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Electrooculography Dataset for Objective Spatial Navigation Assessment in Healthy Participants

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In the quest for understanding human executive function, eye movements represent a unique insight into how we process and comprehend our environment. Eye movements reveal patterns in how we focus, navigate, and make decisions across various contexts. The proposed dataset includes electrooculography (EOG) signals from 27 healthy subjects, capturing both vertical and horizontal eye movements. The recorded signals were obtained during the video-watching stage of the Leiden Navigation Test, designed to assess spatial navigation abilities. In addition to other data, the dataset includes scores from the Mini-Mental State Examination and the Wayfinding Questionnaire. The dataset comprises carefully curated components, including relevant information, the Mini-Mental State Examination scores, and the Wayfinding Questionnaire scores, encompassing navigation, orientation, distance estimation, spatial anxiety, as well as raw and processed EOG signals. These assessments contribute more information about the participants' cognitive function and navigational abilities. This dataset can be valuable for researchers investigating spatial navigation abilities through EOG signal analysis.

Background & Summary

Executive functions constitute fundamental cognitive mechanisms encompassing working memory, cognitive flexibility, and inhibitory control processes. These operations facilitate strategic planning, goal-directed behavior, and adaptive responses to novel situations, particularly in spatial navigation, highlighting the complex interplay between cognitive control and environmental interaction[1,2]. The multidimensional nature of spatial navigation integrates positional awareness, spatial orientation mechanisms, and strategic route planning capabilities. Empirical evidence demonstrates strong correlations between psychometric assessments and performance in dynamic spatial navigation tasks[3–6]. These competencies extend beyond daily activities to specialized domains, as evidenced by research on athletic performance where cognitive mapping abilities influence motor coordination[7–9].

Spatial navigation proficiency, encompassing both cognitive mapping abilities and the utilization of external aids, influences psychological well-being and spatial anxiety management[10]. Its assessment serves as a crucial diagnostic tool, particularly for neurodegenerative conditions such as Alzheimer's disease, where directional perception deficits manifest early[11]. Current evaluation methodologies include eye tracking systems[12], electrooculography (EOG)[13], electroencephalographic (EEG) monitoring[14], and virtual navigation paradigms[15,16]. Additionally, gamified tools like Sea Hero Quest provide comprehensive insights into visuospatial processing and broader cognitive capabilities[3].

Knowledge about spatial navigation and its assessment helps identify early signs of cognitive impairments, assess hippocampal functioning, and develop approaches to improve deficient navigational behavior, especially in the elderly and those with neurological diseases[17]. The EOG measures eye movements through extra-ocular muscle electrical signals. It is nonintrusive and ideal for continuous field use. It can precisely measure eye movements and find applications in brain-computer interfaces[18,19]. While EOG has a lower spatial resolution than eye tracking, it excels in capturing temporal measures. Notably, EOG can assess parameters like Quiet Eye duration and spectral decomposition, which aid in distinguishing between low-frequency oscillations and evoked responses over time[20]. Furthermore, EOG signals can be processed in real-time using model-oriented denoising

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approaches, preserving the inherent characteristics of the signals without distortion, unlike traditional methods such as bandpass filtering[21,22].

Utilizing engineering tools for data collection in cognitive psychology can significantly enhance relevant research by yielding more detailed and profound insights. This approach leads to increased efficiency, improved data quality, and, in some instances, reduced participant burden. Existing literature highlights that engineering tools offer cost-effective ways to enhance data quality[23]. Moreover, such tools facilitate the conversion of data types between devices and applications, thus ensuring seamless interpretation and analysis[24]. Moreover, they increase the reliability and validity of collected information and reduce participant fatigue and practice effects, thereby enhancing overall research outcomes and insights into cognitive processes[23].

Recent progress in EOG technology has led to various approaches for capturing and analyzing eye movements. A new EOG system using an ATmega AVR microcontroller to capture vertical and horizontal eye movements has been developed. This system integrates dual-channel filtering with High-Pass and Low-Pass Filters to manage the signal range of 0.1 to 10 Hz. Tested with diverse volunteers, this setup effectively gathers eye movement data, demonstrating potential applications in rehabilitation and assistive technologies[25]. Additionally, another study offered a dataset of EEG and EOG recordings from four patients with advanced locked-in syndrome (LIS) due to amyotrophic lateral sclerosis (ALS). The data, collected across several visits, contributes valuable insights into the progression of ALS and supports the development of assistive technologies and brain-computer interfaces (BCIs), enhancing clinical management and therapeutic strategies[26]. Researchers also investigated EOG while participants tracked a moving cross that shifted every 1,250 ms. The cross's horizontal displacements ranged from 1 to 7 degrees, with occasional vertical shifts. Participants were also instructed to blink when the cross changed to a circle. This setup provided calibrated data on the EOG signal's response to different gaze shifts and blinks[27]. Another research employed the g.tec USBamp biosignal amplifier, sampling at 256 Hz, to record EOG data. Their methodology included bandpass filtering from 0 to 30 Hz and a 50-Hz notch filter. The study involved recording eye movements from six healthy individuals, focusing on 600 saccades and 300 blinks per participant using a conventional electrode arrangement, including horizontal and vertical electrodes and ground and reference electrodes positioned on the forehead and behind the left ear[28]. However, existing EOG datasets have largely overlooked cognitive assessment. The primary focus has been on technical performance and practical applications rather than evaluating cognitive abilities. In contrast, this study aims to fill this gap by utilizing the EOG device to assess cognitive functions, exploring how eye movement patterns can provide insights into human spatial navigation ability.

Eye movement datasets for effectively evaluating spatial navigation are currently limited and not widely available. Existing datasets primarily rely on eye tracker devices. However, there is a need for more diverse datasets to assess spatial navigation. EOG devices offer several advantages over traditional eye trackers. Unlike eye trackers, which require a direct line of sight to the eye, EOG measures electrical signals generated by eye movements through electrodes placed around the eyes. This allows EOG devices to function without requiring direct visual contact. Additionally, EOG devices perform well under various lighting conditions, including bright light, darkness, and rapid changes in lighting. In contrast, eye trackers may lose accuracy in poor lighting conditions. EOG devices offer a straightforward design, making them cost-effective and minimizing power consumption. These attributes make EOG devices particularly well-suited for applications with resource constraints. Moreover, their compact size and portability enable their use in various environments. The proposed dataset comprises EOG signals collected from healthy and young subjects. These signals were recorded during the video-watching phase of a previously validated navigation assessment, the Leiden Navigation Test (LNT)[29], designed to evaluate spatial navigation abilities. Additionally, the dataset includes scores from questionnaires, such as the Mini-Mental State Examination (MMSE)[30] and the Wayfinding Questionnaire (WQ)[31]. We hope researchers investigating spatial navigation abilities through EOG signal analysis find this dataset valuable.

Methods

This section overviews the study methodology, including participant details, equipment and scale specifications, task execution protocols, and data preprocessing procedures applied to the collected EOG signals.

Participants. Thirty-two healthy university students were initially recruited for the study. Following a rigorous data quality assessment, five participants were excluded due to anomalies detected in their vertical or horizontal electrooculogram (EOG) signals. Consequently, the final dataset comprised twenty-seven participants (14 males and 13 females) with a mean age of 21.78 ± 1.59 years. While the sample size is modest, we addressed potential limitations by implementing stringent data quality control protocols and tailoring our analytical methods to ensure alignment with the study objectives. This data was collected in the Mechatronics Laboratory, K. N. Toosi University of Technology. All the participants reported no known diseases or visual impairments. Those who required glasses were instructed to wear them during the tasks. All participants received the required information about the study, and to safeguard their privacy, a unique ID number was assigned to each participant. Ethical approval for this study was obtained from the Research Ethics Committee (REC) of the Faculty of Electrical Engineering, K. N. Toosi University of Technology, under reference number 39328-B-D. The study involved the collection of data from young adult students across K. N. Toosi University of Technology. It was conducted in accordance with the ethical guidelines and regulations set forth by the REC. All participants provided informed consent prior to their involvement, and they agreed to the publication of de-identified data for research purposes. The study was also conducted in full compliance with the ethical principles outlined in the Declaration of Helsinki.

Equipment. A two-channel EOG headband (Zehnafzar Rayan Co., Isfahan, Iran) was employed to record the eye movement signals with high precision. The first channel captures vertical eye signals in this device, while the

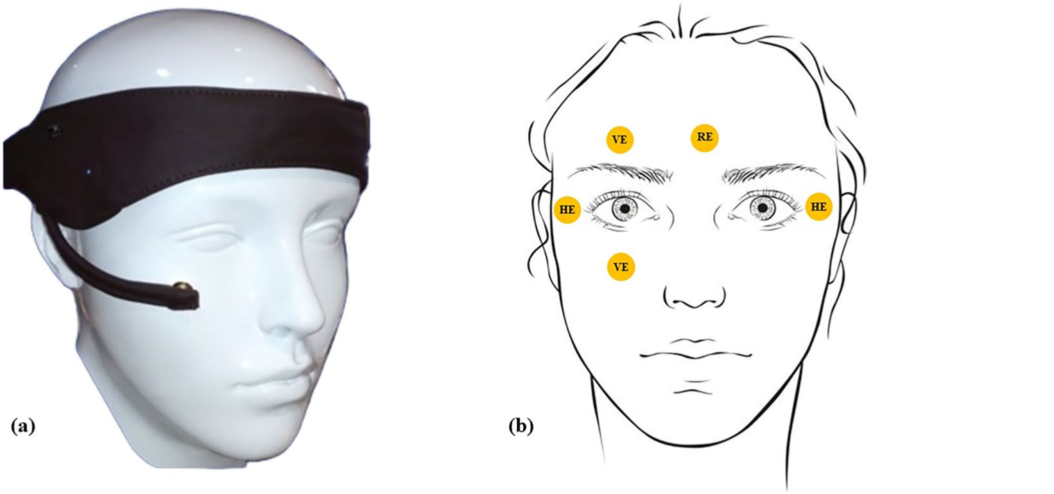

Fig. 1 (**a**) The placement of the headband on the participant's head. (**b**) The positioning of each electrode on the EOG headband: VE = Vertical Electrode, HE = Horizontal Electrode, RE = Reference Electrode.

second records horizontal eye signals. The device functions at a sampling rate of 250 Hz, producing signals within the voltage range of ± 2.4 volts. It includes five gold cup electrodes integrated into flexible material. According to Fig. 1, two electrodes are positioned near the temples to monitor horizontal eye movements, while two more electrodes are placed above and below one eye to capture vertical movements. A fifth electrode, serving as the reference, is located on the opposite side of the forehead.

The device operates wirelessly, is powered by a rechargeable battery, and connects to a PC via Bluetooth. This wireless link enables real-time signal display and automatic recording through a dedicated MATLAB® software, ensuring efficient and accurate data collection. The headband's design and connectivity allow uninterrupted eye movement monitoring, enhancing the collected dataset's robustness.

Scales. The WQ[31] is a 22-item tool designed to assess spatial navigation skills across three dimensions: Navigation and Orientation (11 items), Distance Estimation (3 items), and Spatial Anxiety (8 items). Responses were recorded on a 7-point Likert scale, where 1 represented "Not at all relevant to me" and 7 indicated "Completely relevant to me." Items measuring anxiety utilized a similar scale, with 1 signifying "no discomfort" and 7 reflecting "extreme discomfort." To ensure uniform interpretation, spatial anxiety scores were reversed so that lower values correspond to more severe navigation difficulties.

The MMSE[30] is a cognitive assessment tool used to screen for impairments and monitor changes over time. It measures cognitive domains like orientation, memory, attention, language, and visuospatial abilities. The MMSE includes recalling objects, naming items, and copying shapes. Scoring ranges from 0 to 30, with scores from 24 to 30 indicating normal cognition, 18 to 23 suggesting mild impairment, 10 to 17 indicating moderate impairment, and below 10 denoting severe impairment.

The LNT[29] is a structured test with five categories: landmark recognition, path survey, path route, allocentric, and egocentric location understanding navigation. Each category contains a predefined number of questions. Responses are scored on a binary scale, with correct answers receiving one point and incorrect answers receiving zero.

In a recent work[32], we detailed the Persian adaptation of the WQ. The translation of the WQ and all materials associated with this study followed a rigorous forward-backward protocol to ensure linguistic accuracy and cultural relevance. Two independent bilingual experts initially translated the materials from English to Persian, after which a third expert reviewed and reconciled discrepancies to refine the wording for clarity and consistency. To confirm fidelity to the original, a separate bilingual professional performed a back-translation into English, which was compared to the source text to identify and address any semantic deviations. The finalized version was further validated through cognitive debriefing sessions with three Persian-speaking participants, ensuring the translated tool was comprehensible and psychologically consistent with the original assessment. This process guarantees the Persian WQ's reliability and validity for Persian-speaking populations.

Protocols. All individuals provided informed consent before participating in the study, confirming their comprehension of the study's objectives and their voluntary participation. They then filled out the Persian version of WQ[32], which assessed their navigational strategies and preferences. The examiner then administered the MMSE to evaluate cognitive function. All the questionnaires and forms also were translated into Persian.

Participants were seated on a chair positioned 2.15 meters away from a 46-inch monitor, as shown in Fig. 2. The EOG headband, with electrodes coated in TEN20 conductive gel, was carefully fitted onto the participant's head. Special attention was given to ensure the electrodes made proper contact with the skin, avoiding interference from hair. The headband was powered on and automatically connected to the examiner's computer via Bluetooth, ensuring seamless data transmission.

Fig. 2 The participant wearing the EOG headband is sitting in front of the monitor.

Once the setup was complete, participants were briefed on the procedure, and the LNT video segment was initiated. This phase involved watching an animated navigational task to assess spatial awareness and navigation skills. Upon completing the test, participants were given a wireless mouse to answer the image questionnaire. This offered insights into their perception and understanding of the navigational tasks. Then, test results were recorded under the participant's assigned ID to ensure confidentiality and accurate data tracking.

Data processing. The proposed methodology, referred to as Algorithm 1, which can be found in the Supplementary Material, utilizes advanced signal processing techniques to detect ocular events, specifically blinks, saccades, and fixations, across both horizontal and vertical electrooculography (EOG) channels. The algorithm is structured into six primary stages, each aimed at enhancing the precision and robustness of eye movement detection.

The initial stage encompasses preprocessing vertical and horizontal EOG signals by applying a moving median filter for smoothing, followed by a bandpass filter. These preprocessing steps are designed to attenuate noise and eliminate low-frequency drift, effectively improving the signal-to-noise ratio and facilitating subsequent analytical processes. The algorithm focuses predominantly on the vertical EOG channel for blink detection, identifying potential blinks by pinpointing peaks that surpass a predefined threshold. The derivative of the signal is scrutinized to accurately ascertain the onset and offset of each blink, thereby enabling precise temporal localization of blink events. Detected blinks are marked with a value of 3 in the vertical label signal.

The detection of saccades is conducted independently on both vertical and horizontal channels. The algorithm employs thresholds on the derivative of the EOG signal, with the onset and offset of saccades identified through zero-crossing analysis of this derivative. Importantly, the algorithm for detecting saccades in the vertical channel excludes regions previously identified as blinks, thereby minimizing the incidence of false positives. Detected saccades are designated a value of 2 in their respective label signals.

Following the initial detection phase, a minimum duration threshold is applied to the identified saccades in both channels to differentiate genuine saccades from potential artifacts or microsaccades. Events that meet or exceed this duration threshold retain their value of 2 in the label signal, while those falling short are disregarded in subsequent analyses. The vertical and horizontal label signals are integrated using a maximum function, yielding a composite label signal that comprehensively represents eye movement events across both channels. In overlapping events, the algorithm prioritizes blink detection (value 3) over saccade detection (value 2) to ensure clear delineation of eye movements[33].

The final stage involves identifying and thresholding fixations initially recognized as periods between detected saccades and blinks. A minimum duration threshold is applied to these potential fixations, with those that meet or exceed the threshold assigned a value of 1 in the composite label signal, while those that do not are categorized as unknown events and designated a value of 0. The resulting composite label signal provides a comprehensive representation of eye movement events, classified as follows: 3 for blinks, 2 for saccades, 1 for fixations, and 0 for unknown or ambiguous events. This methodological approach offers a robust framework for EOG signal analysis, yielding detailed insights into eye movement patterns. The systematic design ensures efficient processing and clear delineation of eye movements, even in contexts characterized by overlapping events. Furthermore, integrating duration thresholds and post-processing strategies enhances accuracy while mitigating false positives, providing a comprehensive analysis.

Data Records

The data comprises several components, succinctly illustrated in Fig. 3. The files containing the raw data and the codes for data analysis are available at Figshare[34] (https://doi.org/10.6084/m9.figshare.27156459.v3).

- Dataset.csv: This section encompasses an Excel file that details pertinent information about each of the 27 participants. The dataset includes age, gender, educational level, and MMSE scores. Additionally, it provides detailed scores for each of the subcomponents of the WQ. Similarly, it includes scores for the LNT image questionnaire. Table 1 presents the range and definitions for each abbreviated concept, which is crucial for interpreting the results accurately.
  The MMSE which is a cognitive assessment tool designed to evaluate cognitive function, the scoring ranges

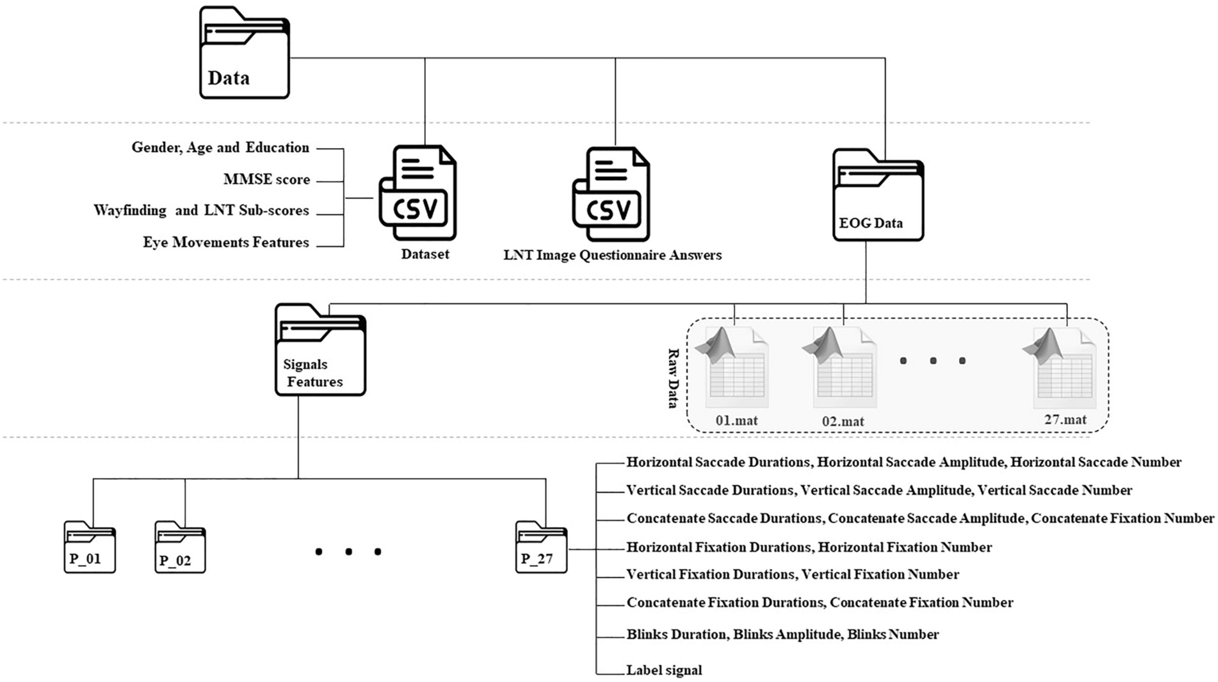

Fig. 3 Data folder structure.

Column Names	Range and Concepts
Gender	M = Male, F = Female
Age	$19 \leq$ Age ≤ 25
Education	B = Bachelor, M = Master
MMSE Score	$0 \leq$ MMSE ≤ 30
Navigation and orientation (WQ)	$11 \leq$ Navigation and orientation ≤ 77
Distance estimation (WQ)	$3 \leq$ Distance estimation ≤ 21
Spatial anxiety (WQ)	$8 \leq$ Spatial anxiety ≤ 56
Landmark recognition (LNT)	$0 \leq$ Landmark recognition ≤ 8
Path survey (LNT)	$0 \leq$ Path survey ≤ 4
Location allocentric (LNT)	$0 \leq$ Location allocentric ≤ 4
Location egocentric (LNT)	$0 \leq$ Location egocentric ≤ 4
Path route (LNT)	$0 \leq$ Path route ≤ 4

Table 1. Summary of demographic and range of variables.

from 0 to 30, with higher scores indicating better cognitive function. In this dataset, all participants scored above 27, indicating minimal to no cognitive impairment. The WQ evaluates three aspects of navigational skills: the navigation and orientation subscore ranges from 11 to 77, the distance estimation subscore ranges from 3 to 21, and the spatial anxiety subscore ranges from 8 to 56. The LNT assesses participants' ability to recognize and interpret landmarks and paths in the video segment of this test. It comprises five subcategories: landmark recognition from 0 to 8, path survey from 0 to 4, location allocentric from 0 to 4, location egocentric from 0 to 4, and path route from 0 to 4. A correct response is awarded 1 point, while an incorrect response receives 0 points. While adapting to Persian, a translation issue altered the meaning of the egocentric location subscore questions. Consequently, this subscore was excluded from the final dataset to maintain the accuracy of the assessment.

Additionally, the file includes several features designed for easy access and use. These features cover vital metrics; it provides a summary of extracted features from each EOG signal, detailing crucial metrics like the number of blinks (blinks_num), the number of concatenated saccades (concat_sacc_num), summation concatenated saccades (concat_sacc_SumDuration), and average concatenated saccades durations (concat_sacc_MeanDuration), the number of concatenated fixations (concat_fix_num), and the summation of concatenated fixations (concat_fix_SumDuration), and the average concatenated fixations durations (concat_fix_MeanDuration) for each participant.

- LNT Image Questionnaire Answer.csv: This section features an organized Excel file that captures participants' responses to the LNT image questionnaire questions. In addition to the participants' answers, the file includes the correct answers for each question, facilitating a comparison and analysis of the participants' performance.

This structured data allows for an in-depth examination of individual and group accuracy in identifying and interpreting the LNT landmarks, thereby contributing valuable insights into spatial cognition and navigational abilities.

- EOG Data: This section is organized into two parts. The first part contains a folder filled with raw EOG signals recorded from each participant as they watched the LNT video segment. These files are saved in the.mat format, ensuring compatibility with various versions of MATLAB® software. Each file is labelled with the participant's unique identification number. Upon opening these files, researchers will find horizontal signals labelled as A and vertical signals labelled as B, reflecting the eye movements recorded during the video. The signal span corresponds precisely to the video's length, providing a complete and uninterrupted record of the eye movement data for that period.

  The second part of this section comprises Excel files that offer a comprehensive summary of features extracted from each participant's EOG signals. These files contain key metrics, including the total count, amplitude, and duration of blinks (blinks_num.csv, blinks_amp.csv, blinks_dur.csv); the total count, amplitude, and duration of saccades for the horizontal signal (sacc_hor_num.csv, sacc_hor_amp.csv, sacc_hor_dur.csv); and the total count, amplitude, and duration of horizontal fixations (fix_hor_num.csv, fix_hor_dur.csv). Additionally, these measurements are provided for the vertical saccade (sacc_ver_num.csv, sacc_ver_amp.csv, sacc_ver_dur.csv), vertical fixation (fix_ver_num.csv, fix_ver_dur.csv), concatenated saccade (sacc_concat_num.csv, sacc_concat_dur.csv, sacc_concat_amp.csv), and concatenated fixations (fix_concat_num.csv, fix_concat_dur.csv). A label signal file (label_sig.csv) is included, and its extraction process is detailed in the processing section.

  These measurements cover all relevant dimensions of oculomotor behavior. The data offers a comprehensive analysis of blink, saccadic, and fixation activity across vertical, horizontal, and concatenated signals, ensuring a detailed understanding of eye movement patterns. They are invaluable for analyzing the participants' visual attention and eye movement patterns in response to the LNT video segment. The nature of this data allows for in-depth studies into visual and cognitive processing during navigation tasks, offering rich insights into how individuals perceive and interact with the environment.

Technical Validation

In this study, we curated an EOG dataset using a dual-channel headband. The EOG signals were recorded at a sample rate of 250 Hz, ensuring a fine temporal resolution for capturing eye movement dynamics. The system employed a wide dynamic range, enabling precise detection of subtle and pronounced eye movements. The utilized analog-to-digital converter had a high resolution of 24 bits, facilitating accurate digitization of the analog EOG signals.

Our recording device incorporated low-pass and high-pass filters during data collection to enhance data quality and maintain data integrity. Specifically, the low-pass filter was configured with a cut-off frequency of 20 Hz to eliminate high-frequency noise that might otherwise contaminate the EOG signals. Simultaneously, the high-pass filter's cut-off frequency was set at 0.05 Hz to remove slow drifts and baseline shifts. This filtering process preserved the essential characteristics of eye movements while effectively minimizing the impact of irrelevant noise and artifacts.

To enhance the reliability of the EOG recordings, we conducted calibration sessions before each recording. During these sessions, the system was adjusted to minimize measurement error. Following calibration, validation sessions were performed to verify the system's accuracy, with recording commencing only once the measurement error was within acceptable limits. This calibration and validation process ensured the data were accurate and reliable. The recording system's noise characteristics were also carefully managed. The input short circuit noise was measured at 4 μV, indicating a high-quality signal with minimal interference. Additionally, the system's least significant bit (LSB) corresponded to 2.86 μV, allowing for detecting small changes in the EOG signal. This high resolution enhances the accuracy of the recorded data.

Several measures were implemented to maintain high data quality throughout the data recording process. Notably, the impedance of the electrodes was continuously monitored to ensure it remained within acceptable levels. This proactive approach significantly reduced artifacts and improved signal quality. The recorded data were also inspected for artifacts, such as those caused by muscle movements or blinks, and these artifacts were either corrected or marked for exclusion in subsequent analyses. These steps, particularly the continuous monitoring of electrode impedance, ensured the highest possible quality and reliability of the EOG data.

The dual-channel EOG data were recorded with high temporal and voltage resolution, low noise levels, and rigorous calibration and validation procedures. Including both low-pass and high-pass filtering during data collection further ensured the high quality and reliability of the EOG data presented in this study. However, some limitations must be noted. While EOG provides high temporal precision in capturing rapid eye movements, it is constrained by its relatively lower spatial accuracy compared to advanced optical eye-tracking systems, which may limit the precision of gaze analysis. Furthermore, the quality of the recorded signals can be affected by factors such as the precise placement of the electrodes and the quality of skin contact, with potential artifacts arising from sources like muscle contractions or movements.

Usage Notes

Data collection was performed utilizing Matlab R2023b. The data is also executable and verified for compatibility and functionality across other MATLAB versions.

Code availability

The code is publicly available on both the Figshare[34] repository (https://doi.org/10.6084/m9.figshare.27156459.v3), where the corresponding dataset files can also be accessed and GitHub[35] (https://github.com/abbrash/Eye-Movement-Analysis-Algorithm-Using-EOG).

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Author contributions
M.Z. conceived the experiments, and M.Z., F.A. and A.A. wrote the manuscript. A.A. and S.T. handled data processing, debugging, and graph preparation. M.D. managed the project and provided essential revisions to the paper. All authors reviewed and approved the final manuscript and are responsible for all elements of the work.

Competing interests
The authors declare no competing interests.

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