Human Factors in Sports, Preventive Medicine and Innovative Agonology, Vol. 188, 2025, 1–7
https://doi.org/10.54941/ahfe1006475

SynTec: A Low-Cost Eye-Tracking and EEG-Based Diagnostic System for Concussion Assessment in Sports

Mohammadmehdi Mortazavi[1], Min Kang[2], and Jeff Feng[1]

[1]Department of Industrial Design, University of Houston, Houston, TX, USA
[2]Health Design Lab, University of Houston, Houston, TX, USA

ABSTRACT

Concussions are a common form of mild traumatic brain injury (mTBI), particularly among athletes in high-impact sports. Existing diagnostic tools such as SCAT, VOMS, and EEG are limited by cost, subjectivity, or complexity. This paper presents SynTec, a novel wearable system that integrates eye-tracking and EEG technologies to support concussion screening in a compact, affordable format. A user-centered design process was employed, including stakeholder interviews, surveys ($n = 36$), and iterative prototyping. The device supports vestibular and ocular motor assessments through eye-tracking and records electrical brain activity from frontal regions using low-cost EEG sensors. Results are processed via an accompanying mobile application. SynTec demonstrates a new direction for rapid, accessible, multi-modal concussion diagnostics, particularly for youth and amateur sports.

Keywords: Concussion, Mild traumatic brain injury, EEG, Eye-tracking, Sports safety, Wearable technology, Human-centered design

INTRODUCTION

Concussions, classified as a form of mild traumatic brain injury (mTBI), affect an estimated 3.8 million individuals annually in the United States alone, particularly within the context of contact sports (Daneshvar et al., 2011). Despite their prevalence, nearly 50% of these injuries go unreported due to underrecognition, stigma, and limited access to timely diagnostic resources (Torres et al., 2013). If left untreated, repeated concussions can lead to serious neurological complications such as Second Impact Syndrome, post-concussion syndrome, or long-term cognitive deficits (Military Health System, 2020).

Standard diagnostic approaches—including the Standardized Assessment of Concussion (SAC), Sport Concussion Assessment Tool (SCAT), Vestibular/Ocular Motor Screening (VOMS), and electroencephalography (EEG)—offer important clinical insights but suffer from key limitations. These include observer bias, subjectivity, limited portability, and high implementation costs (Rosenblum et al., 2024; Haneef et al., 2013; Ianof et al., 2017). Although EEG and eye-tracking technologies have shown promise in concussion detection, current systems remain expensive, complex, or research-exclusive (Grand View Research, 2023).

There is a growing need for accessible, rapid, and accurate diagnostic systems that can be used in decentralized environments such as schools, athletic fields, and community clinics. This paper introduces SynTec, a compact, wearable diagnostic system that combines eye-tracking and EEG technology into a single, low-cost device. The system enables both vestibular-ocular assessment and real-time brainwave analysis through a smartphone interface. By leveraging user-centered design methods, including survey data and ergonomic testing, SynTec aims to democratize concussion diagnostics and reduce reliance on high-cost, hospital-based tools.

The remainder of this paper presents a review of related work (Section 2), followed by the research methodology and user-centered design process (Section 3). Section 4 details the results of functional prototyping and user testing. Section 5 provides a discussion of implications, limitations, and opportunities for future development. The paper concludes in Section 6 with a summary of contributions.

RELATED WORK

Numerous tools and protocols have been developed to identify concussions in athletic and clinical settings. The Standardized Assessment of Concussion (SAC) and the Sport Concussion Assessment Tool (SCAT) are commonly used sideline screening tools, offering a combination of cognitive and symptom-based checks. However, these tools rely heavily on subjective reporting and observational interpretation, which reduces reliability and may lead to underdiagnosis (Daneshvar et al., 2011; Torres et al., 2013).

The Vestibular/Ocular Motor Screening (VOMS) test addresses vestibular and oculomotor impairments by assessing smooth pursuit, saccades, gaze stability, convergence, and visual motion sensitivity (Military Health System, 2020). Despite its clinical value, VOMS still depends on the examiner's interpretation of a patient's performance, introducing human error and inconsistencies. Moreover, studies have noted a higher rate of false positives among female athletes and individuals with a history of migraines (Rosenblum et al., 2024).

Electroencephalography (EEG) has shown potential for detecting functional brain changes following concussion. While not yet a gold standard for mTBI diagnosis, several studies have reported meaningful EEG patterns associated with post-concussive symptoms, including reductions in alpha wave activity and increased theta power (Haneef et al., 2013; Ianof et al., 2017). However, current EEG systems are either research-grade and cost-prohibitive, or require specialized environments and personnel, limiting their utility in the field.

Several emerging products attempt to address these limitations. Devices like the Oculogica EyeBox and RightEye EyeQ use eye-tracking to assess neurological function. VR-based systems such as Neuro Kinetics' IPAS and SyncThink's Eye-Sync combine visual stimuli with motion tracking to evaluate vestibular function. While innovative, these systems are often expensive, bulky, and not designed for rapid deployment or consumer-level use (Grand View Research, 2023).

The integration of EEG and eye-tracking into a single diagnostic platform is rare. High-end research-grade systems like the Cognixion Axon-R and OpenBCI's Galea offer multimodal capabilities but are priced upwards of $25,000 and primarily used in laboratory settings. These platforms highlight the potential of multimodal systems, but also underscore a lack of accessible solutions for everyday use by athletic organizations, schools, and frontline clinicians.

In summary, existing concussion diagnostic tools either suffer from subjectivity, are limited to single modalities, or are inaccessible due to cost and complexity. There remains a critical need for a field-deployable, multimodal system that combines objective physiological measurements—such as EEG and eye movement tracking—within a user-friendly, low-cost platform. SynTec was developed in response to this gap.

METHOD

This study followed a user-centered design methodology to inform the development of SynTec, an accessible, multi-modal diagnostic system for concussion assessment. The process included background research, user surveys and interviews, concept ideation, and iterative prototyping informed by ergonomic and functional testing.

User Research

To understand the lived experiences of individuals with concussions and the limitations of current diagnostic approaches, a survey was distributed to 36 respondents who had previously experienced a concussion. The survey included both quantitative and open-ended qualitative questions. Key areas of focus included causes of injury, diagnosis experiences, symptom progression, recovery timeline, and access to healthcare resources.

Results indicated that 55.9% of respondents had experienced a second concussion after the first, and 94.1% had sought medical evaluation. However, several respondents noted delays in diagnosis, misclassification of injury severity, or dissatisfaction with clinical encounters. Recurring symptoms reported included fatigue, vestibular imbalance, memory loss, and emotional dysregulation.

In addition, two in-depth interviews were conducted. The first participant, age 61, described long-term post-concussion symptoms and the eventual onset of Parkinson's-like tremors. The second participant, age 22, described multiple sports-related concussions and limited institutional support for treatment. These qualitative insights highlighted the urgency of developing affordable, non-invasive, and rapid diagnostic tools capable of use outside of traditional medical environments.

Design and Development Approach

Initial ideation focused on integrating validated diagnostic modalities—specifically eye-tracking and EEG—into a compact, wearable form. Early concepts explored virtual reality (VR) and augmented reality (AR) headset platforms. However, many commercial devices included unnecessary features or lacked ergonomic flexibility for diverse users. Inspired by lightweight AR glasses and ergonomic consumer products (e.g., Oakley "Over the Top" frames), the design evolved into a low-profile wearable with modular sensor mounts.

Eye-tracking functionality was prototyped using low-cost webcams and open-source pupil tracking software. A dual-camera configuration was mounted on safety goggles, allowing the tracking of ocular saccades, convergence, and gaze fixation. Testing confirmed that the system could replicate key elements of the VOMS protocol.

For EEG integration, the design incorporated frontal electrode placement (AF7, FP1, AFZ, FP2, and AF8) using dry-contact electrodes embedded into the headband. The system was designed to interface with a companion mobile application, which received and visualized real-time eye-tracking and EEG data. Calibration time was reduced to under 5 minutes.

Prototyping and Testing

Multiple low-fidelity prototypes were developed using 3D-printed shells and flexible materials to evaluate fit and comfort across head sizes and hairstyles. Feedback from peer testers guided refinements to strap configuration, material softness, and weight distribution. Subsequent iterations improved sensor alignment and introduced a rigid internal frame with an outer flexible shell, modeled after over-ear headphones.

The final design emphasized manufacturability, modularity, and ease of cleaning. Although not yet clinically validated, the prototype demonstrated proof-of-concept for a multimodal system combining VOMS-based visual assessments with EEG brain activity monitoring in a single device.

RESULTS

The SynTec system underwent three phases of development, during which its usability, comfort, and technical feasibility were evaluated. The final prototype integrated functional eye-tracking and EEG systems into a single, compact wearable that could perform concussion screening in under 15 minutes.

Survey and Interview Findings

Survey results revealed that 61.8% of respondents expressed concern about future concussions, particularly in the context of unstable physical conditions, work-related anxiety, or histories of untreated injuries. While 94.1% had eventually sought medical evaluation, common concerns included cost, delayed diagnosis, and insufficient clinical understanding of symptoms. Notably, several participants reported delayed diagnosis by months or years, and some experienced long-term cognitive or motor complications.

The qualitative interviews provided deeper insight into diagnostic gaps. One participant described a progression to Parkinson's-like symptoms years after multiple concussions. Another described institutional reluctance to authorize physical therapy, leading to self-withdrawal from sports and a loss of trust in medical systems. These narratives underscored the need for accessible, self-administered diagnostic tools.

Eye-Tracking Prototype Performance

The eye-tracking prototype used two low-cost webcams—one directed at the user's eye and the other at external visual stimuli—combined with open-source tracking software. The setup was tested against standard VOMS test elements such as smooth pursuit, horizontal and vertical saccades, and convergence. The system reliably captured pupil motion and saccadic latency, indicating feasibility for tracking vestibular-ocular abnormalities.

Despite minimal calibration, the prototype demonstrated sufficient frame rate and precision to distinguish between smooth pursuit and saccadic movements. While performance was not yet benchmarked against clinical eye-tracking systems, qualitative feedback indicated it could reproduce essential elements of the VOMS protocol.

EEG Electrode Testing

Five frontal EEG electrode positions were tested using dry-contact sensors embedded into a flexible headset. The target regions—AF7, FP1, AFZ, FP2, and AF8—were selected based on prior research indicating frontal lobe sensitivity to concussive injury (Daneshvar et al., 2011; Torres et al., 2013). Early tests confirmed reliable signal acquisition in resting states, with signal clarity improved by refining electrode pressure and headband stability.

Data was streamed to a desktop interface via serial communication for visualization. While the system did not include automated diagnostic classification, signal consistency showed promise for detecting changes in brainwave patterns relevant to concussion screening.

Ergonomic and Usability Feedback

Usability testing focused on fit, weight distribution, and user comfort. Initial prototypes using rigid shells resulted in poor fit across users with varying head shapes and hairstyles. Later iterations added a flexible outer frame inspired by over-ear headphone structures. The final version included an internal support core, soft padding, adjustable side arms, and modular sensor mounts. Testers reported improved comfort and ease of donning/doffing.

Combined, these results indicate that the SynTec prototype is functionally and ergonomically viable. While further clinical validation is required, preliminary findings support the feasibility of an affordable, field-ready diagnostic system that integrates EEG and eye-tracking in a single device.

DISCUSSION

The results of this study demonstrate the feasibility of designing a multimodal, low-cost concussion screening system that integrates eye-tracking and EEG technologies. SynTec addresses a significant gap in current diagnostic approaches by combining objective physiological data with user-centered design principles, enabling deployment outside of hospital environments. This is particularly relevant for youth sports organizations, schools, and community clinics where access to clinical-grade neurodiagnostic tools is limited.

The prototype effectively recreated core components of the Vestibular/Ocular Motor Screening (VOMS) test while adding the capability to record frontal EEG activity. By using accessible hardware and open-source software, SynTec provides an opportunity to decentralize concussion screening and reduce reliance on subjective symptom checklists. The inclusion of a companion mobile app for real-time results visualization further supports the system's usability in field settings.

From a design perspective, iterative testing revealed the importance of ergonomic adaptability in wearable headgear. Factors such as head shape, hair volume, and comfort significantly influenced user acceptance. The final prototype resolved many of these issues by introducing a hybrid structure with a flexible outer shell and an internal rigid frame. This approach could serve as a model for other wearable health technologies requiring stable sensor placement.

Despite these strengths, the study has several limitations. First, the eye-tracking and EEG systems, while functional, have not yet been benchmarked against clinical-grade devices in controlled environments. Validation studies involving medical professionals and athletes are required to confirm diagnostic reliability. Second, the current EEG system captures raw signals but does not yet support real-time classification or anomaly detection. Future iterations should explore the integration of machine learning models for automated assessment.

Additionally, while the survey and interview data provided valuable insights, the sample size was limited and may not fully represent the diversity of concussion experiences across age, gender, or sport type. Expanding user research to include clinicians, athletic trainers, and rural healthcare providers would further refine design requirements and use case scenarios.

Nevertheless, the development of SynTec marks a promising step toward democratizing brain health diagnostics. The system's affordability, portability, and user-friendly interface position it as a potential tool for early concussion screening, follow-up monitoring, and even baseline data collection in sports preseason evaluations.

CONCLUSION

This paper presented the research and development of SynTec, a wearable concussion screening system that combines eye-tracking and electroencephalography (EEG) to offer a portable, low-cost diagnostic alternative for use in sports and field settings. Through a user-centered design approach incorporating survey responses, interviews, and iterative prototyping, SynTec was developed to address the shortcomings of current concussion assessment tools—namely their subjectivity, limited accessibility, and high cost.

Preliminary results suggest that SynTec can replicate key components of established tests such as VOMS, while also enabling the acquisition of frontal EEG signals relevant to concussion monitoring. The system's ergonomic form factor, paired with its ease of use and compatibility with mobile interfaces, makes it a viable candidate for non-clinical use by athletes, coaches, and caregivers.

Future work will involve clinical validation, refinement of EEG signal interpretation, and integration of AI-based diagnostic algorithms. Broader stakeholder engagement and real-world field testing will be necessary to further establish SynTec as a credible and scalable tool for improving concussion safety and brain health monitoring.

REFERENCES

Centers for Disease Control and Prevention: Guidelines for concussions in youth sports. MMWR Morb. Mortal. Wkly. Rep. 69(27), 875–882 (2020)

Children's Hospital of Philadelphia: Visio-vestibular markers of concussion. https://injury.research.chop.edu/research/concussion-and-brain-health/objective-measures-concussion

D. Rosenblum et al.: False-positive rates, risk factors, and interpretations of the Vestibular/Ocular Motor Screening in collegiate athletes. J. Athl. Train. 59(6), 600–607 (2024).

D. H. Daneshvar, C. J. Nowinski, A. C. McKee, R. C. Cantu: The epidemiology of sport-related concussion. Clin. Sports Med. 30(1), 1–17 (2011).

D. M. Torres et al.: Sports-related concussion: Anonymous survey of a collegiate cohort. Neurol. Clin. Pract. 3(4), 279–287 (2013).

Grand View Research: Artificial intelligence (AI) in healthcare market size, share & trends analysis report. https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-ai-healthcare-market (2023).

J. N. Ianof, R. Anghinah: Traumatic brain injury: An EEG point of view. Dement. Neuropsychol. 11(1), 3–5 (2017).

Military Health System: Vestibular/Ocular Motor Screening (VOMS). Health.mil (2020). https://health.mil/Reference-Center/Publications/2020/07/31/Vestibular-Ocular-Motor-Screening-VOMS

Oculogica: EyeBox. https://www.oculogica.com/ (Accessed March 2025).

RightEye: EyeQ. https://www.righteye.com/ (Accessed March 2025).

University of California, San Francisco: TRACK-TBI. https://tracktbi.ucsf.edu/transforming-research-and-clinical-knowledge-tbi

Z. Haneef, H. S. Levin, J. D. Frost Jr., E. M. Mizrahi: Electroencephalography and quantitative EEG in mild traumatic brain injury. J. Neurotrauma 30(8), 653–656 (2013).