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Present knowledge of modern technology and virtual computer reality to assess the angle of strabismus

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ABSTRACT

The article constitutes a review of studies about diagnosis of strabismus using advanced technology, the use of virtual reality as well as other applications of already well-known devices such as optical coherence tomography in the diagnosis of strabismus. Technological advances should shorten the examination time significantly and make the result independent of the investigator's experience. The future of strabismic ophthalmology lies in the use of innovative equipment to enable objective, reliable and reproducible measurements of the type of muscle disorder.

KEY WORDS: virtual reality, strabismus, diagnosis of strabismus, computer methods.

INTRODUCTION

Strabismus is any misalignment of the visual axis involving an uneven alignment of eyeballs, which is essential for proper binocular vision [1–3]. It occurs in 4-6% of the population worldwide, in both adults and children, with the same frequency in women and men [3]. Strabismus is the most common cause of amblyopia in children and, if not detected and treated early, leads to a permanent reduction in vision [1]. Research results show that in 65% of cases, strabismus appears by the age of 3 [4]. The results of some studies show the beneficial effect of early treatment of strabismus in order to reduce the emotional and social consequences for person with strabismus, such as depression, low self-esteem and problems in partner relationships [4, 5]. Adults who suffer strabismus for various neurological reasons, e.g. due to strokes or brain injuries, complain about double vision, an increased risk of injuries or falls and a reduced quality of life [6, 7].

Strabismus, as a dysfunction of the extraocular muscles, in addition to conservative treatment, often requires surgical treatment to correct the misalignment [8]. The aim of surgical treatment, apart from the cosmetic effect and good appearance, is among others to reduce or eliminate double vision in adults and to preserve binocular vision in children [9]. Accurate measurement of the deviation angle in strabismic disease is crucial for further beneficial effects of surgery. One study shows that about 50% of the reoperations in strabismus surgery are caused by human error – inaccurate measurement of the strabismic angle or imprecise surgery [9].

The most common tests used to detect abnormal eye deviation are observation of corneal reflections and the cover test (the cover/uncover test and the alternate cover test). To measure the strabismus angle the Hirschberg test and the prism cover test (PCT) are used, among other methods. The PCT requires the patient's cooperation and a temporary fixation of the gaze on an object, while the second test allows for approximate determination of the strabismus angle by evaluating the glare from the illuminated corneal surfaces. Hirschberg's test is performed when the patient does not cooperate and fixates his eyes on objects [10]. The PCT is much more accurate, but the variability in the results obtained is influenced by subjective factors such as the examiner's evaluation of eye movements, his/her experience as well as the patient's cooperation. This lack of uniformity in testing standards can lead to a situation where test results performed by different, even equally experienced, professionals may differ [11].

In one study, the test results showed that the measurement of the horizontal strabismus angle using the PCT with near fixation is unreliable, with a mean standard deviation of 5.44 ±3.07° [9]. If three measurements are taken before surgery and the mean value of the strabismus angle is included in the surgical plan, this inaccuracy can be reduced to one fifth of the variation in the strabismus angle [9].

Another method used to assess ocular motility and to determine deviations from the normal state are subjective

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screening tests performed on a screen, e.g. Hess's and Lancaster's [12, 13]. The Hess screen test was designed by Walter Rudolf Hess in 1908 with later modifications [12]. Walter Brackett Lancaster introduced his test in 1939 [13]. Both tests used red and green dissociation in their version. With good patient co-operation, both tests are reasonably accurate, but they are also time-consuming, biased, not very repeatable and cannot be carried out in patients with visual impairment and abnormal retinal correspondence and require additional staff to carry them out [14].

The number of specialists working in strabology clinics is relatively small and it is difficult to find such a specialist in non-urban areas. The availability and use of high-tech tools for the diagnosis and treatment of strabismus are currently limited, despite the publications on this topic in recent years [4].

Computer-assisted high-speed processing of images obtained as a result of a medical examination could contribute to earlier detection and detailed diagnosis of strabismus. The study of strabismus angle deviation by means of computer methods may represent a new tool to help minimise the degree of uncertain diagnosis and measurement errors, while providing the specialist with a source of reliable and objective measurement. Therefore, it is important to review the literature on this topic, especially since the available Internet search browsers indicate the lack of an effective research tool in the field of strabismus angle assessment. The aim of this article is to present modern, innovative methods for measuring the angle of deviation in strabismic disease.

DISCUSSION

In 2010 Liu Qiwei, Liang Ping and others constructed an intelligent synoptophore equipped with liquid-crystal displays (LCDs), cameras and automatic diagnostic software [15]. The synoptophore is computer controlled. The results and diagnostic procedure are not influenced by subjective factors and the efficiency and precision of deviation detection have been significantly improved compared to synoptophores used earlier [16, 17]. In this method, however, no method for calibrating the system has been specified, which represents a limitation of the presented technique in the precise determination of large strabismic angle ranges.

Currently, in ophthalmology, among the tools for strabismus examination are synoptophores, which are rather complicated to use and require a lot of experience on the part of the examiner. In addition, the need for them to be operated by orthoptic personnel trained for this purpose limits the availability of these devices in ophthalmic offices.

In 2017 Weber *et al.* published the results of a multi-centre study on the detection and diagnosis of strabismus using a new digital vision method [14]: goggles with integrated infrared (IR) cameras for observing pupil movements and LCD screens for alternating eye shadowing. The solution was used in a prototype device which simulates the standard Hess test. The goggles make a laser projection of a grid of nine points with specific angular distances on the screen and the patient observes the specified points one after the other and his/her eye movements are recorded by cameras [14]. The test showed 95% agreement with the standard Hess test. This type of test requires good cooperation with the patient, but according to the authors it is suitable for use in a group of children over 6 years of age. The test is quick and easy to perform, while the result is only information about the abnormal function of selected eye muscles. The test does not measure strabismic angles with high accuracy directly and no calibration techniques have been suggested to adapt such a device for measuring strabismic angles [14].

In 2018 Shrinivas *et al.* assessed strabismic eye angle using the EyeTurn smartphone app in which an automated photographic Hirschberg test measuring eye deviation can be performed. Using any smartphone with a high-resolution rear camera and flash and the EyeTurn app, the difference in position of corneal glare relative to the centre of the eye can be automatically detected, thus calculating misalignment and providing an objective measurement of eye deviation [1]. The obtained images are entirely processed on the smartphone using appropriate algorithms and the measurements are displayed on the screen within seconds. The examiner records a video while the patient fixes both eyes on the target. The fusion is interrupted in the traditional way by covering and uncovering the eye, as in the "cover test". The entire event is recorded by the app as a video sequence.

The use of the app, despite its 95% reproducibility, cannot completely replace other tests because of the errors that occur. One of the possible sources of error is the use of the average Hirschberg ratio (HR) for the population. The application is more accurate when used in people with small angle strabismus. The authors focus on creating an application with variable HR which can be adapted to different populations and races, and can also be used in children. To achieve this, reliable biometric data are required. The authors assure that the development of the application will ensure the test of deviation of the eye during far fixation and the influence of glasses on the results obtained will also be taken into account, which was not possible to assume with the current device [1].

In 2018 Reena Chopra *et al.* created a prototype using simultaneous binocular optical coherence tomography (OCT) to study strabismus [18].

It is well known that optical coherence tomography equipment is becoming omnipresent in ophthalmic clinics as it provides objective and quantitative data on the structures of the eye, both anterior and posterior, to help diagnose and monitor ophthalmic diseases. In the study group, primary deviation was measured by OCT. The target of fixation was manually selected relative to the eye without abnormal deviation. For the control group, the fixation target was positioned in front of the dominant eye (the right eye in all participants). The spherical equivalent of the subjects' refractive error was corrected in the device. The device took 128 type B scans of the anterior segment in both the horizontal and vertical planes. Only one central anterior segment image for each surface was used for the analysis. The central image can be obtained by visualising the reflection of the corneal tip in the fixed eye [19]. Using appropriate software, the difference in deviation of the fixating and non-fixating eye was calculated. In both eyes, a line was drawn in the device with the pupil width in the surface of the posterior iris epithelium. These points were chosen due to their visibility on the horizontal and vertical scans. The angle between the lines was counted as the angle of deviation [18].

The test results suggest that binocular OCT of the anterior segment may provide clinicians with an accurate measurement of strabismus. The prototype could potentially include several binocular vision tests which will provide quantitative data and facilitate the diagnosis and monitoring of ocular misalignment. However, the device may not be reliable for diagnosing small deviations (< 2 DP), vertical deviations in particular. A larger sample is required as the test results suggest that this method is not compatible with results obtained using a standard PCT. As the authors of the device point out, an important limitation is the inability to determine whether phoria or tropia is present, which is related to the fact that if the device were used as a screening test for strabismus it would guarantee many false positives. Although the current prototype has many caveats, it could be useful in the future with the right configuration to measure the strabismus angle before, during and after surgery or for patients who are undergoing botulinum toxin injections [18].

In 2019 Yinan Miao *et al*. published the results of a study with a modern device based on a virtual reality (VR) display system for measuring eye angle, which can be easily applied using a computer and a headset. It does not require a large space in the room to use it, and what distinguishes it from previous devices is that it also has a high tolerance for unexpected movements of the patient's head. The device uses pupil tracking technology and direct measurement to estimate the angle of strabismus based on eye movement [8]. Virtual reality has evolved considerably over the last few decades, for both personal and professional use, and the cost of the equipment no longer restricts its use in practice [20]. Virtual reality can create impressive 3D scenes using an ordinary computer, allowing the simulation of a standard strabismus examination. The measurement duration is less than 1 min. The results are displayed immediately after the measurement via a MATLAB GUI interface developed for this test. The results are also compared with diagnostic results performed by a physician to confirm the accuracy of the proposed system.

The researchers of the above device point out that VR users have a misperception of space and movement. The first factor responsible for the misperception of distance is a mismatch between the patients' pupillary distance (PD) and the device's PD. The equipment has a fixed PD of 63.5 mm, which is the most common value for human eyes. The target is perceived to be further away in patients with short PD distances and closer in patients with larger pupil spacing.

The second controversial factor in this device is the compression of all distances in the virtual environment. Recent studies have shown an underestimation of distance for a consumer-grade VR kit [21]. At present, works are under way to correct the estimated distance by manipulating the rendering, which is a graphical representation of the information in digital form, or by adding sensory information [8].

In 2020, Oren *et al.* published a paper comparing diagnosis and testing for strabismus using a manual method with an automated method using their innovative device [22]. Of the manual methods, the cover-uncover test (CUT) and the prismatic cover-uncover test were used. The automatic strabismus measurement device included automatic image analysis and an infrared eye tracker used with a pair of wireless glasses. The innovation of this device is the ability to detect and differentiate heterophoria from heterotropia, determine their extent and automatically assess deviation simultaneously in both eyes. The participants were tested from a distance of 50 cm in a manual test and the same distance was monitored in the device using two independent methods. The first uses the eye tracker's ability to measure the distance between the eyes and a camera placed on the screen of the device. The second method uses the signed marks on the eyeglass covers which are part of the test kit. In addition, the operator's screen indicates each change in the patient's position. The system did not require any verbal skills. The first step of the procedure was to use an automated CUT to assess the presence of tropia and, if present, to determine the deviating eye and the amount of deviation. The second step was to use the automatic alternating cover test (ACT) to measure the amount of total deviation and its direction, similar to the manual PACT, but without the physical presence of the prism. If tropia was detected using the CUT, a deviated eye was reported. If the deviation was detected using only the ACT and not the CUT, a phoria was reported. At the end of the test, numerical and graphical results of deviation type, direction and magnitude were recorded.

In this test, the automated system identified the same deviation direction as the manual PCT in all cases. The results of the automated ACT showed 95% compliance with the results of the PACT in measuring eye deviation of both horizontal and vertical deviation.

Another important point indicating the good sensitivity of the device is the demonstration of significant variability in the results of the manual prismatic alternating cover test among highly experienced examiners of 11.95 prismatic dioptres, compared to 4.25 prismatic dioptres with the automated measurement. Moreover, there were times when the device detected a deviation and the double manual test did not.

An additional advantage of the device is that the system does not require eye tracker calibration, unlike other automated tests. In the method described here, the eye tracker is not used directly to detect eye position, but to determine whether the eyes are moving in the target directions. The exact deviation is calculated by combining the distance obtained between the two monocular targets on the monitor in relation to the seating distance. This enables one to test participants even with large refractive errors who have non-standard eye dimensions. An additional advantage of the automated system is that prisms larger than 20 DP are usually only available every 5 DP, whereas the automated system is suitable for measuring the full range of deviation every 1 DP.

The researchers point out, however, that poor head positioning in the device taken by the participant during the automated examination may have contributed to the failure to detect the hypodeviation observed in the manual examination. Furthermore, the eye-tracker method is not feasible in patients with extraocular muscle paralysis. For the same reason, this method cannot be used in patients with high amplitude nystagmus, as repeated, uncontrolled eye movements may mislead the system. The device was also not programmed to determine eye torsion, but only to examine deviations in horizontal and vertical directions. In contrast, the authors claim that the next device will assess 9 gaze directions and the test will be performed from 6 m.

CONCLUSION

The use of innovative optometric devices could enable an accurate and fast strabismus angle assessment in an ophthalmologist's or orthoptist's office. In contrast to the traditional method of strabismus examination, the modified evaluation will not require the use of prism bars and the assistance of an additional person (holding the child's head, holding an additional prism bar for the calculation of vertical or oblique deviations coexisting with horizontal deviations). Automated optometric tests also provide a modern telemedicine solution for the detection and assessment of strabismus, without requiring the presence of an ophthalmologist or orthoptist during the test. The results obtained can be transmitted remotely to a selected specialist.

Use of the new technology may also translate into more accurate results of the extraocular muscle surgery, as the measurements of the strabismus angle are not only the basis for the diagnosis of the type of strabismus, the degree of deviation of the eyeballs, and the extent of the deviation, but also on the basis of these measurements the type and extent of the extraocular muscle surgery are planned. At present, there is no equipment available on the world market which can replace the traditional test entirely, but researchers are getting closer to the goal of creating such an ideal device.

DISCLOSURE

The authors declare no conflict of interest.

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