Low–Cost Eye–Trackers: Useful for Information Systems Research?*

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Abstract. Research investigating cognitive aspects of information systems is often dependent on detail–rich data. Eye–trackers promise to provide respective data, but the associated costs are often beyond the researchers' budget. Recently, eye–trackers have entered the market that promise eye–tracking support at a reasonable price. In this work, we explore whether such eye–trackers are of use for information systems research and explore the accuracy of a low–cost eye–tracker (Gazepoint GP3) in an empirical study. The results show that Gazepoint GP3 is well suited for respective research, given that experimental material acknowledges the limits of the eye–tracker. To foster replication and comparison of results, all data, experimental material as well as the source code developed for this study are made available online.

Key words: Eye–tracking, eye movement analysis, accuracy of fixations

1 Introduction

To facilitate the development of information systems, numerous modeling languages, –methods and –tools have been devised over the last decades [1]. Thereby, researchers found that not only the technical perspective—such as correctness and expressiveness—are central requirements, but also the human perspective needs to be taken into account. For instance, in the field of business process management, researchers found that a good understanding of a process model has a measurable impact on the success of a modeling initiative [2]. Likewise, business process vendors and practitioners ranked the usage of process models for understanding business processes as a core benefit [3].

To support humans in their interaction with artifacts created during the development of information systems, e.g., models or source code, various research methods have been followed. For instance, researchers analyzed communication protocols gathered in modeling workshops [4], sought to adapt theories from cognitive psychology [5], investigated think aloud protocols [6] or adopted techniques from eye movement analysis for assessing the comprehension of business process models [7]. In this work, we focus on the role of eye movement analysis, as we think that the adoption of eye movement analysis is still below its

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full potential. In particular, it seems plausible that the costs of eye tracking infrastructure poses a considerable burden for the adoption of eye movement analysis [8].[1] To counteract this problem, efforts have been undertaken for developing eye–trackers at a low price by assembling off–the–shelf components, e.g., [9]. However, it is questionable in how far researchers who are not deeply involved in the peculiarities of assembling hardware are able to set up such an infrastructure on their own. Rather, we see a big potential in low–cost ready–to–use eye–trackers that have entered the market, seeking to compete with the high–priced versions.[2] Particularly in times of shortened research budgets, respective cost–efficient infrastructure seems indispensable.

In this sense, the research question investigated in this study can be defined, as follows: *Are low–cost eye–trackers useful for information systems research? If yes, which limitations apply?* To approach this research question, we bought *Gazepoint GP3*[3] and employed it in an empirical study for assessing its accuracy. Likewise, the contribution of this work is threefold: First, we report on the accuracy of Gazepoint GP3 with respect to the detection of fixations. Second, we use respective data for describing how experimental material, e.g., models, source code or tools, should be designed so that acceptable error rates can be expected. Third, we provide the source code used for this study, thereby providing an infrastructure for evaluating Gazepoint GP3 in different settings. Likewise, the remainder of this paper is structured, as follows. Section 2 introduces background information on eye–tracking. Then, Section 3 describes the experimental design of this study, whereas results are described in Section 4. Finally, Section 5 discusses related work and Section 6 concludes with a summary and an outlook.

2 Eye Movement Analysis

Before describing the experimental design followed in this study, we briefly introduce basic concepts related to eye movement analysis (for a more detailed introduction, see e.g., [10]). The fundamental idea of eye movement analysis is capturing the position a person is currently focusing on. To this end, usually the *pupil center corneal reflection method* [11] is adopted, in which the center of the pupil is computed by assessing the corneal reflection (Purkinje reflection) through infrared light. Thereby, either remote systems (i.e., video and infrared cameras that are affixed to a table) or head–mounted systems (i.e., devices that are fixed on the person's head) are employed [12]. However, only capturing the position a person is looking at is not enough, as it is known that high–resolution visual information input can only occur during so–called *fixations*, i.e., when the person fixates the area of interest on the fovea, the central point of highest visual

[1] High–precision eye–trackers can cost more than several ten–thousand US$, see: `http://www.arringtonresearch.com/prices.html` (accessed February 2014).

[2] For instance: `http://theeyetribe.com/`, `http://gazept.com/`, `http://mygaze.com/` (accessed February 2014)

[3] `http://gazept.com/products/` (accessed February 2014)

acuity [13]. These fixations can be detected when the velocity of eye movements is below a certain threshold for a pre-defined duration [14]. Using eye fixations, we can identify areas on the screen the person is focusing attention on [15], e.g., features of the modeling environment or modeling constructs. Due to the central role of fixation for processing visual information, we focus on the accuracy of fixation detection in the following.

3 Experimental Design

The goal of this empirical investigation is to determine whether low–cost eye–trackers provide enough accuracy to be of use for information systems research. As discussed in Section 2, fixations are of central interest, hence next we describe the experimental design followed for investigating the accuracy of fixations.

Experimental Procedure The procedure followed in this experimental design consists of 5 steps. First, the subject is informed about potential risks involved in participating in the experiment and that all data is collected anonymously. Second, the eye tracker is calibrated by a 9–point calibration, as provided by the Gazepoint GP3 API. Third, the first visual task is presented to the subject, which basically asks the subject to look at specific points at the screen (details are provided in Paragraph *Visual Tasks*). Fourth, as it may be the case that the subject was not entirely focused on the visual task, the task is repeated once more. Finally, each experimental session is concluded by administering a survey about demographical information. To enable replication, the entire experimental material and data is freely available.[4]

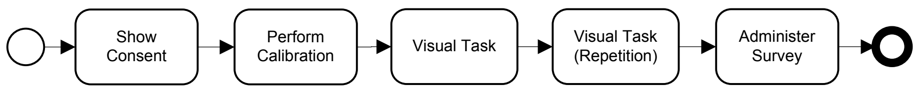

Fig. 1. Experimental design

Visual Tasks The visual tasks administered in this study were designed for measuring accuracy, i.e., computing the difference between the position on the screen the subject looked and the fixations the eye tracker computed. To this end, subjects are asked to look at a specific position for a given time interval. To ensure that subjects were indeed looking at this specific point, we asked to press a key as soon as the subject fixated on the point. As it is then known where the subject looked, fixations can be compared with this position. Technically, we implemented a Java component, which displays a configurable list of points according to the following procedure:

[4] The experimental material and data are available at: `http://bpm.q-e.at/eye-tracking-accuracy`

1. Fill the screen with white color
2. For each point in the configured lists of points
   a) Draw solid black point on the screen (10 * 10 pixel) at given position
   b) Wait until user presses arbitrary key
   c) Capture the moment when the user presses the key
   d) Wait for 500 ms
   e) Fill the screen with white color

Using this mechanism, we configured 9 points, equally distributed on a grid on the screen. Since the employed eye–tracker is not able to track points outside the screen, we avoided points near the ending of the screen, i.e., the grid started at point (0.25 * width, 0.25 * height) and ended at point (0.75 * width, 0.75 * height). Apparently, subjects require time to locate and fixate on the current point. Hence, we only captured data between the moment when the subject pressed the key and the next 500 ms. The duration in which fixations are collected for analysis, i.e., 500 ms, is a trade–off between the amount of data points that can be collected and the quality of the data. In a longer time window more data can be collected, but at the same time it becomes likelier that the subject gets distracted, and vice versa. The eye–tracker's cameras operate at 60 Hz, likewise 60 points are recorded per second. Thus, 500 ms, resulting in approximately 30 data points per subject seem to be an acceptable trade–off.

Subjects The population under examination in this study were all persons that may participate in eye–tracking research. The tasks involved in this experimental design does not require special training, rather basic reading skills are sufficient. However, during the preparation of the software displaying the visual tasks, we observed that the eye–tracker could not properly handle the reflections of glasses (no complications could be observed for persons wearing contact lenses). Hence, we exclude persons wearing glasses from our experimental setup.

Experimental Setup For performing the eye movement analysis, a table mounted eye tracker, i.e., Gazepoint GP3, was used, recording eye movements at a frequency of 60 Hz. The visual tasks were performed on a 20" monitor with a resolution of 1600 * 1200 pixels and a dimension of 40 cm * 30 cm. In addition, we attached a second monitor, on which the eye–tracking software was running, allowing to monitor whether subjects were within the area accessible to the eye–tracker's cameras. The second monitor was positioned away from the main monitor, allowing the subject to fully concentrate on the visual tasks. The subject was seated comfortably in front of the screen in a distance of approximately 65cm (as recommended by the eye–tracker's manual). To minimize undesired fluctuations regarding light, we closed blinds of the office windows.

Response Variable The interest of this study is to examine the accuracy of an eye–tracker with respect to the detection of fixations. Hence, the response variable of this study is the distance between the point the subject was supposed to look at and the corresponding fixations measured by the eye–tracker, subsequently referred to as *error*. As described in Paragraph *Visual Tasks*, we stored the moment when the subject pressed any key and showed the point for another 500 ms; only data points collected during this time window are used for analysis. For all of the data points falling into this time frame, in turn, the error is computed as the Euclidean distance between the measured fixation and the point displayed. Furthermore, data points are only taken into account when considered to be a valid fixation according to the eye–tracker's internal fixation filter.

Instrumentation and Data Collection To allow for an efficient collection and analysis of data, we implemented the experimental procedure shown in Fig. 1 as an experimental workflow in Cheetah Experimental Platform (CEP) [16]. In other words, each activity from the experimental procedure was supported by a Java component, which in turn was executed in the order prescribed by the experimental procedure. Thereby, CEP provided ready–to–use components for displaying a consent dialog and administering a survey, whereas eye–tracking related components had to be implemented.

4 Results and Discussion

So far we described the experimental design adopted in this study. In the following, we focus on the execution of the empirical study in Section 4.1, discuss implications in Section 4.2, and present its limitations in Section 4.3. We would like to repeat at this point that all data collected is available on–line.[5]

4.1 Experimental Execution

In the following, we describe the preparation of the experiment, before we turn to the execution of the experiment and subsequently present the collected data.

Experimental Preparation Preparation for this empirical study included acquiring the eye–tracker, implementing components accessing the eye–tracker's API, configuring the experimental procedure in CEP and acquiring subjects. Since our experimental procedure does not involve any particular skills besides reading, we relied on a convenience sample, i.e., we acquired friends and co–workers at the Department of Computer Science at the University of Innsbruck. As described in Section 3, none of the persons wore glasses during the experiment. However, we included subjects that wore glasses in daily life, but were able to read texts without glasses (these subjects participated without glasses).

Experimental Execution The eye–tracking sessions were performed in February 2014 at the University of Innsbruck, where 16 subjects participated. However, for one subject the eye–tracker had problems identifying the subject's pupils, so we decided to exclude the data from analysis, leaving 15 data sets for analysis. Due

[5] All data collected in this study is available at: `http://bpm.q-e.at/eye-tracking-accuracy`

to the nature of eye–tracking, only one subject could participate at a time. In this way, each subject could be welcomed, introduced to the experimental procedure and guided through the eye–tracking session. To reward and motivate subjects, a plot showing all fixations was produced immediately *after* each session, allowing subjects to see how well they performed.

Data Validation To assess whether the collected data is valid, we plotted the results of each visual task for each subject and inspected the plots for abnormalities. Interestingly, the analysis revealed that for certain subjects the fixations of the visual task that was intended as familiarization were more accurate than for the second visual task. Knowing that subjects usually need a little training to get acquainted with tasks, these results seemed implausible. However, a discussion revealed that certain subjects had remembered where the next dot would appear and did not fully concentrate on the current point, but already moved on to the next point. To compensate for this shortcoming, we compared the results for the first and the second visual task and selected the task showing the *lower median* of error values. We argue that this procedure is acceptable, since it can be assumed that the eye–tracker's accuracy is stable for the *same* task and *same* subject. In other words, fluctuations can be rather attributed to subject–related factors, e.g., familiarization with the task or the discussed anticipation of points, hence selecting the visual task with lowest errors will probably result in selecting the visual task with the least influence of subject–related factors.

Results Next, we describe the data obtained in this study from three perspectives. First, we look into demographical statistics, second, turn to error quantiles and, third, discuss the results of one subject. A summary of demographical data can be found in Table 1. Subjects were on average 30.67 years old ($SD = 3.27$) and 33.3% female. None of the subjects reported eye diseases or wore glasses. However, 5 subjects used contact lenses during the experiment.

Variable	**Data**
Age	Min: 26, Max: 41, M: 30.67, SD: 3.27
Gender	Female: 5 (33.3%), Male: 10 (66.7%)
Eye diseases	0 (0%)
Glasses during experiment	0 (0%)
Contact lenses during experiment	5 (33.3%)

Table 1. Demographical data

To give an overview of the collected fixations, we have summarized the error occurred during calibration (ε_{calib}), quantiles describing the error distributions (Q_{95} to Q_{80}) as well as the median of errors. In particular, as shown in Table 2, the average error measured during calibration was 45.20 pixel and quantiles range from 116.38 (Q_{95}) to 58.00 (Q_{80}); the median of errors was 32.20 pixel. All in all, 4,122 fixations were captured, of which 3,869 were considered to be valid according to the eye–tracker's fixation filter. Furthermore, it can be observed that fixations seem to be rather homogeneous—a box plot of median values only detected S_8 and S_{13} as outliers.

Subject	ε_{calib}	Q_{95}	Q_{90}	Q_{85}	Q_{80}	**Median**
S_1	47.14	59.91	47.30	37.64	31.32	21.00
S_2	62.59	66.22	62.77	59.48	50.45	30.27
S_3	53.19	92.46	87.86	68.18	65.37	44.91
S_4	28.86	46.10	37.95	34.79	32.70	17.03
S_5	43.96	103.62	97.51	58.18	52.35	27.29
S_6	49.67	43.42	38.12	31.40	29.83	19.72
S_7	38.24	96.13	73.82	71.69	70.26	27.78
S_8	74.56	180.50	166.21	146.01	128.23	56.63
S_9	37.74	86.76	84.91	51.43	48.26	34.07
S_{10}	47.74	86.59	66.94	61.55	57.01	34.46
S_{11}	43.23	121.25	117.69	67.78	66.48	33.94
S_{12}	43.48	88.20	76.55	71.87	65.51	33.62
S_{13}	42.85	181.11	178.02	173.00	152.27	116.87
S_{14}	24.02	51.88	50.25	48.26	47.10	35.18
S_{15}	40.65	43.57	41.76	40.31	38.28	21.93
Total	45.20	116.38	84.96	66.73	58.00	32.20

Table 2. Results for fixations (in pixel)

So far, we have discussed the error distributions measured in pixel. To give an impression what these errors mean with respect to screen size, we have listed the error in mm in Table 3. As described in Section 3, the eye–tracking sessions were performed on a screen with an extent of 1600 * 1200 pixel and a screen size of 40 * 30 cm, i.e., 4 pixels were displayed per mm. In other words, values listed in Table 3 were computed by dividing the pixel–values from Table 2 by factor 4.

For visualizing how these ranges of errors relate to a screen of 1600 * 1200 pixel, we have selected the fixations for a subject with approximately average errors, i.e., subject S_3, and visualized the results in Fig. 2. In particular, the box to the left represents the screen with the 9 points at which S_3 was asked to look at. The green dots, in turn, represent the fixations as obtained through the eye–tracker. To the right, we have selected three regions to show patterns we could observe in the data. Mostly, as shown in the square at top right, fixations were measured in a rather small region, which does not necessarily directly overlap with the point the subject was supposedly looking. Also, as shown in the square in the middle right, fixations may have also been scattered over a larger region. This behavior could particularly be observed for subjects with large errors, e.g., subject S_8. Finally, as shown in the square bottom right, fixations for almost the same location were reported. However, the fixations were not necessarily directly at the location the subject was supposedly looking. We do not want to

Subject	ε_{calib}	Q_{95}	Q_{90}	Q_{85}	Q_{80}	Median
S_1	11.78	14.98	11.82	9.41	7.83	5.25
S_2	15.65	16.55	15.69	14.87	12.61	7.57
S_3	13.30	23.11	21.97	17.05	16.34	11.23
S_4	7.22	11.52	9.49	8.70	8.17	4.26
S_5	10.99	25.90	24.38	14.55	13.09	6.82
S_6	12.42	10.85	9.53	7.85	7.46	4.93
S_7	9.56	24.03	18.46	17.92	17.57	6.95
S_8	18.64	45.12	41.55	36.50	32.06	14.16
S_9	9.44	21.69	21.23	12.86	12.06	8.52
S_{10}	11.94	21.65	16.74	15.39	14.25	8.62
S_{11}	10.81	30.31	29.42	16.94	16.62	8.49
S_{12}	10.87	22.05	19.14	17.97	16.38	8.40
S_{13}	10.71	45.28	44.50	43.25	38.07	29.22
S_{14}	6.00	12.97	12.56	12.06	11.77	8.79
S_{15}	10.16	10.89	10.44	10.08	9.57	5.48
Total	11.30	29.10	21.24	16.68	14.50	8.05

Table 3. Results for fixations (in mm)

speculate here about potential reasons for these results, but rather give some visually accessible perspective on the data.

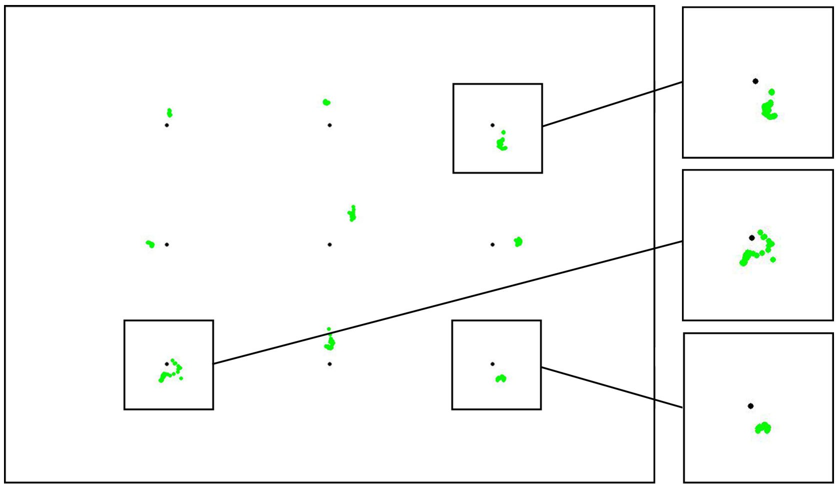

Fig. 2. Fixations measured for subject S_3

4.2 Discussion

So far we described the data, next we discuss implications with respect to the adoption of low–cost eye–trackers. Basically, certain criteria must be fulfilled so that Gazepoint GP3 can be used in a meaningful way.[6] As described in Section 3, we could not manage to get the eye–tracker working for subjects wearing glasses, since reflections of the glasses were confused with reflections of the eyeball. Also, subjects with small eyes caused significant troubles in identifying pupils. Interestingly, also particularly glossy hair caused problems—in fact, for one subject it was only possible to conduct the session after the subject covered the hair. In addition, direct sunlight complicated the identification of fixations. However, as all of these problems could be identified and resolved during calibration, they presumably did not influence the results of this study. Regarding the accuracy promised by the vendor, the manual specifies an accuracy of 0.5° to 1° *of visual angle*. Assuming that the line of sight, error and screen form a right angle, an error of 1° results approximately in an error of 1.05 cm, or 42 pixels (tan(1) * 60 cm $\approx$ 1.05 cm). These promises are in line with our findings: As shown in Table 3, the median error for fixations was 8.05 mm.

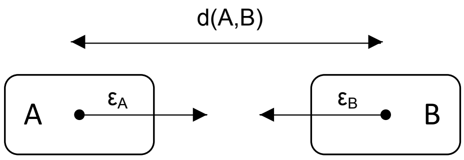

Fig. 3. Distinguishing objects

To finally answer the research question approached in this work, i.e., whether low–cost eye–trackers are useful for information systems research, we discuss whether these accuracies are good enough for identifying where subjects looked. For this purpose, consider the illustration in Fig. 3, showing two objects (A and B) that should be identified in a study, e.g., activities in business process models, source code snippets or parts of a user interface. In particular, the figure shows objects A and B, the distance between the center of A and the center of B ($d(A, B)$) as well as the errors involved in measuring fixations for the position of A (ε_A) and the position of B (ε_B). Conservatively assuming that errors are always directed toward the opposite object, fixations can only be unambiguously assigned to an object if the distance between the objects is smaller than the sum of error, i.e., $d(A, B) < \varepsilon_A + \varepsilon_B$. As listed in Table 2, the median error was 32.20 pixel, i.e., if the difference between 2 objects is less than 64.40, the objects cannot be distinguished anymore. Likewise, when increasing the distance between objects, the probability of properly identifying objects increases. Whether these distances can be achieved in a meaningful way then depends on the specific research question. On the one hand, for instance, studies that investigate reading source code respective distances between source code characters seems infeasible. On the other hand, for instance, when evaluating, the user adoption of recommendations (e.g., [17]), respective distances in a

[6] We are not aware of any published studies utilizing this particular device.

user interface can easily be achieved. Hence, depending on the specific research question, the accuracy of Gazepoint GP3 may or may not be sufficient.

4.3 Limitations

As in every empirical study, the results have to be seen in the light of several limitations. First, the question arises in how for results can be generalized to the population under examination, i.e., all persons that potentially participate in eye–tracking studies. Since only data of 15 subjects was used for analysis, results need to be generalized with care. Similarly, subjects were of rather young age, i.e., on average 30.67 years old, hence it is not clear whether results also apply to older persons. Second, it must be acknowledged that the performance of the visual tasks depends on whether subjects were indeed looking at the points they were asked to focus on. For instance, subjects remarked that they knew where the next point would appear, making it difficult to focus on the current point. By selecting the task with higher accuracy, we sought to compensate for this issue. Third, results are applicable only to Gazepoint GP3 and cannot be generalized to other eye–tracking devices as produced by other vendors. Finally, we tried to provide similar settings for all subjects, e.g., same tasks, instructions and monitor size. However, we could not fully control all external influences, such as light. Also, we would like to emphasize that it is out of the scope of this contribution to compare these results with high–end eye–trackers.

5 Related Work

In this work, we focused on eye–tracking in information systems research, seeing eye–trackers from the perspective of users. However, also on the developers' side vivid research activities can be observed, e.g., investigating the feasibility of self–built eye–tracking systems [9], developing support for eye–tracking on mobile devices [18] and designing new algorithms for the detection of eye movements [19]. However, these works rather focus on the development of new methods and applications than on evaluation the feasibility, as done in this work. Regarding the use of eye–tracking, applications in a variety of domains can be observed. For instance, experiments have been conducted for investigating the understandability of UML models [20] and the interpretation of data models [21]. Similarly, a research agenda for investigating user satisfaction has been proposed in [22]. Other works employed eye–tracking for investigating process model comprehension [7] or for inspecting the way how modelers create process models [23]. However, all these works focus on the direct application of eye movement analysis rather than seeking to examine its usefulness, as done in this work. Even though we focus on eye–tracking, it is clearly not the only promising approach for investigating cognitive aspects in information systems. For instance, think aloud protocols, i.e., the thoughts subjects uttered during an empirical study, may be used to get insights into the cognitive processes involved in working with information systems artifacts [6, 24]. Also, researchers have sought to transfer theoretical concepts from other domains, e.g., cognitive psychology, for advancing information systems research [25, 26] and to conduct controlled experiments, e.g., [27, 28]. It is important to stress that these approaches should be not seen as competing. Rather, best results can be expected by combining two or more paradigms, i.e., through method triangulation [29].

6 Summary and Conclusion

In this work, we set out to examine the accuracy of a low–cost eye–tracker regarding the detection of fixations. In an empirical study, we asked participants to look at specific positions at the screen and recorded the computed fixations. The analysis of errors showed that the median error lies well within the accuracy promised by the vendor. In a next step, we discussed the implications of these findings with respect to the development of experimental material, showing that the eye–tracker is well suited—given that elements at the screen are placed in proper distance. Thus, we conclude that if certain preconditions are fulfilled, e.g., not wearing glasses, appropriate light and covering glossy objects, Gazepoint GP3 appears to be a suitable choice for affordable eye–tracking studies.

Particularly for research that focuses on cognitive aspects, multiple perspectives as well as detail–rich data is indispensable. By providing data about the eye–tracker's accuracy, respective recommendations for developing experimental material and making available the source code involved in this study, we hope to help spreading and establishing eye–tracking for information systems research in general and research on cognitive aspects in particular. Regarding our research, we seek to employ the findings of this study for developing algorithms that automatically detect the modeling element a process modeler is looking at. With respective support, the cognitive processes involved in creating process models could then be investigated in an even more efficient and detailed manner.

References

1. Mylopoulos, J.: Information modeling in the time of the revolution. Information Systems **23** (1998) 127–155
2. Kock, N., Verville, J., Danesh-Pajou, A., DeLuca, D.: Communication flow orientation in business process modeling and its effect on redesign success: results from a field study. DSS **46** (2009) 562–575
3. Indulska, M., Green, P., Recker, J., Rosemann, M.: Business Process Modeling: Perceived Benefits. In: Proc. ER'09. (2009) 458–471
4. Hadar, I.: When intuition and logic clash: The case of the object-oriented paradigm. Science of Computer Programming **78** (2013) 1407–1426
5. Zugal, S.: Applying Cognitive Psychology for Improving the Creation, Understanding and Maintenance of Business Process Models. PhD thesis, University of Innsbruck, Department of Computer Science (2013)
6. Haisjackl, C., Zugal, S., Soffer, P., Hadar, I., Reichert, M., Pinggera, J., Weber, B.: Making Sense of Declarative Process Models: Common Strategies and Typical Pitfalls. In: Proc. BPMDS '13. (2013) 2–17
7. Petrusel, R., Mendling, J.: Eye-tracking the factors of process model comprehension tasks. In: Proc. CAiSE'13. (2013) 224–239
8. Hennessey, C., Duchowski, A.T.: An open source eye-gaze interface: expanding the adoption of eye-gaze in everyday applications. In: Proc. ETRA'10. (2010) 81–84

9. Li, D., Babcock, J., Parkhurst, D.J.: openEyes: a low-cost head-mounted eye-tracking solution. In: Proc. ETRA'12. (2006) 95–100
10. Duchowski, A.: Eye Tracking Methodology. Springer (2007)
11. Ohno, T., Mukawa, N., Yoshikawa, A.: Freegaze: A gaze tracking system for everyday gaze interaction. In: Proc. ETRA'02. (2002) 125–132
12. Rauthmann, J.F., Seubert, C.T., Sachse, P., Furtner, M.: Eyes as windows to the soul: Gazing behavior is related to personality. Journal of Research in Personality **46** (2012) 147–156
13. Posner, M.I.: Attention in cognitive neuroscience. In: The cognitive neurosciences. MIT Press (1995) 615–624
14. Jacob, R.J.K., Karn, K.S.: Eye Tracking in Human-Computer Interaction and Usability Research: Ready to Deliver the Promises. In: The mind's eye. Cognitive and applied aspects of eye movement research. Elsevier (2003) 573–603
15. Furtner, M., Sachse, P.: The psychology of eye-hand coordination in human computer interaction. In: Proc. HCI'08. (2008) 144–149
16. Pinggera, J., Zugal, S., Weber, B.: Investigating the Process of Process Modeling with Cheetah Experimental Platform. In: Proc. ER-POIS'10. (2010) 13–18
17. Zangerle, E., Gassler, W., Specht, G.: Recommending#-Tags in Twitter. In: Proc. SASWeb'11. (2011) 67–78
18. Dybdal, M.L., Agustin, J.S., Hansen, J.P.: Gaze Input for Mobile Devices by Dwell and Gestures. In: Proc. ETRA'12. (2012) 225–228
19. Vidal, M., Bulling, A., Gellersen, H.: Detection of Smooth Pursuits Using Eye Movement Shape Features. In: Proc. ETRA'12. (2012) 177–180
20. Cepeda Porras, G., Guéhéneuc, Y.G.: An empirical study on the efficiency of different design pattern representations in uml class diagrams. Empirical Software Engineering **15** (2010) 493–522
21. Nordbotten, J.C., Crosby, M.E.: The effect of graphic style on data model interpretation. Information Systems Journal **9** (1999) 139–155
22. Hogrebe, F., Gehrke, N., Nüttgens, M.: Eye Tracking Experiments in Business Process Modeling: Agenda Setting and Proof of Concept. In: Proc. EMISA'11. (2011) 183–188
23. Pinggera, J., Furtner, M., Martini, M., Sachse, P., Reiter, K., Zugal, S., Weber, B.: Investigating the Process of Process Modeling with Eye Movement Analysis. In: Proc. ER-BPM'12. (2013) 438–450
24. Seeber, I., Maier, R., Weber, B.: Macrocognition in Collaboration: Analyzing Processes of Team Knowledge Building with CoPrA. Group Decision and Negotiation **22** (2013) 915–942
25. Zugal, S., Pinggera, J., Reijers, H., Reichert, M., Weber, B.: Making the Case for Measuring Mental Effort. In: Proc. EESSMod'12. (2012) 37–42
26. Zugal, S., Pinggera, J., Weber, B.: Assessing Process Models with Cognitive Psychology. In: Proc. EMISA '11. (2011) 177–182
27. Pinggera, J., Zugal, S., Weber, B., Fahland, D., Weidlich, M., Mendling, J., Reijers, H.: How the Structuring of Domain Knowledge Can Help Casual Process Modelers. In: Proc. ER'10. (2010) 231–237
28. Claes, J., Vanderfeesten, I., Reijers, H., Pinggera, J., Weidlich, M., Zugal, S., Fahland, D., Weber, B., Mendling, J., Poels, G.: Tying Process Model Quality to the Modeling Process: The Impact of Structuring, Movement and Speed. In: Proc. BPM'12. (2012) 33–48
29. Jick, T.D.: Mixing Qualitative and Quantitative Methods: Triangulation in Action. Administrative Science Quarterly **24** (1979) 602–611