Minimizing Attention Costs of Visual OHMD Notifications

Category: Author Draft

Abstract

Notifications provide crucial secondary information but can also interrupt users and interfere with their primary tasks. Given the increased usage of mobile devices and digital services, reducing the adverse effects of notifications has become an essential research challenge in the Human-Computer Interaction (HCI) field. The Optical See-Through Head-Mounted Display (OST HMD, OHMD, augmented-reality smart glasses) is an emerging mobile and wearable device platform that could potentially supplant the mobile phone as a daily device companion. This work explores ways of minimizing the attention costs of OHMD notifications based on human visual perception. We propose 1) the utilization of paracentral and near-peripheral regions, 2) transforming text content into a graphical format, and 3) altering the luminance of notification content when displaying OHMD notifications. Each proposed OHMD notification design was evaluated through a series of user studies. Our results suggest that by modifying the information presentation of OHMD notifications, users can obtain secondary information with less distraction to primary tasks than with existing presentation techniques. Finally, we suggest a three-step process to manage the attention costs of OHMD notifications using multiple strategies.

Index Terms: [Human-centered computing]: Mixed / augmented reality; [Human-centered computing]: Ubiquitous computing; [Visualization]: Empirical studies in visualization;

1 Introduction and Related Work

Despite the immense convenience offered by ubiquitous information access [42], excessive information can distract and overwhelm users [1, 33]. A typical mobile device user receives more than 60 notifications per day [49], while tech-savvy users like college students receive over 400 [29]. Furthermore, most notifications are attended to within a few minutes [43, 49]. With the increasing use of notifications on mobile platforms [5, 29, 49], the need to minimize their attention costs has become paramount [2, 36–38].

Various strategies, including *mediating* strategies (i.e., deferring notifications until the user is more receptive to them), *indicating* strategies (i.e., indicating the availability of the receiving party to the sending party), and *mitigating* strategies (i.e., changing the device or presentation of the notifications to make them less distracting), have been proposed to minimize the attention costs of notifications [2, 32]. Of these, *mitigating* strategies allow timely notification, which can be particularly useful if prompt attention is required.

The emerging platform of optical see-through head-mounted displays (OST HMDs, OHMDs, augmented-reality smart glasses) [17] offers just-in-time information assistance anywhere and anytime [15, 25, 46] with increased situational awareness [19, 21, 30, 41, 56]. For OHMDs, notifications often attract users' attention, potentially interrupting and distracting them from ongoing tasks [30, 34, 44, 48]. Various *mitigating* strategies have been explored to lessen these adverse effects, including the use of visual regions, as shown in Table 1.

Previous research has primarily focused on using peripheral vision to minimize distraction by offloading information from the central vision [3, 7, 14, 16, 27, 31, 39, 45]. However, this approach has limitations as the peripheral vision has restricted information processing capabilities (e.g., limited text recognition abilities) [24, 50]. Thus, our research aims to design notifications that effectively balance communication and minimize attention costs to primary tasks.

Table 1: A summary of some previous OHMD notification explorations.

Main Category	Factor	Description of the Factor	Related work
Modality	Multi	Visual vs Auditory	[6, 8, 9, 40]
	Single	Visual, Textual vs Graphical	[30, 52]
Vision regions	Peripheral vision	Out of focus, Retinal variables (e.g., shape, color)	[16, 31]
	Central vision	Central vs Peripheral presentation	[3, 27]
Timing	Timing	Batches, Intermittent vs Continuous, Animations	[40, 52]
Placement	Position	(Left, Center, Right)×(Top, Middle, Bottom)	[4, 26, 47]
	Stabilization	Head-locked, Body-Locked, World-locked	[11, 26, 28, 47]

Visual notifications directly influence visual attention as they are presented directly in the near-eye displays of OHMDs. We aimed to address this challenge by leveraging *human visual perception*, which influences attention and associated costs [12, 13, 24, 51]. Successful perception of visual information can be influenced by several factors, including the vision regions, patterns of the information, and luminance contrast [54, Ch 6]. Thus, our research explores the use of visual perception properties to **design** the presentation format of OHMD notifications that maintain communication effectiveness while minimizing distraction.

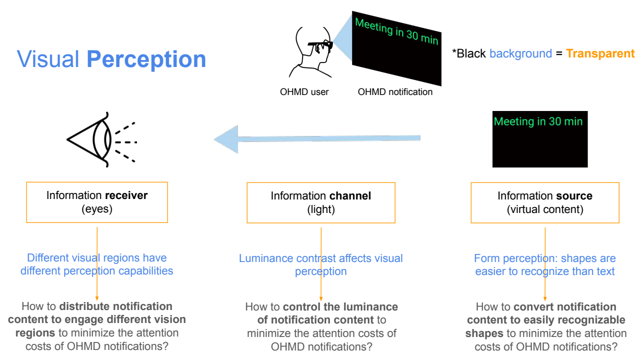

Figure 1: The research question structure shows how the visual perception properties are used to answer the selected research questions in the scope of visual OHMD notifications.

McCrickard et al. [34–37] developed a conceptual model, the *IRC framework* (Figure 2), focusing on user goals to improve design decisions for notification systems based on the attention-utility trade-off. This descriptive and prescriptive model uses three crucial parameters: *Interruption* (I), *Reaction* (R), and *Comprehension* (C). As this model can identify the differences between the expected design model (i.e., expected parameters) and the actual user's model (i.e., resulting parameters), we used this model to **evaluate** our proposed notification designs.

2 Studies

In this work, we strive to answer the overarching research question: *How can we minimize the attention costs of visual OHMD notifications?* We investigate this through the following focal question:

- *How do we modify the information presentation of visual OHMD notifications to minimize attention costs while maintaining communicative effectiveness during multitasking?*

As delineated in Figure 1, we examine multiple mitigating strategies to harness visual perception properties in the *design* of OHMD

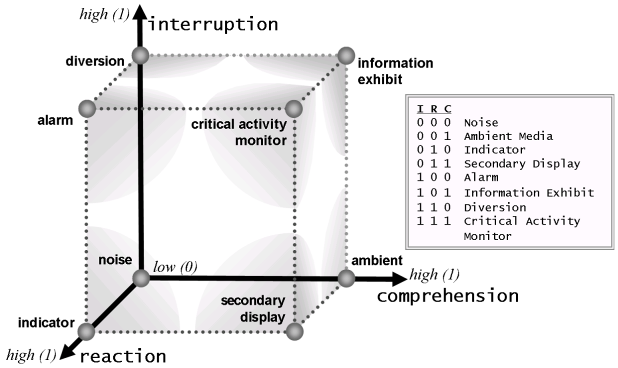

Figure 2: Notification systems categorizations according to the blend of design model objectives (representing user goals) of interruption (I), reaction (R), and comprehension (C) with low (0) or high (1) values. Source: McCrickard et al. [37].

notifications to minimize unwanted distractions. Visual perception is affected by elements such as the information receiver (i.e., the eyes), the information source (e.g., virtual content on OHMD), and the information channel (i.e., light). We thus center our attention on three primary factors impacting these elements: vision region (receiver), form/pattern (source), and luminance (channel) [24, 54, Ch 6].

Our first project [20] examines the use of different vision regions, especially paracentral and near-peripheral vision, to distribute OHMD notification contents, thereby alleviating the information load on central vision. The research question driving this exploration is:

- *How can we distribute notification content to engage different vision regions to minimize the attention costs of OHMD notifications?*

To tackle this question, we developed a circular progress bar, an OHMD progress notification displayed in the paracentral and near-peripheral vision areas to convey time availability and task completion information during social interactions.

In the second project [23], we investigate the utility of *form* perception property, considering that shapes are more readily recognizable than text [53], for OHMD notifications. This project is steered by the research question:

- *How do we convert notification content to easily recognizable shapes to minimize the attention costs of OHMD notifications?*

Addressing this question required us to study the usage of icons to represent text notifications in a work environment, a topic that had received limited attention in previous research.

Our third project [22] explores how adjustments in luminance [54, Ch 3] can curtail the disruptive influence of abrupt visual stimuli from OHMD notifications. This project revolves around the research question:

- *How can we control the luminance of notification content to minimize the attention costs of OHMD notifications?*

In response, we designed fading text notifications, where the light intensity of the notification changes gradually, with the goal of determining the ideal fading duration in a work setting.

To address each research question, we conducted controlled studies, specifically randomized controlled trials, approved by our university's institutional review board (IRB). Further details of these studies are expounded in each **respective paper [20, 22, 23]**.

3 Results and Discussion

Each assessment revealed that our novel visualizations lessened *Interruption*, maintained *Reaction* and *Comprehension*, and increased *Satisfaction*.

3.1 Distribution of Information Across Different Visual Regions

This research used different visual perception regions, particularly paracentral and near-peripheral vision, to distribute OHMD notification content during social interactions [20]. We proposed and empirically evaluated new OHMD progress notifications designed to utilize both paracentral and near-peripheral vision in simulated and real-world environments. This evaluation allowed us to assess the trade-off between notification design and social interaction quality. Furthermore, our findings indicate that by presenting secondary information within the circular area of paracentral and near-peripheral vision promotes attention-maintaining visualizations and reduces attention costs. Based on these results, we also propose potential designs for multitasking scenarios in OHMDs that utilize these vision regions.

3.2 Conversion of Information to Easily Recognizable Formats

We introduced a novel technique for minimizing the disturbance caused by OHMD notifications by leveraging the visual perception property that shapes are typically easier to identify than text [23]. Our empirical study demonstrates the feasibility and desirability of converting text notifications into pictorial ones during multitasking with OHMDs. We examined influential factors such as familiarity, encoding density, and external brightness in the context of pictorial notifications. An ecological study provided insights into the trade-offs between text and pictorial notifications. Our findings indicate that pictorial notifications effectively mitigate unwanted interruptions from frequently received short notifications in both stationary and mobile multitasking scenarios, thus enhancing attention management. These results imply that converting secondary information into easily identifiable formats, like icons, in OHMDs minimizes attention costs.

3.3 Gradual Presentation of Information

Our investigation also focused on examining the potential of controlled luminance to reduce the disruption caused by the sudden visual stimuli of OHMD notifications [22]. We conducted a comparative analysis of fading animations and other common animations to understand the role of luminance control in minimizing disruptions from sudden visual stimuli in near-eye displays. Our results suggest that fading animations can significantly reduce interruptions from OHMD notifications, considering factors like fade duration, primary task location, and primary task complexity. This implies that the gradual presentation of notification content can reduce attention costs associated with OHMD notifications.

3.4 Implications: Visual Perception and Attention Costs

These projects collectively aimed to address the principal research question: *How do we modify the information presentation of visual OHMD notifications to minimize attention costs while maintaining communicative effectiveness during multitasking?* They have established that efficiently distributing OHMD notification content across different visual areas based on their importance, presenting the information in easily recognizable formats (such as graphics instead of text), and using gradual presentation techniques (like fading animations) can facilitate a quicker return to primary tasks and help minimize attention costs related to visual OHMD notifications. Moreover, these results collectively show that utilizing visual perception properties enables the minimization of visual attention costs while preserving utility, particularly the communication effectiveness of OHMD notifications.

However, we note that merely employing mitigation strategies alone may not be enough to address the attention costs associated with the plethora of daily notifications. Thus, we propose a three-step process. The first step entails delivering only the "necessary" information (e.g., critical notifications) to the user, which can be achieved through compact representations (e.g., removing filler words) and filtering strategies. Moreover, OHMD operating systems could default to opt out of notifications or require individual apps to seek user permission during their initial use (e.g., [55]). The second step involves employing mediation and scheduling strategies to present information when users are most receptive, necessitating the modeling of user receptivity in various contexts (e.g., [10]). Finally, as explored in this study, the last step is to implement mitigation strategies that reduce the attention cost of information by exploiting visual perception properties and designing better-suited visualizations for OHMDs. For more details, please refer to [18].

4 Conclusion and Future Work

This paper undertook an effort to understand and optimize OHMD notification presentation through three distinct projects. By leveraging human visual perception properties, we investigated innovative ways to decrease attention costs and enhance user experience. Future work will explore different visual perception properties, combine various modalities, evaluate OHMD notifications in real-world environments, and explore new application areas for OHMD notifications. We envision this research fostering further exploration and advancements in heads-up computing [56], leading to more efficient and user-friendly interactions with digital information.

References

[1] D. K. Allen and M. Shoard. Spreading the load: Mobile information and communications technologies and their effect on information overload. *Information Research: An International Electronic Journal*, 10(2):n2, 2005.

[2] C. Anderson, I. Hübener, A.-K. Seipp, S. Ohly, K. David, and V. Pejovic. A Survey of Attention Management Systems in Ubiquitous Computing Environments. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 2(2):1–27, July 2018. doi: 10.1145/3214261

[3] I. Chaturvedi, F. H. Bijarbooneh, T. Braud, and P. Hui. Peripheral vision: a new killer app for smart glasses. In *Proceedings of the 24th International Conference on Intelligent User Interfaces - IUI '19*, pp. 625–636. ACM Press, Marina del Ray, California, 2019. doi: 10.1145/3301275.3302263

[4] S. H. Chua, S. T. Perrault, D. J. C. Matthies, and S. Zhao. Positioning Glass: Investigating Display Positions of Monocular Optical See-Through Head-Mounted Display. In *Proceedings of the Fourth International Symposium on Chinese CHI - ChineseCHI2016*, pp. 1–6. ACM Press, San Jose, USA, 2016. doi: 10.1145/2948708.2948713

[5] L. Chuang, S. Gehring, J. Kay, and A. Schmidt. Ambient Notification Environments (Dagstuhl Seminar 17161). *Dagstuhl Reports*, 7(4):38–82, 2017. doi: 10.4230/DagRep.7.4.38

[6] M. Cidota, S. Lukosch, D. Datcu, and H. Lukosch. Workspace Awareness in Collaborative AR using HMDs: A User Study Comparing Audio and Visual Notifications. In *Proceedings of the 7th Augmented Human International Conference 2016 on - AH '16*, pp. 1–8. ACM Press, Geneva, Switzerland, 2016. doi: 10.1145/2875194.2875204

[7] E. Costanza, S. A. Inverso, E. Pavlov, R. Allen, and P. Maes. eye-q: eyeglass peripheral display for subtle intimate notifications. In *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services - MobileHCI '06*, p. 211. ACM Press, Helsinki, Finland, 2006. doi: 10.1145/1152215.1152261

[8] I. Damian, C. S. S. Tan, T. Baur, J. Schöning, K. Luyten, and E. André. Augmenting Social Interactions: Realtime Behavioural Feedback using Social Signal Processing Techniques. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, pp. 565–574. ACM Press, Seoul, Republic of Korea, 2015. doi: 10.1145/2702123.2702314

[9] N. Farve, T. Achituv, and P. Maes. User Attention with Head-Worn Displays. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '16*, pp. 2467–2473. ACM Press, Santa Clara, California, USA, 2016. doi: 10.1145/2851581.2892530

[10] J. E. Fischer. *Understanding Receptivity to Interruptions in Mobile Human-Computer Interaction*. PhD thesis, University of Nottingham, Dec. 2011.

[11] S. Fukushima, T. Hamada, and A. Hautasaari. Comparing World and Screen Coordinate Systems in Optical See-Through Head-Mounted Displays for Text Readability while Walking. In *2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 649–658. IEEE, Porto de Galinhas, Brazil, Nov. 2020. doi: 10.1109/ISMAR50242.2020.00093

[12] E. B. Goldstein and J. Brockmole. *Sensation and Perception*. Cengage Learning, Boston, MA, 10th edition ed., Feb. 2016.

[13] E. B. Goldstein, G. W. Humphreys, M. Shiffrar, and W. A. Yost, eds. *Blackwell handbook of sensation and perception*. Number 1 in Blackwell handbooks of experimental psychology. Blackwell Pub, Oxford, UK ; Malden, MA, 2005.

[14] U. Gruenefeld, T. C. Stratmann, J. Jung, H. Lee, J. Choi, A. Nanda, and W. Heuten. Guiding Smombies: Augmenting Peripheral Vision with Low-Cost Glasses to Shift the Attention of Smartphone Users. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, pp. 127–131. IEEE, Munich, Germany, Oct. 2018. doi: 10.1109/ISMAR-Adjunct.2018.00050

[15] S. Hobert and M. Schumann. Application Scenarios of Smart Glasses in the Industrial Sector: Results of an Empirical Study Among Domain Experts. *i-com*, 15(2):133–143, Aug. 2016. doi: 10.1515/icom-2016-0016

[16] Y. Ishiguro and J. Rekimoto. Peripheral vision annotation: noninterference information presentation method for mobile augmented reality. In *Proceedings of the 2nd Augmented Human International Conference on - AH '11*, pp. 1–5. ACM Press, Tokyo, Japan, 2011. doi: 10.1145/1959826.1959834

[17] Y. Itoh, T. Langlotz, J. Sutton, and A. Plopski. Towards Indistinguishable Augmented Reality: A Survey on Optical See-through Head-mounted Displays. *ACM Computing Surveys*, 54(6):120:1–120:36, July 2021. doi: 10.1145/3453157

[18] N. Janaka. *HEADS-UP VISUAL OHMD NOTIFICATIONS*. Thesis, 2023.

[19] N. Janaka, J. Gao, L. Zhu, S. Zhao, L. Lyu, P. Xu, M. Nabokow, S. Wang, and Y. Ong. GlassMessaging: Towards Ubiquitous Messaging Using OHMDs. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 7(3), Sept. 2023. doi: 10.1145/3610931

[20] N. Janaka, C. Haigh, H. Kim, S. Zhang, and S. Zhao. Paracentral and near-peripheral visualizations: Towards attention-maintaining secondary information presentation on OHMDs during in-person social interactions. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, pp. 1–14. Association for Computing Machinery, New York, NY, USA, Apr. 2022. doi: 10.1145/3491102.3502127

[21] N. Janaka, X. Wu, S. Zhang, S. Zhao, and P. Slovak. Visual Behaviors and Mobile Information Acquisition, Feb. 2022. doi: 10.48550/arXiv.2202.02748

[22] N. Janaka, S. Zhao, and S. Chan. NotiFade: Minimizing OHMD Notification Distractions Using Fading. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI EA '23, pp. 1–9. Association for Computing Machinery, New York, NY, USA, Apr. 2023. doi: 10.1145/3544549.3585784

[23] N. N. P. K. Janaka, S. Zhao, and S. Sapkota. Can Icons Outperform Text? Understanding the Role of Pictograms in OHMD Notifications. In *Proceedings of the 2023 CHI Conference on Human Factors in*

Computing Systems, CHI '23, pp. 1–23. Association for Computing Machinery, New York, NY, USA, Apr. 2023. doi: 10.1145/3544548.3580891

[24] J. W. Kalat. *Biological Psychology*. Cengage Learning, Jan. 2012.

[25] K. Klinker, L. Berkemeier, B. Zobel, H. Wüller, V. Huck-Fries, M. Wiesche, H. Remmers, O. Thomas, and H. Krcmar. Structure for innovations: A use case taxonomy for smart glasses in service processes. Leuphana Universitat Luneburg, 2018.

[26] E. M. Klose, N. A. Mack, J. Hegenberg, and L. Schmidt. Text Presentation for Augmented Reality Applications in Dual-Task Situations. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 636–644. IEEE, Osaka, Japan, Mar. 2019. doi: 10.1109/VR.2019.8797992

[27] P.-S. Ku, Y.-C. Lin, Y.-H. Peng, and M. Y. Chen. PeriText: Utilizing Peripheral Vision for Reading Text on Augmented Reality Smart Glasses. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 630–635, Mar. 2019. doi: 10.1109/VR.2019.8798065

[28] F. Lauber and A. Butz. In-your-face, yet unseen?: improving head-stabilized warnings to reduce reaction time. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, pp. 3201–3204. ACM Press, Toronto, Ontario, Canada, 2014. doi: 10.1145/2556288.2557063

[29] U. Lee, J. Lee, M. Ko, C. Lee, Y. Kim, S. Yang, K. Yatani, G. Gweon, K.-M. Chung, and J. Song. Hooked on smartphones: an exploratory study on smartphone overuse among college students. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, pp. 2327–2336. Association for Computing Machinery, New York, NY, USA, Apr. 2014. doi: 10.1145/2556288.2557366

[30] A. Lucero and A. Vetek. NotifEye: using interactive glasses to deal with notifications while walking in public. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology - ACE '14*, pp. 1–10. ACM Press, Funchal, Portugal, 2014. doi: 10.1145/2663806.2663824

[31] K. Luyten, D. Degraen, G. Rovelo Ruiz, S. Coppers, and D. Vanacken. Hidden in Plain Sight: an Exploration of a Visual Language for Near-Eye Out-of-Focus Displays in the Peripheral View. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, pp. 487–497. ACM Press, Santa Clara, California, USA, 2016. doi: 10.1145/2858036.2858339

[32] P. P. Maglio and C. S. Campbell. Tradeoffs in displaying peripheral information. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, CHI '00, pp. 241–248. Association for Computing Machinery, New York, NY, USA, Apr. 2000. doi: 10.1145/332040.332438

[33] J. Matthes, K. Karsay, D. Schmuck, and A. Stevic. "too much to handle": Impact of mobile social networking sites on information overload, depressive symptoms, and well-being. *Computers in Human Behavior*, 105:106217, 2020. doi: 10.1016/j.chb.2019.106217

[34] G. McAtamney and C. Parker. An examination of the effects of a wearable display on informal face-to-face communication. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '06, pp. 45–54. Association for Computing Machinery, New York, NY, USA, Apr. 2006. doi: 10.1145/1124772.1124780

[35] D. McCrickard, R. Catrambone, C. Chewar, and J. T. Stasko. Establishing tradeoffs that leverage attention for utility: empirically evaluating information display in notification systems. *International Journal of Human-Computer Studies*, 58(5):547–582, May 2003. doi: 10.1016/S1071-5819(03)00022-3

[36] D. S. McCrickard and C. M. Chewar. Attuning notification design to user goals and attention costs. *Communications of the ACM*, 46(3):67, Mar. 2003. doi: 10.1145/636772.636800

[37] D. S. McCrickard, C. M. Chewar, J. P. Somervell, and A. Ndiwalana. A model for notification systems evaluation—assessing user goals for multitasking activity. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 10(4):312–338, Dec. 2003. doi: 10.1145/966930.966933

[38] A. Mehrotra and M. Musolesi. Intelligent Notification Systems: A Survey of the State of the Art and Research Challenges. *arXiv:1711.10171 [cs]*, Jan. 2018.

[39] T. Nakuo and K. Kunze. Smart glasses with a peripheral vision display. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, pp. 341–344. ACM, Heidelberg Germany, Sept. 2016. doi: 10.1145/2968219.2971393

[40] E. Ofek, S. T. Iqbal, and K. Strauss. Reducing disruption from subtle information delivery during a conversation: mode and bandwidth investigation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, pp. 3111–3120. Association for Computing Machinery, New York, NY, USA, Apr. 2013. doi: 10.1145/2470654.2466425

[41] J. Orlosky, K. Kiyokawa, and H. Takemura. Managing mobile text in head mounted displays: studies on visual preference and text placement. *ACM SIGMOBILE Mobile Computing and Communications Review*, 18(2):20–31, June 2014. doi: 10.1145/2636242.2636246

[42] M. Perry, K. O'hara, A. Sellen, B. Brown, and R. Harper. Dealing with mobility: understanding access anytime, anywhere. *ACM Transactions on Computer-Human Interaction*, 8(4):323–347, Dec. 2001. doi: 10.1145/504704.504707

[43] M. Pielot, K. Church, and R. de Oliveira. An in-situ study of mobile phone notifications. In *Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services - MobileHCI '14*, pp. 233–242. ACM Press, Toronto, ON, Canada, 2014. doi: 10.1145/2628363.2628364

[44] L. Plabst, S. Oberdörfer, F. R. Ortega, and F. Niebling. Push the Red Button: Comparing Notification Placement with Augmented and Non-Augmented Tasks in AR. In *Proceedings of the 2022 ACM Symposium on Spatial User Interaction*, SUI '22, pp. 1–11. Association for Computing Machinery, New York, NY, USA, Dec. 2022. doi: 10.1145/3565970.3567701

[45] B. Poppinga, N. Henze, J. Fortmann, and W. Heuten. AmbiGlasses – Information in the Periphery of the Visual Field. In *Mensch & Computer 2012: interaktiv informiert – allgegenwärtig und allumfassend!?*, pp. 153–162, 2012.

[46] B. J. Rhodes. *Just-In-Time Information Retrieval*. PhD thesis, 2000.

[47] R. Rzayev, S. Korbely, M. Maul, A. Schark, V. Schwind, and N. Henze. Effects of Position and Alignment of Notifications on AR Glasses during Social Interaction. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society*, pp. 1–11. ACM, Tallinn Estonia, Oct. 2020. doi: 10.1145/3419249.3420095

[48] E. E. Sabelman and R. Lam. The real-life dangers of augmented reality. *IEEE Spectrum*, 52(7):48–53, July 2015. doi: 10.1109/MSPEC.2015.7131695

[49] A. Sahami Shirazi, N. Henze, T. Dingler, M. Pielot, D. Weber, and A. Schmidt. Large-scale assessment of mobile notifications. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, pp. 3055–3064. ACM Press, Toronto, Ontario, Canada, 2014. doi: 10.1145/2556288.2557189

[50] H. Strasburger, I. Rentschler, and M. Juttner. Peripheral vision and pattern recognition: A review. *Journal of Vision*, 11(5):13–13, Dec. 2011. doi: 10.1167/11.5.13

[51] E. A. Styles. *The psychology of attention*. Taylor & Francis e-Library, London, 2006.

[52] M. I. Tanveer, E. Lin, and M. E. Hoque. Rhema: A Real-Time In-Situ Intelligent Interface to Help People with Public Speaking. In *Proceedings of the 20th International Conference on Intelligent User Interfaces - IUI '15*, pp. 286–295. ACM Press, Atlanta, Georgia, USA, 2015. doi: 10.1145/2678025.2701386

[53] C. Tijus, J. Barcenilla, B. C. d. Lavalette, and J.-G. Meunier. The Design, Understanding and Usage of Pictograms. *Written Documents in the Workplace*, pp. 17–31, Jan. 2007. doi: 10.1163/9789004253254_003

[54] C. Ware. *Information Visualization: Perception for Design*. Waltham, MA, 2013.

[55] T. Westermann. *User Acceptance of Mobile Notifications*. T-Labs Series in Telecommunication Services. Springer Singapore, Singapore, 2017. doi: 10.1007/978-981-10-3851-8

[56] S. Zhao, F. Tan, and K. Fennedy. Heads-Up Computing: Moving Beyond the Device-Centered Paradigm, May 2023. arXiv:2305.05292 [cs]. doi: 10.48550/arXiv.2305.05292