Eye-Tracking for Cognitive Well-Being: Balancing Detection and Ethical Feedback

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Abstract

This work explores the ethical challenges of presenting cognitive health data using eye-tracking technology, focusing on when and how to provide feedback that fosters reflection without causing distress. The prototype system, which delivers eye-tracking games through a head-worn eye tracker, has two primary objectives: to investigate whether training eye movements can positively impact cognitive health and to explore ethical approaches for presenting cognitive feedback to users. By evaluating different feedback strategies—including user-controlled notifications, gradual disclosure, and emotional framing—we aim to better understand how to balance early awareness with user autonomy while ensuring that sensitive information is presented thoughtfully.

Keywords

Eye Tracking, User-Centered Design, Behavioral Interventions, Cognitive Health

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1 Introduction and Motivation

As the proverbial "windows to the soul," research has shown that eye movements, or the inhibition thereof, can work as an indicator of cognitive health. Research shows that certain eye movement patterns correlate with cognitive decline: for example, individuals with mild cognitive impairment (MCI) or dementia exhibit less ocular control than healthy peers and commit more errors in gaze inhibition tasks [Noiret et al. 2018]. These correlations have spurred efforts to use eye tracking for early detection of cognitive impairment, especially considering the importance of timely intervention and therapy in delaying the onset of such impairments [Karssemeijer et al. 2017; Livingston et al. 2017]. This has become increasingly feasible with recent advancements in eye-tracking technology, allowing for the continuous unobtrusive monitoring of cognitive health indicators "in the wild". An increasing number of studies are supporting the efficacy of using eye tracking as a tool for cognitive interventions [Arabi et al. 2019; García-Baos et al. 2019].

However, this also raises a crucial question: when and how should a person be informed of potential signs of cognitive decline? In other words, what is the ethical timing and manner of presenting sensitive health data to users during daily life, in a way that respects user autonomy and emotional well-being, especially when the nature of the data being presented pertains to one's cognitive health and the possible deterioration thereof?

Therefore, in this work, we propose an eye-tracking training system aimed at exploring its viability as a day-to-day detection and intervention tool for cognitive decline, as well as how it can deliver feedback to encourage personal reflection without causing distress. We discuss the ethical challenges of disclosing such information and how users might react, drawing on related work for preliminary insights. We outline how our approach differs from existing eye-tracking applications by focusing not only on what data to collect, but also on how to deliver feedback so that it enables personal reflection without causing distress. We also describe our planned investigations into optimal data presentation strategies and detail ethics considerations for responsible use of this technology.

2 Related Work

2.1 Eye Movements and Cognitive Health

Abnormalities in eye movements have been linked to problems with cognitive functions such as working memory and disinhibition in a wide range of conditions [Hoffman and Subramaniam 1995]. For example, a lower degree of saccadic control has been correlated with executive deficits in inhibitory control, attention, working memory, and self-monitoring [Pereira et al. 2020]. One of the widely used tasks that demonstrate this concept is known as the anti-saccade task, where individuals are asked to fixate on a stationary target, after which a new stimulus image is presented adjacent to the old one. The individual is then asked to look in the opposite direction of the new stimulus, thereby measuring the ability to inhibit a reflexive saccade; failure to do so is recorded as an error [Munoz and Everling 2004]. Individuals with MCI or dementia have been shown to exhibit a higher rate of error in such tests [Wilcockson et al. 2019]. Such individuals have also shown to have significantly higher eye blink rates [Ladas et al. 2014] as well as lower accuracy

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and speed in smooth pursuit [Pavisic et al. 2017] and fixations [Crutcher et al. 2009; Kim et al. 2022].

As these examples illustrate, specific eye-tracking metrics can serve as proxies for underlying cognitive states. For instance, prolonged saccade latencies and higher antisaccade error rates may reflect slowed processing speed or executive dysfunction [Pereira et al. 2020], while elevated blink rates have been linked to cognitive fatigue or neurological impairment [Ladas et al. 2014]. Such metrics are often validated against standard neuropsychological assessments, supporting their use as indirect indicators of cognitive health.

2.2 Presenting Sensitive Health Data

Prior HCI research has explored how to present sensitive health data to users through intuitive, user-centered interfaces. In our context of cognitive health, this means designing feedback that is understandable and respectful of users' emotional needs, avoiding alarm while conveying important changes. HCI work on persuasive and reflective feedback mechanisms also informs our approach. Persuasive interfaces have been used to motivate healthy behavior – a classic example is the UbiFit system's "garden" display, which visualizes physical activity progress as a growing garden to encourage exercise [Consolvo et al. 2008]. In regards to cognitive health, prior work suggests that interactive feedback can indeed drive improvement – for instance, giving older adults engaging feedback through games or visualizations has been shown to improve aspects of memory and cognitive function [Benitez-Lugo et al. 2022].

Our preliminary insights from literature highlight the complexity of designing technology-based interventions of this nature. While parallels can be drawn to similar situations where healthcare professionals have to "deliver bad news", this specific problem has a twist: the giver of bad news tends to be just an app or a computer notifying the user directly, which raises new questions around message delivery timing and interface design. Addressing it is key to distinguishing our approach from prior eye-tracking applications that simply detect or train, as we focus on the human factors of feedback delivery. Thus, our work aims to fill this gap by investigating how an eye-tracking system could ethically integrate cognitive health feedback into everyday life. This entails addressing questions of timing (when to interrupt or notify the user), modality and content of feedback (how to communicate results), and user agency (how to give users control over their data and its disclosure).

3 Proposed Approach and Strategies

Our project explores solutions through a combination of technology design and user studies. We have developed a prototype system named "The Firefly" using the Pupil Labs Neon eye tracker [Baumann and Dierkes 2023] to periodically collect eye movement data in everyday contexts. The system can periodically administer brief gaze-based tasks in the form of short eye-tracking games, where the user has to follow a firefly's flight in different patterns and speeds around the screen; the firefly lights up to show the user is correctly staying on target, while passively recording eye metrics such as blink rate, saccade length, and smooth pursuit accuracy, all of which would be utilized in post-hoc data analysis.

In addition, we are planning a series of studies to investigate optimal data presentation strategies. A key aspect is user autonomy in feedback timing. Rather than the device unilaterally pushing alerts, one strategy is user-controlled feedback: the user could specify when they want to review their cognitive data (for instance, setting a weekly summary, or only receiving alerts if metrics cross a certain threshold). This approach respects the user's control and "right not to know" until they are ready or willing. We will contrast it with automated, immediate feedback in terms of user satisfaction, anxiety, and knowledge gain.

Another strategy we will explore is gradual disclosure. Instead of bluntly stating that the user is showing signs of cognitive decline, the system may start with more subtle subtle cues or partial information. For example, an initial message might simply encourage the user to perform a certain cognitive exercise or might visualize a small change in performance without interpretation. Only upon further inquiry or continuation of certain trends would more explicit information be revealed. This tiered approach could acclimate users to the idea of change and gauge their desire to learn more. We hypothesize that gradual, layered feedback can prevent sudden distress and give users a sense of control over learning about themselves. Through controlled studies with participants, we hope to shed light on user reception of these different strategies. Metrics will include the users' emotional responses (using standardized mood questionnaires), subjective cognitive self-assessments, their perceived control and trust in the system, and their recall/understanding of the information. We will also examine behavioral outcomes (do they engage in recommended exercises after receiving feedback? Do they choose to adjust their feedback settings over time?). By comparing conditions, we aim to derive insights into which methods best enable productive self-reflection while minimizing negative effects (e.g., users misinterpreting ambiguous feedback or reacting to false-positive results). Our ultimate goal is to formulate design guidelines for cognitive health feedback interfaces, which could generalize to other sensing domains beyond eye tracking.

4 Conclusion and Future Work

This work tackles an often overlooked question at the intersection of eye-tracking technology, cognitive health, and human-computer interaction: how can we ethically integrate sensitive health information such as cognitive decline into everyday life? Our approach reframes the problem from simply detecting cognitive change to presenting the data to the user in a more user-friendly fashion. By engaging users in the design of feedback, we hope to develop strategies that let people benefit from early awareness of cognitive changes without undue distress. This endeavor goes beyond existing eye-tracking applications by focusing on when and how information is delivered, not just on what is measured.

In an age where digital biomarkers are increasingly available, the ethical timing and modality of feedback becomes an important design consideration. We also consider potential risks at both the individual and societal levels. For individuals, protecting the privacy of sensitive cognitive data and mitigating psychological harm are key concerns, whereas at the societal level, issues such as data misuse, unfair bias, or stigmatization of cognitive conditions must be addressed. The preliminary insights and proposed studies

described here lay the groundwork for more extensive exploration. We hope that the insights from this work could contribute to establishing guidelines for eye tracking and other pervasive health monitoring technologies, fostering a more user-centered approach to not only eye-tracking applications but also to assistive solutions as a whole across the field of HCI.

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