

Ubiquitous Smart Eyewear Interactions using Implicit Sensing and Unobtrusive Information Output

Qiushi Zhou

The University of Melbourne
Melbourne, Australia
qiushi.zhou@unimelb.edu.au

Joshua Newn

The University of Melbourne
Melbourne, Australia
joshua.newn@unimelb.edu.au

Benjamin Tag

The University of Melbourne
Melbourne, Australia
benjamin.tag@unimelb.edu.au

Hao-Ping Lee

National Chiao Tung University
Hsinchu, Taiwan
dimension4.cs03@nctu.edu.tw

Chaofan Wang

The University of Melbourne
Melbourne, Australia
chaofanw@student.unimelb.edu.au

Eduardo Velloso

The University of Melbourne
Melbourne, Australia
eduardo.velloso@unimelb.edu.au

ABSTRACT

Premature technology, privacy, intrusiveness, power consumption, and user habits are all factors potentially contributing to the lack of social acceptance of smart glasses. After investigating the recent development of commercial smart eyewear and its related research, we propose a design space for ubiquitous smart eyewear interactions while maximising interactivity with minimal obtrusiveness. We focus on implicit and explicit interactions enabled by the combination of miniature sensor technology, low-resolution display and simplistic interaction modalities. Additionally, we are presenting example applications outlining future development directions. Finally, we aim at raising the awareness of designing for ubiquitous eyewear with implicit sensing and unobtrusive information output abilities.

CCS CONCEPTS

• **Human-centered computing** → **User interface toolkits**; **Ubiquitous computing**; *Ubiquitous and mobile computing systems and tools*; *Mobile devices*.

KEYWORDS

eyewear, wearable, sensor, context awareness

ACM Reference Format:

Qiushi Zhou, Joshua Newn, Benjamin Tag, Hao-Ping Lee, Chaofan Wang, and Eduardo Velloso. 2019. Ubiquitous Smart Eyewear

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

UbiComp/ISWC '19 Adjunct, September 9–13, 2019, London, United Kingdom

© 2019 Association for Computing Machinery.

ACM ISBN 978-1-4503-6869-8/19/09...\$15.00

<https://doi.org/10.1145/3341162.3348392>

Interactions using Implicit Sensing and Unobtrusive Information Output. In *Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the 2019 International Symposium on Wearable Computers (UbiComp/ISWC '19 Adjunct)*, September 9–13, 2019, London, United Kingdom. ACM, New York, NY, USA, 6 pages. <https://doi.org/10.1145/3341162.3348392>

1 INTRODUCTION

Humans interact with the world by perceiving it through sensory input, identifying action affordance and then producing motor output [7]. As most sensory input are received by the organs on human face, it makes the face especially interesting for collecting physiological data as well as for delivering information for Human-Computer Interaction. Glasses are among the most common devices that we wear on our faces daily. They have the natural advantage as potential interactive devices by always being available within close proximity with the main sensory organs, for physiological information input and discrete yet unobtrusive information output.

Since the 13th century, spectacles (prescription glasses) have been used primarily to alleviate visual impairments, and later developed as a fashion accessory [12]. Glasses with computational functionality and sensing abilities, nevertheless, have not yet reached that level of acceptance. Smart glasses and Head-Mounted-Device (HMD) have been added with layers of high-tech functions by ambitious developers while only resulting in low social acceptance due to their obtrusive appearance, form factor and other issues.

While smart eyewear with high-resolution displays combined with sophisticated input technologies present their own set of challenges, sole sensing devices with no displays remain limited in their usability beyond specific research applications. The rich potential of outputting information is hence wasted. An example are the JINS MEME glasses that come equipped with sensors to track physiological signals but rely on an external device, such as a computer or a smartphone to process the collected data and to display the acquired insights. While these devices are characterised by

an everyday-use form factor and are able to collect physiological signals, their abilities to utilise the obtained data and their dependence on external processing devices make them limited in functionality.

Inspired by the evolution from wristwatches to smartwatches, we argue that designing for smart eyewear interaction should avoid solely stacking advanced technologies or only focusing on data collection, and fully exploit the potential of eyewear as ubiquitous interactive devices. We call attention to an intermediate level of ubiquitous smart eyewear design with unobtrusive output, minimal power consumption, intermediate interaction affordance and contextual sensing abilities.

2 RELATED WORK

As smart wearable devices gain traction from consumers as ubiquitous computers, a range of smart eyewear devices has emerged in the market. Head-Mounted Displays (HMD) such as Microsoft HoloLens¹ and Magic Leap² are equipped with state-of-the-art holographic projection technology to enable augmented reality applications and interactions. Other devices provide similar functions at a smaller scale, such as Google Glass³, Focals⁴ and Vuzix Blade⁵. These glasses utilise projection technology to achieve high-resolution information display with smaller form factor. However, the HMDs and the smart glasses are often costly to purchase and their obtrusive design makes them unsuitable for everyday use, especially while interacting face-to-face with others.

Other commercial smart eyewear abandoned advanced display technologies for a more compact form factor to suit everyday use scenarios. Vue⁶ supports essential functions that require connectivity with a smartphone. It provides functions such as calling, navigation and a music player implemented with bone conduction for audio output and an integrated touchpad for control. It is also equipped with Inertial Measurement Unit (IMU) and infrared proximity sensors for activity tracking. Other eyewear devices are explicitly designed for sensing purposes. JINS MEME⁷ is equipped with Electrooculography (EOG) and IMU sensors for physiological data logging in everyday settings. Pupil Invisible⁸ is embedded with miniature infrared eye trackers to provide everyday gaze tracking. Due to the lack of output channels for these devices, their appeal to the general public is limited. Privacy is another concern regarding the use of Pupil

Invisible because of its discrete environmental data collection ability. Other eyewear such as SKUGGA⁹ and CTRL Eyewear¹⁰ provide automatic tinting control using ambient light sensors without any interaction functionality.

Equipping eyewear with miniature sensing abilities provides opportunities for researchers to explore and expand the application realm of these devices. Zhou et al. [15] presented the feasibility of measuring mental workload with infrared thermal sensors in the lab setting. Tag et al. [13] assessed fatigue levels by capturing participants' (EOG) signals in-the-wild. Uema and Inoue [14] used EOG data to measure users' concentration levels in different contexts. Ishimaru et al. [4] captured eye blink data using infrared sensors to predict users' high-level on-going activities and Dementyev and Holz [3] used IR information to log blink frequencies and alleviate dry eyes by triggering blinks through stimuli.

Other than for data collection purposes, researchers also exploited sensors to combine with other miniature technologies for alternative output modalities. Rantala et al. [10] proposed gaze gestures combined with haptic feedback to enable reliable input on such devices. Costanza et al. [1] utilized peripheral vision to deliver less obtrusive visual notifications using such devices. Olwal and Kress [9] used low-power LED on the inner side of the frame for navigation guidance and projected pre-recorded computer-generated holographic (CGH) icons for limited in-lens display.

The often bulky form factor induced by excessive functionality in high-end smart glasses and the scarcity of output channels in eyewear for sensing purposes both contribute to the lack of social acceptance of those devices as ubiquitous eyewear for everyday use. We propose an intermediate design space on the functionality-simplicity spectrum for an everyday smart eyewear design.

3 DESIGN SPACE FORMULATION

Glasses and wristwatches are two of the most common functional gadgets found on our bodies in our everyday life [5, 8]. Despite sharing the early inceptions, the two devices followed distinct digitisation processes. Whereas analogue watches face steadily decreasing user numbers, smartwatches are catching up [2]. During the evolution of analogue watches to becoming smartwatches, hybrid systems were developed. The development presented with devices that displayed limited digital information, with low-resolution digital watches utilizing numerical interfaces, and, more recently, fitness wristbands with similar displays. These low-resolution devices are still popular despite the advent of smartwatches because of their simplistic functionality, low cost and often specific use scenarios.

¹<https://www.microsoft.com/en-us/hololens>

²<https://www.magicleap.com/>

³<https://www.google.com/glass/start/>

⁴<https://www.bynorth.com/>

⁵<https://www.vuzix.com/products/blade-smart-glasses>

⁶<https://www.enjoyvue.com/>

⁷<https://jins-meme.com/en/>

⁸<https://pupil-labs.com/news/2019-01-09/pupil-invisible-beta-launch.html>

⁹<http://skuggaeyewear.com/>

¹⁰<http://www.e-tintproducts.com/ctrl-eyewear/>

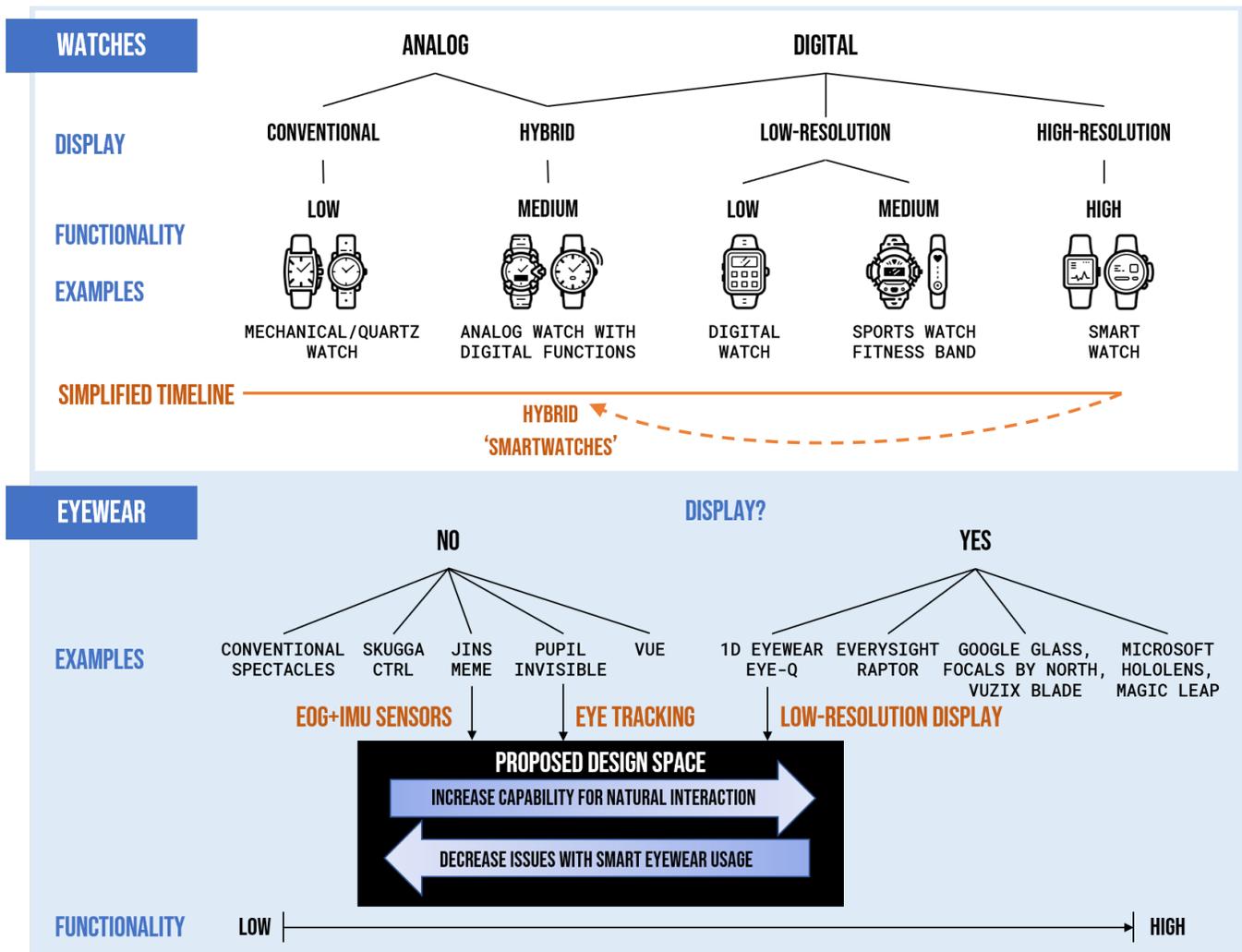


Figure 1: Design Space Formulation.

In contrast to the gradual evolution of smartwatches, the evolution of smart eyewear has included a discontinuity—it is not as easy to find devices which sit between traditional prescription glasses and smart glasses. Smart glasses, such as Google Glass and Focals, share similar functionality with smartwatches as secondary and ubiquitous digital displays embedded on devices which are already habitually worn by users. Even though there is a larger population wearing glasses than that wearing watches, smart glasses are rarely seen in everyday life compared to smartwatches [5, 8]. Potential reasons for lower social acceptance include obtrusive form factor, distraction and privacy concerns and conflict with existing prescription glasses.

Figure 1 illustrates the motivation behind our proposed design space. Inspired by the evolution of smartwatches, we propose to bridge the gap between everyday glasses and

smart glasses with an intermediate type of eyewear. We formulate a design space for eyewear with unobtrusive form factor, low-resolution display, simplistic functionality and context-awareness through environmental and physiological sensing. These devices should be easily incorporated with prescription frame glasses without structural modification.

Table 1 summarises our design space analysis covering different input and output modalities in implicit and explicit forms. We focus on implicit input and low-resolution output modalities to explore interaction affordance.

Input Modalities

In this work, we use Schmidt’s definition of *implicit input* as “an action, performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input.” We define *explicit input* as

	Implicit	Explicit
Input Modality	Gaze direction; Stress; Workload; Fatigue; Head Movement; Facial Expression	Touch; Smooth Pursuit
Output Modality	Automatic tinting; Background data logging; Peripheral notification	Peripheral display; LED; See-through OLED; Symbolic holograph; Audio; Haptic

Table 1: Design Space

users' deliberate manipulation of the device for the purposes of interacting with it [11].

Implicit Input. The numerous miniaturised environmental and physiological sensors embedded in existing wearable devices enable potential input modalities with implicit context detection and data collection without users' awareness. Gaze direction can be detected by training algorithms to recognise patterns in EOG signal from users' eyes. Electrodermal activity (EDA), facial temperature and blink rate enable detection of users' cognitive state variations including stress, workload and alertness. Miniature EDA sensors and infrared temperature sensors can be unobtrusively embedded in eyewear frames and blink rate can be captured by EOG sensors. Natural movement from users' head can be detected by the IMU sensors and used for activity logging and motion-related interaction. Facial expression can be detected by training algorithms to recognise facial skin deformation with photo reflective sensors [6]. Ambient light sensors can inform the device when the lighting condition is uncomfortable.

Explicit Input. In the context of ubiquitous smart eyewear interaction, we explore simplistic explicit input modalities which do not require complex hardware support. Instead of advanced gesture recognition as implemented in HoloLens, simple directional touch gestures can be utilised by embedding miniature capacitive touchpads on the outside of the temples. EOG signals can be used to utilize eye movements for smooth pursuit interactions and to enable calibration-free gaze input.

Output Modalities

In this work, we define *explicit output* as the presentation of information which leads to users' immediate awareness. We define *implicit output* as notifications or background data logging which do not require users' immediate attention or continuous engagement.

Implicit Output. As discussed above, physiological sensors enable passive background data logging. This can be used to monitor vital signs and other health or fitness-related indicators such as the number of steps walked, heart rate, blood oxygen levels, and distance travelled within certain time periods¹¹¹². Costanza et al. have used LED lights in the peripheral vision field, which can be attached to the inside of eyewear temples to enable implicit notifications without occupying users' attention [1]. Subtle self-tinting can provide users with a comfortable vision in combination with ambient light sensors without their notice.

Explicit Output. In the context of this work, we focus on the simplistic presentation of notification and other explicit information which induce users' immediate awareness but do not require their continuous engagement. LEDs can be embedded and activated at different locations on the frame to present directional information. Transparent OLED screens with small form factor, such as SparkFun Transparent OLED¹³, provide a simplistic graphical display for necessary information such as time, temperature, and notification summary that is available with limited computing power and power consumption. Symbolic holograph projections are a visual alternative to graphical displays which present symbolic information from a predefined set, instead of continuously generating new patterns. Acoustic, haptic and bone conduction output can present notifications or as secondary feedback modalities to compensate for other primary output modalities [10].

4 APPLICATIONS

With our enumeration of potential interactions afforded, we illustrate three applications as examples of implementing our design space. We focus on practical everyday scenarios to explore different combinations of contextual sensor input and unobtrusive output.

Context-Aware Information

Combining head movement detection by IMU sensors with physical contextual information collected by environmental sensors, the device can infer users' underlying intentions and provide simple feedback. For example, time, weather and agenda icons can be displayed as a holographic projection or transparent OLED content when users look up at the sky.

Implicit Assistance

Implicit assistance contributes to better accessibility in scenarios where users could not reach other devices, such as

¹¹<https://www.apple.com/au/apple-watch-series-4>

¹²<https://buy.garmin.com/en-AU/AU/p/605739>

¹³<https://core-electronics.com.au/sparkfun-transparent-oled-hud-breakout-qwiic.html>

	Implicit Input	Explicit Output
Implicit Output	Automatic tinting under sunlight; Unobtrusive message notification during task [1]; Background lifelogging (heart rate, steps, etc.); Facial expression detection; Stress and fatigue detection.	Lifelogging with camera.
Explicit Output	Drowsiness alert; Attention alert; Emotion regulation; Stress regulation.	Notification responding; Face-touching input; Smooth pursuit.

Table 2: Applications

phones and computers, while being occupied with demanding tasks. For example, symbolic left/right arrows can be displayed during running or cycling to support navigation. Symbolic notifications can be displayed to alert users if negative physiological features are detected such as fatigue, stress, and drowsiness. For example, this feature could be useful in detecting fatigue driving.

Cross-Device Interaction

As everyday wearable devices, smart eyewear has the advantage of ubiquitous availability. While smartphones can display sophisticated semantic and graphical information, users can spend an unnecessarily long time to find the information intended through different software due to the overpowering interactivity. This process can be further simplified by combining mobile interaction with smart eyewear while utilizing its sensing abilities. For example, users can receive a notification of an incoming email as an icon displayed on the glasses. Instead of unlocking the phone and navigating to the email interface, the new email can automatically present itself after the phone is unlocked when the glasses detect that the user is facing the phone while there is an incoming email icon displayed.

5 CONCLUSION

In this paper, we first identified the problem of the low acceptance of smart glasses by society and discussed its potential reasons. We summarised previous research works exploring alternative input and output modalities with smart eyewear. We also investigated state-of-the-art commercial technology-embedded eyewear with novel sensing abilities. Inspired by the evolution of smartwatches, we formulated a design space

for eyewear with intermediate interaction affordance which utilises miniature sensing, low-resolution displays and other assistive interaction modalities. Finally, we proposed example applications utilising different combinations of implicit and explicit interaction modalities to call attention to future works towards ubiquitous smart eyewear interaction.

REFERENCES

- [1] Enrico Costanza, Samuel A. Inverso, Elan Pavlov, Rebecca Allen, and Pattie Maes. 2006. 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)*. ACM, New York, NY, USA, 211–218. <https://doi.org/10.1145/1152215.1152261> event-place: Helsinki, Finland.
- [2] Tony Danova. 2015. THE SMARTWATCH REPORT: The market for luxury wristwatches, retail distribution, and Apple Watch’s big opportunity. <https://www.businessinsider.com/the-smartwatch-report-the-market-for-luxury-wristwatches-retail-distribution-and-apple-watches-big-opportunity-2015-2>
- [3] Artem Dementyev and Christian Holz. 2017. DualBlink: A Wearable Device to Continuously Detect, Track, and Actuate Blinking For Alleviating Dry Eyes and Computer Vision Syndrome. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 1 (March 2017), 1–19. <https://doi.org/10.1145/3053330>
- [4] Shoya Ishimaru, Kai Kunze, Koichi Kise, Jens Weppner, Andreas Dengel, Paul Lukowicz, and Andreas Bulling. 2014. In the Blink of an Eye: Combining Head Motion and Eye Blink Frequency for Activity Recognition with Google Glass. In *Proceedings of the 5th Augmented Human International Conference (AH '14)*. ACM, New York, NY, USA, 15:1–15:4. <https://doi.org/10.1145/2582051.2582066> event-place: Kobe, Japan.
- [5] Natasha Lomas. 2014. Global wearables market to grow 17% in 2017, 310M devices sold, \$30.5BN revenue: Gartner. <http://social.techcrunch.com/2017/08/24/global-wearables-market-to-grow-17-in-2017-310m-devices-sold-30-5bn-revenue-gartner/>
- [6] Katsutoshi Masai, Yuta Sugiura, Masa Ogata, Kai Kunze, Masahiko Inami, and Maki Sugimoto. 2016. Facial Expression Recognition in Daily Life by Embedded Photo Reflective Sensors on Smart Eyewear. In *Proceedings of the 21st International Conference on Intelligent User Interfaces - IUI '16*. ACM Press, Sonoma, California, USA, 317–326. <https://doi.org/10.1145/2856767.2856770>
- [7] Bence Nanay. 2013. *Between perception and action*. Oxford University Press.
- [8] Statistics Netherlands. 2013. More than 6 in 10 people wear glasses or contact lenses. <https://www.cbs.nl/en-gb/news/2013/38/more-than-6-in-10-people-wear-glasses-or-contact-lenses>
- [9] Alex Olwal and Bernard Kress. 2018. 1D eyewear: peripheral, hidden LEDs and near-eye holographic displays for unobtrusive augmentation. In *Proceedings of the 2018 ACM International Symposium on Wearable Computers - ISWC '18*. ACM Press, Singapore, Singapore, 184–187. <https://doi.org/10.1145/3267242.3267288>
- [10] Jussi Rantala, Jari Kangas, Poika Isokoski, Deepak Akkil, Oleg Ääpakov, and Roope Raisamo. 2015. Haptic Feedback of Gaze Gestures with Glasses: Localization Accuracy and Effectiveness. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers (UbiComp/ISWC'15 Adjunct)*. ACM, New York, NY, USA, 855–862. <https://doi.org/10.1145/2800835.2804334> event-place: Osaka, Japan.

- [11] Albrecht Schmidt. 2005. Interactive context-aware systems interacting with ambient intelligence. *Ambient intelligence* 159 (2005).
- [12] E Temple Smith. 1928. THE HISTORY OF SPECTACLES. *Medical Journal of Australia* 2, 19 (1928), 578–587. <https://doi.org/10.5694/j.1326-5377.1928.tb13682.x>
- [13] Benjamin Tag, Andrew W. Vargo, Aman Gupta, George Chernyshov, Kai Kunze, and Tilman Dingler. 2019. Continuous Alertness Assessments: Using EOG Glasses to Unobtrusively Monitor Fatigue Levels In-The-Wild. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*. ACM Press, Glasgow, Scotland Uk, 1–12. <https://doi.org/10.1145/3290605.3300694>
- [14] Yuji Uema and Kazutaka Inoue. 2017. JINS MEME algorithm for estimation and tracking of concentration of users. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers*. ACM, 297–300.
- [15] Qiushi Zhou, Joshua Newn, Namrata Srivastava, Tilman Dingler, Jorge Goncalves, and Eduardo Velloso. 2019. Cognitive Aid: Task Assistance Based On Mental Workload Estimation. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM, New York, NY, USA, LBW2315:1–LBW2315:6. <https://doi.org/10.1145/3290607.3313010> event-place: Glasgow, Scotland Uk.