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Reviews

Utility of eye-tracking methodology in health science research

Użyteczność metodologii analizy ruchów oka w badaniach z dziedziny nauk o zdrowiu

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A – koncepcja i przygotowanie projektu badań, B – wykonanie analiz diagnostycznych, zbieranie danych, C – analiza statystyczna, D – interpretacja danych, E – przygotowanie manuskryptu, F – opracowanie piśmiennictwa, G – pozyskanie funduszy.

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SUMMARY

Background. This article is a systematic review of research using eye-tracking as a main methodology in the field of health science. It also describes the main eye-tracking groups of methods.

Objectives. The aim of the study is to describe eye-tracking methodology and to analyse its' usefulness in public health research.

Material and methods. A systematic review of all English language PubMed articles from the last 5 years (2011 – 2016) has been done using keywords: health research, EOG, VOG, IROG, oculography, scleral search coil. The articles not-related have been excluded.

Results. Electro-oculography which is used in sleep research is based on measuring the differences in corneoretinal potential during eye movement. Magneto-oculography enables to measure eye movements in three dimensions: vertical, horizontal, torsional. It uses special contact lenses with embedded coil of wire which are moving together with the eyes – changes in the voltage induced show eye movements. Infra-red oculography uses infra-red light emitters placed on a head mounted device and is well suited to be used as a portable ambulatory screening technique. It is used in research with neurological, psychiatric and ophthalmological patients. Video-oculography uses cameras to record eye movements either in visible of infra-red spectrum, it enables to track what the subject was looking at.

Conclusions. Main eye tracking methodologies (electrooculography (EOG), sclear search coil (MOG), infra-red oculography (IROG), video-oculography (VOG)) are being used in health research. Each one of these is best suited for different type of research. Recently a growing number of research started using VOG at the expense of other mentioned methods.

Key words: h**ealth research, eye movement, eye-tracking, neuroscience**

STRESZCZENIE

Wstęp. Artykuł powstał w efekcie przeglądu badań z zakresu nauk o zdrowiu, gdzie śledzenie ruchu gałek ocznych było główną stosowaną metodologią. Opisano główne techniki okulograficzne.

Cel pracy. Opisanie metodologii badania ruchu gałek ocznych a także ocena użyteczności tych badań w dziedzinie nauk o zdrowiu.

Materiał i metody. Przeszukano bazę artykułów Medline z ostatnich 5 lat (2011 – 2016) używając słów kluczowych: health research, EOG, VOG, IROG, oculography, scleral search coil. Wykluczono artykuły niepowiązane z tematyką pracy.

Wyniki. Metodologia elektro-okulografii wykorzystywana jest przy badaniu snu, oparta jest na mierzeniu różnicy potencjałów podczas poruszania się gałki ocznej. Magneto-okulografia pozwala badać ruchy oka w trzech płaszczyznach, wykorzystuje szkła kontaktowe z zatopionymi wewnątrz drutami, które przemieszczają się wraz z gałką oczną w polu magnetycznym – zmiany indukowanego napięcia obrazują ruchy oka. Metodologia okulografia podczerwieni pozwala na dokładny pomiar ruchów oka względem głowy. Ze względu na dokładność pomiaru wykorzystywana jest często w badaniach klinicznych, m.in. z dziedziny neurologii, psychiatrii, okulistyki oraz otolarygologii. Video-okulografia wykorzystuje kamery do rejestrowania ruchów oka w świetle widzialnym lub podczerwieni, pozwala badań gdzie patrzyła osoba badana.

Wnioski. Główne metodologie badań ruchu oka (EOG, MOG, IROG, VOG) są stosowane w dziedzinie nauk o zdrowiu. Każda sprawdza się najlepiej w różnych obszarach. Ostatnio rośnie liczba badań korzystających z metody VOG.

Słowa kluczowe: **badania nauk o zdrowiu, ruchy gałek ocznych, śledzenie ruchów oka, neuronauka**

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BACKGROUND

Cognitive science has been paying a great attention to getting to know neurophysiological roots of human cognition. One of the most significant group of research techniques used in this area is eye-tracking also called oculography which gives a way to measure eye movement with a very high temporal resolution [1]. The development of methodologies examining cognitive functions is also a topic of interest of health sciences.. Advancing research affecting the situation of old adults, patients with neurological diseases (which risk increases with age) and disabled people is a crucial challenge of today's public health. It can be addressed with the help of new technologies which have been used to aid research giving hope for help to many of those patients.

Technology advancement requires scientific background from basic and clinical research in the field of cognitive science. One of the group of methods used in that field is eye-tracking. This review article describes main eye-tracking methods and analyses their potential applicability in public health research.

The aim of the study is to describe eye-tracking methodology in a view of its usefulness in health science research. It's achieved by comparing advantages and disadvantages of main eye tracking methods with a description of exemplary devices.

MATERIAL AND METHODS

A systematic review of all English language PubMed articles from the last 5 years (2011 – 2016) using the terms ("health" OR "health research") AND ("EOG" OR "search coil" OR "scleral search coil" OR "VOG" OR "IROG" OR "oculography") was conducted. At first 66 articles were returned, after articles from bioethics and other non-related were excluded, leaving 31 articles to be further examined.

RESULTS

There are four main eye tracking methods groups: Electro-Oculography (EOG), magneto-oculography (MOG) also called scleral search coil system (SSCS), Infra-Red Oculography (IROG) and Video-Oculography (VOG) [2,3], (Tab. 1). It should be mentioned that although EOG and SSCS have established standard devices used in research both VOG and IROG are represented by many devices. Each of them has some distinguishing features which should be taken into account by researchers planning include them in their research project (e.g. necessity of head stabilization or point-of-regard data gathering).

The EOG method

The EOG is based on the fact that there is a permanent electrical potential difference of 1mV between the two sides of the eye (cornea, retina) – so called corneoretinal potential [1]. Placing small electrodes on two eye sides enables capturing small variations in the voltage during eye movement. That recorded signal reflects the position of the eye and is in 15-200 μV range with nominal sensitivity of around 20 μV/deg [3].

This method is used by clinicians especially common in audiology examination for vestibular system, however recently the IROG [4] and VOG [1] tend to be more and more often used for that purpose. Among the advantages of EOG method is the ability to record eye movements behind closed lids – which enables examination of sleeping subjects. The drawbacks of EOG are artifacts from eye velocity as well as proneness to eye drift. As the calibration procedure requires fixation on a set of predefined targets some people suffering from neurological diseases are not able to take part in EOG examination. It concerns patients whose condition interfere with voluntary eye movements what makes proper eye signal calibration in this methodology impossible [1].

EOG is a part of a criterion standard also called gold standard [5] battery of tests in neuroscience of sleep research which is called polysomnography (PSG) [6,7]. PSG consists of: electroencephalography (EEG), EOG, electromyography (EMG) and electrocardiograph (ECG).

Research which uses EOG are focused among other on psychiatric diagnosis of major depressive disorder [8], to normalize EOG's values e.g. slow and fast oscillation results by different variables [9], to evaluate vision disorders like birdshots [10] or serious retinopathy [11]. There are also many application of EOG in sleep research among others examining muscle activity during sleep [12] or sleep quality after physical activity [13].

The SSCS method

Scleral search coil system also known as magneto-oculography proposed by Robinson [14] is based on a principles of the Faraday's law. When a conductor is moving relative to a magnetic field there are changes in its voltage induced [15]. The subject is sitting in a weak, oscillating magnetic field and is wearing special contact lenses with embedded one or two coil of wire. Subject's eye movements are inducing voltage in the search coils proportional to the angle the eyes have moved.

The advantage of this technique is that it records eye movements in three dimensions: vertical, horizontal, torsional. What is more, it can be calibrated without subject's participation which enables examining subjects who are unable to fixate targets. Disadvantages include high cost of the system and the fact that it is not portable. Recording on a human subject is limited to around 30 minutes and requires usage of anesthetics due to reported discomfort of wearing the contact lenses with the coils [1].

Search coil provide a unique way to examine subjects suffering from some neurological diseases. Some of the research areas include the abnormality in eye movements like nystagmus syndrome [16] or control of saccadic movements [17].

The infra-red oculography method

Infra-red oculography is based on detecting the amount of infra-red (IR) light that is reflected by the sclera and detected by a sensor placed near the eye. The key requirement in this method is subjects wearing IR light emitters and detectors with fixed positions around the eyes placed on a head-mounted device. This method uses IR light which is not visible to subjects and does not alter their field of view.

The main advantage of this method is its portability and ease of use even in very demanding conditions like in a hand-held manner in ambulatory screening [18]. Some of devices are also used under Magnetic Resonance Imaging (MRI) examination [19]. One of the disadvantage is that IROG has limited spatial range and is sensitive to slippage – it can occur either when the subject blinks or when the detectors are even slightly misplaced in relation to the eye. This method is also not well suited for subjects which are not able to voluntarily fixate on a target because calibration would not be possible [1].

IROG gives a way to measure eye movements in different settings and conditions. As the method does not alter the field of vision and is portable it is often used in the field of occupational health research e.g. for examining during work activities of operators or drivers [20], safety during driving following night-shift work [21], circadian rhythm – shift workers: ocular measures of sleepiness [22], real time drivers drowsiness feedback [23].

An exemplary device of the IROG is Jazz-novo [24], which is a head mounted eye-tracker with sensors placed between the subject's eyes mounted on the nasal bridge. The system consists of two main parts, which are eye-movement board and signal conversion board. Jazz-novo sensor board is equipped with a set of sensors measuring various subject's biological parameters. It measures different environmental parameters like ambient sound, plethysmography, pulse oximetry, two-axis acceleration and ambient illumination [25]. Jazz-novo eye-movements data is captured with 1 kHz frequency with horizontal plane of $\pm$ 35° and vertical plane of $\pm$ 20° [24]. Jazz-novo with a gyroscope minimizes head movements artefacts in eye movement data. It does not provide point-of-regard data.

System JAZZ-novo had been used in many research. In the Center for Neurological Restoration in Cleveland visual process of siblings with cerebellar atrophy were studied. Saccades misdirected towards target were observed. Typical changes in eye position were analyzed as signals of neuropathology. Those changes were also scrutinizing as presumable indicators of various humans brain parts functioning relevance [26].

Possibility of precise eye-activity measurement has allowed to search for correlations between individuals genotype and intentional oculus movement accuracy. It's also conjectured that genetic correlates of perception capabilities may have been found in the feature [27]. Data from the eye tracker has been also used for potential optimization of prosthetic vision [28].

The video-oculography method

Video-oculography uses recording subject's face to identify position of the eyes basing on video-image analysis algorithms as well as determining the center of the pupil [29]. The video is recorded using one or many normal or IR spectrum cameras. To increase the accuracy and overcome possible image slippages some additional IR light sources are used to light the eyes to also analyze the corneal reflections as well as the position of the limbus. Systems with high frame rate cameras enable eye torsion measurement. It is accomplished either by analyzing rotating motion of vessels patterns of the sclera or within the iris [1]. The biggest advantage of the system is that it is relatively noninvasive to the subjects. Old generation of tools based on VOG methodology had lower temporal and spatial resolution in comparison to direct infra-red oculography [30]. Recently the advances in video cameras hardware, especially frame rate increases as well as recording resolution combined with lower cost of such systems, made these disadvantages gradually minimalized [1].

VOG broad spectrum of possible application range from examining new ways of refining vestibular rehabilitation methods [31] to comparing EOG results with VOG to check automatic EOG analysis algorithm's reliability [32]. Recent advances in VOG have also opened new clinical applications for this method of eye tracking – like e.g. a portable bedside stroke screening test battery [33].

Exemplary eye-trackers belonging to this methodology are Eye-link 1000 [34] and Tobii TX300 [35]. The former provides point-of-regard data and can operate in two ways: with head stabilized or without the need for head stabilization, however with a loss of accuracy by lowering the sampling rate. It's sampling frequency in free head movement option is 500Hz and it recovers from subject's blink in 2 ms [34]. It has also an option to measure a single eye position with 2 kHz frequency. The latter also enables the subject to move the head freely within the IR video signal detection boundaries with sampling frequency of 300Hz and blink recovery time of around a few hundred milliseconds [35].

Table 1 consists of a comparison of the four main eye-tracking methods on four categories: invasiveness, accuracy, temporal resolution and possible drawback of a methodology.

Table 1. Summary of eye tracking methods. [1,3,15,36,37,38*]

METHOD	INVASSIVENESS	ACCURACY	TEMPORAL RESOLUTION	POSSIBLE DRAWBACKS
Electro-Oculography (EOG)	Electrodes placed on subject's skin	Recorded potentials range: 15–200 μV, nominal sensitiveness: 20 μV/deg 1° - 2°	0 – 40 Hz, in certain systems up to 500Hz*	measures eye movements relative to head position – not suitable for point of regard
Magneto-oculography (MOG), Scleral contact lens/search coil system (SSCS)	Subject needs to wear special contact lenses with embedded coil of wire.	0.02°	0 – 500 Hz	Discomfort while wearing the lenses
Infra-Red Oculography (IROG)	Head-mounted sensors and led infrared (IR) light sources.	around 0.1°	0 - 1000Hz, depends on the particular device used	Some devices don't provide point of regards measurement.
Video-Oculography (VOG)	Invassive/non-invassive (depending on the device they can be head-mounted or allow to head free examination)	around 0.05° - 1°	From 0 – 30 Hz, up to 500 – 2000 Hz (depends on the camera used)	Accuracy and resolution depend on optical magnification – more magnification produces better resolution and accuracy but narrows the examined field of view

CONCLUSIONS

Eye tracking is a research method which has significant potential in examining the quality of cognitive functioning. It enables gathering quite extensive subject's cognitive functioning data in a relatively short experiment. These main advantages make it especially useful in clinical research.

A distinctive feature especially important in the case of research involving people suffering from different illnesses is the level of invasiveness. In medicine the term invasiveness is linked to entering the living body by incision or by insertion of an instrument [39]. Hence judging by that term almost all eye tracking techniques are noninvasive with an exception of EOG being used in animals by implanting the coils into cornea surgically [40]. Authors in medical journals tend to use the term invassiveness, e.g. when describing a head-mounted eye-tracker as a noninvasive device [41]. However, in eye movement research a more broad meaning of invasiveness is used. According to Duchowski [3] the invasive method include also wearing the contact lens as opposed to the noninvasive and sometimes called remote methods (e.g. VOG) which does not involve any subject's body contact by the eye-tracking device (ibidem). It is worth mentioning that some authors use the term intrusive interchangeable with invasive in the context of eye tracking devices. Morimoto and Mimica [42] indicate that an "intrusive equipment has to be put in physical contact with the user" so they list the following examples: contact lenses, electrodes as well as head mounted devices (ibidem). According to the last distinction only a part of VOG devices are nonintrusive, the rest of the methods (EOG, MOG, IROG) are intrusive [43].

All of the described methodologies can be applied to health research. They use either quantitative or qualitative approach to providing eye movement measurements. The former examines a group or groups in order to find some differences among them like checking how people with Parkinson's Disease are able to constrain eye-movements compared to healthy adults (Ambati et al., 2016), the latter focuses on a single subject with rare health conditions or facing a task with a fine-grained examination [44,45].

The ability to accurately monitor eye movements enables to examine the process of solving cognitive tasks by the subject without interfering that process. Eye-tracker aided examination enables directly analyzing visual cognitive functions [46-48] and with the high accuracy of the measurement those methods are important contributors to research of cognitive functions pathology. The most important research involves neurological and psychiatric patients.

All the methods can be applied to health research, however the frequency of usage across fields of research differs. VOG seems to be the most useful method in analysis of social behaviors [47]. IROG has more accurate measurements and is better suited for neuropsychological studies [49], although some newest VOG tools can achieve comparable characteristics in specific setup. EOG is being used in research among others when the subject has closed eyes, especially common in sleep research [50]. SSCS is used in research with patients suffering from neurological diseases causing eyes fixation difficult or impossible.

Eye tracking is an important part of current public health research. This set of techniques is useful in many applications for both healthy subjects and patients and can be widely applied in the health science.

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