infer the intensity of this influence at a level of linear correlation. To do so, we used Pearson's Correlation Coefficient – or just Pearson's ρ – as a parameter, also between the Comprehension Test scores and the touchscreen gestures count. However, unlike what occurred in Student's t-test, this analysis was within-subjects, meaning we compared the results of each subject individually, not as a group. Pearson's Correlation Coefficient measures the degree of correlation (and the direction of this correlation, whether positive or negative) between two metric scale variables [16]. We based the test on the hypothesis that there should be at least a moderate to a strong correlation between the variables ($\pm$<0.5).

Retrospective Think Aloud (RTA). Through the verbal protocol RTA, we sought to collect the qualitative material for analysis, complemented by the support of the eye-tracking device. We instructed the participants to perform the tasks without communicating with the moderator. Only at the end of the session, we requested the participants to explain the reasoning behind their actions. We used RTA with eye tracking so participants could provide context for their actions while observing video data collected by the eye tracker.

3 Results

We were able to experiment with 12 participants, six of low-comprehensibility and six of high. Among these 12, one from each group fits into the definition of a backup. We recruited them since some of the regular participants in our pre-selection were unable to attend the laboratory or did not respond to the invitation to schedule the session. We based our conclusions on the Visual-Digital Literacy relation on the empirical data collected in the experiment. In this, we observed the effect that the score on the Iconographic Comprehension Test produced on the performance of our subjects in the accomplishment of tasks.

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[2] Alpha (α) is the percentage or margin of error accepted by the test and is equal to a 95% confidence interval.

Regarding task completion, we segregated the data by task, from one to five, and by subjects' sample, from low or high-comprehensibility. In comparing performance, low-comprehensibility subjects had less success in completing tasks (see Fig. 2).

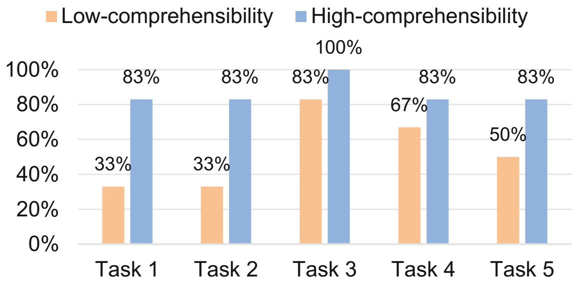

Fig. 2. Task completion rates between low and high visual comprehensibility subjects.

3.1 Student's t-Test and Pearson's Correlation Coefficient

Regarding the number of touchscreen gestures, the data crossing sought to validate if the first test scoring influences on the touchscreen gestures count. We verified that the test statistic exceeds the critical value, which rejects Student's t-test. By rejecting the null hypothesis, we can conclude that populations with low and high visual comprehensibility have statistically different averages; with the mean number of touchscreen gestures being higher for the low-comprehensibility population. This analysis, therefore, corroborates with the hypothesis of our paper, which points to the better overall performance of the subjects with a greater visual repertoire. Then, we calculated Pearson's Correlation Coefficient to measure the intensity of the independent variable's influence on the dependent variable. First, we had to deal with one outlier in our sampling, subject *P48*. In statistics, an outlier is an element in a data set that lies an abnormal distance from other values. Failure to detect these atypical values may lead to a compromised interpretation of test results. The analysis should reflect the majority of the data and not be influenced by points outside the curve [13].

The subject *P48* stood out among the low-comprehensibility subjects for not completing any of the five tasks proposed. Because he/she gave up after only a very few attempts, the participant also registered a low number of screen touches, which would mistakenly make him/her appear as a high-comprehensibility subject. Because it is a within-subject analysis, Pearson's ρ does not require a symmetric sample. Therefore, we chose to exclude *P48* from our sample since we considered it an outlier.

Regarding Pearson's Correlation, we found our sample coefficient (ρ) to indicate a moderate inverse correlation ($-0.7 > \rho < -0.5$). When the coefficient is negative, with the line declining downward, it means that one variable tends to increase as the other decreases. With this analysis, we attested that the higher the score of participants in the Comprehension Test, the smaller the number of touchscreen gestures in the experiment (see Fig. 3).

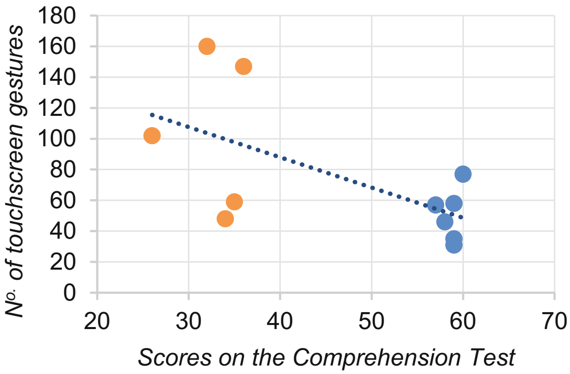

Fig. 3. Moderate-level inverse correlation: on the scatter plot we see that the number of touchscreen gestures in the experiment (Y) tends to decrease as the scores on the Comprehension Test (X) increase.

3.2 Retrospective Think Aloud (RTA)

During the RTA procedure, all 12 participants reported an initial shock with the Windows Phone System's GUI, with the six low-comprehensibility subjects having more resistance in establishing interaction strategies with the new interface. About *Task 1* ("Add contact number"), four of the five high-comprehensibility subjects who achieved task completion did so without major obstacles, except for some delay in finding navigation shortcuts on the home screen. Among the icons most searched by these participants were the ones that represented the notion of *address book*, *people* or *phone*. According to the subjects, the established search strategy was to make associations with the graphical representations presented on their Android or iOS devices.

In *Task 2* ("Disable mobile data"), four out of six low-comprehensibility participants failed completeness, with two stating to not knowing how to disable internet access on their own devices. Subject *P15*, e.g., explained that the internet is something that he/she uses "without realizing it". On that, he/she said, "If you ask me which signal is this (indicating a sign related to the mobile data) and why I'm using it, I do not know. I have no technical knowledge of the thing [sic]. I go on trying". Participants shared this sort of view throughout the sessions. Both low and high-comprehensibility people have justified many of their failures to the fact that they do not stop to reflect on how and why they perform certain actions on their own devices.

Of the 12 subjects of the experiment, only one, *P48*, was unable to complete *Task 3* ("Set a screen lock"). This participant was an outlier, as previously discussed. *Task 4* ("Save calendar appointment") had a good completion rate between both groups of participants. Only three of the 12 subjects failed task completion, two in the low-comprehensibility group and one in the high. At last, in *Task 5* ("Change system font size"), participants had to interact primarily with verbal texts in the settings menu. In the high-comprehensibility group, failure occurred only for one participant, who even went to *Settings*, but was distracted because "it had a lot of text". After exploring a few menu links, he/she gave up on finishing the task. Other participants voiced about the presence of much text in the interface by explaining: "When there is a lot of textual information, we have to stop and check everything up".

In the course of the sessions, it was tangible the greater ease of interaction of the users of high visual comprehensibility, a quality that resulted in better identification of shortcuts and icons; understanding the device features; in being straightforward while completing tasks. Low-comprehensibility subjects on many occasions seemed to explore the interface with little to no criteria, as one explained that if he/she had a whole day to accomplish the task, he/she would eventually do it: "I would end up accessing a link, one by one". On the other hand, the high-comprehensibility people were more likely to make associations and to evoke images from their repertoires.

4 Conclusion

In summary, by converging the two techniques applied in this study, we reached the goal of drawing an association between Visual and Digital Literacy. We also proved the influence of a high visual repertoire on the interaction of users with digital devices, particularly mobile devices. The experiment reinforced the validity of the deductions we raised, proving that there is a linear correlation between Visual and Digital Literacy. In an overview, high visual comprehensibility subjects obtained a higher degree of task completion and performed tasks with fewer touchscreen gestures, which indicates a more efficient performance. Although exposed to a different system than they were accustomed to, high-comprehensibility subjects were more successful in identifying pathways in navigation through shortcuts and icons, a behavior disparate to that of most low-comprehensibility people. In addition, we noticed that the low-comprehensibility subjects preferred to navigate through verbal texts, while the high-comprehensibility ones stated to be more inclined to graphical information.

With this paper, we advocate that research on Digital Literacy should be conducted with the purpose of promoting greater inclusion of people in the globalized world. For this, we find relevant to consider people with verbal communication challenges as well, as it happens with functional illiteracy and illiteracy in the strict sense. After all, when verifying the influence of Visual Literacy in the interaction of users with digital devices, it is valid to investigate if merely visual interfaces would be able to soften the barriers between illiterate people and technology. Finally, the techniques applied in this study also led to important learning. We chose to adapt the Comprehension Test, used in Informational Ergonomics, and the experiment, recurring in the fields of Ergonomics and Human-Computer Interaction. Here, instead of evaluating interface elements, we applied the techniques in the measurement of the performance of the research subjects. This applicability has proved to be successful in answering the questions of the research and could apply in future studies of the genre.

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