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Eye-tracking for IS Research: A Literature Review

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Completed Research

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ABSTRACT

In this literature review, we describe the Information Systems (IS) research using eye-tracking. Based on a sample of 60 papers published since 2008 in journals and conference proceedings, we examine i) what is the trend in eye-tracking IS research, ii) what types of experimental design have been used, iii) what types of metrics have been collected and iv) what constructs and topics have been investigated. We found that IS research using eye-tracking is broad in its research themes but concentrated in its methods of analysis. All the research is quantitative and mostly use fixation counts on computer desktop. A limited number of articles take advantage of pupil dilation measure or mobile eye-tracking. We call for broadening the methods of collection and analysis in eye-tracking IS research.

Keywords

Literature review, eye-tracking, neuroIS.

INTRODUCTION

Eye-trackers are nowadays affordable and accessible tools that continuously measure the eye position and movement with high temporal precision using an unobtrusive method based on the reflection of the cornea (Duchowski, 2007; Etco et al., 2017). Eye-trackers have been used in Information Systems (IS) research to measure what people attend to during human-computer interaction, and they are one of the many tools that the Neuro-Information-Systems (NeuroIS) field uses in order to collect unobtrusively neurophysiological data on participants (Riedl & Léger, 2016). It is the only NeuroIS method used by both scientists and practitioners and with a fast decreasing cost, we expect its usage to grow in the IS research.

Eye-tracking represents 31.5% of the NeuroIS research in the last decade (Rield et al., Forthcoming). Call for research to use eye-tracking in IS is now over a decade old and it is important to review to what extent and for what purpose it has been used so far.

We build on Riedl et al. (Forthcoming) review of NeuroIS research by specifically examining eye-tracking research. The goal of this research is to describe the state of the field over the past decade by answering the following research questions (RQs):

RQ1: What is the trend of publication in information systems using eye-tracking technology?
RQ2: What experimental designs are used when doing eye-tracking research?
RQ3: What types of eye-tracking metrics have been used to assess eye-tracking results?
RQ4: What constructs are investigated with eye-tracking?

METHODOLOGY

Search process

The 63 papers using eye-tracking from the initial sample in Riedl et al. (Forthcoming) were considered for inclusion in this review.

Inclusion and exclusion criteria

From this initial sample, we selected only full empirical studies that collected eye-tracking data. One article was a proposal with no data collection, one article was not IS related, and one article was developing a technology related to eye-tracking but did not collect eye-tracking data. Our final sample was composed of 60 publications and conference proceedings.

Data collection

We collected general information on the articles such as authors, year, title, publication type, and name of journal or conference proceedings. Then, each article was coded for multiple dimensions. We extracted the topic of each paper, the number of participants, the type of experimental design, the independent and dependent variables, and the eye-tracking metrics used. The full list of articles included in this review is available on demand.

RESULTS

RQ1: What is the trend of publication in Information Systems using eye-tracking technology?

In total, we analyzed 60 articles, 42 journal publications, and 18 conference papers. Figure 1 shows the evolution of the number of articles within conference proceedings or journals over the years.

There is a growing trend of eye-tracking based research. The number of articles published in both conference proceedings and journals went from an average of 3.3 articles per year in the 2008 - 2013 period to an average of

9.75 in the 2014 - 2017 period (2018 excluded because the database search stopped in February). Eye-tracking appears to be more and more accepted as a useful and valid method of choice for IS research. We start to observe publications using eye-tracking in high ranking journals such as MIS Quarterly (2 papers) or Information Systems Research (1 paper). Computer in Human Behavior seems the most fruitful avenue for researchers willing to publish eye-tracking studies (17 papers), and the Hawaii International Conference on System Sciences offers an excellent opportunity to present that type of research (6 conference proceedings).

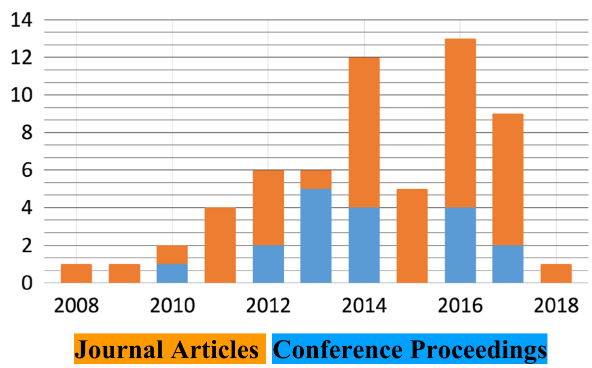

Figure 1. Repartition of eye-tracking based IS research per type and year.

RQ2: What experimental designs are used when doing eye-tracking research?

This question is investigating the type of experimental design, and the number of participants per eye-tracking study. Each selected article was coded as a within, between or mixed study (Table 1).

Within	Each participant is going through all the conditions. Statistical analyses are using repeated-measures.
Between	Participants are assigned randomly to specific conditions. Statistical analyses are conducted as between-subject.
Mixed	Statistical analyses are done between and within-groups.

Table 1. Definition of the experimental design codes

We also collected data on the number of participants per study. When an article conducted multiple studies, the average of participants for all studies was reported. Figure 2 shows the distribution of participant number by design type, and Table 2 shows the major descriptive statistics.

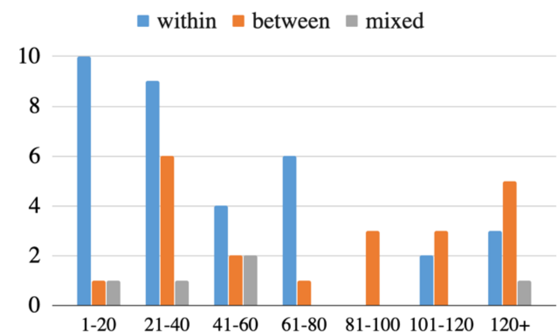

Figure 2. Distribution of the number of participants per study by experimental design type

As with most research, within-subject designs require fewer participants, which explains why accepted papers using this type of design have a much lower average number of participants (Table 2). It is also relevant to use this type of design for neurophysiological studies in order to control for individual differences (Riedl & Léger, 2016).

Another interesting point is that there is a significant standard deviation (average 43.87) in the number of participants per study. This could be a sign that early studies were not sure about the number of participants required to be published in IS outlets. We observe that a large number of studies using within-subject experimental design has less than 20 participants, while between-subject experimental design has between 20 and 40. These results are in line with guidelines from other NeuroIS tools, where the average number of participants is 31 (Riedl et al., Forthcoming).

Design	Average	Min	Max	St. Dev.	Median
Between	94.5	14.5	451	90.7	90
Mixed	63.6	16	156	54.6	54
Within	50.1	5	197	43.9	38
All	66.8	5	451	67.1	47

Table 2. Number of research participants per design type

RQ3: What types of metrics have been used to assess eye-tracking results?

Eye-tracking data can be aggregated to provide the density of eye fixation for a group of participants during a particular time window in the form of heat maps (See Figure 3). Seventeen articles provided heat maps as an illustration of findings but never used them to test hypotheses.

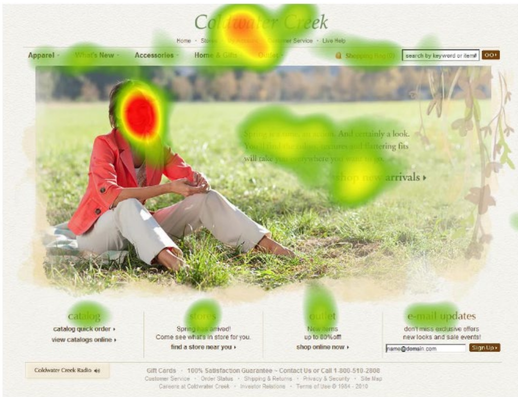

Figure 3. Heat map from one of the selected papers, reproduced from Djamasbi et al., 2014

Indeed, all articles studied are using quantitative eye-tracking features to compare and contrast results. In this paper, we report on the use of eye-tracking measures in IS research (Table 3). It is also possible to create more complex metrics from these simple measures such as frequency of fixation on a specific location, or duration of first fixation, etc. However, to provide a clear picture of IS research, we report on the primary measures below.

Fixation	Moments when the eyes are relatively stationary, taking in information (Rayner, 1998)
Fixation Count	The number of fixations that the participant was gazing at the area of interest.
Fixation Duration	Duration of the fixation on the specific AOIs or the whole screen.
Fixation Sequence	Using both spatial and temporal information to construct a view of how the fixations switch between AOIs.
Time to fixation	The time before a fixation was recorded on the screen or on a specific AOI.
Pupil Dilation	Size of the pupil.

Table 3. Definition of eye-tracking primary metrics

The articles selected usually report more than one measure (average 2.7; st.dev 1.2). FC and FD are the most commonly used measures, they appear respectively in 38 (63%) and 41 (68%) of the 60 selected articles, see Table 4. FS is used in 7 articles. The sequence is typically used to calculate deviation from areas of interest or the consistency of the viewing patterns. TTF is used in 11 articles (18%) and is helping researchers identify the moment when the users looked at their area of interest. This metric can be used on its own for statistical analysis, or to retrieve information from other tools at the exact time an element was observed by the participant (such as automatic facial analysis or other physiological measures). PD has been used in 8 articles (13%) as an indicator of the cognitive load or arousal of participants.

	FC	FD	TTF	PD	FS
Num.	38	41	11	8	7
Percent.	63.3%	68.3%	18.3%	13.3%	11.7%

Table 4. Metrics used in IS research using eye-trackers

Figure 4 shows the percentage of each metric used in IS research over the years. FC and FD have been consistently used over the years, while PD and FS seem to be more recent, except for the study in 2008 that only used pupil dilation, no other study made use of that metric until 2012 and then 2015.

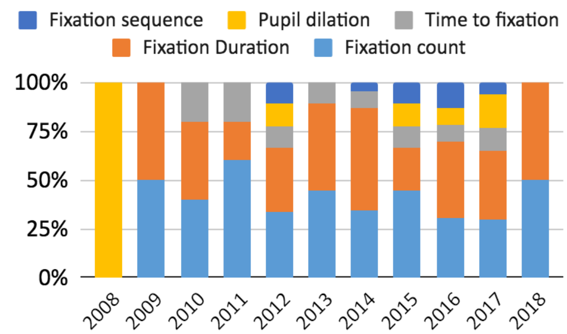

Figure 4. Percentage of metrics used in eye-tracking IS research, per year.

RQ4: What constructs are investigated with eye-tracking?

Eye-tracking has been used in IS research to accomplish a variety of objectives. In this section, we are interested to see whether eye-tracking has been used as an independent variable (IV) or a dependent variable (DV). The majority (80%) of papers uses eye-tracking measures as a DV, and only 16.7% as an IV (Figure 5). Only one empirical article from our sample (Yang & Lin 2014) use eye-tracking as a mediator and one (Fehrenbacher, 2017) use eye-tracking as a triangulation tool by identifying the time of fixation of an element to then analyze face-reading measures rather than eye-tracking ones.

Eye-tracking measures as an independent variable

When eye-tracking measures have been used as IVs, they have been used to predict correctness (3 papers); visual appeal (2 papers); task type (1 paper); performance (1 paper); redundancy (1 paper); willingness to share (1 paper); and user opinion (1 paper) (see Figure 5). It is interesting to point out that only FD and FC have been used as IVs, and that the measures have been discussed directly without being attributed to specific constructs.

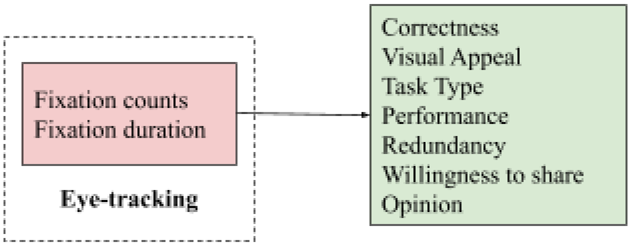

Figure 5. Eye-tracking as an independent variable

Eye-tracking measures as a dependent variable

In contrast, when eye-tracking measures are used as DVs, they are often used as a proxy for other constructs in addition to being used directly in the hypotheses as raw data (14 papers). We regrouped each eye-tracking related construct studied under categories related to the task (15), individual characteristics (5), patterns (6) or pupil dilation (8) related mental states.

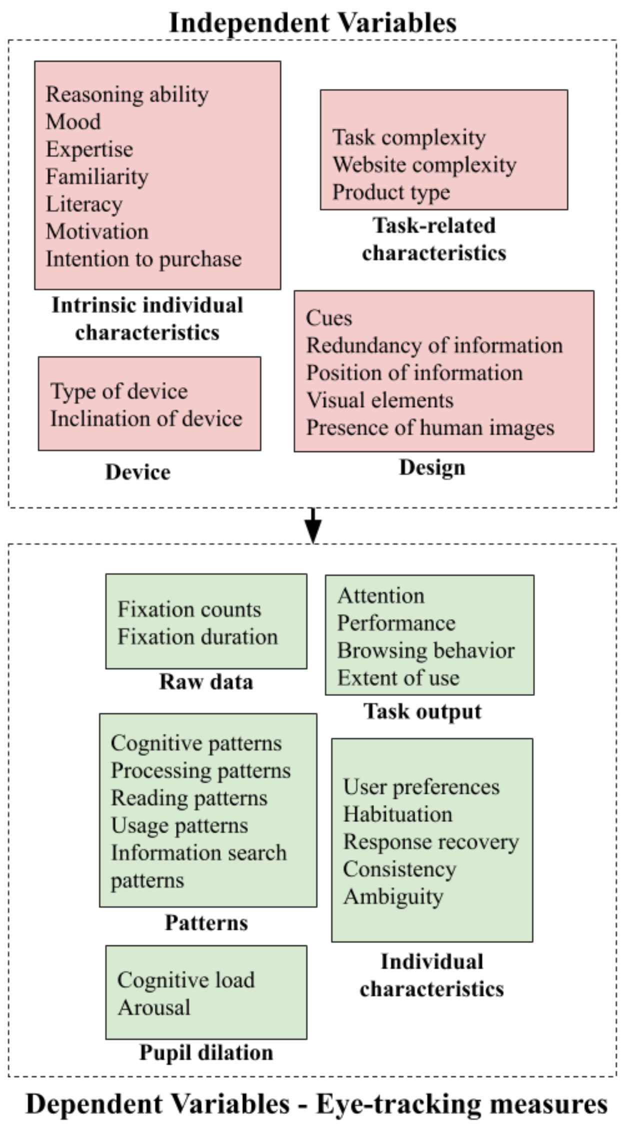

Figure 7. Eye-tracking as a dependent variable

In addition, we classified the IVs studied in relationship with eye-tracking measures and found that research was divided into four main categories related to design of visual features (17 papers), device features (2), individual characteristics (14) and task-related features (15). Table 5 shows these relationships, and figure 6 displays the list of constructs and their categories.

Dependent variables	**Independent variables**				
	Design	Device	Individual	Task	**Total**
Individual	2		2	1	**5**
Patterns	1	1	2	2	**6**
Pupil	1		2	5	**8**
Raw	8		3	3	**14**
Task	5	1	5	4	**15**
Total	**17**	**2**	**14**	**15**	**48**

Table 4. Relationships explored with eye-tracking

DISCUSSION

IS research has focused on answering three main types of questions with eye-tracking: (1) What and when are individuals looking at specific areas of interest? (2) Is there consistency in the patterns in which individuals are completing specific tasks? (3) What is the cognitive load of the individual? This was possible by using the primary measures described in the review (FC, FD, FS, TTF, PD). However, there are other types of metrics that are available to the researchers using eye-trackers. Other fields of research have developed and used transitional matrices (Chuk et al., 2014; Sharafi et al., 2015) to identify the probability to switch from an area of interest to the next. It is also possible to measure the number and duration of saccades which correlates with the mental workload and provides information on the visual effort (Fritz et al., 2014). It would be interesting to see the IS field make use of such metrics to answer research questions that have not been able to be asked with the current practices in IS. Using transitional matrices, we could look at which elements are driving users to switch from an area of interest to the next. Chuk et al. (2014) also developed a classifier in cognitive psychology to automatically create areas of interest from the eye movement of participants. All the research in IS that is using areas of interest is using predefined values arbitrarily chosen. By applying the same type of classifiers, we can automatically extract areas of interest that are data-driven and representative of users' behaviors.

Conclusion 1: IS research using eye-tracking does not take advantage of more advanced analysis techniques used in engineering or cognitive psychology and is limiting itself to basic measures.

In our review, we found only one article who used eye-tracking in conjunction with other signals in order to collect face-reading information at the specific time an AOI was seen. However, the real value of eye-tracking is to be used in conjunction with other signals such as EEG and other physiological measures (Courtemanche et al., 2018; Léger et al., 2014).

Conclusion 2: IS research could gain insights from taking advantage of synchronization and triangulation of eye-tracking measures with other signals.

As we have illustrated, eye-tracking has been used to tackle a large variety of research questions, both as an IVs and DVs. However, 97% of eye-tracking research has been done on desktop computers. The role of the device is largely understudied. Only two studies in our sample are looking at how the device impact eye-movement patterns and task completion. With the growing use of mobile technology and its impact on individuals and organisations, it is essential to start to take advantage of eye-tracking to expand its use beyond desktop computers.

Conclusion 3: Eye-tracking IS research has focused on desktop computers and lack coverage on mobile devices.

8 out of the 48 articles are looking at how design choices (visual, speed of animation, and type of menus) impact FC and FD. This is the most often studied relationship and shows that the power of eye-tracking measures is still yet not harnessed in the IS field. This type of questions has been asked on for many years in the industry to inform User Experience designers. It is crucial that IS research move beyond and explore higher-level relationships between not only eye-tracking measures, but the constructs they represent such as cognitive load, or even personality traits (Hoppe et al., 2018).

Conclusion 4: The IS community has not harnessed the full power of eye-tracking measures and would benefit from studying higher-level constructs.

CONCLUSION

This literature review has examined a sample of 60 papers in IS research using eye-tracking measures in order to provide a descriptive representation of current research and identify areas of improvement. Most of the research has focused on desktop computers and was interested in using eye-tracking as a dependent variable rather than as a predictor of behavior. The areas studied with eye-tracking is large and representative of the multidisciplinary aspect of the IS field. However, the methods of analysis are concentrated and lack diversity. The IS field would benefit from getting inspired by other fields, such as cognitive psychology and engineering.

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