ILLUMINATIONS

Seeing is believing: a demonstration of critical fusion frequency and its multidimensional nature

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CRITICAL FUSION FREQUENCY (CFF), or the flicker fusion threshold, is defined as the critical frequency above which a flickering light source appears steady to the observer (see Fig. 1). It is known to depend on a number of parameters, namely, intensity of the light source (5, 15), wavelength (color) of the light, retinal locus (11), binocular or monocular vision (9, 14), light-dark ratio of the stimulus (12), stimulus area (18), the level of central fatigue of the subject being tested (4), and age (24).

CFF has been suggested as a diagnostic tool in certain nervous system disorders like Alzheimer’s disease (1, 2), multiple sclerosis (13, 19, 22), and schizophrenia (20). It has been used to assess the postoperative visual outcome of cataract surgeries (16) and to detect early visual field loss in patients with primary open-angle glaucoma (17). CFF has been used to quantify and diagnose minimal hepatic encephalopathy (10, 21). It is also used to quantify the cognitive side-effects in psychopharmacological studies (7, 23) and workplace fatigue (8). Thus a detailed knowledge of CFF will help the students interpret CFF laboratory test values that they will encounter later in their career as a physician or a medical researcher.

Pedagogical methods like a didactic lecture, a classroom or a small group demonstration, students’ presentations, reading assignments in textbooks and journals, and classroom discussion can be used to teach the concept of CFF and its multifactorial dependence. We thought the students would have a better understanding, if it were taught using a lecture supplemented by a demonstration. The equipment used to estimate CFF in the past had rotating disks, arc lamps, and optics (6), and the cost of commercial equipment ranged from $200 to $2,000. Hence, a simple, low-cost, easily available electronic development board-based (Arduino Uno) (3) device was constructed for student demonstration purposes. This device was used to demonstrate 1) CFF; 2) effect of light intensity on CFF; 3) how CFF differs between monocular and binocular vision; and 4) CFF difference between the fovea and peripheral retina. The students were taught these concepts either by a combination of the didactic lecture and a demonstration (group A students) or by a didactic lecture (group B students) alone. Students’ understanding of the concepts was assessed by pre- and posttests. The scores in the tests were used to compare these two modes of teaching.

MATERIALS AND METHODS

Materials Required

The following materials are required: Arduino Uno development board, two potentiometers (1 kΩ and 10 kΩ), a light emitting diode (LED), and a computer system installed with Arduino integrated development environment (Arduino IDE).

Construction of the Model

A simple electronic circuit was constructed, as shown in Fig. 2. The LED was connected to pin 12 of the Arduino board. The microcontroller was programmed to output a square wave of 20% duty cycle in pin 12 (see Supplemental Material for the program source code; Supplemental Material for this article is available online at the Journal website). Potentiometers were used to control the LED’s flickering frequency (10 kHz) and its intensity (1 kΩ). The values of the frequency and the intensity were displayed by the computer system (“Serial Monitor” in the Arduino IDE). The setup used is shown in Fig. 3.

Methodology

This project was approved by the Institutional Review Board before the onset of the study. The first-year medical graduates were involved in this study. Students were randomly allotted into two groups, namely group A and group B, which consisted of 77 and 76 students, respectively. Group A students were taught using a lecture and were also shown the demonstration. Group B students were taught using a lecture alone.

All students were briefed about the study and then given the pretest in a lecture hall. The pretest questionnaire consisted of five multiple choice questions, of which four were designed to test a student’s knowledge of CFF and its dependence on light intensity, retinal locus, and monocular/binocular vision (see Table 1). Students then attended a lecture that covered the above concepts. Group A students were shown the demonstration, and group B students attended the lecture alone.

The demonstration was conducted in a dark room with small groups of 10 students each. A student from each group was chosen as the subject for the demonstration. The LED was placed 1 m away from the subject, and its height was adjusted such that it was at the same level of that of the subject’s eye. The subject was then dark adapted for 15 min. Other students were briefed about the demonstration setup by a faculty during this time.

Demonstration of concept of CFF. The potentiometer knobs were adjusted to bring the flickering frequency and the intensity to the minimum-most level. The subject was instructed to close the right eye with the palm and look at the LED with the left eye. The frequency was increased, and an alarm bell was rung by the subject when the...
light source appeared steady. The frequency displayed by the computer was shown to the other students.

**Demonstration of differences in CFF for binocular and monocular vision.** The subject was now asked to open the right eye and look at the LED with both eyes. The subject was now questioned as to whether the light appeared steady or not.

Expected outcome: Binocular CFF is greater than monocular CFF.

**Demonstration of how intensity of light source influences CFF.** The subject was instructed to close the right eye again. The flickering frequency was again determined, as described above, with the minimum-intensity value. The intensity of the light source was increased, and an alarm bell was rung by the subject when the flickering of light reappeared.

Expected outcome: CFF increases with an increase in intensity of illumination of the light source.

**Demonstration of how CFF differs between fovea and peripheral retina.** The intensity and the flickering frequency were set to the lower-most values. The subject turned his/her head to the right with the right eye closed and focused on a vertical reflective tape stuck on the adjacent wall. It was ensured that the subject was able to view the light through “the corner of the eye.” The frequency of the flicker was slowly increased, and the subject rang the alarm bell when the light appeared steady. The students were asked to comment on the CFF values of the fovea and the peripheral retina.

Expected outcome: CFF in the peripheral retina is less than that of the CFF of the fovea.

Discussions were carried out concurrently with the demonstrations to aid the students in their understanding of the concepts. At the end of each demonstration session, an anonymous written feedback (see Table 2) was obtained from the students.

A posttest was conducted after 2 days of completion of the demonstration. The posttest questionnaire was the same as that of the pretest questionnaire (see Table 1). The scores obtained in the pretest and the posttest were used for analysis. Maximum number of marks in both tests were 4, and the first question in both of the questionnaires was left out of scoring; as, it was not designed to test a student’s understanding of the concepts. Scores of 39 students in group A and 40 students in group B were used for analysis. The marks of the students who were not present during either the pretest or posttest or during the demonstration were not included in the analysis.

**RESULTS**

One hundred and ten students attended the pretest and the lecture. Thirty-nine students from group A attended the pretest, lecture, demonstration, and the posttest; the remaining 38 students were not present for either the pretest, the lecture, the demonstration, or the posttest. Forty students from group B attended the pretest, lecture, and the posttest; 36 students of this group were not present for either the pretest, the lecture, or for the posttest.

The scores obtained by the students were expressed as means ± SD. There were 39 students in group A and 40 students in group B. Pretest scores of group A and group B students were 1.8 ± 1.17 and 1.63 ± 1.19, respectively. Posttest scores of group A and group B students were 3.28 ± 0.89 and 2.9 ± 0.96, respectively. The pretest scores of group A were compared against group B using an unpaired t-test and were not found to be statistically significantly different (P = 0.17). Posttest scores of each group were compared with their respective pretest scores using a paired t-test and were found to be statistically significantly different in both groups (P < 0.001). Comparison of the posttest scores of group A against those of group B using an unpaired t-test showed that they were significantly different (P = 0.03).

The results of the written feedback are summarized in Table 2. “Exciting,” “useful,” and “interesting” were some words used by the students to describe the demonstration. None of the comments was negative.

**DISCUSSION**

The device used here is very simple to construct and can be used for demonstration purposes. Commercial instruments are available to estimate CFF. They feature manual and automatic control of stimulus frequency, selection of a sweep rate for an automatic control of stimulus frequency, manual control of stimulus luminance, and data logging capabilities. Our equipment was designed to have only manual control of the stimulus frequency and the stimulus intensity. Suitable alteration of the microcontroller program and addition of a switch to the circuit will enhance our equipment’s capability to autocontrol the stimulus frequency and to log the required data onto a computer system. However, this was not attempted. Although commercial instruments have many features out of the box, buying them for demonstration purposes may be a costly affair. On the other hand, instruments of the past could be reconstructed, but construction and testing require a considerable amount of time. Transporting them may not be easy. The device we constructed was cheaper than commercial instruments and could be constructed faster than the instruments of the past. Hence, our device is suited for student demonstration purposes.

The results showed that both groups performed similarly in the pretest and that group A students performed better than group B students in the posttest. Students in group A had the opportunity to observe the concepts in real time that were taught during the lecture. Group B students attended...
the lecture alone. Students in both groups would have had mental visualizations of the concepts at the end of the lecture. Students in group A alone had the opportunity to compare and contrast their visualizations with the actual reality. We believe that both groups performed differently in the posttest because of their difference in opportunities. Feedback from group A students showed that they felt their understanding was better after the demonstration than after the lecture. They opined that the demonstration was more interesting and exciting than the lecture. Other pedagogical methods, like classroom discussion among students, reading assignments in journals or textbooks, and student presentations, are good alternatives. However, all of the mentioned methods fail to show things in action. Hence, a supplemental demonstration may be considered along with such pedagogical strategies for teaching CFF.

Mental visualizations are part of the learning process. A demonstration allows students to compare and contrast their ideas with reality. This allows for better comprehension of concepts. A mismatch between a student’s idea and reality would enhance analytic skills. Demonstrations not only add excitement to learning, they also aid in better comprehension and stimulate higher order thinking.

Limitations

Only three factors that influence CFF were demonstrated. The influence of other factors on CFF may be demonstrated in the future to the students. Not all students had a first-hand
experience of CFF estimation. This could be done later. The intensity values that were displayed were arbitrary numbers rather than actual values: a higher number indicated a higher intensity, and a lower number indicated a lower intensity.

Conclusion

Our equipment described here offers advantages over the equipment that was used in the past and present-day commercial ones. First, the device could be assembled with easily available electronic components in a short time. With Arduino being an open-source hardware, the entire setup could be constructed from scratch by anyone with competent electronic knowledge. Second, our entire equipment cost less than $10, while the commercial instruments are priced $200 and above.

This demonstration is suitable for teaching within small groups. Students found this demonstration to be interesting and exciting. It has enhanced the students understanding of the concept of CFF and its dependence on light intensity, location on the retina, and monocular/binocular vision more than the didactic lecture alone.

Hence, we conclude that our demonstration is cheaper than buying commercial equipment and easier than building instruments that were used in the past to enhance the students understanding of the concept of CFF and its multifactorial dependence.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS


Table 1. The questions that were used in pretest and the posttest

<table>
<thead>
<tr>
<th>Question</th>
<th>n</th>
<th>%</th>
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<tbody>
<tr>
<td>1. How well do you understand critical fusion frequency?</td>
<td></td>
<td></td>
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<tr>
<td>a. Poor</td>
<td></td>
<td></td>
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<tr>
<td>b. Fair</td>
<td></td>
<td></td>
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<tr>
<td>c. Good</td>
<td></td>
<td></td>
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<tr>
<td>d. Very good</td>
<td></td>
<td></td>
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<tr>
<td>e. Excellent</td>
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<tr>
<td>2. An intermittently illuminated field appears to be continuously illuminated when:</td>
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<tr>
<td>a. The frequency of interruptions is sufficiently low.</td>
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<td></td>
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<tr>
<td>b. The frequency of interruptions is sufficiently high.</td>
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<td></td>
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<tr>
<td>c. The field will never become continuously illuminated.</td>
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<td>3. Which of the following statements is true?</td>
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<tr>
<td>a. When the intensity of illumination of the light source increases, the CFF increases.</td>
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<td></td>
</tr>
<tr>
<td>b. When the intensity of illumination of the light source decreases, the CFF increases.</td>
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<td></td>
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<tr>
<td>c. Intensity of illumination of the light source does not affect CFF.</td>
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<tr>
<td>4. The CFF is:</td>
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<tr>
<td>a. Lower in the peripheral retina than in the fovea.</td>
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<td></td>
</tr>
<tr>
<td>b. Higher in the peripheral retina than in the fovea.</td>
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<td></td>
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<tr>
<td>c. Equal in both peripheral retina and in the fovea.</td>
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<tr>
<td>5. Which of the following statements is true?</td>
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</tr>
<tr>
<td>a. Binocular CFF is higher than monocular CFF.</td>
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<td></td>
</tr>
<tr>
<td>b. Binocular CFF is always lower than monocular CFF.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Binocular CFF is always equal to monocular CFF.</td>
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</tbody>
</table>

Question 1 was not used to calculate the scores. The correct response to each question is italicized.
REFERENCES


