A Systematic Literature Review on Code Comprehension using Eye Tracking Cameras

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Summary of the Review Studies

ID	Base	Authors	Study	RQ	Type	Publication venues	Year
13	ACM	Begel, and Vrzakova	Eye Movements in Code Review	1 ● 2 ◑ 3 ●	Empirical	EMIS	2018
44	GS	Chandrika and Amudha	A fuzzy inference system to recommend skills for source code review using eye movement data	1 ● 2 ◑ 3 ○	Empirical	Journal of Intelligent & Fuzzy Systems	2018
27	IEEE	Fakhoury, S. et al.	The Effect of Poor Source Code Lexicon and Readability on Developers' Cognitive Load	1 ● 2 ● 3 ●	Empirical	ICPC	2018
2	GS	Nagaraj, S.	Enabling Eye Tracking to Study the Use of Software Artifacts on Code Summarization	1 ● 2 ○ 3 ○	Empirical	Doctoral dissertation	2018
4	ACM	Obaidellah et al.	A Survey on the Usage of Eye-Tracking in Computer Programming	1 ● 2 ◑ 3 ○	Literature Review	ACM Computing Surveys	2018
74	GS	Wrobel, M.	Applicability of Emotion Recognition and Induction Methods to	1 ● 2 ● 3 ○	Empirical	Applied Sciences	2018

			Study the Behavior of Programmers				
9	GS	Abid et al.	Using developer eye movements to externalize the mental model used in code summarization tasks	1 ● 2 ◑ 3 ○	Empirical	ACM Symposium on Eye Tracking Research & Applications (ETRA)	2019a
43	GS	Abid et al.	Developer Reading Behavior While Summarizing Java Methods: Size and Context Matters	1 ● 2 ◑ 3 ○	Empirical	ICSE	2019b
1	ACM	Blascheck, T. e Sharif, B.	Visually Analyzing Eye Movements on Natural Language Texts and Source Code Snippets	1 ● 2 ◑ 3 ○	Empirical	ETRA	2019
124	GS	Choma et al.	An Empirical Study of Test-Driven Development vs. Test-Last Development using Eye Tracking	1 ● 2 ◑ 3 ○	Empirical	Agile Methods: 10th Brazilian Workshop	2019
9	IEEE	Couceiro et al.	Spotting problematic code lines using nonintrusive programmers' biofeedback	1 ● 2 ◑ 3 ○	Empirical	ISSRE	2019a

2	IEEE	Couceiro et al.	Pupillography as indicator of programmers' mental effort and cognitive overload	1 ● 2 ◑ 3 ○	Empirical	International Conference on Dependable Systems and Networks (DSN)	2019b
95	GS	Hauser, F. et al.	EYE MOVEMENTS IN SOFTWARE MODELLING – WHAT DO THEY TELL US ABOUT HEURISTICS	1 ● 2 ○ 3 ○	Empirical	ICERI2019 proceedings	2019
60	GS	Ishida, T., & Uwano, H.	Synchronized Analysis of Eye Movement and EEG during Program Comprehension	1 ● 2 ● 3 ○	Empirical	International Workshop on Eye Movements in Programming (EMIP)	2019
11	GS	Kaplan	THE ROLE OF EXPERTISE ON CODE REVIEW FOR SECURITY: AN EYE TRACKING STUDY	1 ● 2 ○ 3 ○	Empirical	Master's thesis	2019
34	GS	Nyqvist and Rutqvist	The Impact of Colour Themes on Code Readability	1 ● 2 ○ 3 ◑	Empirical	-	2019
48	GS	Saddler, J.	Looks Can Mean Achieving: Understanding Eye Gaze Patterns of Proficiency in Code Comprehension	1 ● 2 ○ 3 ○	Empirical	ACM Symposium on Eye Tracking Research & Applications (ETRA)	2019

142	GS	Shakil et al.	CodeGazer: Making Code Navigation Easy and Natural with Gaze Input	1 ● 2 ○ 3 ○	Empirical	CHI Conference on Human Factors in Computing Systems	2019
177	GS	Vrzakova, H.	MACHINE LEARNING METHODS IN INTERACTION INFERENCE FROM GAZ	1 ● 2 ● 3 ○	Empirical	Doctoral dissertation	2019
24	IEEE	Zhang et al.	Exploring Eye Tracking Data on Source Code via Dual Space Analysis	1 ● 2 ◑ 3 ◑	Empirical	VISSOFT	2019
3	GS	Chandrika et al.	Identification and Classification of Expertise Using Eye Gaze—Industrial Use Case Study with Software Engineers	1 ● 2 ○ 3 ○	Empirical	ICCIS	2020
14	ACM	De Oliveira, B. et al.	Atoms of Confusion: The Eyes Do Not Lie	1 ● 2 ◑ 3 ●	Empirical	SBES	2020
10	ACM	Dias et al.	Evaluating a Visual Approach for Understanding JavaScript Source Code	1 ● 2 ◑ 3 ○	Empirical	ICPC	2020
115	GS	Eiroa-Lledo et al.	Do Experienced Programmers put too Much Confidence in Comments?	1 ● 2 ○ 3 ○	Empirical	International conference on software engineering & knowledge engineering	2020

93	GS	Fakhoury et al.	Measuring the impact of lexical and structural inconsistencies on developers' cognitive load during bug localization	1 ● 2 ● 3 ◑	Empirical	Empirical Software Engineering	2020
163	GS	Gralha et al.	Are there gender differences when interacting with social goal models?	1 ● 2 ● 3 ○	Empirical	Empirical Software Engineering	2020
7	GS	Ioannou et al.	Mining reading patterns from eye-tracking data: method and demonstration	1 ● 2 ◑ 3 ○	Empirical	Software and Systems Modeling	2020
15	IEEE	Saddler et al.	Studying Developer Reading Behavior on Stack Overflow during API Summarization Tasks	1 ● 2 ◑ 3 ○	Empirical	International Conference on Software Analysis, Evolution and Reengineering (SANER)	2020
20	GS	Sharafi, Z. et al.	A practical guide on conducting eye tracking studies in software engineering	1 ● 2 ◑ 3 ◑	Literature Review	Empirical Software Engineering	2020
105	GS	Ahrens and Schneider	Improving Requirements Specification Use by Transferring Attention with Eye Tracking Data	1 ● 2 ○ 3 ○	Empirical	Information and Software Technology	2021

13	GS	Aljehane et al.	Determining Differences in Reading Behavior Between Experts and Novices by Investigating Eye Movement on Source Code Constructs During a Bug Fixing Task	1 ● 2 ○ 3 ○	Empirical	ACM Symposium on Eye Tracking Research and Applications	2021
8	GS	Bryant, C.	ITRACE: AN INFRASTRUCTURE TO SUPPORT EYE-TRACKING STUDIES IN INTEGRATED DEVELOPMENT ENVIRONMENTS	1 ● 2 ○ 3 ○	Theoretical	Doctoral dissertation	2021
2	Sprin-ger	Da Costa et al.	Evaluating refactorings for disciplining ifdef annotations: An eye tracking study with novices.	1 ● 2 ◑ 3 ●	Empirical	Empirical Software Engineering	2021
16	IEEE	Hijazi et al.	iReview: an Intelligent Code Review Evaluation Tool using Biofeedback	1 ● 2 ● 3 ○	Empirical	ISSRE	2021
119	GS	Huang, Y.	Understanding User Cognition: From Spatial Ability to Code Writing and Review	1 ● 2 ● 3 ○	Empirical	Doctoral dissertation	2021

4	GS	Jessup et al.	Using Eye-Tracking Data to Compare Differences in Code Comprehension and Code Perceptions between Expert and Novice Programmers	1 ● 2 ○ 3 ○	Empirical	-	2021
17	ACM	Kather et al.	Through (Tracking) Their Eyes: Abstraction and Complexity in Program Comprehension	1 ● 2 ◑ 3 ◑	Empirical	ACM Transactions on Computing Education	2021
24	GS	Katona, J.	Analyse the Readability of LINQ Code using an Eye-Tracking-based Evaluation	1 ● 2 ○ 3 ◑	Empirical	Acta Polytechnica Hungarica	2021
110	GS	Matzen et al.	Effects of Precise and Imprecise Value-Set Analysis (VSA) Information on Manual Code Analysis	1 ● 2 ◑ 3 ◑	Empirical	SAND2021	2021
15	ACM	Sharafi et al.	Toward an Objective Measure of Developers' Cognitive Activities	1 ● 2 ● 3 ○	Empirical	ACM Transactions on Software Engineering and Methodology	2021
18	ACM	Weber et al.	A Closer Look at Machine Learning Code	1 ● 2 ◑ 3 ◑	Empirical	Conference on Human Factors in Computing Systems	2021

29	GS	Abbad-Andaloussi et al.	Estimating Developers' Cognitive Load at a Fine-grained Level Using Eye-tracking Measures	1 ● 2 ◑ 3 ○	Empirical	ICPC	2022
61	GS	Aljehane, S.	EYE MOVEMENTS CHARACTERIZING FOR THE ASSESSMENT OF EXPERTISE IN SOURCE CODE READING	1 ● 2 ○ 3 ○	Empirical	Doctoral dissertation	2022
18	IEEE	Hijazi et al.	Quality Evaluation of Modern Code Reviews Through Intelligent Biometric Program Comprehension	1 ● 2 ● 3 ○	Empirical	IEEE Transactions on Software Engineering	2022
152	GS	Lindberg	Exposing novice programmers to an expert's eye-gaze	1 ● 2 ◑ 3 ○	Empirical	Master's thesis	2022
37	GS	Mondal et al.	Measuring code comprehension effort using code reading pattern	1 ● 2 ◑ 3 ○	Empirical	-	2022
33	GS	Paltenghi et al.	EXTRACTING MEANINGFUL ATTENTION ON SOURCE CODE: AN EMPIRICAL STUDY OF DEVELOPER AND NEURAL MODEL CODE	1 ● 2 ◑ 3 ◑	Empirical	arXiv preprint	2022

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8	ACM	Peitek et al.	Correlates of Programmer Efficacy and Their Link to Experience: A Combined EEG and Eye-Tracking Study	1 ● 2 ● 3 ◑	Empirical	ESEC/FSE	2022
94	GS	Rezaei Sepasi, E.	Analyzing comprehension of models of variable software systems with eye-tracking technologies	1 ● 2 ◑ 3 ○	Empirical	Doctoral dissertation	2022
21	IEEE	Sharafi et al.	Eyes on Code: A Study on Developers' Code Navigation Strategies	1 ● 2 ○ 3 ○	Empirical	IEEE TRANSAC TIONS ON SOFTWAR E ENGINEER ING	2022
101	GS	Sorg et al.	Towards a Fine-grained Analysis of Cognitive Load During Program Comprehension	1 ● 2 ○ 3 ○	Empirical	IEEE International Conference on Software Analysis, Evolution and Reengineeri ng (SANER)	2022
16	ACM	Aljehane et al.	Studying Developer Eye Movements to Measure Cognitive Workload and Visual Effort for Expertise Assessment	1 ● 2 ◑ 3 ○	Empirical	ETRA	2023

1 (ESE)	ACM	Da Costa et al.	Seeing confusion through a new lens: on the impact of atoms of confusion on novices' code comprehension	1 ● 2 ◑ 3 ●	Empirical	Empirical Software Engineering	2023
5	ACM	Homann et al.	An Eye Tracking Study on MISRA C Coding Guidelines	1 ● 2 ◑ 3 ◑	Empirical	ECSEE	2023
10	GS	Park et al.	An eye tracking study assessing the impact of background styling in code editors on novice programmers' code understanding	1 ● 2 ◑ 3 ◑	Empirical	ACM Conference on International Computing Education Research	2023

References

Abbad-Andaloussi, A., Sorg, T., and Weber, B. (2022). Estimating developers' cognitive load at a fine-grained level using eye-tracking measures. In 2022 IEEE/ACM 30th International Conference on Program Comprehension (ICPC), pages 111–121.

Abid, N. J., Maletic, J. I., and Sharif, B. (2019a). Using developer eye movements to externalize the mental model used in code summarization tasks. In Proceedings of the 11th ACM Symposium on Eye Tracking Research and Applications, ETRA '19. ACM.

Abid, N. J., Sharif, B., Dragan, N., Alrasheed, H., and Maletic, J. I. (2019b). Developer reading behavior while summarizing java methods: Size and context matters.

Ahrens, M. and Schneider, K. (2021). Improving requirements specification use by transferring attention with eye tracking data. Information and Software Technology, 131:106483.

Aljehane, S. (2022). Eye Movements Characterizing For The Assessment Of Expertise In Source Code Reading. PhD thesis, Kent State University.

Aljehane, S., Sharif, B., and Maletic, J. (2021). Determining differences in reading behavior between experts and novices by investigating eye movement on source code constructs during a bug fixing task. In ACM Symposium on Eye Tracking Research and

Applications, pages 1–6.

Aljehane, S. D., Sharif, B., and Maletic, J. I. (2023). Studying developer eye movements to measure cognitive workload and visual effort for expertise assessment. Proceedings of the ACM on Human-Computer Interaction, 7(ETRA):1–18.

Begel, A. and Vrzakova, H. (2018). Eye movements in code review. In Proceedings of the Workshop on Eye Movements in Programming, ETRA '18. ACM.

Blascheck, T. and Sharif, B. (2019). Visually analyzing eye movements on natural language texts and source code snippets. In Proceedings of the 11th ACM Symposium on Eye Tracking Research and Applications, ETRA '19, New York, NY, USA. Association for Computing Machinery.

Bryant, C. (2021). Itrace: an Infrastructure to Support Eye-Tracking Studies in Integrated Development Environments. PhD thesis, Kent State University.

Chandrika, K. and Amudha, J. (2018). A fuzzy inference system to recommend skills for source code review using eye movement data. Journal of Intelligent & Fuzzy Systems, 34(3):1743–1754.

Chandrika, K., Amudha, J., and Sudarsan, S. D. (2020). Identification and classification of expertise using eye gaze - industrial use case study with software engineers. In Communication and Intelligent Systems: Proceedings of ICCIS 2019, pages 391–405. Springer.

Choma, J., Guerra, E. M., da Silva, T. S., Albuquerque, T., Albuquerque, V. G., and Zaina, L. M. (2019). An empirical study of test-driven development vs. test-last development using eye tracking. In Agile Methods: 10th Brazilian Workshop, WBMA 2019, Belo Horizonte, Brazil, September 11, 2019, Revised Selected Papers 10, pages 11–24. Springer.

Couceiro, R., Barbosa, R., Duráes, J., Duarte, G., Castelhano, J., Duarte, C., Teixeira, C., Laranjeiro, N., Medeiros, J., Carvalho, P., et al. (2019a). Spotting problematic code lines using nonintrusive programmers' biofeedback. In 2019 IEEE 30th International Symposium on Software Reliability Engineering (ISSRE), pages 93–103. IEEE.

Couceiro, R., Duarte, G., Durães, J., Castelhano, J., Duarte, C., Teixeira, C., Branco, M. C., Carvalho, P., and Madeira, H. (2019b). Pupillography as indicator of programmers' mental effort and cognitive overload. In 2019 49th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN), pages 638–644. IEEE.

da Costa, J. A. S., Gheyi, R., Castor, F., de Oliveira, P. R. F., Ribeiro, M., and Fonseca, B. (2023). Seeing confusion through a new lens: on the impact of atoms of confusion on novices' code comprehension. Empirical Software Engineering, 28(4).

da Costa, J. A. S., Gheyi, R., Ribeiro, M., Apel, S., Alves, V., Fonseca, B., Medeiros, F., and Garcia, A. (2021). Evaluating refactorings for disciplining ifdef annotations: An eye tracking study with novices. Empirical Software Engineering, 26(5):92.

De Oliveira, B., Ribeiro, M., da Costa, J. A. S., Gheyi, R., Amaral, G., de Mello, R., Oliveira, A., Garcia, A., Bonifácio, R., and Fonseca, B. (2020). Atoms of confusion: The eyes do not lie. In Proceedings of the XXXIV Brazilian Symposium on Software Engineering, SBES '20. ACM.

Dias, M., Orellana, D., Vidal, S., Merino, L., and Bergel, A. (2020). Evaluating a visual approach for understanding javascript source code. In Proceedings of the 28th International Conference on Program Comprehension, pages 128–138.

Eiroa-Lledo, E., Bechtel, A., Daskas, E., Foster, L., Pirzadeh, R., Rodeghiero, K., and Linstead, E. (2020). Do experienced programmers put too much confidence in comments? In SEKE, pages 281–286.

Fakhoury, S., Ma, Y., Arnaoudova, V., and Adesope, O. (2018). The effect of poor source code lexicon and readability on developers' cognitive load. In 2018 IEEE/ACM 26th International Conference on Program Comprehension (ICPC), pages 286–28610.

Fakhoury, S., Roy, D., Ma, Y., Arnaoudova, V., and Adesope, O. (2020). Measuring the impact of lexical and structural inconsistencies on developers' cognitive load during bug localization. Empirical Software Engineering, 25:2140–2178.

Gralha, C., Goulao, M., and Araujo, J. (2020). Are there gender differences when interacting with social goal models? a quasi-experiment. Empirical Software Engineering, 25:5416–5453.

Hauser, F., Reuter, R., Gegenfurtner, A., Gruber, H., and Mottok, J. (2019). Eye movements in software modelling- what do they tell us about heuristics. In ICERI2019 proceedings, pages 6064–6070. IATED.

Hijazi, H., Cruz, J., Castelhano, J., Couceiro, R., Castelo-Branco, M., de Carvalho, P., and Madeira, H. (2021). ireview: an intelligent code review evaluation tool using biofeedback. In 2021 IEEE 32nd International Symposium on Software Reliability Engineering (ISSRE), pages 476–485.

Hijazi, H., Duraes, J., Couceiro, R., Castelhano, J., Barbosa, R., Medeiros, J., Castelo-Branco, M., de Carvalho, P., and Madeira, H. (2022). Quality evaluation of modern code reviews through intelligent biometric program comprehension. IEEE Transactions on Software Engineering, 49(2):626–645.

Homann, A., Grabinger, L., Hauser, F., and Mottok, J. (2023). An eye tracking study on misra c coding guidelines. In Proceedings of the 5th European Conference on Software Engineering Education, ECSEE 2023. ACM.

Huang, Y. (2021). Understanding User Cognition: From Spatial Ability to Code Writing and Review. PhD thesis.

Ioannou, C., Nurdiani, I., Burattin, A., and Weber, B. (2020). Mining reading patterns from eye-tracking data: method and demonstration. Software and Systems Modeling, 19:345–369.

Ishida, T. and Uwano, H. (2019). Synchronized analysis of eye movement and eeg during program comprehension. In 2019 IEEE/ACM 6th International Workshop on Eye Movements in Programming (EMIP), pages 26–32. IEEE.

Jessup, S., Willis, S. M., Alarcon, G., and Lee, M. (2021). Using eye-tracking data to compare differences in code comprehension and code perceptions between expert and novice programmers.

Kaplan, U. (2019). The role of expertise on code review for security: an eye tracking study. Master's thesis, Middle East Technical University.

Kather, P., Duran, R., and Vahrenhold, J. (2021). Through (tracking) their eyes: Abstraction and complexity in program comprehension. ACM Transactions on Computing Education, 22(2):1–33.

Katona, J. (2021). Analyse the readability of linq code using an eye-tracking-based evaluation. Acta Polytech. Hung, 18:193–215.

Lindberg, S. B. (2022). Exposing novice programmers to an expert's eye-gaze. Master's thesis, NTNU.

Matzen, L. E., Leger, M. A., and Reedy, G. E. (2021). Effects of precise and imprecise value-set analysis (vsa) information on manual code analysis. Technical report, Sandia National Lab. (SNL-NM), Albuquerque, NM (United States).

Mondal, S., Das, P. P., and Bhattacharjee Rudra, T. (2022). Measuring code comprehension effort using code reading pattern. Sādhanā, 47(3):117.

Nagaraj, S. (2018). Enabling Eye Tracking to Study the Use of Software Artifacts on Code Summarization. PhD thesis, Carleton University.

Nyqvist, A. and Rutqvist, J. (2019). The impact of colour themes on code readability.

Obaidellah, U., Al Haek, M., and Cheng, P. C.-H. (2018). A survey on the usage of eye-tracking in computer programming. ACM Computing Surveys, 51(1):1–58.
Paltenghi, M., Pandita, R., Henley, A. Z., and Ziegler, A. (2022). Extracting meaningful attention on source code: An empirical study of developer and neural model code exploration.

Park, K.-i., Weill-Tessier, P., Brown, N. C. C., Sharif, B., Jensen, N., and Kölling, M. (2023). An eye tracking study assessing the impact of background styling in code editors on novice programmers' code understanding. In Proceedings of the 2023 ACM Conference on International Computing Education Research - Volume 1, ICER '23, page 444–463, New York, NY, USA. Association for Computing Machinery.

Peitek, N., Bergum, A., Rekrut, M., Mucke, J., Nadig, M., Parnin, C., Siegmund, J., and Apel, S. (2022). Correlates of programmer efficacy and their link to experience: a combined eeg and eye-tracking study. In Proceedings of the 30th ACM Joint European Software Engineering Conference and Symposium on the Foundations of Software

Engineering, ESEC/FSE ’22. ACM.

Rezaei Sepasi, E. (2022). Analyzing comprehension of models of variable software systems with eye-tracking technologies. PhD thesis, École de technologie supérieure.

Saddler, J. A. (2019). Looks can mean achieving: understanding eye gaze patterns of proficiency in code comprehension. In Proceedings of the 11th ACM Symposium on Eye Tracking Research & Applications, pages 1–3.

Saddler, J. A., Peterson, C. S., Sama, S., Nagaraj, S., Baysal, O., Guerrouj, L., and Sharif, B. (2020). Studying developer reading behavior on stack overflow during api summarization tasks. In 2020 IEEE 27th International Conference on Software Analysis, Evolution and Reengineering (SANER), pages 195–205.

Shakil, A., Lutteroth, C., and Weber, G. (2019). Codegazer: Making code navigation easy and natural with gaze input. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pages 1–12.

Sharafi, Z., Bertram, I., Flanagan, M., and Weimer, W. (2022). Eyes on code: A study on developers’ code navigation strategies. IEEE Transactions on Software Engineering, 48(5):1692–1704.

Sharafi, Z., Huang, Y., Leach, K., and Weimer, W. (2021). Toward an objective measure of developers’ cognitive activities. ACM Transactions on Software Engineering and Methodology, 30(3):1–40.

Sharafi, Z., Shaffer, T., Sharif, B., and Guéhéneuc, Y.-G. (2015). Eye-tracking Metrics in Software Engineering. In 2015 Asia-Pacific Software Engineering Conference (APSEC), pages 96–103. IEEE.

Sharafi, Z., Sharif, B., Guéhéneuc, Y.-G., Begel, A., Bednarik, R., and Crosby, M. (2020). A practical guide on conducting eye tracking studies in software engineering. Empirical Software Engineering, 25(5):3128–3174.

Sorg, T., Abbad-Andaloussi, A., and Weber, B. (2022). Towards a fine-grained analysis of cognitive load during program comprehension. In 2022 IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER). IEEE.

Vrzakova, H. (2019). Machine learning methods in interaction inference from gaze. PhD thesis, Itä-Suomen yliopisto.

Weber, T., Winiker, C., and Hußmann, H. (2021). A closer look at machine learning code. In Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems, pages 1–6.

Wrobel, M. R. (2018). Applicability of emotion recognition and induction methods to study the behavior of programmers. Applied Sciences, 8(3):323.

Zhang, L., Sun, J., Peterson, C., Sharif, B., and Yu, H. (2019). Exploring eye tracking

data on source code via dual space analysis. In 2019 Working Conference on Software Visualization (VISSOFT), pages 67–77.