


EOG-Based Human–Computer Interface: 2000–2020 Review

Chama Belkhiria ¹, Atlal Boudir ², Christophe Hurter ²  and Vsevolod Peysakhovich ^{1,*} ¹ ISAE-SUPAERO, Université de Toulouse, 31400 Toulouse, France; belkhiria.chama@gmail.com² ENAC, Université de Toulouse, 31400 Toulouse, France; atlal.boudir@gmail.com (A.B.); christophe.hurter@enac.fr (C.H.)

* Correspondence: vsevolod.peysakhovich@isae-superaero.fr

Abstract: Electro-oculography (EOG)-based brain–computer interface (BCI) is a relevant technology influencing physical medicine, daily life, gaming and even the aeronautics field. EOG-based BCI systems record activity related to users’ intention, perception and motor decisions. It converts the bio-physiological signals into commands for external hardware, and it executes the operation expected by the user through the output device. EOG signal is used for identifying and classifying eye movements through active or passive interaction. Both types of interaction have the potential for controlling the output device by performing the user’s communication with the environment. In the aeronautical field, investigations of EOG-BCI systems are being explored as a relevant tool to replace the manual command and as a communicative tool dedicated to accelerating the user’s intention. This paper reviews the last two decades of EOG-based BCI studies and provides a structured design space with a large set of representative papers. Our purpose is to introduce the existing BCI systems based on EOG signals and to inspire the design of new ones. First, we highlight the basic components of EOG-based BCI studies, including EOG signal acquisition, EOG device particularity, extracted features, translation algorithms, and interaction commands. Second, we provide an overview of EOG-based BCI applications in the real and virtual environment along with the aeronautical application. We conclude with a discussion of the actual limits of EOG devices regarding existing systems. Finally, we provide suggestions to gain insight for future design inquiries.



Citation: Belkhiria, C.; Boudir, A.; Hurter, C.; Peysakhovich, V. EOG-Based Human–Computer Interface: 2000–2020 Review. *Sensors* **2022**, *22*, 4914. <https://doi.org/10.3390/s22134914>

Academic Editor: Wataru Sato

Received: 24 May 2022

Accepted: 25 June 2022

Published: 29 June 2022

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: human–computer interaction; electrooculography; EOG; human–computer interface; BCI

1. Introduction

Human–computer dialogue has hinged upon input from manual devices (keyboard, mouse, tactile display, etc.) and relies on the visual display—until today. Despite being “ready to deliver the promises” to enhance human–computer interaction for about 20 years now [1], eye-tracking technology use remains narrowed down to applications for disabled users, as eye movements are sometimes their only way to communicate. The gaming industry recently started to adopt eye-tracking to intensify gamers’ experience and enjoyment. Laptops and monitors with integrated eye-tracking devices are available on the market. However, most of these devices are based on video processing, illumination with infra-red light and complex computer vision algorithms. This power-greedy approach is unsuited for prolonged use (energy consumption, produced heat, etc.). Moreover, video-based eye-tracking requires either an integration of a remote camera into an existing environment, which may be difficult, especially in the case of retrofitting; or eyewear, which is mostly incompatible with eyeglasses’ users and partly blocks the field of view for the others.

A power-efficient alternative to eye tracking is the application of electrodes on the scalp and face surface known as electro-oculography (EOG). The use of the EOG system was one of the first techniques to analyze eye movements [2], and it has been thought to be a valuable source for communications between humans and computers. One advantage of EOG is that the electrodes avoid the obstruction of the vision. Electro-encephalography (EEG) and electro-oculography are well-suited for brain–computer interfaces and are

used to deduce users' eye movements for passive and active interaction [3]. A complete methodology of EOG based on human–computer interface research is demonstrated in Figure 1. Recent advances in dry [4] and even wearable and flexible textile electrodes [5] increase the comfort of use and the application ease. The recent progress in biopotential signal monitoring lets us imagine embedded EEG and EOG sensors in everyday objects such as a knit cap or an earring. A headset of an airline pilot decoding the fatigue state to adapt the automation level? Or a pair of in-ear headphones changing the music track with a blink of an eye? We propose a literature review of the last two decades' research on the EOG-based human–computer interaction.

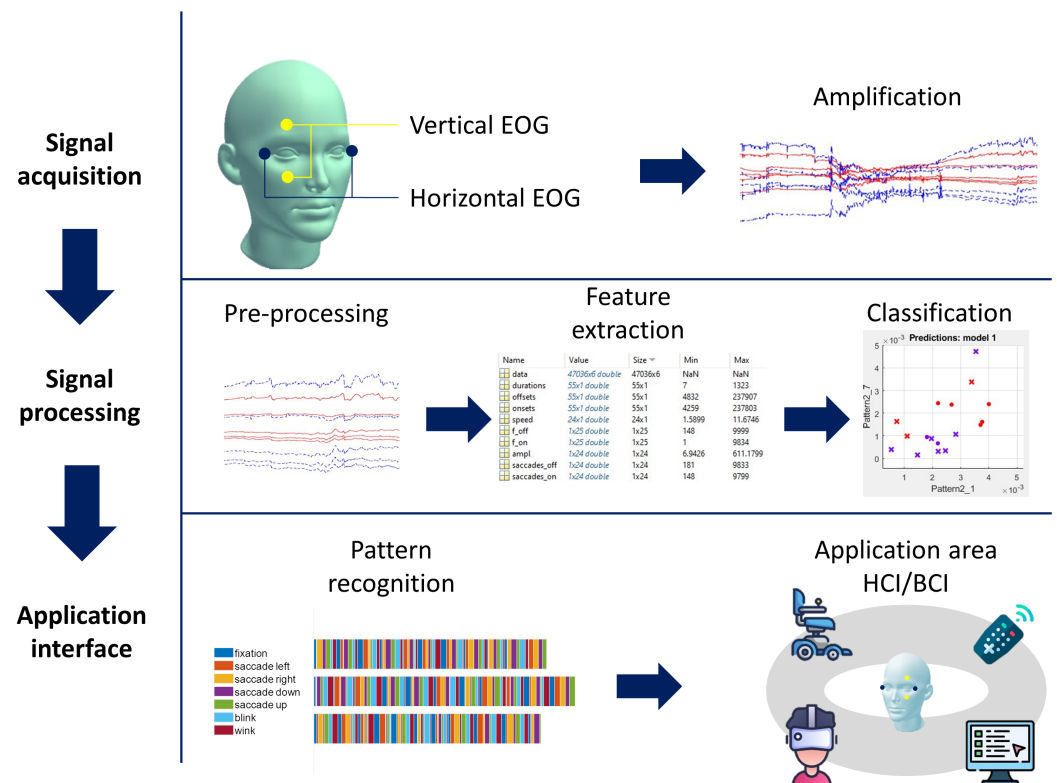


Figure 1. General scheme of an EOG-based BCI. First step, EOG acquisition: EOG is recorded using vertical and horizontal electrodes by an amplified ADC. Second step, Signal processing: after pre-processing, computer processing extracts the most relevant features for identifying the subject's intentions. Third step, Application area: When the command is recognized and the intention is classified, the instruction is sent to an external device (e.g., web browser, wheelchair, or text display). Feedback informs the user of the results of their actions to allow them to prepare for the next command.

This paper presents a non-exhaustive review of studies published between the years 2000 and 2020 that are based on the EOG eye movement's interaction in human models. This review provides a precious time- and resource-saving guidebook to exploring the EOG interaction tendency for the last two decades, making it relevant of interest for EOG novices as well for specialists. We included 112 English peer-reviewed journal articles and conference papers that met the inclusion criteria and were published in PubMed, the Institute of Electrical and Electronics Engineers (IEEE), or the Association for Computing Machinery (ACM) digital library. Figure 2 represents the PRISMA flow diagram of the review process. The research of three cited databases was performed in parallel. After the exclusion of non-relevant records, the results were put together and duplicate records removed. The records that were identified contained, in the title and/or abstract the following keywords: (EOG OR electrooculography) AND (interaction OR interface).

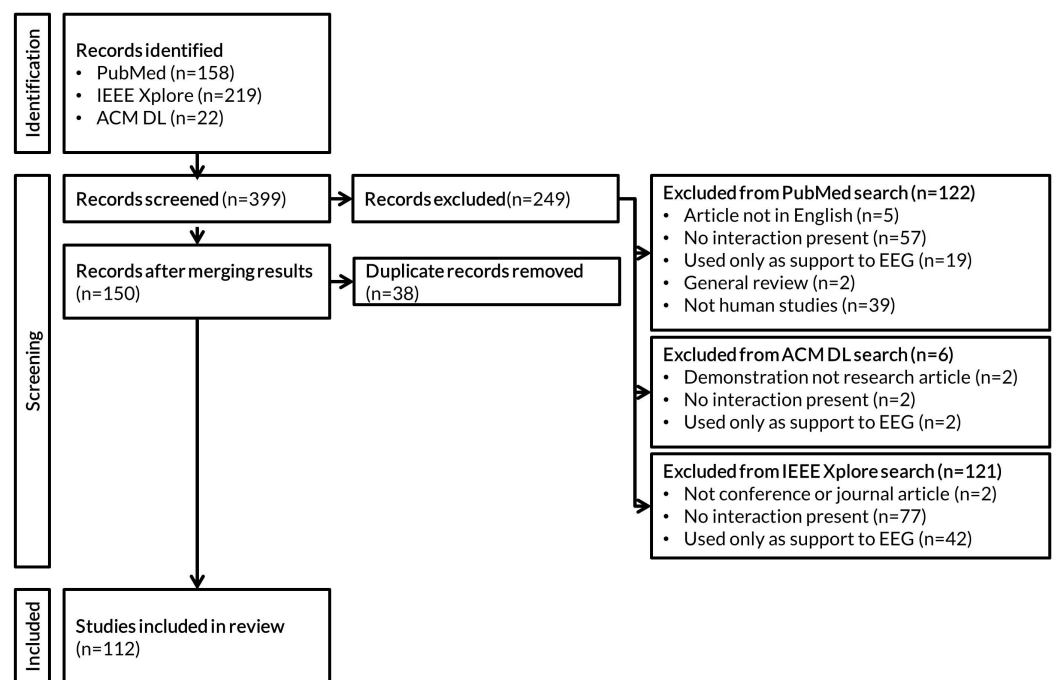


Figure 2. The PRISMA flow diagram of the review process. Please note that, given the work organisation during the project, the review of the databases was paralleled, and, therefore, the removal of duplicate records was done after the non-relevant records were removed from each database list separately.

The particularity of the used devices, the extracted features, the category of the algorithms and the nature of the interaction (passive or active) of each study have been emphasized in the Tables 1 and 2. Figure 3 indicates the number of included publications per 5-year periods. It shows the increasing interest in the technology. Figure 4 illustrates the distribution of different studies characteristics per 5-year period.

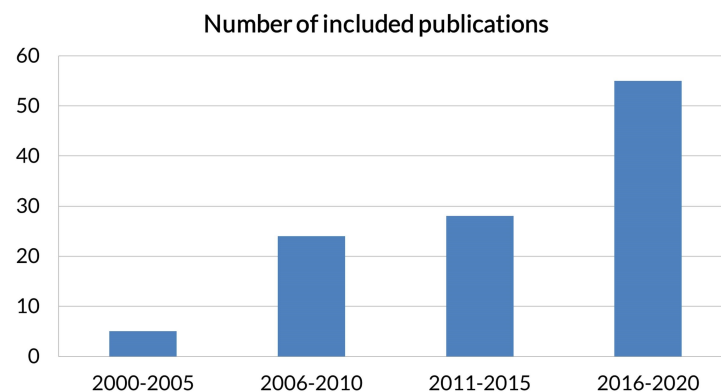


Figure 3. The number of publications per 5-year period.

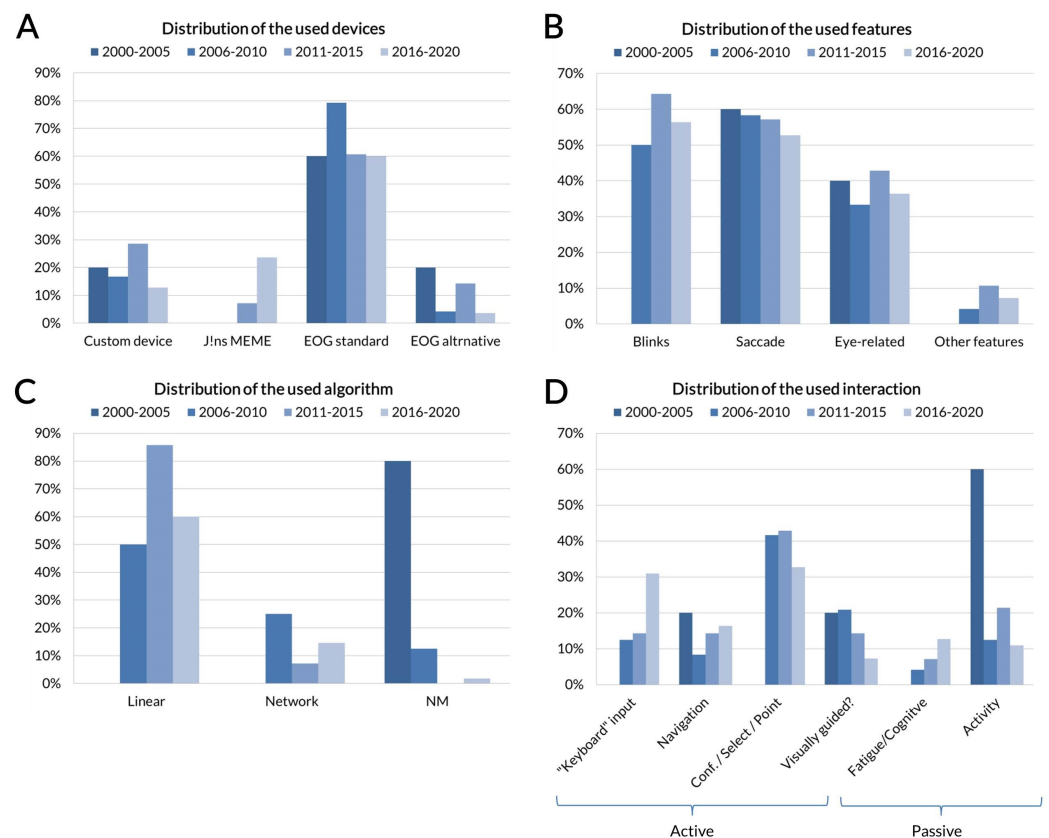


Figure 4. The percentage of references per 5-year period according the (A) used device, (B) used features, (C) used algorithms and (D) used interaction.

2. Acquiring EOG Signal

The eye is an important source of the relevant information associated with the user's activities and cognitive functions. It can be modeled as an electrical dipole (between the retina and the cornea) that follows eye movements. If we place two electrodes near two eyes' corners and two electrodes on the top and bottom of one eye, there will be a voltage difference between the vertical and horizontal electrodes, which is known as the EOG signal. When the eyeball moves in the direction of the electrode, the electrical potential increases, and if the eye moves in the other direction, the electrical potential decreases. The EOG signal is a measure of the corneal–retinal potential difference with signal amplitude ranging 15–200 μV . Using an adequate calibration procedure, the signal can be mapped to the eyeball angular position with a 2-degree range in the vertical direction and a 1.5-degree range in the horizontal one [6–8].

Interestingly, EOG signals can be obtained using cheap and simple electrodes. Generally, horizontal electrodes are placed on the outer boundary of the eye, while vertical electrodes are placed above and below the eye. The reference electrode is often positioned on the forehead [9]. Other alternative electrode placements have been broadly described in our former review [3]. The EOG signal is proportional to the eye gaze move and it is commonly distinct from other bioelectric potentials. Concerning hardware requirements, EOG signal acquisition is based on cheap equipment with extensive eye-tracking capabilities allowing the field of view to not be limited to cameras or sensors.

3. EOG Devices

There are different EOG devices found across our literature review and which are summarized in the Tables 1 and 2. Four categories were distinguished: standard EOG, alternative EOG mounting, J!NS MEME glasses and customized EOG devices.

- (i) The standard EOG consisted of the placement of two electrodes at the left and right corners of the participant's eyes to measure the horizontal movement. Two other electrodes were placed up and down of one eye to obtain the vertical movement. A ground electrode was positioned on AFz (as required by the International 10/10 System) and the reference electrode was positioned on the right or left earlobe [10].
- (ii) The alternative EOG mounting represented an uncommon position of surface electrodes such as around the ears. Manabe et al. [11] placed four electrodes on the head at the locations of the common headphone cushion. Ang et al. [12] used an alternative EOG system where activities were recorded by a single-channel commercial headset NeuroSky MindWave Mobile Headset (NeuroSky, San Jose, CA, USA). The device was formed by a single-channel sensor based on a dry electrode with stainless steel. The sensor was placed on the participant's forehead to capture electrical signals produced by the brain and the muscles.
- (iii) The J!NS MEME glasses (JINS MEME ES Digital Innovation Lab, Fujitsu, Tokyo, Japan) employs 3-point stainless steel EOG electrodes on the nose bridge and IMU, battery, and Bluetooth units on the eyeglasses temples. The J!NS MEME are not a common computing interface but rather a sensing device. They stream the data from the sensor to smartphones or laptops via Bluetooth. The sensor data corresponds to vertical and horizontal EOG signal, accelerometer and gyroscope data. The equipment has an operating time of 8 hours. It allows a long duration of real-time streaming of eye and head movements. The J!NS MEME are unobtrusive and look like ordinary glasses.
- (iv) The customized EOG device category presents the mounted system elaborated by the experimental group according to their objectives. Here we introduce a brief presentation of each customized device included in this review. Vehkaoja et al. [13] used a prototype of a wearable and wireless device designed for EOG and also for facial electromyography (EMG) data recorded from the participant's forehead. The device was based on five easy-to-proceed textile electrodes that were inserted into a head cap. Bulling et al. [14] employed a wearable and standalone device. It was formed by dry electrodes integrated into goggles with a small pocket-worn constituent with a digital signal processor to explore EOG signals in real-time. Bulling et al. [15] recorded EOG data from the commercial Mobile Brain/Body Imaging (MoBI) from Twente Medical Systems. The device was formed by four-channel EOG that was worn on a belt around the participant's waist and data were transmitted via Bluetooth. Kuo et al. [16] captured the horizontal eye-gaze direction to control wheelchair driving. They used a pair of eyeglasses to set up left and right surface electrodes as a compact modular. Zhang et al. [17] developed a wireless and lightweight head-mounted system that measured both EOG and EEG for interacting in a virtual reality environment. They positioned six horizontal and vertical electrodes symmetrically around both eyes. This device captures azimuth, elevation and vergence of gaze. Xiao et al. [18] proposed a single-channel EOG device that enables real-time interactions with the virtual reality environment. They designed a graphical user interface for the EOG-based BCI in virtual reality that contains several buttons. The user had to blink while the algorithm identifies the eye blinks and detects the user's target button. Vidal et al. [19] measured eye movements' amplitude and duration in reaction to the stimulus with an elaborated experimental system consisting of three devices. First, they connected EOG electrodes to the Mobile Brain/Body Imaging (MoBI) approach developed by Scott Makeig's group. Second, they implemented an infrared eye tracker from Ergoneers GmbH. Third, they recorded head movements by connecting a cap with an inertial quantification. Inaez et al. [20] integrated five EOG electrodes into a pair of glasses. They incorporated electronic and mechanical elements including a printed circuit board, batteries, communication module electrode holders, lenses and frame. English et al. [21] analyzed four electrodes from the EEG Emotive EEG Headset (San Francisco, CA, USA) to process small and large amplitude of EOG signals. Their conceptualized EOG eyephone system was efficient during sitting, standing

and walking. Valeriani et al. [22] recorded EOG signals utilizing two facial electrodes placed on the forehead. The interaction was realized through eye winks by comparing the peak amplitudes and an app installed on the smartphone. Kosmyna et al. [23] included EEG and EOG electrodes, an amplifier, a Bluetooth module and a speaker for bone conduction auditory feedback in a pair of glasses. The operator rather received feedback or nudges sent by a wireless vibration brooch. Despite the varied and diverse acquisition devices, the different investigations shared the next step which concerns features extraction.

Figure 4A shows that the most used electrode placement is the standard scheme. It also shows that there is a recent increasing interest in using J!NS MEME glasses. It might show that it is a off-the-shelf product that allows the use of EOG technology without any wire nor sticking the electrodes.

4. Extracted Features

EOG signal is commonly used as a human–computer interface tool to control signals [24] and plays a crucial role in the description and classification of eye movements. EOG is used in a diversity of applications, such as eye writing ordering [25], electric wheelchair control [26], cursor mouse selection [27], eye movement recognition [28] and mobile robot direction [29]. To achieve high performance in identifying and classifying EOG signal, several methods have been presented, including derivative technique [30], threshold evaluation [31], slope analysis method [32] and peak detection exploration [33].

Feature extraction methods and analysis of EOG artifacts are one the most important challenges in this field. The study of Aungsakul et al. [34] evaluated 14 EOG features based on a class separation point of view. All the extracted features were performed on the time domain toward the simplification of the calculations. They used both horizontal and vertical EOG channels and they combined seven methods: maximum peak amplitude value, maximum valley amplitude value, maximum peak amplitude position value, maximum valley amplitude position value, areas under a curve, number of threshold crossing values, and variance of EOG signal. All of these extracted features showed a statistical significance with $p < 0.0001$. To extract EOG features, Pournamdar et al. [35] explored the extreme point strategy that considers the time of occurrence of maximum and minimum values. The polynomial fitting method and eye movement artefacts have been extracted and categorized.

Vidal et al. [19] developed a feature-based method that allows differentiating between saccades, smooth pursuits and vestibulo–ocular reflex movements. They extracted features related to range, velocity, and acceleration from raw and filtered EOG signals: mean velocity, maximum velocity, mean acceleration, maximum acceleration, range of amplitude, mean velocity, maximum velocity, mean acceleration, maximum acceleration, range of amplitude, coefficients of polynome fitted to the signal and the slope of the signal. Even though they did not include fixation and blinks in their model, they were among the first groups to analyze eye movement features to provide a base of eye movement recognition algorithms for exploration in mobile environments.

The number and quality of the signal extracted features are affected by the degree of freedom of the end effector. For instance, controlling a computer mouse or robotic arm needs 2 to 4 degrees of freedom [36], while achieving the dexterity of a single joint of the hand may require up to 22 degrees of freedom. The advantage of the EOG system is that is well suited for applications with limited degrees of freedom, although it is difficult to extract a large number of control signals from the average neuron population activity and may limit the scalability of such a technique.

Feature extraction allows obtaining an optimal subset of elements to classify a selection of collected data according to the criterion functions. Nowadays, an important number of robust and flexible classification algorithms have been developed to recognize and classify the extracted features from EOG signals.

Figure 4B shows that most studies are using blinks and saccades as features. No particular trend can be seen.

5. Classification Algorithms

To classify the EOG signal extracted from the eye movements, several algorithms are often used to identify the eye movements classification including saccades, blinks, fixations, smooth pursuits and artifacts removal. EOG signal data are predominantly detected in low-frequency bands. Generally, the band-pass filter ranging from 0.1 to 30 Hz with a sampling rate of 128 Hz is performed. After that, a moving average filter is used to eliminate the existing noise components. The eye movements classification is based on an algorithm that computes the derivative of the EOG signal. The EOG derivative is measured through the amplitude value of the EOG signal. Two values are needed, one representing the previous value of the amplitude (n samples before), $e(t - n)$, and the other representing the current value, $e(t)$ [37].

An important number of algorithms were designed and employed in several studies to classify eye movement signals. Each decoding algorithm is unique to each BCI and needs to be adaptable to new users, and can self-calibrate. EOG mutual adaptation of “user-to-system and system-to-user” is unique to BCI. The k-nearest neighbors’ algorithm is particularly selected in brain–computer interface investigation for its relevant outcomes. It is one of the simplest and most efficient algorithms for the classification of samples. The procedure requires firstly detecting the k parameter (corresponding to the number of neighbors). After that, the distance of the unknown sample is designed with all known samples. When the samples are categorized according to their distance and value of k, the class that has the majority of nearest samples is chosen as the class of unknown samples (L. Pan 2015). One of the several versions of this algorithm is called random sub-sampling [38].

The Time Delay Neural Network is another dynamic network that classifies EOG signals. The input delay feedforward feedback neural network is a time-delay neural network, and its hidden and output neurons will be copied over the entire time. The delay is computed from top to bottom, so the network has a tapped delay line, which can connect the current signal, the previous signal and the delayed signal to the network weight matrix through the delay time unit (such as 0, 1 and 2). To identify the eye patterns, the Time Delay Neural Network replicated the former activation at each step and updated the outgoing connection with the original unit. These units are coupled to the next layer called the receiving field. The Time Delay Neural Network uses the Levenberg backpropagation training algorithm where the samples are normalized from 0 to 1 with a binary normalization algorithm [39].

Other algorithms contain filtering, feature extraction, training and actual event detection stages to detect eye movements. The minimum redundancy and maximum relevance algorithm allows the number of features to be reduced by selecting the most relevant ones. Clearness Based Feature Selection calculates the distance between the target sample and the center of each category and then compares the class of the nearest center with the class of the objective sample [40]. The eye movements have non-repetitive and unstable features. The EOG signal processing is often challenging to denoise and classify. Therefore, an algorithm-based classification that requires both structural and temporal analysis is constantly being developed.

Figure 4C shows that most studies are using linear algorithms. It also shows that the majority of recent studies indicate the used algorithm that was not the case in the years 2000–2005.

Table 1. Years 2000–2015. Pair rows are highlighted in gray for the ease of the reading.

Reference		Device				Extracted Features				Algorithm			Interaction					
First Author	Year	Custom Device	Jins MEME	EOG Standard	EOG Alternative	Blinks	Saccades	Eye-related	Other Features	Linear	Network	NM	"Keyboard" Input	Navigation	Conf./Select/Point	Visually Guided?	Fatigue/Cognitive	Passive Activity
		Chen [41]	2000	•			•					•						
Rosander [42]	2000		•		•					•							•	
Barea [43]	2002	•						•		•		•						
Ding [44]	2005	•						•							•			
Vehkaoja [13]	2005	•						•				•						•
Manabe [11]	2006		•	•	•	•		•					•					
Ding [45]	2006	•			•	•		•					•					
Trejo [46]	2006	•				•			•				•					
Yamagishi [31]	2006	•		•					•		•							
Akan [47]	2007	•		•	•								•					
Bashashati [48]	2007	•		•				•									•	
Krueger [49]	2007	•				•		•					•					
Skotte [50]	2007	•		•				•							•			
Estrany [51]	2008	•			•					•			•					
Bulling [14]	2008	•				•	•				•			•				
Cheng [52]	2008	•			•			•							•			
Mühlberger [53]	2008	•						•		•						•		
Bulling [15]	2009	•				•	•	•		•						•		
Estrany [54]	2009	•		•					•						•			
Bulling [55]	2009	•		•	•			•		•						•		
Kuo [16]	2009	•						•		•					•			
Zheng [56]	2009	•		•	•			•					•					
Keegan [57]	2009	•			•				•				•					
Usakli [58]	2009	•		•	•					•	•							
Yagi [59]	2010	•		•				•					•					
Usakli [60]	2010	•			•	•					•							
Belov [61]	2010	•			•			•									•	
Zhang [17]	2010	•						•									•	
Punsawad [62]	2010	•				•		•							•			
Vidal [19]	2011	•				•	•	•		•								•
Bulling [28]	2011	•		•	•				•						•			
Li [63]	2011	•						•								•		
Liu [64]	2011	•		•				•			•							
Banarjee [37]	2012		•		•	•		•				•						
Tangsuksant [65]	2012	•		•	•	•		•			•							
Swami Nathan [66]	2012	•		•	•			•			•							
Iañez [20]	2013	•		•		•	•			•						•		
English [21]	2013	•				•	•	•	•	•						•		
Ubeda [67]	2013	•			•	•		•					•	•				
Li [68]	2014	•		•		•		•		•						•	•	
Manabe [69]	2014	•						•		•							•	
Ishimaru [70]	2014		•			•				•								•
Witkowski [71]	2014	•				•		•		•						•		
Ma [72]	2014	•				•		•	•	•					•			
Jiang [73]	2014	•			•	•		•					•					
Wang [74]	2014	•		•														
Aziz [75]	2014	•				•		•				•						
Hossain [76]	2014	•		•	•			•					•					
D'Souza [77]	2014	•				•		•	•								•	
Manmadhan [78]	2014	•		•	•			•					•					
OuYang [79]	2015	•		•	•	•		•									•	
Manabe [80]	2015	•				•		•									•	
Ishimaru [81]	2015		•			•	•			•					•		•	•
Hossain [82]	2015	•		•	•			•			•							
Valriani [22]	2015	•			•	•				•					•			
Banik [83]	2015		•		•								•					
Ang [12]	2015		•	•				•					•					

Table 2. Years 2016–2020. Pair rows are highlighted in gray for the ease of the reading.

Reference		Device				Extracted Features				Algorithm			Interaction			Passive		
First Author	Year	Custom Device	Jins MEME	EOG Standard	EOG Alternative	Blinks	Saccades	Eye-related	Other Features	Linear	Network	NM	“Keyboard” Input	Navigation	Conf./Select/Point	Visually Guided?	Fatigue/Cognitive	Activity
		Kumar [84]	2016	•				•				•					•	
Dhuliawala [85]	2016		•					•		•					•			
Shimizu [86]	2016		•			•	•			•						•		
Shimizu bis [87]	2016		•					•		•								
Bissoli [88]	2016	•				•		•					•					
Wilaiprasitporn [89]	2016	•		•					•						•			
Fang [90]	2016	•			•	•		•			•							
Tamura [91]	2016	•		•		•	•			•			•		•			
Barbara [92]	2016		•			•	•			•			•					
Atique [93]	2016	•		•	•						•		•					
Naijian [94]	2016	•						•							•			
Ogai [95]	2017	•			•	•		•					•					
Lee [96]	2017		•						•	•								•
Robert [97]	2017		•				•			•								•
Ishimaru [98]	2017		•				•				•							•
Kise [99]	2017		•				•			•								•
Augereau [100]	2017		•				•			•				•				
Tag [101]	2017		•			•						•		•				
Thakur [102]	2017	•				•			•							•		
Chang [103]	2017	•			•	•					•							
Huang [104]	2017	•		•									•					
López [25]	2017	•		•	•					•								
Heo [105]	2017		•	•	•	•		•		•	•							
He [106]	2017	•		•	•			•		•								
Lee [107]	2017	•		•	•			•		•								
Zheng [56]	2017		•	•	•			•							•			
Zhang [108]	2017	•		•		•		•					•					
Zhi-Hao [109]	2017	•		•									•					
Hossain [27]	2017	•			•			•					•					
Soundariya [110]	2017	•			•	•		•							•			
O’Bard [111]	2017	•			•	•		•		•	•							
Perin [112]	2017	•			•	•		•				•						
Karagöz [113]	2017	•		•	•			•										
Crea [114]	2018	•																
Zhang [115]	2018	•		•									•	•				
Lee [107]	2018	•		•							•			•				
Kim [116]	2018	•			•	•				•								
Fang [117]	2018	•			•	•		•		•								
Bastes [118]	2018	•		•	•	•	•	•			•							
Hou [119]	2018	•		•	•			•		•								
Jialu [120]	2018	•			•	•			•		•							
Sun [121]	2018	•		•	•	•				•								
Xiao [18]	2019	•				•				•					•	•		
Lu [122]	2019	•		•				•					•					
Garrote [123]	2019	•		•	•				•			•						
Tag [124]	2019		•						•	•								•
Findling [125]	2019	•					•			•			•					
Rostaminia [126]	2019		•			•					•							•
Kosmyna [23]	2019	•				•	•				•						•	
Badesa [127]	2019	•				•		•					•					
Zhang [128]	2019	•		•	•							•						
Wu [129]	2019	•		•											•			
Mocny-Pachońska [130]	2020		•			•	•	•	•	•							•	
He [131]	2020	•		•				•					•					
Huang [132]	2020			•		•		•					•					

6. EOG-Based Interaction

Figure 5 presents the percentage of each type of interaction based on our investigation of the published EOG-based BCI works of the last 20 years. The interactions can be generally classified into active and passive [133]. During active interactions, the EOG signal is intentionally used to control the system by the user. During passive interactions, EOG signal is used to monitor the user's state without explicitly controlling the system. According to our observation, active interaction contributed with 76% while passive interaction contributed with only 24% of the total included number of EOG-based BCI applications. The active interaction was distributed between 43% for pointer/selection, 25% for visual keyboard, 17% for web navigation and 15% for monitor visual guide. The passive interaction was divided between 62% of activity recognition and 38% of cognitive demand. The important involvement of the active interaction can be considered as an important indicator of EOG signal simplicity. In contrast, passive interaction may require more complicated feature extraction and classification approaches.

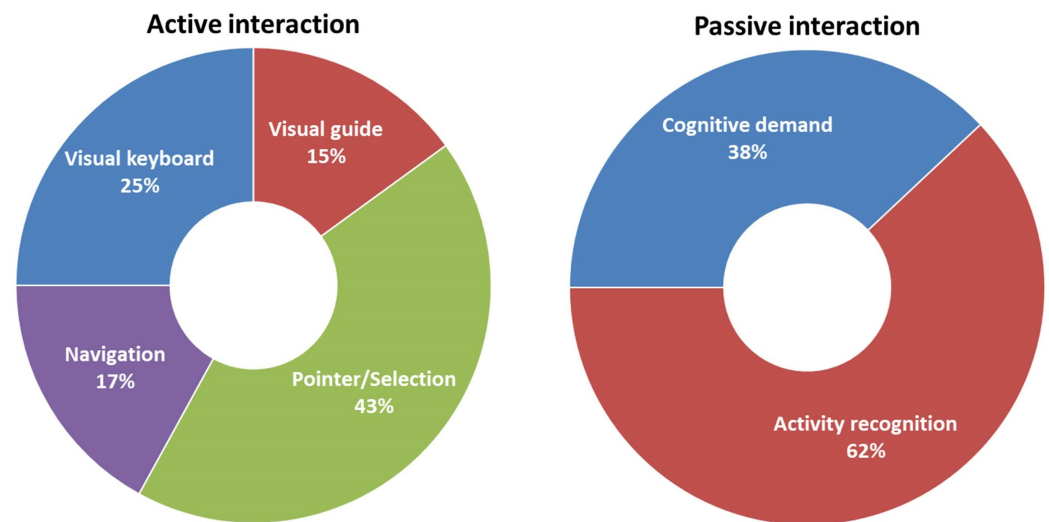


Figure 5. The percentage of each type of active and passive interaction in the included EOG-based BCI publications during the last 20 years.

The central role of BCI systems is to transduce the neural signal from the brain into signals understandable by an external piece of hardware. The interface implements direct communication access between the brain and the device to be controlled. The EOG system has the potential to create active or passive user interaction with the environment. The interaction based on EOG is explored in an important number of applications, including eye writing commands [25], eye movement recognition [24], wheelchair drive [26], pointer mouse selection [27] and movable robot activity [29].

The nature of the user interaction depends on the target and the field of application including rehabilitation (e.g., exoskeleton), virtual reality, response to physical stimuli (e.g., pain), or identification of brain states (e.g., fatigue or frustration). The EOG similar to other BCI systems, allows the user to interact and control different environments and actions, such as computer function (e.g., word writing and web browsing), mobility conduction (e.g., wheelchair driving) and daily environmental manipulation (e.g., light, television). Interestingly, EOG can be explored as a BCI tool for the therapeutic purpose to rehabilitate normal visual sensory system control by generating activity-dependent neural plasticity.

Figure 4D shows the distribution of the used interactions per 5-year period. It shows that in the years 2000–2005, the dominant interaction was passive detection of user's activity. Recent studies suggest a trend towards using EOG as keyboard-like input, and increasing interest in using EOG as passive method to determine the level of fatigue. Eventually, the most popular interaction is for actions of confirmation, selection, and pointing.

6.1. Real Environment Interaction

Vidal et al. [134] suggested considering smooth pursuit data to analyze calibration-free gaze interaction. Their method is not based on the gaze position, as the traditional gaze interaction methods are, but it associates smooth pursuit with targets that move dynamically on the interface. A hands-free and calibration-free interactive technology were presented by Esteves et al. [135] for smartwatches. It is based on smooth pursuit targets that rotate on the interface along a radial trajectory.

Kangas et al. [136] analyzed visual, auditory and haptic feedback methods to achieve smooth pursuit gaze tracking. They found a significant user preference for haptic and audio feedback. Another study was conducted by Khamis et al. [137] on spontaneous gaze-based interaction when users are displaying pursuits. The study of Jalaliniya et al. [138] presented a method to recognize objects of interest only by analyzing the movement of the eyes while presenting visual stimuli that move horizontally or vertically. Schenk et al. [139] exposed a gaze interaction method based on eye movements for static user interfaces.

6.2. Virtual Reality Interaction

EOG is being studied as BCI for virtual and augmented reality, particularly in the case of gaming, rehabilitation, or for training and evaluation of motion, image-based decoding [140,141]. Kumar and Sharma [84] introduced an EOG hands-free natural system that increases the involvement in virtual games. Six EOG electrodes were used for signal acquisition and seven directions were realized by eye movements (left, right, up, down, gaze, wink and double-blink). One of the advantages of combining the EOG system with a virtual environment is to enhance the opportunities for users to participate in retraining by increasing visual feedback. Another benefit is the rapid recruitment of cortical motor networks throughout the motion images to control the interaction. Moreover, EOG interaction in virtual reality can help promote the participation of motor learning mechanisms through repeated training, even if the user can control their limbs [142].

In addition, the importance of the EOG-based HCI for interaction in a virtual reality environment concerns the following points: Firstly, the EOG-based HCI hardware system is effortless and wearable. Then, the EOG-based HCI presents gratifying efficacy. Third, several virtual reality applications might be applied through the EOG-based HCI. A prominent method of virtual reality interaction is gesture tracking which includes two types: optical tracking (e.g., Leap Motion or Nimble VR depth sensors) and the sensors positioned on the hand (e.g., data gloves) [143]. Although an important number of works prove the flexibility and attractiveness of eye movements for natural and uncalibrated interaction, they are still video-based eye-tracking.

6.3. Aircraft Pilot Interaction

In the aviation field, it is known that errors related to sleepiness and fatigue in the cockpit lead to fatal accidents [144]. Even in the military environment, pilot fatigue can lead to the inability to invest in enemy targets, mistargeting, or to bombing familiar resources in the air or on the ground. Caldwell et al. [144] showed that even professional Air Force fighter pilots are vulnerable to the effects of fatigue during prolonged waking periods. Wilson et al. [145] recorded electrophysiological pupil area data to evaluate fatigue during task performance in aviation. They showed concomitant and decremented performance changes and they emphasized the importance of brain interaction in this environment. Increasing pupil area was associated with increased task difficulty which is consistent with a large body of literature demonstrating the correlation between increasing pupil diameter and cognitive task loads [146]. One obstacle with interpreting the eye data results is the variability of the light levels from the operator interface during the flight. Low and high luminance conditions may impact the cognitive changes in pupil diameter [147].

One advantage of EOG-based interaction is that the light conditions have only little effect on the EOG signal, which is principally important for mobile recording such in daily life or even in extreme environments. Contrary to video-based eye-tracking, EOG

assessments do not require light to come into the eyes to trigger the electrical potential. EOG measurement can be realized in obscurity or even with closed eyes. Due to this feature, EOG is particularly used for eye movement measurements during normal [148] and pathological sleep such detection [149] that can be applied to analyze pilots' sleepiness.

Another potential benefit of EOG for application in aviation domain is the light-weight computational analysis. It is not based on complex video and image processing. Therefore, EOG-based interaction can be commonly used in a laboratory environment [150], as well as a completely mobile system operable during simulated or real flight. EOG-based systems offer also the possibility to perform mobile long-term recording that does not require additional apparatus for data recording and storing allowing the live capture of pilots' eyes activity during real flight situations [151,152].

7. EOG Limits

Although EOG-based BCI systems have made important advances in exploring eye movement signals for interactions, the methods show some complications with an important number of applied operations. A limitation of the conventional EOG-based BCI paradigm is that the operators may be willing to adjust the eye movements for few seconds by fixing the gaze at an accurate position. When compared with video-based tracking, EOG has the limitation to be based on the around-eyes electrodes that are attached to the skin. EOG signal generates a simple waveform, a linear correlation with eye movement and it produces a considerable signal-to-noise ratio. Furthermore, EOG delivers worse spatial point of gaze tracking accuracy so it is more suitable for relative eye movements' analysis. EOG signals are also susceptible to artifacts and drifting, mainly when recorded with a mobile system. Similar to other physiological signals, EOG signals are often corrupted by noise from the electrical activity of the body, electrodes, residential power lines, measuring circuits and other interference physiological sources. In addition, similar to EEG, EOG suffers from poor spatial resolution such can be obtained from other neuroimaging techniques. Contrary to eye-tracking systems using videos based on infrared cameras, the EOG-based BCI systems do not use complementary systems. However, the EOG requires the operator's voluntary movement of eyeballs. Therefore, it is complicated for participants with oculomotor impairments to guide their eyeballs during a basic psychological paradigm such as the orientation of their attention in the direction of a sound source. Finally, EOG data, such as general data processing, deserves specific care before being analysed. As an initial step, data cleaning must be applied with a signal detrending. To do so, a bandwidth filtering can be applied. This will remove high frequency noise but also the continuous component of the signal. Since EOG signal have low voltage amplitude, they are very sensitive to external electrical context. For this reason, extra filtering is usually recommenced with the standard electrical frequency wave removal (50 or 60 Hz). Next, artefacts such as blinks, or parts of the signal that cannot be analysed have to be removed. For instance, when the user speaks, the activation of the jaw muscles spoils the signals and generally resulting into altered collected data. Other data processing stages may be required depending of the recording context and we only give here the most general ones.

8. Conclusions

The use of the EOG signal is emerging as one of the most successfully explored bioelectric signals in the BCI domain, and this review showed an increasing interest over the last 5 years. We included 112 relevant studies after the screening of PubMed, ACM DL and IEEE Xplore databases. We presented the results as an overview table according to four design space dimensions: used device, features extracted from the signal, algorithm used for features computation and designed signal-based interaction. We also compared the trends in studies' distribution per 5-year period. The results showed that the most used electrode placement is the standard scheme, but there is a recent increasing interest in using an off-the-shelf product that allows using EOG technology without wires or sticky electrodes setup. The majority of studies use blinks and saccades as features without any particular

trend over the last years. The most popular detection algorithms are the linear ones due to their ease of use for real-time applications. The results of the designed interaction show that while early studies investigated the general passive activity recognition application, recent studies tended to design EOG-based keyboard-like interactions. Eventually, the most popular interaction is for actions of confirmation, selection and pointing.

We also presented the EOG based on BCI applications in the real and virtual environments along with the aeronautical application. Finally, we exposed the limits of the EOG devices regarding existing systems and user perspectives regarding BCI technology. We conclude that almost all the designed EOG systems are highly promising in terms of performance and do not require heavy signal processing and complex pattern recognition algorithms such as those used with other systems as EEG. Nevertheless, most of the EOG-based BCI systems are still based more on theoretical rather than practical models and are suffering from the lack of concrete practice, particularly mobile EOG. Mobile EOG-based BCI systems are considered a relatively new research topic. An important number of investigations should be carried out to explore innovative protocols with mobile interaction control. An efficient system should constantly strive to improve speed and accuracy to eliminate the operator's frustration and to enable a stable performance level. In addition, the new-generation models may continually take into consideration the user experience, which may reduce the physical and mental stress.

Author Contributions: Conceptualization, V.P.; Investigation, C.B. and A.B.; Writing—Original Draft Preparation, C.B.; Writing—Review & Editing, V.P. and C.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the ANR ASTRID program (Grant no. ANR-18-ASTR-0026 – ELOCANS project).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jacob, R.J.; Karn, K.S. Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. In *The Mind's Eye*; Elsevier: Amsterdam, The Netherlands, 2003; pp. 573–605.
2. Ottoson, D. Analysis of the electrical activity of the olfactory epithelium. *Acta Physiol. Scand.* **1956**, *35*, 122.
3. Belkhiria, C.; Peysakhovich, V. Electro-Encephalography and Electro-Oculography in Aeronautics: A Review Over the Last Decade (2010–2020). *Front. Neuroergon.* **2020**, *3*, 606719. [[CrossRef](#)]
4. Di Flumeri, G.; Aricò, P.; Borghini, G.; Sciaraffa, N.; Di Florio, A.; Babiloni, F. The dry revolution: Evaluation of three different EEG dry electrode types in terms of signal spectral features, mental states classification and usability. *Sensors* **2019**, *19*, 1365. [[CrossRef](#)]
5. Acar, G.; Ozturk, O.; Golparvar, A.J.; Elboshra, T.A.; Böhringer, K.; Yapici, M.K. Wearable and flexible textile electrodes for biopotential signal monitoring: A review. *Electronics* **2019**, *8*, 479. [[CrossRef](#)]
6. Young, L.R.; Sheena, D. Survey of eye movement recording methods. *Behav. Res. Methods Instrum.* **1975**, *7*, 397–429. [[CrossRef](#)]
7. Brown, M.; Marmor, M.; Zrenner, E.; Brigell, M.; Bach, M. ISCEV standard for clinical electro-oculography (EOG) 2006. *Doc. Ophthalmol.* **2006**, *113*, 205–212. [[CrossRef](#)]
8. Chen, Y. Design and Evaluation of a Human-Computer Interface Based on Electrooculography. Ph.D. Thesis, Case Western Reserve University, Cleveland, OH, USA, 2003.
9. Singh, H.; Singh, J. Human eye tracking and related issues: A review. *Int. J. Sci. Res. Publ.* **2012**, *2*, 1–9.
10. Scherer, R.; Lee, F.; Schlogl, A.; Leeb, R.; Bischof, H.; Pfurtscheller, G. Toward self-paced brain-computer communication: Navigation through virtual worlds. *IEEE Trans. Biomed. Eng.* **2008**, *55*, 675–682. [[CrossRef](#)]
11. Manabe, H.; Fukumoto, M. *Full-Time Wearable Headphone-Type Gaze Detector*; Association for Computing Machinery: New York, NY, USA, 2006. [[CrossRef](#)]
12. Ang, A.M.S.; Zhang, Z.; Hung, Y.S.; Mak, J.N. A user-friendly wearable single-channel EOG-based human-computer interface for cursor control. In Proceedings of the 2015 7th International IEEE/EMBS Conference on Neural Engineering (NER), Montpellier, France, 22–24 April 2015; pp. 565–568.

13. Vehkaoja, A.T.; Verho, J.A.; Puurtinen, M.M.; Nojd, N.M.; Lekkala, J.O.; Hyttinen, J.A. Wireless head cap for EOG and facial EMG measurements. In Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, 17–18 January 2006; pp. 5865–5868.
14. Bulling, A.; Roggen, D.; Tröster, G. *It's in Your Eyes: Towards Context-Awareness and Mobile HCI Using Wearable EOG Goggles*; Association for Computing Machinery: New York, NY, USA, 2008. [[CrossRef](#)]
15. Bulling, A.; Ward, J.A.; Gellersen, H.; Tröster, G. Eye movement analysis for activity recognition. In Proceedings of the 11th International Conference on Ubiquitous Computing, Orlando, FL, USA, 30 September–3 October 2009. [[CrossRef](#)]
16. Kuo, F.Y.; Hsu, C.W.; Day, R.F. An exploratory study of cognitive effort involved in decision under Framing—An application of the eye-tracking technology. *Decis. Support Syst.* **2009**, *48*, 81–91. [[CrossRef](#)]
17. Zhang, L.; Chi, Y.M.; Edelstein, E.; Schulze, J.; Gramann, K.; Velasquez, A.; Cauwenberghs, G.; Macagno, E. Wireless physiological monitoring and ocular tracking: 3D calibration in a fully-immersive virtual health care environment. In Proceedings of the 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology, Buenos Aires, Argentina, 31 August–4 September 2010; pp. 4464–4467.
18. Xiao, J.; Qu, J.; Li, Y. An Electrooculogram-based interaction method and its music-on-demand application in a virtual reality environment. *IEEE Access* **2019**, *7*, 22059–22070. [[CrossRef](#)]
19. Vidal, M.; Bulling, A.; Gellersen, H. *Analysing EOG Signal Features for the Discrimination of Eye Movements with Wearable Devices*; Association for Computing Machinery: New York, NY, USA, 2011. [[CrossRef](#)]
20. Iáñez, E.; Azorin, J.M.; Perez-Vidal, C. Using eye movement to control a computer: A design for a lightweight electro-oculogram electrode array and computer interface. *PLoS ONE* **2013**, *8*, e67099. [[CrossRef](#)] [[PubMed](#)]
21. English, E.; Hung, A.; Kesten, E.; Latulipe, D.; Jin, Z. EyePhone: A mobile EOG-based human-computer interface for assistive healthcare. In Proceedings of the 2013 6th International IEEE/EMBS Conference on Neural Engineering (NER), San Diego, CA, USA, 6–8 November 2013; pp. 105–108.
22. Valeriani, D.; Matran-Fernandez, A. Towards a wearable device for controlling a smartphone with eye winks. In Proceedings of the 2015 7th Computer Science and Electronic Engineering Conference (CEEC), Colchester, UK, 24–25 September 2015; pp. 41–46.
23. Kosmyna, N.; Morris, C.; Nguyen, T.; Zepf, S.; Hernandez, J.; Maes, P. AttentivU: Designing EEG and EOG compatible glasses for physiological sensing and feedback in the car. In Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Leeds, UK, 9–14 September 2019; pp. 355–368.
24. Aungsakun, S.; Phinyomark, A.; Phukpattaranont, P.; Limsakul, C. *Robust Eye Movement Recognition Using EOG Signal for Human-COMPUTER interface*, International Conference on Software Engineering and Computer Systems, Pahang, Malaysia, 27–29 June 2011; Springer: Berlin/Heidelberg, Germany, 2011; pp. 714–723.
25. López, A.; Ferrero, F.; Yangüela, D.; Álvarez, C.; Postolache, O. Development of a computer writing system based on EOG. *Sensors* **2017**, *17*, 1505. [[CrossRef](#)] [[PubMed](#)]
26. Rajesh, A.N.; Chandralingam, S.; Anjaneyulu, T.; Satyanarayana, K. Eog controlled motorized wheelchair for disabled persons. *Int. J. Med. Health Biomed. Bioeng. Pharm. Eng.* **2014**, *8*, 302–305.
27. Hossain, Z.; Shuvo, M.M.H.; Sarker, P. Hardware and software implementation of real time electrooculogram (EOG) acquisition system to control computer cursor with eyeball movement. In Proceedings of the 2017 4th International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, Bangladesh, 28–30 September 2017; pp. 132–137.
28. Bulling, A.; Roggen, D. *Recognition of Visual Memory Recall Processes Using Eye Movement Analysis*; Association for Computing Machinery: New York, NY, USA, 2011. [[CrossRef](#)]
29. Goto, S.; Yano, O.; Matsuda, Y.; Sugi, T.; Egashira, N. Development of Hands-Free Remote Operation System for a Mobile Robot Using EOG and EMG. *Electron. Commun. Jpn.* **2017**, *100*, 38–47. [[CrossRef](#)]
30. Barea, R.; Boquete, L.; Bergasa, L.M.; López, E.; Mazo, M. Electro-oculographic guidance of a wheelchair using eye movements codification. *Int. J. Robot. Res.* **2003**, *22*, 641–652. [[CrossRef](#)]
31. Yamagishi, K.; Hori, J.; Miyakawa, M. Development of EOG-based communication system controlled by eight-directional eye movements. In Proceedings of the 2006 International Conference of the IEEE Engineering in Medicine and Biology Society, New York, NY, USA, 30 August–3 September 2006; pp. 2574–2577.
32. Tsai, J.; Lee, C.; Wu, C.; Wu, J.; Kao, K. A feasibility study of an eye-writing system based on electro-oculography. *J. Med. Biol. Eng.* **2008**, *28*, 39.
33. Gandhi, T.; Trikha, M.; Santhosh, J.; Anand, S. Development of an expert multitask gadget controlled by voluntary eye movements. *Expert Syst. Appl.* **2010**, *37*, 4204–4211. [[CrossRef](#)]
34. Aungsakul, S.; Phinyomark, A.; Phukpattaranont, P.; Limsakul, C. Evaluating feature extraction methods of electrooculography (EOG) signal for human-computer interface. *Procedia Eng.* **2012**, *32*, 246–252. [[CrossRef](#)]
35. Pournamdar, V.; Vahdani-Manaf, N. Classification of eye movement signals using electrooculography in order to device controlling. In Proceedings of the 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI), Tehran, Iran, 22 December 2017; pp. 339–342.
36. Widge, A.S.; Moritz, C.T.; Matsuoka, Y. Direct neural control of anatomically correct robotic hands. In *Brain-Computer Interfaces*; Springer: Berlin/Heidelberg, Germany, 2010; pp. 105–119.
37. Banerjee, A.; Datta, S.; Pal, M.; Konar, A.; Tibarewala, D.; Janarthanan, R. Classifying electrooculogram to detect directional eye movements. *Procedia Technol.* **2013**, *10*, 67–75. [[CrossRef](#)]

38. Syal, P.; Kumari, P. Comparative Analysis of KNN, SVM, DT for EOG based Human Computer Interface. In Proceedings of the 2017 International Conference on Current Trends in Computer, Electrical, Electronics and Communication (CTCEEC), Mysore, India, 8–9 September 2017; pp. 1023–1028.
39. CR, H.; MP, P. Classification of eye movements using electrooculography and neural networks. *Int. J. Hum. Comput. Interact. (IJHCI)* **2014**, *5*, 51.
40. Mala, S.; Latha, K. Feature selection in classification of eye movements using electrooculography for activity recognition. *Comput. Math. Methods Med.* **2014**, *2014*, 713818. [[CrossRef](#)] [[PubMed](#)]
41. Chen, S.C.; Tsai, T.T.; Luo, C.H. Portable and programmable clinical EOG diagnostic system. *J. Med. Eng. Technol.* **2020**, *24*, 154–162. [[CrossRef](#)]
42. Rosander, K.; von Hofsten, C. Visual-vestibular interaction in early infancy. *Exp. Brain Res.* **2000**, *133*, 321–333. [[CrossRef](#)] [[PubMed](#)]
43. Barea, R.; Boquete, L.; Mazo, M.; Lopez, E. System for assisted mobility using eye movements based on electrooculography. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2002**, *10*, 209–218. [[CrossRef](#)]
44. Ding, F.; Chen, T. Gradient based iterative algorithms for solving a class of matrix equations. *IEEE Trans. Autom. Control* **2005**, *50*, 1216–1221. [[CrossRef](#)]
45. Ding, Q.; Tong, K.; Li, G. Development of an EOG (electro-oculography) based human-computer interface. In Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, hanghai, China, 17–18 January 2006; pp. 6829–6831.
46. Trejo, L.J.; Rosipal, R.; Matthews, B. Brain-computer interfaces for 1-D and 2-D cursor control: Designs using volitional control of the EEG spectrum or steady-state visual evoked potentials. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2006**, *14*, 225–229. [[CrossRef](#)]
47. Akan, B.; Argunsah, A.O. A human-computer interface (HCI) based on electrooculogram (EOG) for handicapped. In Proceedings of the 2007 IEEE 15th Signal Processing and Communications Applications, Eskisehir, Turkey, 11–13 June 2007; pp. 1–3.
48. Bashashati, A.; Nouredin, B.; Ward, R.K.; Lawrence, P.; Birch, G.E. Effect of eye-blinks on a self-paced brain interface design. *Clin. Neurophysiol.* **2007**, *118*, 1639–1647. [[CrossRef](#)]
49. Krueger, T.B.; Stieglitz, T. A Naïve and Fast Human Computer Interface Controllable for the Inexperienced—a Performance Study. In Proceedings of the 2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Lyon, France, 22–26 August 2007; pp. 2508–2511.
50. Skotte, J.H.; Nøjgaard, J.K.; Jørgensen, L.V.; Christensen, K.B.; Sjøgaard, G. Eye blink frequency during different computer tasks quantified by electrooculography. *Eur. J. Appl. Physiol.* **2007**, *99*, 113–119. [[CrossRef](#)]
51. Estrany, B.; Fuster, P.; Garcia, A.; Luo, Y. Human computer interface by EOG tracking. In Proceedings of the 1st International Conference on Pervasive Technologies Related to Assistive Environments, Athens, Greece, 16–18 July 2008; pp. 1–9.
52. Cheng, W.C. *Interactive Techniques for Reducing Color Breakup*; Association for Computing Machinery: New York, NY, USA, 2008. [[CrossRef](#)]
53. Mühlberger, A.; Wieser, M.J.; Pauli, P. Visual attention during virtual social situations depends on social anxiety. *CyberPsychol. Behav.* **2008**, *11*, 425–430. [[CrossRef](#)]
54. Estrany, B.; Fuster, P.; Garcia, A.; Luo, Y. EOG signal processing and analysis for controlling computer by eye movements. In Proceedings of the 2nd International Conference on Pervasive Technologies Related to Assistive Environments, Corfu, Greece, 9–13 June 2009; pp. 1–4.
55. Bulling, A.; Roggen, D.; Tröster, G. *Wearable EOG Goggles: Eye-Based Interaction in Everyday Environments*; Association for Computing Machinery: New York, NY, USA, 2009. [[CrossRef](#)]
56. Zheng, W.L.; Lu, B.L. A multimodal approach to estimating vigilance using EEG and forehead EOG. *J. Neural Eng.* **2017**, *14*, 026017. [[CrossRef](#)]
57. Keegan, J.; Burke, E.; Condrón, J. An electrooculogram-based binary saccade sequence classification (BSSC) technique for augmentative communication and control. In Proceedings of the 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, MN, USA, 3–6 September 2009; pp. 2604–2607.
58. Usakli, A.; Gurkan, S.; Aloise, F.; Vecchiato, G.; Babiloni, F. A hybrid platform based on EOG and EEG signals to restore communication for patients afflicted with progressive motor neuron diseases. In Proceedings of the 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, MN, USA, 3–6 September 2009; pp. 543–546.
59. Yagi, T. Eye-gaze interfaces using electro-oculography (EOG). In Proceedings of the 2010 Workshop on Eye Gaze in Intelligent Human Machine Interaction, Hong Kong, China, 7 February 2010; pp. 28–32.
60. Usakli, A.B.; Gurkan, S.; Aloise, F.; Vecchiato, G.; Babiloni, F. On the use of electrooculogram for efficient human computer interfaces. *Comput. Intell. Neurosci.* **2010**, *2010*, 135629. [[CrossRef](#)] [[PubMed](#)]
61. Belov, D.P.; Eram, S.Y.; Kolodyazhnyi, S.F.; Kanunikov, I.E.; Getmanenko, O.V. Electrooculogram detection of eye movements on gaze displacement. *Neurosci. Behav. Physiol.* **2010**, *40*, 583–591. [[CrossRef](#)] [[PubMed](#)]
62. Punsawad, Y.; Wongsawat, Y.; Parnichkun, M. Hybrid EEG-EOG brain-computer interface system for practical machine control. In Proceedings of the annual international conference of the IEEE engineering in medicine and biology, Buenos Aires, Argentina, 31 August–4 September 2010; pp. 1360–1363. [[CrossRef](#)]
63. Li, Y.; Li, X.; Ratcliffe, M.; Liu, L.; Qi, Y.; Liu, Q. *A Real-Time EEG-Based BCI System for Attention Recognition in Ubiquitous Environment*; Association for Computing Machinery: New York, NY, USA, 2011. [[CrossRef](#)]

64. Liu, Y.; Zhou, Z.; Hu, D. Gaze independent brain–computer speller with covert visual search tasks. *Clin. Neurophysiol.* **2011**, *122*, 1127–1136. [[CrossRef](#)] [[PubMed](#)]
65. Tangsuksant, W.; Aekmunkhongpaisal, C.; Cambua, P.; Charoenpong, T.; Chanwimalueang, T. Directional eye movement detection system for virtual keyboard controller. In Proceedings of the 5th 2012 Biomedical Engineering International Conference, Muang, Thailand, 5–7 December 2012; pp. 1–5.
66. Nathan, D.S.; Vinod, A.P.; Thomas, K.P. An electrooculogram based assistive communication system with improved speed and accuracy using multi-directional eye movements. In Proceedings of the 2012 35th International Conference on Telecommunications and Signal Processing (TSP), Prague, Czech Republic, 3–4 July 2012; pp. 554–558.
67. Ubeda, A.; Ianez, E.; Azorin, J.M. An integrated electrooculography and desktop input bimodal interface to support robotic arm control. *IEEE Trans. Hum.-Mach. Syst.* **2013**, *43*, 338–342. [[CrossRef](#)]
68. Li, L. The Research and Implementation of the HCI System Based on Bioelectricity. In Proceedings of the 2013 International Conference on Computer Sciences and Applications, Wuhan, China, 14–15 December 2013; pp. 414–417.
69. Manabe, H.; Yagi, T. *EOG-Based Eye Gesture Input with Audio Staging*; Association for Computing Machinery: New York, NY, USA, 2014. [[CrossRef](#)]
70. Ishimaru, S.; Kunze, K.; Uema, Y.; Kise, K.; Inami, M.; Tanaka, K. *Smarter Eyewear: Using Commercial EOG Glasses for Activity Recognition*; Association for Computing Machinery: New York, NY, USA, 2014. [[CrossRef](#)]
71. Witkowski, M.; Cortese, M.; Cempini, M.; Mellinger, J.; Vitiello, N.; Soekadar, S.R. Enhancing brain-machine interface (BMI) control of a hand exoskeleton using electrooculography (EOG). *J. NeuroEng. Rehabil.* **2014**, *11*, 165. [[CrossRef](#)]
72. Ma, J.; Zhang, Y.; Cichocki, A.; Matsuno, F. A Novel EOG/EEG Hybrid Human–Machine Interface Adopting Eye Movements and ERPs: Application to Robot Control. *IEEE Trans. Biomed. Eng.* **2014**, *62*, 876–889. [[CrossRef](#)]
73. Jiang, J.; Zhou, Z.; Yin, E.; Yu, Y.; Hu, D. Hybrid Brain–Computer Interface (BCI) based on the EEG and EOG signals. *Bio-Med. Mater. Eng.* **2014**, *24*, 2919–2925. [[CrossRef](#)]
74. Wang, H.; Li, Y.; Long, J.; Yu, T.; Gu, Z. An asynchronous wheelchair control by hybrid EEG-EOG brain-computer interface. *Cogn. Neurodyn.* **2014**, *8*, 399–409. [[CrossRef](#)]
75. Aziz, F.; Arof, H.; Mokhtar, N.; Mubin, M. HMM based automated wheelchair navigation using EOG traces in EEG. *J. Neural Eng.* **2014**, *11*, 056018. [[CrossRef](#)]
76. Hossain, M.S.; Huda, K.; Ahmad, M. Command the computer with your eye-An electrooculography based approach. In Proceedings of the 8th International Conference on Software, Knowledge, Information Management and Applications (SKIMA 2014), Dhaka, Bangladesh, 18–20 December 2014; pp. 1–6.
77. D’Souza, S.; Natarajan, S. Recognition of EOG based reading task using AR features. In Proceedings of the International Conference on Circuits, Communication, Control and Computing, Bangalore, India, 21–22 November 2014; pp. 113–117.
78. Manmadhan, S. Eye movement controlled portable human computer interface for the disabled. In Proceedings of the 2014 International Conference on Embedded Systems (ICES), Coimbatore, India, 3–5 July 2014; pp. 271–274.
79. OuYang, R.; Lv, Z.; Wu, X. An algorithm for reading activity recognition based on electrooculogram. In Proceedings of the 2015 10th International Conference on Information, Communications and Signal Processing (ICICS), Singapore, 2–4 December 2015; pp. 1–5.
80. Manabe, H.; Fukumoto, M.; Yagi, T. Direct gaze estimation based on nonlinearity of EOG. *IEEE Trans. Biomed. Eng.* **2015**, *62*, 1553–1562. [[CrossRef](#)]
81. Ishimaru, S.; Kunze, K.; Tanaka, K.; Uema, Y.; Kise, K.; Inami, M. *Smart Eyewear for Interaction and Activity Recognition*; Association for Computing Machinery: New York, NY, USA, 2015. [[CrossRef](#)]
82. Hossain, M.S.; Huda, K.; Rahman, S.S.; Ahmad, M. Implementation of an EOG based security system by analyzing eye movement patterns. In Proceedings of the 2015 International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, Bangladesh, 17–19 December 2015; pp. 149–152.
83. Banik, P.P.; Azam, M.K.; Mondal, C.; Rahman, M.A. Single channel electrooculography based human-computer interface for physically disabled persons. In Proceedings of the 2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), Savar, Bangladesh, 21–23 May 2015; pp. 1–6.
84. Kumar, D.; Sharma, A. Electrooculogram-based virtual reality game control using blink detection and gaze calibration. In Proceedings of the 2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI), Jaipur, India, 21–24 September 2016; pp. 2358–2362.
85. Dhuliawala, M.; Lee, J.; Shimizu, J.; Bulling, A.; Kunze, K.; Starner, T.; Woo, W. *Smooth Eye Movement Interaction Using EOG Glasses*; Association for Computing Machinery: New York, NY, USA, 2016. [[CrossRef](#)]
86. Shimizu, J.; Chernyshov, G. *Eye Movement Interactions in Google Cardboard Using a Low Cost EOG Setup*; Association for Computing Machinery: New York, NY, USA, 2016. [[CrossRef](#)]
87. Shimizu, J.; Lee, J.; Dhuliawala, M.; Bulling, A.; Starner, T.; Woo, W.; Kunze, K. *Solar System: Smooth Pursuit Interactions Using EOG Glasses*; Association for Computing Machinery: New York, NY, USA, 2016. [[CrossRef](#)]
88. Bissoli, A.L.C.; Coelho, Y.L.; Bastos-Filho, T.F. *A System for Multimodal Assistive Domotics and Augmentative and Alternative Communication*; Association for Computing Machinery: New York, NY, USA, 2016. [[CrossRef](#)]

89. Wilaiprasitporn, T.; Yagi, T. Feasibility Study of Drowsiness Detection Using Hybrid Brain-Computer Interface. In Proceedings of the international Convention on Rehabilitation Engineering & Assistive Technology, Singapore, 25–28 July 2016; pp. 1–4. [[CrossRef](#)]
90. Fang, F.; Shinozaki, T.; Horiuchi, Y.; Kuroiwa, S.; Furui, S.; Musha, T. Improving Eye Motion Sequence Recognition Using Electrooculography Based on Context-Dependent HMM. *Comput. Intell. Neurosci.* **2016**, *2016*, 6898031. [[CrossRef](#)] [[PubMed](#)]
91. Tamura, H.; Yan, M.; Sakurai, K.; Tanno, K. EOG-sEMG Human Interface for Communication. *Comput. Intell. Neurosci.* **2016**, *2016*, 7354082. [[CrossRef](#)] [[PubMed](#)]
92. Barbara, N.; Camilleri, T.A. Interfacing with a speller using EOG glasses. In Proceedings of the 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Budapest, Hungary, 9–12 October 2016; pp. 001069–001074.
93. Atique, M.M.U.; Rakib, S.H.; Siddique-e Rabbani, K. An electrooculogram based control system. In Proceedings of the 2016 5th International Conference on Informatics, Electronics and Vision (ICIEV), Dhaka, Bangladesh, 13–14 May 2016; pp. 809–812.
94. Naijian, C.; Xiangdong, H.; Yantao, W.; Xinglai, C.; Hui, C. Coordination control strategy between human vision and wheelchair manipulator based on BCI. In Proceedings of the 2016 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA), Hefei, China, 5–7 June 2016; pp. 1872–1875.
95. Ogai, S.; Tanaka, T. A drag-and-drop type human computer interaction technique based on electrooculogram. In Proceedings of the 2017 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC), Kuala Lumpur, Malaysia, 12–15 December 2017; pp. 716–720.
96. Lee, K.R.; Chang, W.D.; Kim, S.; Im, C.H. Real-Time “Eye-Writing” Recognition Using Electrooculogram. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2017**, *25*, 37–48. [[CrossRef](#)] [[PubMed](#)]
97. Robert, H.; Kise, K.; Augereau, O. *Real-Time Wordometer Demonstration Using Commercial EoG Glasses*; Association for Computing Machinery: New York, NY, USA, 2017. [[CrossRef](#)]
98. Ishimaru, S.; Hoshika, K.; Kunze, K.; Kise, K.; Dengel, A. *Towards Reading Trackers in the Wild: Detecting Reading Activities by EOG Glasses and Deep Neural Networks*; Association for Computing Machinery: New York, NY, USA, 2017. [[CrossRef](#)]
99. Kise, K.; Augereau, O.; Utsumi, Y.; Iwamura, M.; Kunze, K.; Ishimaru, S.; Dengel, A. *Quantified Reading and Learning for Sharing Experiences*; Association for Computing Machinery: New York, NY, USA, 2017. [[CrossRef](#)]
100. Augereau, O.; Sanches, C.L.; Kise, K.; Kunze, K. Wordometer Systems for Everyday Life. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* **2018**, *1*, 1–21. [[CrossRef](#)]
101. Tag, B.; Mannschreck, R.; Sugiura, K.; Chernyshov, G.; Ohta, N.; Kunze, K. *Facial Thermography for Attention Tracking on Smart Eyewear: An Initial Study*; Association for Computing Machinery: New York, NY, USA, 2017. [[CrossRef](#)]
102. Thakur, B.; Syal, P.; Kumari, P. *An Electrooculogram Signal Based Control System in Offline Environment*; Association for Computing Machinery: New York, NY, USA, 2017. [[CrossRef](#)]
103. Chang, W.D.; Cha, H.S.; Kim, D.Y.; Kim, S.H.; Im, C.H. Development of an electrooculogram-based eye-computer interface for communication of individuals with amyotrophic lateral sclerosis. *J. NeuroEng. Rehabil.* **2017**, *14*, 89. [[CrossRef](#)]
104. Huang, Q.; He, S.; Wang, Q.; Gu, Z.; Peng, N.; Li, K.; Zhang, Y.; Shao, M.; Li, Y. An EOG-Based Human-Machine Interface for Wheelchair Control. *IEEE Trans. Biomed. Eng.* **2018**, *65*, 2023–2032. [[CrossRef](#)]
105. Heo, J.; Yoon, H.; Park, K.S. A Novel Wearable Forehead EOG Measurement System for Human Computer Interfaces. *Sensors* **2017**, *17*. [[CrossRef](#)]
106. He, S.; Li, Y. A Single-Channel EOG-Based Speller. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2017**, *25*, 1978–1987. [[CrossRef](#)]
107. Lee, M.H.; Williamson, J.; Won, D.O.; Fazli, S.; Lee, S.W. A High Performance Spelling System based on EEG-EOG Signals with Visual Feedback. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2018**, *26*, 1443–1459. [[CrossRef](#)]
108. Zhang, J.; Wang, B.; Zhang, C.; Hong, J. Volitional and Real-Time Control Cursor Based on Eye Movement Decoding Using a Linear Decoding Model. *Comput. Intell. Neurosci.* **2016**, *2016*, 4069790. [[CrossRef](#)]
109. Zhi-Hao, W.; Yu-Fan, K.; Chuan-Te, C.; Shi-Hao, L.; Gwo-Jia, J. Controlling DC motor using eye blink signals based on LabVIEW. In Proceedings of the 2017 5th International Conference on Electrical, Electronics and Information Engineering (ICEEIE), Malang, Indonesia, 6–8 October 2017; pp. 61–65.
110. Soundariya, R.; Renuga, R. Eye movement based emotion recognition using electrooculography. In Proceedings of the 2017 Innovations in Power and Advanced Computing Technologies (i-PACT), Vellore, India, 21–22 April 2017; pp. 1–5.
111. O’Bard, B.; Larson, A.; Herrera, J.; Nega, D.; George, K. Electrooculography based iOS controller for individuals with quadriplegia or neurodegenerative disease. In Proceedings of the 2017 IEEE International Conference on Healthcare Informatics (ICHI), Park City, UT, USA, 23–26 August 2017; pp. 101–106.
112. Perin, M.; Porto, R.; Neto, A.Z.; Spindola, M.M. EOG analog front-end for human machine interface. In Proceedings of the 2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Turin, Italy, 22–25 May 2017; pp. 1–6.
113. Karagöz, Y.; Gül, S.; Çetnel, G. An EOG based communication channel for paralyzed patients. In Proceedings of the 2017 25th Signal Processing and Communications Applications Conference (SIU), Antalya, Turkey, 15–18 May 2017; pp. 1–4.
114. Crea, S.; Nann, M.; Trigili, E.; Cordella, F.; Baldoni, A.; Badesa, F.J.; Catalán, J.M.; Zollo, L.; Vitiello, N.; Aracil, N.G.; Soekadar, S.R. Feasibility and safety of shared EEG/EOG and vision-guided autonomous whole-arm exoskeleton control to perform activities of daily living. *Sci. Rep.* **2018**, *8*. [[CrossRef](#)] [[PubMed](#)]

115. Zhang, R.; He, S.; Yang, X.; Wang, X.; Li, K.; Huang, Q.; Yu, Z.; Zhang, X.; Tang, D.; Li, Y. An EOG-based human-machine interface to control a smart home environment for patients with severe spinal cord injuries. *IEEE Trans. Biomed. Eng.* **2018**, *66*, 89–100. [[CrossRef](#)] [[PubMed](#)]
116. Kim, D.Y.; Han, C.H.; Im, C.H. Development of an electrooculogram-based human-computer interface using involuntary eye movement by spatially rotating sound for communication of locked-in patients. *Sci. Rep.* **2018**, *8*, 9505. [[CrossRef](#)] [[PubMed](#)]
117. Fang, F.; Shinozaki, T. Electrooculography-based continuous eye-writing recognition system for efficient assistive communication systems. *PLoS ONE* **2018**, *13*, e0192684. [[CrossRef](#)]
118. Bastes, A.; Alhat, S.; Panse, M. Speech Assistive Communication System Using EOG. In Proceedings of the 2018 Second International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 14–15 June 2018; pp. 504–510.
119. Hou, H.K.; Smitha, K. Low-cost wireless electrooculography speller. In Proceedings of the 2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Miyazaki, Japan, 7–10 October 2018; pp. 123–128.
120. Jialu, G.; Ramkumar, S.; Emayavaramban, G.; Thilagaraj, M.; Muneeswaran, V.; Rajasekaran, M.P.; Hussein, A.F. Offline analysis for designing electrooculogram based human computer interface control for paralyzed patients. *IEEE Access* **2018**, *6*, 79151–79161. [[CrossRef](#)]
121. Sun, L.; Wang, S.a.; Chen, H.; Chen, Y. A novel human computer interface based on electrooculogram signal for smart assistive robots. In Proceedings of the 2018 IEEE International Conference on Mechatronics and Automation (ICMA), Changchun, China, 5–8 August 2018; pp. 215–219.
122. Lu, Y.Y.; Huang, Y.T. A method of personal computer operation using Electrooculography signal. In Proceedings of the 2019 IEEE Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS), Okinawa, Japan, 31 May–3 June 2019; pp. 76–78.
123. Garrote, L.; Perdiz, J.; Pires, G.; Nunes, U.J. Reinforcement learning motion planning for an EOG-centered robot assisted navigation in a virtual environment. In Proceedings of the 2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), New Delhi, India, 14–18 October 2019; pp. 1–7.
124. Tag, B.; Vargo, A.W.; Gupta, A.; Chernyshov, G.; Kunze, K.; Dingler, T. *Continuous Alertness Assessments: Using EOG Glasses to Unobtrusively Monitor Fatigue Levels In-The-Wild*; Association for Computing Machinery: New York, NY, USA, 2019. [[CrossRef](#)]
125. Findling, R.D.; Quddus, T.; Sigg, S. *Hide my Gaze with EOG! Towards Closed-Eye Gaze Gesture Passwords that Resist Observation-Attacks with Electrooculography in Smart Glasses*; Association for Computing Machinery: New York, NY, USA, 2019. [[CrossRef](#)]
126. Rostaminia, S.; Lamson, A.; Maji, S.; Rahman, T.; Ganesan, D. WINCE: Unobtrusive Sensing of Upper Facial Action Units with EOG-based Eyewear. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* **2020**, *3*, 1–26. [[CrossRef](#)]
127. Badesa, F.J.; Diez, J.A.; Catalan, J.M.; Trigili, E.; Cordella, F.; Nann, M.; Crea, S.; Soekadar, S.R.; Zollo, L.; Vitiello, N.; et al. Physiological Responses During Hybrid BNCI Control of an Upper-Limb Exoskeleton. *Sensors* **2019**, *19*, 4931. [[CrossRef](#)]
128. Zhang, J.; Wang, B.; Zhang, C.; Xiao, Y.; Wang, M.Y. An EEG/EMG/EOG-based multimodal human-machine interface to real-time control of a soft robot hand. *Front. Neurobot.* **2019**, *13*, 7. [[CrossRef](#)]
129. Wu, Y.; Kihara, K.; Takeda, Y.; Sato, T.; Akamatsu, M.; Kitazaki, S. Effects of scheduled manual driving on drowsiness and response to take over request: A simulator study towards understanding drivers in automated driving. *Accid. Anal. Prev.* **2019**, *124*, 202–209. [[CrossRef](#)]
130. Mocny-Pachońska, K.; Doniec, R.; Trzcionka, A.; Pachoński, M.; Piaseczna, N.; Sיעiński, S.; Osadcha, O.; Łanowy, P.; Tanasiewicz, M. Evaluating the stress-response of dental students to the dental school environment. *PeerJ* **2020**, *8*. [[CrossRef](#)]
131. He, S.; Zhou, Y.; Yu, T.; Zhang, R.; Huang, Q.; Chuai, L.; Mustafa, M.U.; Gu, Z.; Yu, Z.L.; Tan, H.; Li, Y. EEG- and EOG-Based Asynchronous Hybrid BCI: A System Integrating a Speller, a Web Browser, an E-Mail Client, and a File Explorer. *IEEE Trans. Neural Syst. Rehabil. Eng.* **2019**, *28*, 519–530. [[CrossRef](#)] [[PubMed](#)]
132. Huang, Q.; Zhang, Z.; Yu, T.; He, S.; Li, Y. An EEG-/EOG-based hybrid brain-computer interface: Application on controlling an integrated wheelchair robotic arm system. *Front. Neurosci.* **2019**, *13*, 1243. [[CrossRef](#)] [[PubMed](#)]
133. Zander, T.O.; Kothe, C.; Jatzev, S.; Gaertner, M. Enhancing human-computer interaction with input from active and passive brain-computer interfaces. In *Brain-Computer Interfaces*; Springer: Berlin/Heidelberg, Germany, 2010; pp. 181–199.
134. Vidal, M.; Bulling, A.; Gellersen, H. Pursuits: Spontaneous interaction with displays based on smooth pursuit eye movement and moving targets. In Proceedings of the 2013 ACM International Joint CONFERENCE on Pervasive and Ubiquitous Computing, Zurich Switzerland, 8–12 September 2013; pp. 439–448.
135. Esteves, A.; Velloso, E.; Bulling, A.; Gellersen, H. Orbits: Gaze interaction for smart watches using smooth pursuit eye movements. In Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology, Charlotte, NC, USA, 8–11 November 2015; pp. 457–466.
136. Kangas, J.; Špakov, O.; Isokoski, P.; Akkil, D.; Rantala, J.; Raisamo, R. Feedback for smooth pursuit gaze tracking based control. In Proceedings of the 7th Augmented Human International Conference 2016, Geneva, Switzerland, 25–27 February 2016; pp. 1–8.
137. Khamis, M.; Alt, F.; Bulling, A. A field study on spontaneous gaze-based interaction with a public display using pursuits. 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, Umeda, Japan, 9–11 September 2015; pp. 863–872.
138. Jalaliniya, S.; Mardanbegi, D. Eyegrip: Detecting targets in a series of uni-directional moving objects using optokinetic nystagmus eye movements. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, San Jose, CA, USA, 7–12 May 2016; pp. 5801–5811.

139. Schenk, S.; Tiefenbacher, P.; Rigoll, G.; Dorr, M. Spock: A smooth pursuit oculomotor control kit. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA, USA, 7–12 May 2016; pp. 2681–2687.
140. Zao, J.K.; Jung, T.P.; Chang, H.M.; Gan, T.T.; Wang, Y.T.; Lin, Y.P.; Liu, W.H.; Zheng, G.Y.; Lin, C.K.; Lin, C.H. Augmenting VR/AR applications with EEG/EOG monitoring and oculo-vestibular recoupling. In *International Conference on Augmented Cognition*, Springer: Berlin/Heidelberg, Germany, 2016, pp. 121–131.
141. Altobelli, F. ElectroOculoGraphy (EOG) Eye-Tracking for Virtual Reality. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2019.
142. Lupu, R.G.; Irimia, D.C.; Ungureanu, F.; Poboroniuc, M.S.; Moldoveanu, A. BCI and FES based therapy for stroke rehabilitation using VR facilities. *Wirel. Commun. Mob. Comput.* **2018**, *2018*, 4798359. [[CrossRef](#)]
143. Bachmann, D.; Weichert, F.; Rinkenauer, G. Review of three-dimensional human-computer interaction with focus on the leap motion controller. *Sensors* **2018**, *18*, 2194. [[CrossRef](#)] [[PubMed](#)]
144. Caldwell, R. Models of change agency: A fourfold classification. *Br. J. Manag.* **2003**, *14*, 131–142. [[CrossRef](#)]
145. Wilson, G.F.; Caldwell, J.A.; Russell, C.A. Performance and psychophysiological measures of fatigue effects on aviation related tasks of varying difficulty. *Int. J. Aviat. Psychol.* **2007**, *17*, 219–247. [[CrossRef](#)]
146. Sirevaag, E.J.; Stern, J.A. Ocular measures of fatigue and cognitive factors. In *Engineering Psychophysiology: Issues and Applications*; CRC Press: Boca Raton, FL, USA, 2000; pp. 269–287.
147. Peysakhovich, V.; Vachon, F.; Dehais, F. The impact of luminance on tonic and phasic pupillary responses to sustained cognitive load. *Int. J. Psychophysiol.* **2017**, *112*, 40–45. [[CrossRef](#)]
148. Jia, Y.; Tyler, C.W. Measurement of saccadic eye movements by electrooculography for simultaneous EEG recording. *Behav. Res. Methods* **2019**, *51*, 2139–2151. [[CrossRef](#)]
149. Penzel, T.; Lo, C.C.; Ivanov, P.; Kesper, K.; Becker, H.; Vogelmeier, C. Analysis of sleep fragmentation and sleep structure in patients with sleep apnea and normal volunteers. In Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, 17–18 January 2006; pp. 2591–2594.
150. Borghetti, D.; Bruni, A.; Fabbrini, M.; Murri, L.; Sartucci, F. A low-cost interface for control of computer functions by means of eye movements. *Comput. Biol. Med.* **2007**, *37*, 1765–1770. [[CrossRef](#)]
151. Rosekind, M.R.; Gander, P.H.; Miller, D.L.; Gregory, K.B.; Smith, R.M.; Weldon, K.J.; Co, E.L.; McNally, K.L.; Lebacqz, J.V. Fatigue in operational settings: Examples from the aviation environment. *Hum. Factors* **1994**, *36*, 327–338. [[CrossRef](#)]
152. Dahlstrom, N.; Nahlinder, S. Mental workload in aircraft and simulator during basic civil aviation training. *Int. J. Aviat. Psychol.* **2009**, *19*, 309–325. [[CrossRef](#)]