

Theoretical and experimental research on the use of the blinking reflex for command and control of human body movement

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Abstract. The blink reflex is a behavioural motor response that is normally found in the process of seeing at newborns and human adults. As with the corneal reflex, the supraorbital branch electrical stimulation of the trigeminal nerve causes a facial nerve bilateral response, namely eyes blinking. Therefore, this sensitive process can also be a neurological control element for performing movements, related to the natural blinking process amplitude, speed and frequency. In the first part of the paper, a series of blinking process physiological aspects are analyzed, in order to identify the movements command and control components. In the second part of the paper, it is analyzed the devices constructive variants for evaluating the blinking process and the connecting possibility with separate sensory elements that can collect information from the visual system neuro-motor level. In the third part of the paper, there are mentioned some aspects related to the experimental installation design and the command and control mode for setting in motion a system using the coordinated ocular and neurosensory blinking mechanism. The final part presents the conclusions of this approach to the development of a system with the use of oculomotor and neurosensory stimuli.

1. Introduction

The blinking mechanism of the eye in response to environmental stimuli is a typical defensive response to potential threats to the body [2] and is usually manifested as a variety of somatosensory and non-somatosensory stimuli. When brought into the state of stimulation by a series of intense somatosensory stimuli, the blink reflex is analyzed as a manual and non-automatic reflex. A series of studies [3] have shown that the blinking reflex has two components (figure 1), a component that determines an anterior-initial response R1 and a component with a posterior-late response R2.

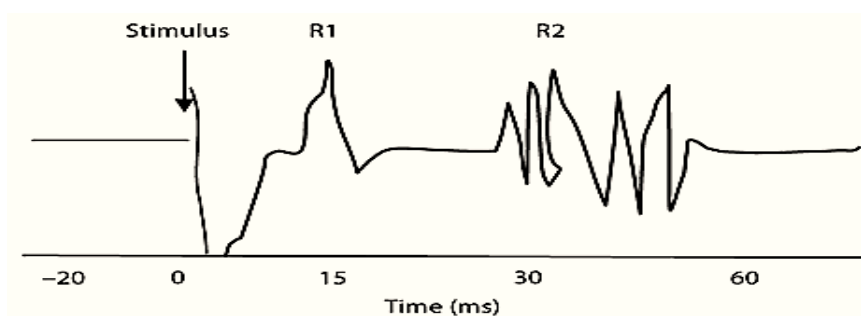


Figure 1. Diagram of the blinking reflex with the two components: R1 - anterior-initial component and R2 - late component [4]

The R1 response is usually present on the stimulated side, while the R2 response is usually present bilaterally. The R1 response is defined as representing the reflex pathway between the main sensory nucleus and the facial nucleus on the stimulated side. Instead, R2-type responses are mediated by a multi-synaptic pathway between the spinal cord nucleus and the inter-neurons that form connections with the facial nuclei on the laterally and counter-laterally stimulated side.

According to the results obtained from recent studies [3], the previous R1 response is usually stable and reproducible, with a biphasic or three-phase morphology, noting that in a small percentage of normal subjects, it cannot be reliably generated by both parties. Posterior R2 responses are polyphasic and variable from one stimulation to stimulation, so that through repeated stimulation, R2 responses tend to stabilize and become normal. A series of neurological-ocular pathologies can present the lack of the blink reflex as a form of manifestation, which leads to obtaining a permanently open eye situation, exposed to the risk of infection, irritation or even pain. At the same time, the loss of the blinking may lead to permanent damage to the cornea due to ulcers or infections caused by the drying process of the corneal surface or the penetration of particles from the environment. As shown in experimental research on the analysis of phenomena in cases of facial paralysis [5] in addition to the functional deficiency of the blinking process and other facial movements, the various forms of facial paralysis are also a major psychological barrier to a healthy social life. A number of researchers have shown in the laboratory that a possible way to restore the blinking process in the case of an eye neurologically affected by paralysis is to place a closed-loop neural prosthesis (facial stimulation device) that can detect normal blinking on one side of the normal face. Depending on this, it can simultaneously generate the stimulation of blinking on the paralyzed side. This is possible because the blinking process (as an automatic reflex), being symmetrical (synergic) process and using the normal state of the healthy eye, can trigger prosthetic assisted blinking on the facial area affected by unilateral paralysis. As shown, [5] "one of the challenges of using healthy blinking as a trigger for induced blinking in facial paralysis is the rapid and accurate detection of healthy blinking in a non-invasive and non-disruptive manner."

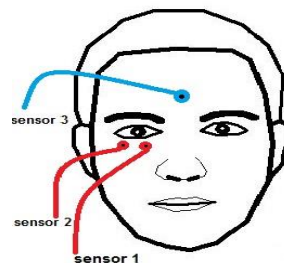


Figure 2. The placement of the sensors in electromyography recordings of the blinking process

Thus, the electromyography (EMG) method of the facial muscle structure in the ocular area can be considered the most frequently proposed and used method for noninvasive detection of blinking on the intact side, followed by the detection of tissue movements in the area of the ocular orbital periphery, by using accelerometers. But even this method, even if it has a high level of accuracy, cannot be used constantly because it requires placing electrodes on the facial surface, in the eye area and this can influence the dynamics of eyelid movements in the process of normal blinking (figure 2). Therefore, in order to increase the comfort and efficiency of the determinations, the detection of the blinking process can be performed without the interaction of the sensors with the skin surfaces in the eye area, and this can be done with the help of video acquisition systems consisting of infrared radiation (IR) lighting sources. This type of illumination of the facial-orbital area makes it possible to record eye movements without taking into account the photo-motor reflex at the pupil level due to light radiation with wavelengths in the visible range (400-700 nm). The video methods for detecting eye movements (the blinking process) are based on the analysis of images purchased with a high-resolution video camera and acquisition frequency, being much more convenient to use and with multiple possibilities to determine the position and shape of the eyelids and the blinking mode (continuous, sequential or

complete/incomplete). This camcorder can be fixed on a chin rest for laboratory testing or on a special pair of glasses for dynamic research in different environments. A very important application of this method is the protection system for drivers against the phenomenon of falling asleep while driving, made with a mobile IR video camera system, mounted on the arm of the glasses with the system with *Raspberry Pi Zero*. Despite the fact that the IR video camera has solved the low performance at night of the cameras with visible radiation, this system is still considered less robust during the day due to the compound white light radiation that interferes with the reflections of the IR radiation. [6,7]

2.Theoretical aspects of blinking process calculus

For fundamental research studies, especially in the field of performance, or the prevention and detection of neurological pathologies, a series of devices and systems for recording and processing images that can indicate the behavior of subjects in different situations related to the orientation of the direction of gaze (convergence, fixation and focus) have been developed in international research centers.

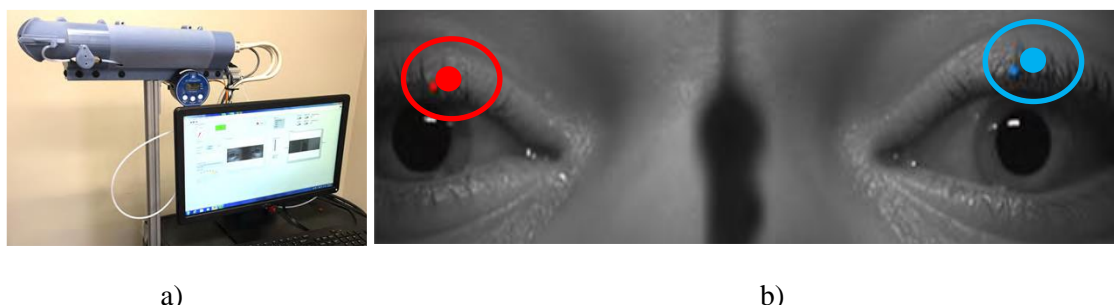


Figure 3. a) Blink reflexometer housing unit and software interface, b) Location of the upper right (red dot) and left (blue dot) eyelids are located in each image acquired during a blink. [8]

These systems although high-performance and high-precision, with real possibilities to obtain quantifiable results, have not yet entered the clinical sphere and are still in various stages of development (figure 3). [8] The theoretical determinations that were the basis for the development of these devices, take into account, in the process of the blinking cycle, the opening of the eyelid slit in the form of the area or the distance between the upper and lower eyelid. Thus, a contour of the orbital area between the upper and lower eyelid is defined and analyzed in the three extreme positions of the blinking process (maximum open, half open and minimum open), according to figure 4.

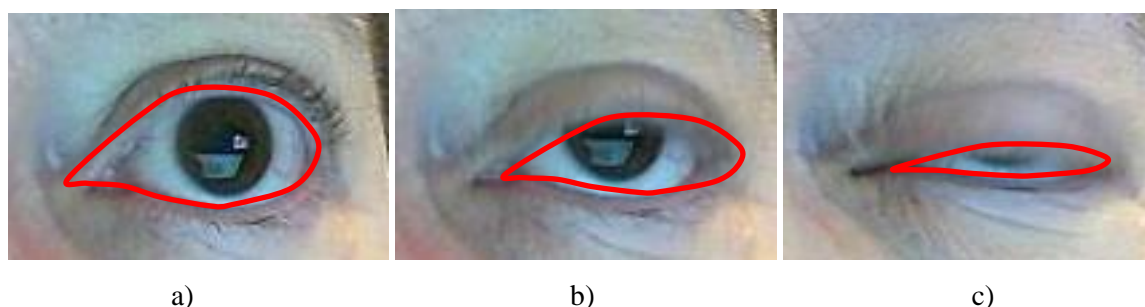


Figure 4. a)Blinking process- maximum opening, b) medium opening, c)minimum opening

Also, in order to be able to calculate the area and the height of the eyelid slit, respectively, 4 main points (upper/lower 1-4) and 4 other cardinal points (up/down, nasal/temporal 5-8) are chosen on the contour of the opening profile, according to figure 5. The calculation of the opening area of the eyelid slit is determined, in ideal format, using the perimeter between points 1-4 together with points 5 and 7 (figure 5), and the distance between the upper and lower eyelid, using points 6 and 8 (figure 5)

The size of the EAR (eye aspect ratio), "defined as the ratio between the height and the width of the eye contour" [9], can be calculated using multiple video recordings of eyeball images and the

determination of mediated values of distances A, B and C (figure 6), as Euclidean distances, as presented in equations (1) and (2).

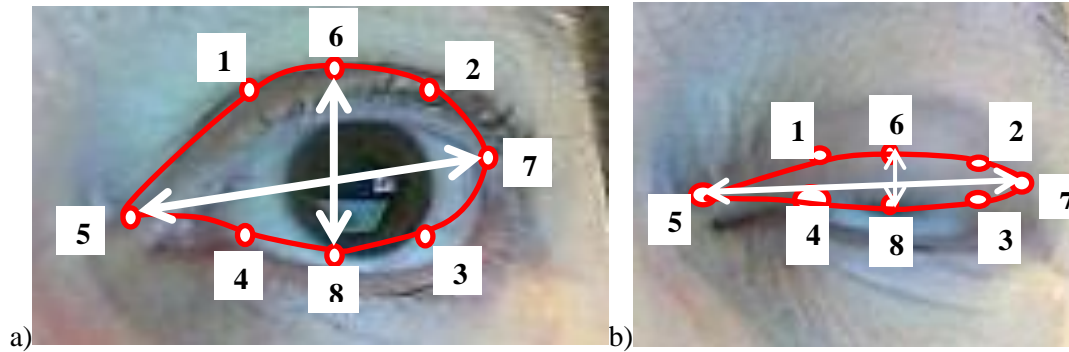


Figure 5. a) Eye open maximum, b) eye open minimum

$$d(p, q) = d(q, p) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \dots + (q_n - p_n)^2} = \sqrt{\sum_{i=1}^n (q_i - p_i)^2} \quad (1)$$

$$EAR = \frac{A+B}{2 \cdot C} \quad (2)$$

From equation (2) it can be seen that the values of the EAR coefficient decrease as the sizes of distances A and B decrease (the eyelid slit decreases) and the upper eyelid approaches the lower one in the blinking process, size C having a small variation.

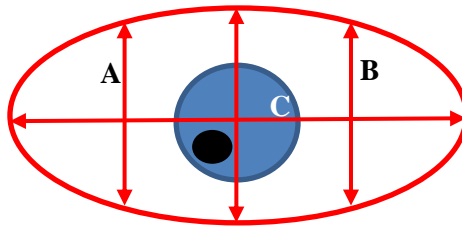


Figure 6. Ideal format to calculate *Eye Aspect Ratio (EAR)*, defined as the ratio between the height and the width of the eye contour [9]

In terms of the area of the eyelid opening, there will always be a T_{eye} threshold (which can be determined experimentally) of this value below which the eyeball is considered closed (the eyelid slit no longer allows light radiation to enter the eyeball to form a whole image on the retina) and therefore, the half-cycle of the blinking process can be considered completed. This opening/closing threshold is determined experimentally and therefore requires a careful analysis of the type of visual system of the subjects participating in the recordings, of the mode of reaction at the ocular level and last but not least, of the refractive state of the visual system (emmetropic or ammetropic). In this way, it will be possible to determine the state of the eyeball, from the point of view of the blinking reflex, comparing the EAR value with the opening/closing threshold established experimentally on a group of subjects as different as possible in relation to the visual system

$$Eye\ state = \begin{cases} open, & EAR \geq T_{eye} \\ closed, & EAR < T_{eye} \end{cases} \quad (3)$$

The closed/open state of the eyeball is thus analyzed in different situations of activity (driving, tracking eye movement for various activities, control of mobile systems with the help of eye movements, medical tests related to neuromotor health, positioning of the head and eyes, ocular ergonomics, etc.)

The optimal value of this threshold of 0.25 has been identified from the literature [9-11], which means that if the eyelid slit is only 25% open, then the eye can be considered closed and the blinking half-cycle achieved, even if the eye has not closed completely.

3. Experimental setup

In order to capture and process the information regarding the control of a mini-car (information recorded in parallel with a neurosensory headset and a video camera integrated in special glasses), an experimental system was designed and developed, using the blinking process (physiological and controlled) to track the movement of the eyeballs, in order to convert it into command and control signals. The experimental system developed in this research consists of a pair of glasses (realized by 3D printing) integrated with a video camera, a NeuroSky type neurosensory headset, both devices being dedicated to capturing blinking eye movements, then an electronic acquisition and compatibility system in real time of the signals coming from the two sensory devices and respectively a computer with dedicated software applications (fig.7). The element that takes over the computer commands according to the information entered and coming from the sensory devices is represented by a mini-automobile with all-wheel drive systems

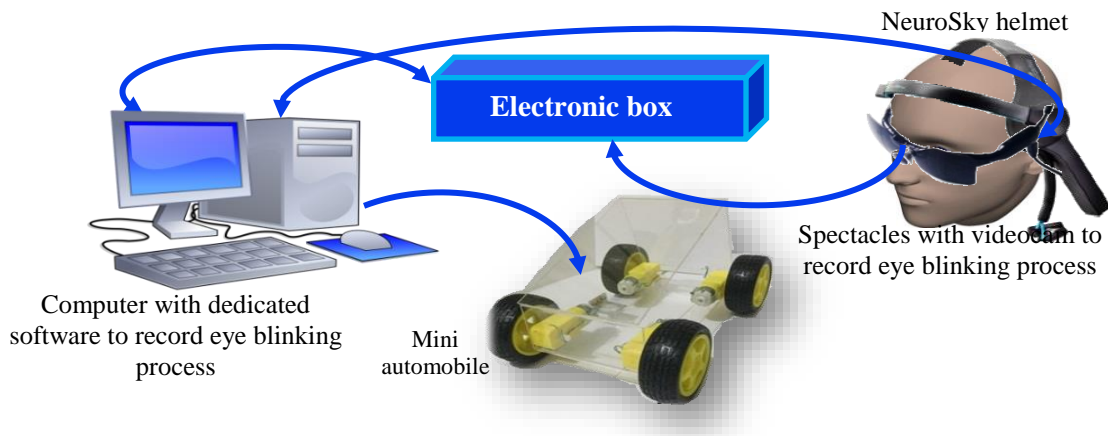


Figure 7. Experimental setup

The experimentation procedures contain a series of modules through which the acquisition of signals from the NeuroSky headset are analyzed in real time and then compared with the commands of the software application developed on the Arduino board for the acquisition of the sequences of the complete blinking cycles.

According to research in the field of visual function, the blinking process takes place, on average, with a frequency of 17 blinks / min, which indicates that the average duration of a full cycle (open-eye-closed-open) of physiological blinking may take between 300-550 ms, with an average interval between two blinking cycles of 2.8-3.1 sec.

Therefore, a complete and controlled blinking cycle, consciously performed to trigger a motion control of the mini-car must last on average at least 5 times longer than the average physiological blinking cycle.

From the value of the duration obtained of this complete blinking cycle, the open-closed and closed-open transitions of the target eyeball must take place within a range of approximately 40% of this estimated duration and the closed eyeball period must be about 60%. This accentuated, controlled and conscious form of the blinking process is necessary to enable the optoelectronic system to capture the image, to transmit it to the computer, to be analyzed and transformed, through the software application on the Arduino board, into a control signal for mini-car's motors.

The control of the mobile must also take into account the travel requirement, in relation to the space and trajectory required. As such, blinking commands will be quantified, based on a programming code, so that they can be recognized, analyzed and transformed into appropriate commands (forward, left,

right, etc.) for the mini-car used. If it is necessary to travel with a larger and heavier vehicle, the design difference will only be related to the power of the engines and gear transmissions

4. Results and conclusions

Following the construction of this experimental setup and the development of the command and control activity of the mini-car movement through the blinking process, a series of aspects were found that led to the modification and optimization of the action modules. Thus, it was identified a need for a step of calibrating the video camera in relation to the activity space and a reprogramming of the maneuvers to start, go and stop from the same commands of the blinking process. It was also found during the experiments that there is a need to use a second computer with Bluetooth to communicate with the NeuroSky headset in order not to create a conflict of information transmission in parallel with the acquisition of images from the video camera. This can be done quickly and for the next stage, it is planned to create an external module for the compatibility of signals from both sensory systems.

The design and development of this experimental system proves to be useful also in making records for the analysis of different behavioral states of subjects or for the control of interactive activities with the computer. [12-15]

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