Computers in Biology and Medicine 63 (2015) 178–186

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Surgical planning for horizontal strabismus using Support Vector Regression

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A R T I C L E I N F O

Article history:
Received 12 February 2015
Accepted 29 May 2015

Keywords:
Surgical planning
Horizontal strabismus
Support Vector Regression
Machine learning

A B S T R A C T

Strabismus is a pathology which affects about 4% of the population, causing esthetic problems (reversible at any age) and irreversible sensory disorders, altering the vision mechanism. Many techniques can be applied to settle the muscular balance, thus eliminating strabismus. However, when the conservative treatment is not enough, the surgical treatment is adopted, applying recoils or resections to the ocular muscles affected. The factors involved in the surgical strategy in cases of strabismus are complex, demanding both theoretical knowledge and experience from the surgeon. So, the present work proposes a methodology based on Support Vector Regression to help the physician with decision related to horizontal strabismus surgeries. The efficiency of the method at the indication of the surgical plan was evaluated through the average difference between the values that it provided and the values indicated by the specialists. In the planning of medial rectus muscles surgeries, the average error was 0.5 mm for recoil and 0.7 for resection. For lateral rectus muscles, the mean error was 0.6 for recoil and 0.8 for resection. The results are promising and prove the feasibility of the use of Support Vector Regression in the indication of strabismus surgeries.

1. Introduction

Strabismus is an anomaly of the eyes in which the eyes lose alignment with each other. While one of the eyes fixates on a frontal point, the other eye turns either inward or outward, or even upward and downward. In this way, the brain receives two images that have different focuses instead of two images that should merge into a single image. Strabismus appears in various forms: the affected eye can deviate horizontally, either inward (convergent strabismus) or outward (divergent strabismus), and upward or downward (vertical strabismus). The horizontal and vertical deviations can appear to be combined in the same patient, for example, a deviation that is both inward and upward.

In general, the esthetic aspect of strabismus can be treated at any time of life. However, sensory disorders are more serious and can only be treated during a short period in life, the plasticity phase of the visual system, which lasts until nine years of age. The main sensory complication of a deviation is strabismic amblyopia. Thus, the treatment must start as soon as a strabismus case with amblyogenic characteristics is detected [1,2].

Most cases of strabismus demand surgery when the symptoms are substantial. In most situations, the goal of surgery is solely esthetic; this goal, however, is not less important because the elimination of any physical flaw, especially in the eyes, is directly connected to emotional health. Nevertheless, in many cases, surgery is intended to establish or recover binocular vision,[1] allowing the deviated eye, formerly with amblyopia, to be used with all of its capabilities, including stereopsis[2] and fusion reflection, which grants stability to the surgical results.

The factors that are involved in the planning of the surgical strategy in strabismus cases are complex, which demands both theoretical knowledge and experience from the surgeon [1,2]. Several formulas and tables, which are built with a basis on various cases, supply values for the surgical planning according to the degree of

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[1] Binocular vision is the capability of perceiving visual stimuli with both eyes, which enables the perception of the distances of objects.

[2] The human capability of perceiving depth and three-dimensional space in the images acquired and processed in the brain.

http://dx.doi.org/10.1016/j.compbiomed.2015.05.025

deviation observed [1,2]. The use of formulas and tables has the disadvantage of supplying average values, which are often inappropriate for individual use [2], considering that there is a large variability in the surgical correction obtained in terms of prism diopters[3] (Δ) per millimeter of recoil and/or resection [1].

The field that is concerned with the use of computational tools to assist or monitor the medical diagnosis of strabismus is still considered to be recent. However, some tools were or have been developed for health professionals in such a way that they can make reliable decisions with respect to pathologies of the eyes.

Simons et al. [3] developed a solution that is based on software and hardware to manage the conduct of two clinical tests, namely the covertest and the prism test. The records of eye movements are segmented by the program in the modular test frames to ease the handling and graphical analysis. The eye movement is analyzed with respect to the latency, mean speed, maximum speed, and maximum acceleration/deceleration.

The authors in [4] developed a specialized system (StrabNet), which was intended to help in the differential diagnosis of vertical strabismus (deviations upward and downward) by means of artificial neural networks (ANN). Perceptron Backpropagation networks were used to classify the types of vertical strabismus. The magnitude of the deviation was manually supplied by the specialist physician to the neural network and was measured by means of alternating the cover test and prism test. StrabNet achieved a rate of 100% correct diagnosis and $>94\%$ using artificial data and 99% using clinical data.

In [5], the authors used selective wavelength filters and infrared cameras to measure the binocular alignment. The images of 90 patients were analyzed with the help of 3D Strabimus Photo Analyzer, which resulted in a rate of correct diagnoses of 95%, which was later compared with the alternating cover test and prism test performed by two ophthalmologists.

Almedia et al. [6] presents a methodology to aid in the diagnosis of syndromic strabismus using such techniques as image processing, geostatistical functions, and Support Vector Machines for strabismus automatic diagnosis in digital images through the Hirschberg method. Two hundred images that belong to 40 patients who were previously diagnosed by a specialist were tested. The method was demonstrated to be 88% accurate in esotropias identification (ET), 100% for exotropias (XT), 80.33% for hypertropias (HT), and 83.33% for hypotropias (HoT).

Almedia et al. [7] proposed a computational method for the automatic detection of strabismus by means of the Hirschberg test. The image database that was used was formed from images of 45 patients without strabismus, with deviations that were smaller than or equal to 15Δ. The images were acquired with patients in the primary gaze position (PGP). Strabismus was detected using the measurement of the deviation in pixels and through the definition of cutoff points or thresholds. To be considered normal, patients should have, at most, 1 pixel for vertical deviations and 2 pixels for horizontal deviations. The method achieved an accuracy of 94% for the classification of individuals with or without strabismus.

Looking for computational techniques to assist ophthalmologists at strabismus surgeries, Souza et al. [8] modeled a backpropagation artificial neural network for planning the surgical strategy of patients with a horizontal deviation. The study was conducted with 95 patients, and all of them had an indication of surgery that was restricted to recoil and resection of the horizontal rectus muscle, in only one of the eyes. In the patients with exotropia, the mean error was 0.4 mm for the recoil of the lateral rectus muscle and 0.3 mm for the recoil of the medial rectus muscle. In the cases of esotropia, the mean error was 0.2 mm for the recoil of the medial rectus muscle and 0.5 mm for the recoil of the lateral rectus muscle.

Backpropagation neural networks were also used by Chandna et al. [9] to make the differential diagnosis[4] of vertical strabismus (deviations upward and downward). The magnitude of the deviation that was manually supplied by the specialist to the neural network was measured by alternating the cover test and the prism test. The diagnosis achieved an accuracy of 100%.

In contrast to the proposal in Souza et al. [8], which plans surgery for one eye only, the present study proposes surgical planning by means of several regressors, which are used to estimate the recoil of the medial rectus muscle (RcMR), resection of the medial rectus muscle (RsMR), recoil of the lateral rectus muscle (RcLR) and resection of the lateral rectus muscle (RsLR), for both eyes. Instead of the neural network proposed by Souza et al. [8], we use the Support Vector Machine for Regression (SVR) [10]. We also use new features in the training and testing of the SVR: values of the versions and deviations in the primary and secondary gaze positions.

The remainder of this work is organized in four sections. In Section 2, we present the theoretical background that is needed for understanding this study. Section 4 describes the stages that form the methodology that is used to suggest the surgical planning for horizontal strabismus. In Section 5, we present and discuss the results that are achieved at each stage of the proposed methodology. Finally, Section 6 presents the conclusions, analyzing the efficiency of the techniques used.

2. Planning for strabismus surgery

Many techniques can be used to correct strabismus. These techniques establish the muscular balance and solve the problem of amblyopia. The typical conservative treatment is the prescription of glasses, execution of orthoptic exercises, and obstruction of the fixating eye, alternating with the other eye. When the conservative treatment is not sufficient, the option is the surgical treatment.

Surgical intervention is indicated for most cases with deviations above 15Δ, due to the presence of symptoms such as diplopia,[5] asthenopia,[6] ocular torticollis, nystagmus,[7] decreased field of view, stigmatizing esthetic impairment and sensory changes [11].

The factors that are involved in the planning of the surgical strategy in strabismus cases are complex, demanding both theoretical knowledge and experience from the surgeon [1,2]. Several formulas and tables, built based on various cases, supply values for the surgical planning according to the degree of deviation observed [1,2]. The use of formulas and tables has the disadvantage of supplying average values, which are often inappropriate for individual use [2], and it is well known that there is a large variability in the surgical correction obtained in terms of prism diopters per millimeter of recoil and/or resection [2].

The surgery involves a reduction in the muscular strength, an increase in the muscular tension and realignment of the muscular action. Two basic types of surgical procedures are available: muscular weakening by a reduction in the muscle torque, which can be understood as the capability of converting muscular contractions into

[3] Prism diopters are quantities for the measurement of the diffraction of the light that passes through a prism. A prism diopter is equal to a deviation of one centimeter in a distance of 1 m.

[4] Differential diagnosis occurs when distinguishing between two disorders that look similar.

[5] Double vision, which occurs when the image of an object is formed at mismatching points of the two retinas.

[6] Eye fatigue, which occurs when we must fixate at one point within a fixed distance; there is an uncomfortable ocular sensation.

[7] Nystagmus consists of rhythmic, repeated and involuntary oscillations of one or both eyes, in some or all of the gaze positions.