Report article

Evaluating low-cost eye movement recording apparatuses for effective student practice

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Abstract

Electrophysiological recordings of eye movement are important for the discipline of orthoptics not only in clinical evaluation of visual function but also for understanding the properties of visuomotor coordination. Therefore, low-cost visual stimulators with real-time output of current stimulation status are required for effective student practice. In this report, three types of stimulators were tested for recording saccadic and pursuit eye movements and optokinetic nystagmus in electrooculography practice. These stimulators were built with low-cost, general-purpose parts and might improve the student training courses for certified orthoptists, a specialty that requires thorough knowledge of the complex properties of various human eye movements.

Introduction

An electrophysiological investigation of human oculomotor functions is not only important in clinical evaluation of the visual functions, but it is also valuable in demonstrating the properties of visuomotor coordination with its millisecond-order time resolution and easy data manipulation [1]. However, to utilize these advantages in student practices, low-cost visual stimulators equipped with an output for timing or positional signals are required. Unfortunately, contemporary personal computers (PCs), including tablet PCs, are not suitable for such a time-sensitive purpose due to a lack of parallel input-output ports available to user applications and a time lag in the graphic user interface [2].

Recent reports have identified a low-cost system for electrophysiological recording practices [3]. Similarly, this study will review the efficacy of three visual stimulators for student electrooculogram (EOG) practice in the Department of Orthoptics and Visual Sciences, Niigata University of Health and Welfare. These apparatus were built with low-cost, general-purpose parts and capable of sending the timing or positional signals to the recording system.

Materials and Methods

As shown in Figure 1, the author prepared three types of apparatuses for recording saccadic eye movements, pursuit eye movements, and optokinetic nystagmus (OKN). First, as described in [3], an onboard tri-color light emitting diode (LED) of a micro-controller (GR-COTTON; Renesas Electronics, Tokyo, Japan) was used to produce cue signals for saccadic eye movements

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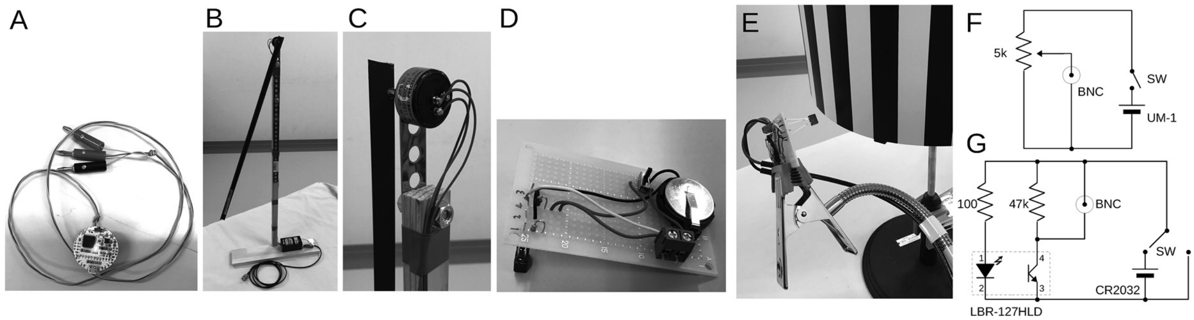
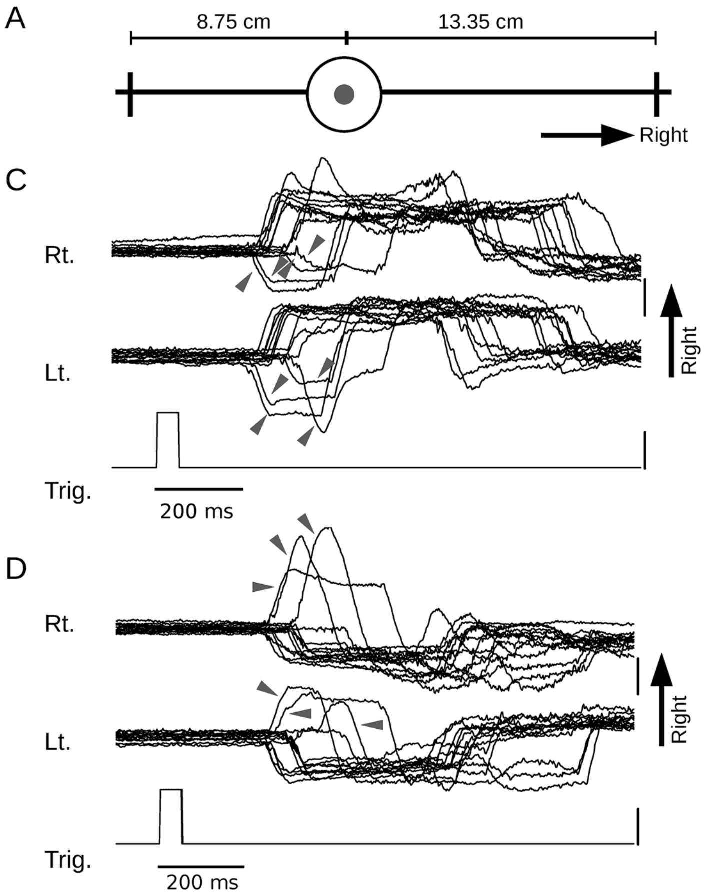


Figure 1. Visual stimulators for eye movement recording practice.
A. A micro-controller (GR_COTTON) with a tri-color LED used as a visual cue for saccadic eye movements. The LED lit green in this photograph (center of the device).
B. A pendulum for eliciting pursuit eye movements. The arm length was 50 cm, and the battery on the base is a UM-1.
C. The rotation angle sensor of the pendulum, connected to the battery and a BNC cable. For convenience of zero-adjustment and changing the period of the pendulum (by changing the arm length), the arm was not glued to the shaft of the sensor.
D. A tachometer for an OKN drum, using a reflective object sensor (the black part on the left of the photograph). A coin battery on the right of the photograph is a CR2032.
E. Application of the tachometer on the OKN drum (the drum with vertical stripes).
F, G. The circuit diagrams of the pendulum and the tachometer, respectively. The 47 kΩ load resistance for LBR-127HLD was experimentally determined for the HE-64 OKN drum. Other OKN drums possibly have different reflectances for the infrared ray. Adjustment of the load resister would be required in these cases (higher resistance should be used for the ONK drum with lower reflectance).

(Figure 1A); the signals were simultaneously sent to the recording system via the banana plugs. Next, a pendulum to elicit pursuit eye movements (Figure 1B) was made of a wooden plate, a battery case with a switch, a wooden bar, a metal plate with holes, a lightweight plastic arm, and a rotation angle sensor (CP-2FB(b), 5 kΩ; Midori precisions, Tokyo, Japan) at the top (Figure 1C). Then, a tachometer (Figure 1D) for a drum chart (OKN drum, HE-64; Handa-ya, Tokyo, Japan), which is used to elicit OKN, utilized a reflective object sensor (LBR-127HLD; Letex technology, Taichung Hsien, Taiwan) to detect the edges between the black and white strips on the OKN drum (Figure 1E). The circuit diagrams of the pendulum and tachometer are shown in Figures 1F and G, respectively.

The horizontal EOGs of both eyes were obtained from the author in accordance with the ISCEV Standard for clinical electrooculography [4] using a system and the filter settings same to those described in [3], but with a lower-cost analog-digital converter (USB-6001; National Instruments, TX, U.S.A.) and a laptop PC (VersaPro; NEC, Tokyo, Japan) instead. The same instrumentation amplifier (INA128) was used in an Arduino-based low-cost EOG recording system [5]. All the visual stimuli were viewed from a distance of 50 cm. At this distance, the maximum visual angle of the pendulum was approximately 50 degrees and the visual angle of the HE-64 OKN drum was 29 degrees. The data were visualized with free statistical software GNU R (http://www.r-project.org/) running on a Macintosh computer.



B

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/*GR-COTTON Sketch Template Version: V1.01*/
#include <Arduino.h>

int delay1    = 2000;
int led_red   = 22; // Red element, LOW active
int led_green = 23; // Green element, LOW active
int led_blue  = 24; // Blue element, LOW active

int PIO_1     = 6;
int PIO_2     = 9;

void setup() {
  pinMode(led_red, OUTPUT);
  pinMode(led_green, OUTPUT);
  pinMode(led_blue, OUTPUT);
  pinMode(PIO_1, OUTPUT);
  digitalWrite(led_red, HIGH); // Red element off
  digitalWrite(led_green, LOW); // Green element on
  digitalWrite(led_blue, HIGH); // Blue element off
  digitalWrite(PIO_1, LOW); // PIO low
}

void loop() {
  delay(delay1 + random(0, 1000));  // wait for 2 to 3 s

  int target_led = (random(0, 2)==1) ? led_red : led_blue;
  digitalWrite(led_green, HIGH);    // Green element off
  digitalWrite(target_led, LOW);    // cue colour element on
  digitalWrite(PIO_1, HIGH);        // trigger on
  delay(50);                        // wait for 50 ms

  digitalWrite(PIO_1, LOW);         // trigger off
  digitalWrite(target_led, HIGH);   // cue colour element off
  digitalWrite(led_green, LOW);     // Green element on
  delay(1500);                      // wait for 1.5 s

  digitalWrite(led_red, LOW);       // LED turns
  digitalWrite(led_blue, LOW);      // white
  delay(500);                       // wait for 0.5 s

  digitalWrite(led_red, HIGH);      // LED turns
  digitalWrite(led_blue, HIGH);     // green again
  }
```

Figure 2. Example saccadic eye movement recordings.
A. A schematic illustration of the stimulation settings. A GR-COTTON micro-controller was placed between the left and right targets. Viewed from a distance of 50 cm, the positions of targets were (left) 9.92 and (right) 14.9 degrees from the center LED (cue LED) of the GR-COTTON. This is essentially same to Figure 1B in [3].
B. The complete source code for the GR-COTTON.
C. Sample eye movements obtained in trials with the rightward cues. The traces represent the horizontal movements of the right eye, the horizontal movements of the left eye, and time mark signals from the GR-COTTON, top to bottom. Data from 13 trials were superimposed in reference to the cue onset. Upward deflection indicates rightward eye movement or cue period. Vertical scales indicate 0.2 mV for the eye movement, and 2 V for the time mark signal.
D. Same as C, except that data from trials with leftward cues are plotted. Gray arrows in C and D indicate saccadic eye movements in a wrong direction. All traces in C and D are the raw data, and no digital filtering was performed.

Results

In Figure 2, example saccadic eye movements were recorded with a GR-COTTON micro-controller, and the complete C++ source code for the GR-COTTON is shown. As shown in C and D, the latencies of the saccadic eye movements were approximately 200 to 300 ms, consistent with Carpenter [6], and the amplitudes of EOGs in the correct direction were approximately 0.29 and 0.17 mV for the saccades to the right and left tar-

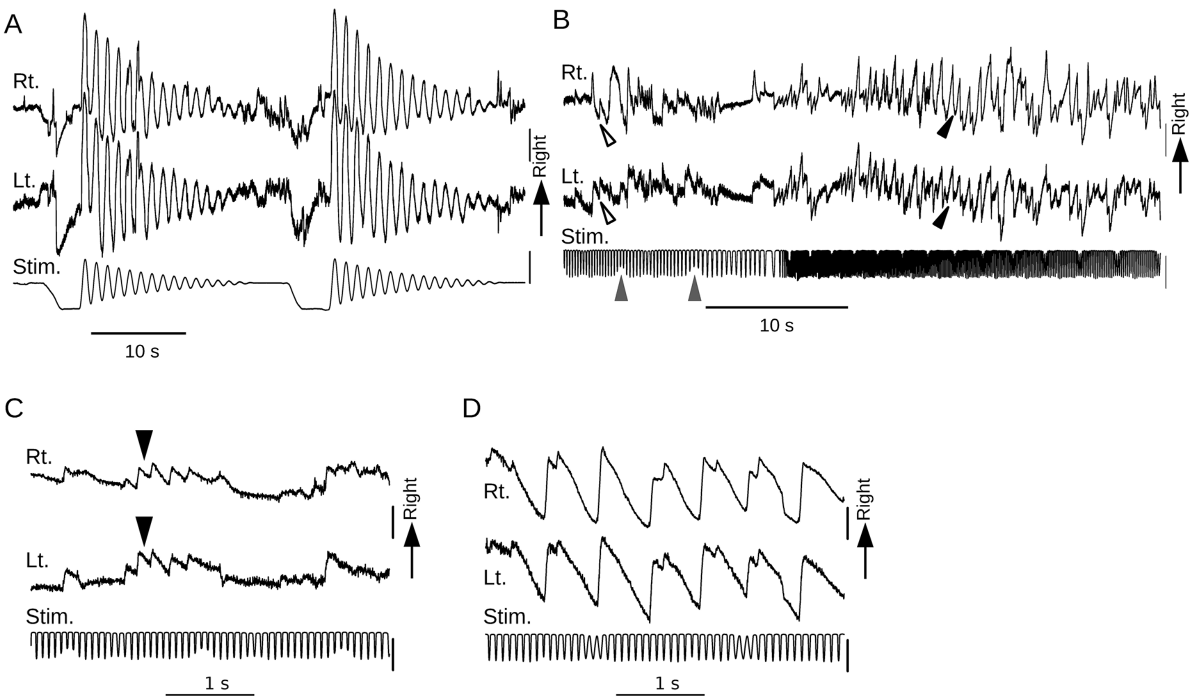

Figure 3. Examples of pursuit eye movements and optokinetic nystagmus.
A. Sample eye movements recorded in trials with a swinging pendulum. The traces represent the horizontal movements of the right eye, the horizontal movements of the left eye, and the angle of the pendulum arm, top to bottom. Upward deflection indicates rightward movements of the eyes or the arm. Vertical scales indicate 0.2 mV for the eye movement, and 2 V for the arm angle. The pendulum arm was initially held at an angle of 40 degrees from vertical then was released.
B. Sample eye movement records in trials with a rotating OKN drum. The traces represent the horizontal movements of the right eye, the horizontal movements of the left eye, and the output of the tachometer, top to bottom. Upward deflection indicates rightward eye movements or weak infrared reflex from the surface of drum. Vertical scales indicate 0.2 mV for the eye movement, and 2 V for the arm angle. White and black arrowheads indicate examples of rightward and leftward OKN, respectively. The vertical dashed line indicates the point when the rotation of the OKN drum was reversed by the hand. Gray arrowheads indicate dips in tachometer output due to a warp of the OKN drum. All traces in A and B are the raw data, and no digital filtering was performed.
C, D. Other examples of rightward OKN with an expanded time scale.

gets (14.9 and 9.9 degrees from the center LED of the GR-COTTON), respectively, consistent with the ISCEV Standard [4]. Pursuit eye movements elicited with the pendulum are shown in Figure 3A. Slow and smooth conjugate movements of both eyes toward the direction of the arm movement were observed during the arm motion. Because of the low torque requirement (< 0.5 mN･m) of the rotation angle sensor [7], the arm swung many times with diminishing amplitudes, which led to diminishing pursuit eye movements in parallel. As shown in Figure 3B, the rotation of the OKN drum was appropriately detected by the tachometer (the bottom trace) totally out of contact (Figure 1E). The angular velocity of the OKN was represented by the pulse frequency because whenever the reflective object sensor faced one of the white strips, the output of the tachometer dropped. In this case, the OKN drum rotated leftward at first, then its rotation was slowed by the friction of the OKN drum itself. At the point indicated by dashed vertical line, rotation of the OKN drum was reversed by a hand, resulting in a reversal in the OKN direction (white and black arrowheads) and an increase in the pulse frequency of the tachometer output. The elicited OKN could be a stare (Figure 3C, black arrows) or a look (Figure 3D) OKN according to the instruction to, or the attitude of, the participant (just to stare or to follow the stripes) [8].

Discussion

Three types of apparatuses were introduced for the EOG practice in this report. They were built with low-cost, general-purpose parts, such as a micro-controller with a tri-color onboard LED, a rotate angle sensor, and a reflective object sensor, which are easily available via electric commerce.

The students have two major learning goals in this EOG practice. Firstly, understanding about various types of eye movements, such as saccadic eye movements (conjugate fast eye movements that can be voluntarily evoked), smooth pursuit eye movements (conjugate slow eye movements reflexively elicited by a moving target), and OKN (a combination of alternating conjugate slow and fast eye movements elicited by a repetitive pattern moving through the visual field). Secondly, realizing the principles of the electrophysiological recordings, such as placing the electrodes, lowering the noises, monitoring signals with an oscilloscope or a PC, and measuring the latencies. The apparatuses introduced here may help students to reach these goals, and thus they can improve student practice of electrophysiology, which is an essential skill for a certified orthoptist, a specialty that requires profound knowledge of the properties of various human eye movements.

In contrast to the clinical apparatuses [9-11] (the retail prices of them are 4,600,000 to 8,800,000 JPY), each part of the apparatuses introduced here costs less than 4,000 JPY. The computer displays (including head mount displays) are widely used for the clinical and research purposes ([11], for examples) due to their ability to produce strictly quantitative stimuli. And there were many projects for low-cost eye trackers [12-15]. However, more intuitive tools might be fruitful for the students who newly learn the electrophysiological recording methods. Additionally, with the main parts exposed, these apparatuses may facilitate students' understanding of the importance of timing signals and the way to acquire them (such as, simple programming,

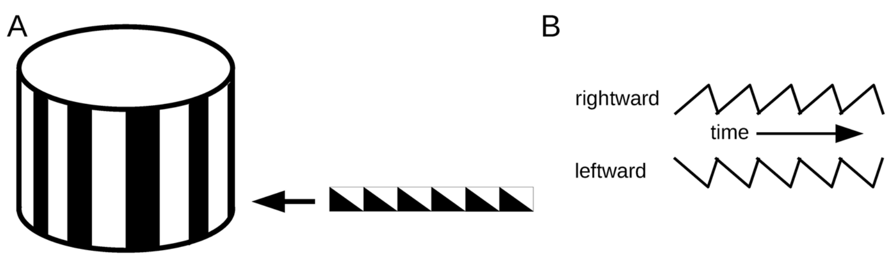

Figure 4. A plan to record rotation direction signal with the tachometer.
A. Wrapping the OKN drum with a narrow band of paper on which a series of right-angled triangles are printed in black and white.
B. Expected outputs of the tachometer for rightward rotation (upper) and leftward rotation (lower).

mechanical sensing, and optical sensing), which is occasionally veiled under a black-box in the clinical apparatuses. Moreover, usage of the general-purpose materials added flexibility to the apparatuses. For example, the tachometer can encode the direction of rotation with a small modification in the OKN drum (Figure 4).

The preciseness of the timing signal from the GR-COTTON and the angular signal from the pendulum introduced here were high enough for a student practice (the micro-controller unit RL78/G13 on the GR-COTTON has a 20-MHz CPU clock and a 32.768-kHz peripheral hardware clock [17, 18], and the rotation angle sensor CP-2FB(b) has a linearity of ± 1% [7]). A voltage-stabilized power supply would be used to improve the positional accuracy of the pendulum. The pulse generation of tachometer is accurate (Figure 3, C–E) but the preciseness is limited because it produces only 21 pulses per round with a HE-64 OKN drum. If more preciseness is required, an additional band with finer stripes would work. In the student practice, the reproducibility of the stimuli depends on trainees' attempts (to keep the pendulum at the same angle before they release it, for example), and such attempts may have an educational importance for students to accomplish precise measurements.

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Conflicts of Interest

There are no conflicts of interest to declare.

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