BBE 238 1–10
ARTICLE IN PRESS
BIOCYBERNETICS AND BIOMEDICAL ENGINEERING XXX (2017) XXX–XXX

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/bbe

Original Research Article

Strabismic amblyopia affects decision processes preceding saccadic response

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ARTICLE INFO

Article history:
Received 12 June 2017
Received in revised form
23 October 2017
Accepted 11 December 2017
Available online xxx

1. Introduction

Amblyopia is a developmental disorder associated with abnormal visual stimulation during early childhood, characterized by unilateral (or less commonly, bilateral) loss of visual acuity that cannot be improved by refractive correction and cannot be directly attributed to pathology of the eyeball [1,2]. In practice, the amblyopic eye usually manifests significantly greater refractive error (anisometropic amblyopia) or misaligned visual axis (strabismic amblyopia) or a combination of those two conditions as compared to the dominant eye. The misalignment of visual axis provides two different images to the central nervous system (CNS) that further influences the optimal brain development. In order to avoid double vision (diplopia) and confusion, the brain can learn to ignore the image provided by the deviated eye. It means that under normal binocular observation (both eyes open), the amblyopic eye provides neural input to the CNS but this input does not reach our awareness – this process is called suppression. It is known that amblyopia affects not only spatial vision function such as visual acuity, contrast sensitivity [1] or crowding [3] but also may affect oculomotor behavior. It was found that strabismic amblyopes may show abnormal smooth pursuit eye movements [4], unsteady visual fixation [5–7] or the increased saccadic reaction time (latency) [8–11]. Saccadic latency refers to the time taken to initiate a saccade [12] and is substantially affected by many factors starting from the visual properties of stimulus, such as contrast, luminance [13] or presented target eccentricity [14], to higher level factors such as urgency or prior probability of target appearance [15,16]. Although the shortest anatomical route through which the visual system may generate a saccade (retino-collicular pathway) allows for saccade initiation within the time range as short as ~80–100 ms [17], human saccadic latencies are in practice at least two–three times as long [18,19]. Moreover, saccadic reaction time tends to vary substantially from trial to trial even when the target and circumstances are identical each time [19]. This high variability is caused by underlying decision process in which higher cortical areas of the brain withhold a possible early responses in order to decide more carefully whether to respond to a stimulus or not [19,20]. In order to investigate the impact of strabismic amblyopia on the decision mechanisms, we decided to broaden the analysis of saccadic reaction time distribution gathered during our recent study [11]. Thus, the present paper complements our previous research [11] on the same group of subjects and includes LATER (Linear Approach to Threshold with Ergodic Rate) model analysis in order to provide further information about visual decision-making processes in individuals with unilat-

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https://doi.org/10.1016/j.bbe.2017.12.003

Please cite this article in press as: Perdziak M, et al. Strabismic amblyopia affects decision processes preceding saccadic response. Biocybern Biomed Eng (2017), https://doi.org/10.1016/j.bbe.2017.12.003

eral-strabismic amblyopia. It is known that strabismic and anisometropic amblyopes may manifest different performance during the same experimental procedure [1,21–23]. Since in our recent research [11] we have also demonstrated the difference between the strabismic and anisometropic amblyopes in terms of saccadic latency-amblyopic eye in the strabismic group showed the increased latency as compared to an amblyopic eye in anisometropic group, we have decided additionally to compare LATER model parameters between the strabismic [11] and anisometropic amblyopes [9] as well as to include the analysis related to early saccadic component in order to verify whether amblyopia affects cortical control of intentional saccades during the delayed saccade paradigm.

When we consider saccadic reaction time as a decision time, the probabilistic nature of the saccadic decision process can be modeled using LATER model [16]. This model postulates that the appearance of a stimulus triggers a neuronal decision signal to rise linearly with the rate (*r*) from the initial level S_O until it reaches a threshold value S_T, when the response is initiated (Fig. 1). The rate of rise (*r*) varies from trial to trial in a Gaussian manner with a mean value μ and a variance σ^2 [20]. Since the resulting latency will be proportional to $(S_T - S_0)/r$, this will make the distribution of latency recinormal [16]. Hence, if a cumulative histogram of reciprocal latencies is plotted on a probit scale, a straight line is obtained [19,20]. By placing subject's saccadic latencies on reciprobit plot (a plot in which a recinormal distribution becomes a straight line), and applying linear fit, it is possible to encapsulate the basic model of latency distribution in just two parameters (μ, σ), which can be used to model the behavior in complex tasks [19]. The mean μ rate of an increase of excitation (as a result of applying the stimulus) can be considered as a supply of information to the visual system, whereas the σ reflects the variability of latency distribution [19,24]. Changes in these parameters (reciprobit plot shift or swivel respectively), induced by the change of experimental condition, represent the differences in decision signal processing (Fig. 1, bottom left). Moreover, study of cumulative distributions of saccadic latencies as reciprobit plots may reveal the existence of early responses, which usually occurs under the condition of decreased involvement of cortical areas in saccade generation. It has been proposed that these early responses are the result of an ''early'' LATER decision unit, having a mean value μ rate equal to zero but a very large σ, what allows in some trials to win the race to the

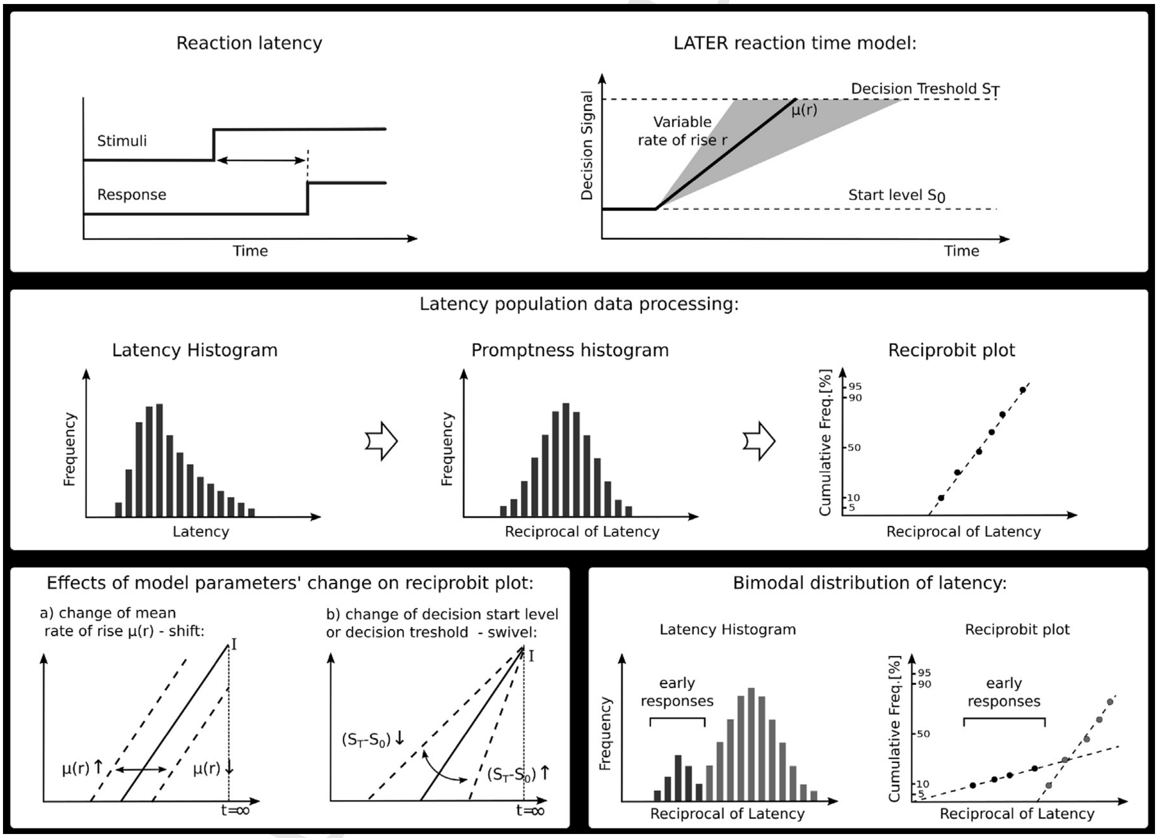

Fig. 1 – LATER model. Latency of subject's response to stimuli change is modeled as the time required for decision signal to reach decision threshold S_T. Rate of rise of decision signal *r* varies randomly between trials, in a Gaussian manner, resulting in a skewed latency distribution. If cumulative distribution of the reciprocal of latency is presented on a probit scale (reciprobit plot), the plot forms a straight line. When the early component is present in the saccadic latency distribution, a separate component is formed on a reciprobit plot (*bottom right*). *Bottom left*: effects of model's parameter change on reciprobit plot. Change of the mean rate of rise of the decision signal $\mu(r)$ results in a horizontal shift of the line, without changing the slope (*a*). Change of the distance between decision levels (e.g. rise of start level S_0 due to alertness) results in the line swivel (*b*), about the interception point of the line and the $t_{lat} = \infty$ axis.

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