Measuring human perception and reaction time with rulers and Pulfrich pendulums

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Abstract

Described is a multi-disciplinary educational project with the aim of investigating human perception of light and sound, and addressing the background physiology, geometry and kinematics. A traditional method of measuring reaction time by the catching of a suddenly dropped marked ruler, was explored in a variety of settings. In particular, the student holding the vertically suspended ruler dropped it on seeing the flash of a distant fire-cracker, while the catching student reacted to the sound produced by it. Knowing the distance to the cracker and how far the ruler dropped, the students could estimate the speed of sound. The reaction-time to visual and audio signals was measured and compared. Using long rulers, the students reversed roles (dropper/catcher) in a single measuring sequence. An entertaining version of this experiment—catching a dropped banknote—was given an extra competitive edge by involving two simultaneous catchers instead of a single one. Even shorter time intervals may be measured with the equally simple apparatus associated with the amazing dynamic visual illusion—the Rotating Pulfrich Effect. Careful observation of the rotating target viewed with an optical filter in front of one eye enables measurement of the visual perception delay associated with retinal images dimmed by the filter. Although the latency time in this case is in the millisecond range, a regular ruler, a stopwatch and a conical pendulum is an adequate apparatus set for this quantitative experiment, in conjunction with some knowledge of geometry and kinematics. Team measurements and studies of the different interesting versions of the Pulfrich Stereo Illusion were suggested for class activities and students' research projects. The students also created interactive computer animations explaining the strange violations of perspective that accompany both the linear and rotating Pulfrich effects.

Keywords: Teaching accelerated and rotational motion, Simple methods to measure short time intervals, Rotating Pulfrich stereo-illusion.

Describimos un proyecto multidisciplinario educativo para investigar la percepción humana del sonido y de la luz con base en la Fisiología, Geometría y en la Cinemática. Se analizó de varias maneras el método tradicional de medir el tiempo de reacción en el cual se deja caer una regla para que otra persona la coja al ser soltada. En particular, un estudiante sostiene una regla y la suelta cuando observa la luz de un cohete explotando a lo lejos mientras que un segundo estudiante reacciona al sonido cogiendo la regla. Conociendo la distancia estudiante-petardo y la distancia que cayó la regla, los estudiantes pudieron estimar la velocidad del sonido. Se midió el tiempo de reacción entre las señales luminosas y de sonido comparándolas. Usando reglas largas, se intercambiaron los papeles del que la suelta y el que la coge en una sola secuencia de medida. Una versión más entretenida de este experimento consiste en soltar un billete involucrando simultáneamente a dos personas que cogen el billete en vez de una. Se pueden medir intervalos de tiempo aún más cortos con un aparato igual de sencillo que usa la ilusión de movimiento-el efecto giratorio Pulfrich. Una observación cuidadosa del objeto giratorio visto con un filtro colocado en uno de los ojos permite la medición del retraso en la percepción visual asociado con las imágenes en la retina atenuadas por el filtro. Aunque el tiempo de desfase en este caso es del orden de milisegundos, solo se necesitan una regla, un cronometro y un péndulo cónico, juntamente con conocimientos básicos de cinemática y geometría para un estudio cuantitativo del experimento. Se sugirieron actividades y proyectos de investigación de mediciones por equipos de las diferentes versiones de la estéreo ilusión de Pulfrich. Los estudiantes crearon animaciones con las cuales explicaron el origen de la ilusión y justificaron las improbables violaciones de la perspectiva lineal que resultan de los efectos Pulfrich lineal y giratorio.

Palabras clave: Enseñanza del movimiento acelerado y giratorio, métodos sencillos para medir intervalos de tiempo cortos, Ilusión estéreo rotatoria de Pulfrich.

1 Introduction

Highschool projects combining mathematics, physics, biology, arts, music or/and other subjects allow thousands of students to benefit from a broad open-ended approach towards education. Some impressive highschool projects of the sort are those led by Chris Chiaverina and Jim Hicks in the USA, in particular the one supported by Toyota *TAPESTRY* Grants for Science Teachers awarded by the National Science Teachers Association (USA) [1], as well as the those of the *Heureka Project* (Czech Republic) [2,3]. Our own projects on dynamic visual illusions are presented in [4] and in a series of student-conference reports. These provided learners with an excellent opportunity to apply their knowledge of basic kinematics, geometry and trigonometry in the study of the various unusual phenomena. The present project is focused on the investigation of human responses to visual and auditory stimuli. Participating students performed measurements, calculations, and built animated computer models that explained the observed effects, and suggested new experiments.

2 Human reaction time measured with a gravity-accelerated ruler

The well known setup of the experiment to measure reaction time with a dropped/caught marked ruler requires some team effort from the pair of students. The 'dropper' suddenly releases a ruler without warning. Accelerated by gravity it falls down between the 'catcher's' fingers. The distance h travelled by the ruler before the 'catcher' reacted and stopped it is read from the ruler. The students then change roles and repeat the procedure. Finally, the results are substituted into a simple formula (Eq.1) to calculate the duration of the fall, i.e., the reaction time τ_r of the 'catcher'.

$$\tau_r = \sqrt{\frac{2h}{g}} \tag{1}$$

where g is the acceleration due to gravity. Typical reaction time measured by students ranged from 0·1 to 0·3 seconds.

This activity inspired the students to come up with quite a few suggestions as follows:

- With long rulers, students could repeat an experiment *without* changing the position of their hands in between the trials. This led to a decrease in the random variation of experimental data and was insightful for the freshman students not yet accustomed to research work.
- Holding *two* rulers one in each hand, and releasing them simultaneously to compare directly the reaction of two catchers. Extra competitive spirit is added when in the entertaining 'catch the banknote' version of the experiment [5] two catchers are trying to grasp simultaneously released bills.
- The catcher had to react to a sharp *sound* produced by the dropper when releasing the ruler. This experiment could be performed in a dark room or by students with their eyes closed. Comparison with the speed of reaction to visual signals is an obvious next step of the project.
- A somewhat complicated suggested technique to measure the *speed of sound* in the air is yet to be perfected. The dropper releases the ruler on seeing the flash of a distant fire-cracker, while the catching student reacts to its sound. Knowing the distance to the cracker and how far the ruler dropped, it is possible to estimate the speed of sound in the air.

Students were surprised to find out that they could reliably measure short time intervals without any advanced apparatus. Limitations of the method were analyzed and tested experimentally. For example, when the 'dropper' and the 'catcher' were reacting to the same signal, errors of direct measurement of their 'reaction difference' were unduly large. This showed the dropping method to have a lower limit of measurable times of about 1/10–1/20 of a second. Relating this limitation to the value of gravity acceleration, students predicted the measurements of reaction time with a dropped ruler to fall on the Moon. Due to the much smaller Moon gravity the ruler will travel no more than a few millimetres before the typical 'catcher' reacts. As a result, only the slowest could be measured accurately on the Moon by this method.

The latter analysis gives students a good idea of how adequate measuring techniques are chosen in real research.

3 Millisecond-range physiological processes measured with a ruler, a stop-watch, and the Pulfrich stereo illusion

Another indisputable favourite for class exercises and multidisciplinary research projects is the amazing visual illusion named after its discoverer Carl Pulfrich [6,7]. The Pulfrich effect (PE) is a dynamic visual illusion seen when a moving object (e.g., a swinging pendulum) is viewed binocularly with an optical filter in front of one eye. This results in an illusion of extra depth so strong that the pendulum bob appears to move out of the plane of the pendulum oscillations. It seems to rotate clockwise or counterclockwise, depending on which eye is dimmed by the filter, while the suspending string appears to describe a cone. Numerous studies of the Pulfrich stereo illusion [6] support the discoverer's hypothesis that explains its origin. According to Pulfrich, dimmer images are processed more slowly by the brain, so when the observed object is moving, an eye with a filter effectively registers it in a different position, delayed in respect to that observed by the unobstructed eye. Fusion of the two images, routinely performed by the brain to overcome the disparity of binocular vision, places the image of the moving object further from its real position, as the delay (latency) time increases.

Among a variety of incredible versions of this illusion, only one was found to allow precise measurement of this delay [8]. An ingenious 'turnaround' of the observational procedure suggested rotating the pendulum rather than swinging it (Fig. 1). Amazingly this allows the 'Pulfrich' image to vary its direction of rotation. Whether the viewer experiences the Rotating Pulfrich Effect (RPE) depends on the conditions of observation, namely, distance to the target L, angular velocity of rotation ω, optical density of the filter which affects the latency time τ, and separation of the pupils d. For a unique combination of the above four values a pendulum rotating circularly appears to swing only from side-to-side in a plane—the transition conditions established in [9,10]. Although the geometrical proof is complicated, the formula for the transition condition is extremely practical and straightforward ([10], see equation 2):

$$\omega\tau = tan^{-1}(d/2L) \qquad (2)$$

3.1 Experimental PE and RPE projects

During the 2010/2011 school year PE and RPE demos and projects were suggested to a variety of student classes ranging from the elementary school to the Physics-majoring university graduates.

Figure 1: Demonstrating the Rotating Pulfrich Effect.

Measurements of RPE transition parameters and calculations of visual latency time were performed by the university Introductory Physics class.

Students working on the creative projects were searching for ways to dim an object other than with a neutral optical filter. Colored plastic and glass, containers of liquid, pinholes (including tiny orifices in a crispy biscuit—Fig. 2), and diverse partial screeners like fabric handkerchiefs were all found to produce the illusion. Among the observed targets were mirror reflections and shadows of pendulums, glowing spheres in the dark, and sets of several objects swinging differently.

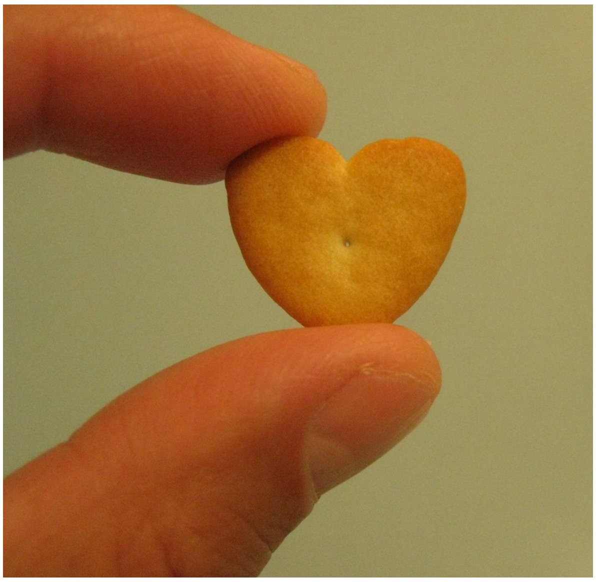

Figure 2: Some of the apparatus used to produce the Pulfrich stereo-illusion and measure visual latency time.

Quantitative experiments employed white and colored round targets rotated on the 30–70 cm long string as shown in Fig. 1. Distance to the target was slowly varied to let the observer experience the change in the direction of rotation. Either an observer or a pendulum swinger adjusted the RPE conditions until the spectacular transitional behaviour was achieved. With the typical distances to the targets at transition conditions being about 1 m, calculations of the visual latency time were performed using the approximate formula

$$\tau \approx d/(2L\omega) \qquad (3)$$

Much to the students' surprise the Pulfrich delay τ was found to be in the millisecond range. Notice that regular cell-phone stop-watches were used to measure periods of the target's rotation (0·5–2 s), while the distances required by Eq. (3) were measured with apparatus as simple as marked tapes and rulers.

3.2 Size effects and computer animation of RPE

Standard animations of PE and RPE usually only explain the observed *position* of the target, not the unusual *size effects*. For example, the viewer is surprised to see the laws of linear perspective (Fig. 3) appear to be violated in the illusion.

Figure 3: A moving sphere used as a target for RPE (left) obeys the laws of linear perspective just as stationary objects do in the right-hand photographs (front and above view).

Moving objects viewed with a filter in front of one eye appear to look bigger the further they seem to be from the observer (Fig. 4, right). Violation of the regular linear perspective in the illusion is a major effect because visible size provides an important monocular depth perception cue [11] severely contradicting placement of the PE image due to the binocular disparity.

The students generated interactive computer models of RPE using an *Excel* spreadsheet. Special macros were designed to animate the target's motion. Figs. 4–6 present a series of screenshots of the animations uploaded to the website of the *Misioneros de la Ciencia* Project [12].

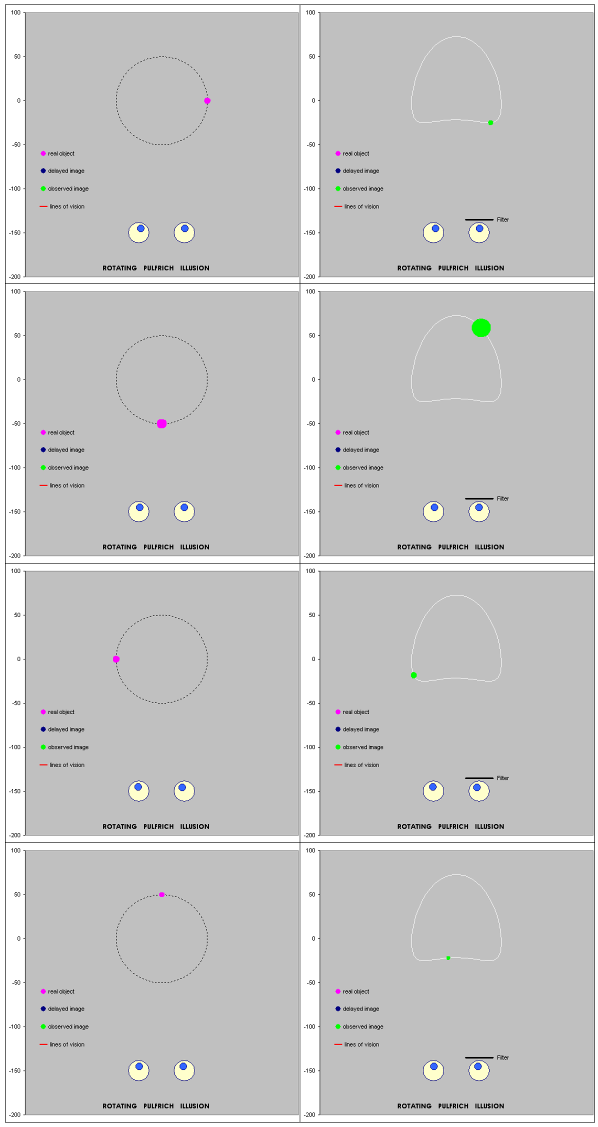

Figure 4: Screenshots of a computer animation model of the target rotating clockwise (left) and deformation of its trajectory, direction of motion and size observed in RPE (right).

Fig. 5 presents an animated explanation of the illusion's origin. Real and delayed images are both shown moving clockwise. The delay (and the resulting space separation) is due to the filter dimming the right eye. The observed fused image is placed at the intersection of the lines connecting *left eye-real object* and *right eye-delayed image*. Its size is modeled linearly proportional to the distance from the observer.

In the left sequence of screenshots (Fig. 5) the angular separation of the real and delayed images is not sufficient to make the fused image reverse its direction of motion. To the right RPE is modeled to show direction reversal.

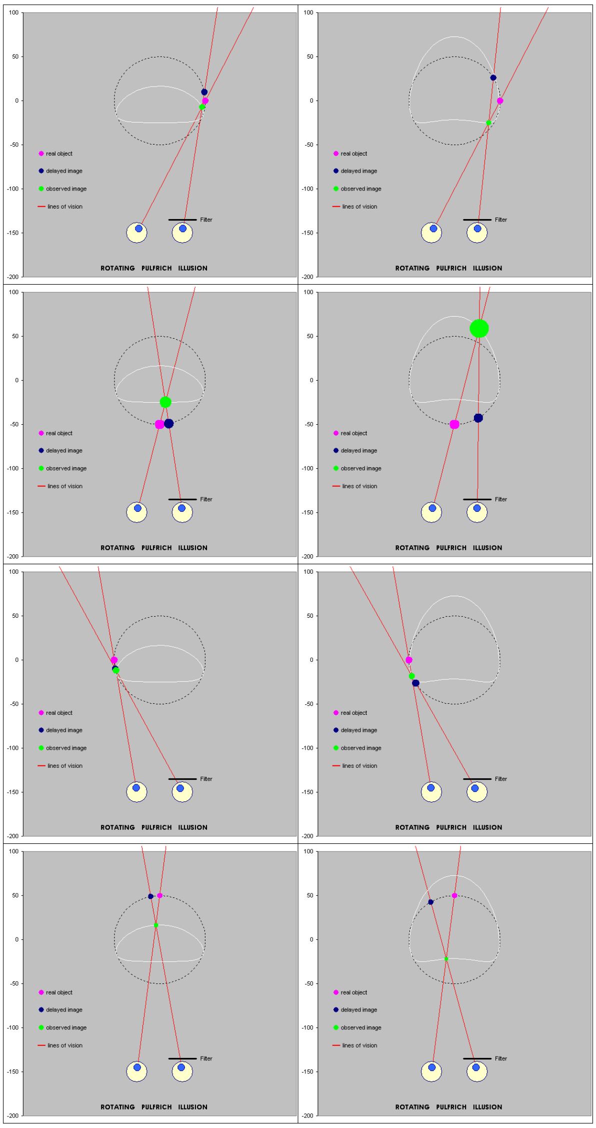

Figure 5: Screenshots of the computer animated model to explain the origin of Rotating Pulfrich Illusion.

The visual size of the target violates linear perspective rules only when the illusion is observed. Nevertheless, students working on the project noticed that the 'Pulfrich' image appears to be bigger when the real object is closer to an observer, and *vice versa*. This means that in some strange way the perspective is obeyed in the illusion.

Even more surprizing size effects are observed at transition (Fig. 6). In the same point of the 'Pulfrich' trajectory the target appears to be either big or small, depending on the direction of motion (left to right, or right to left). Here again, as the students discovered,

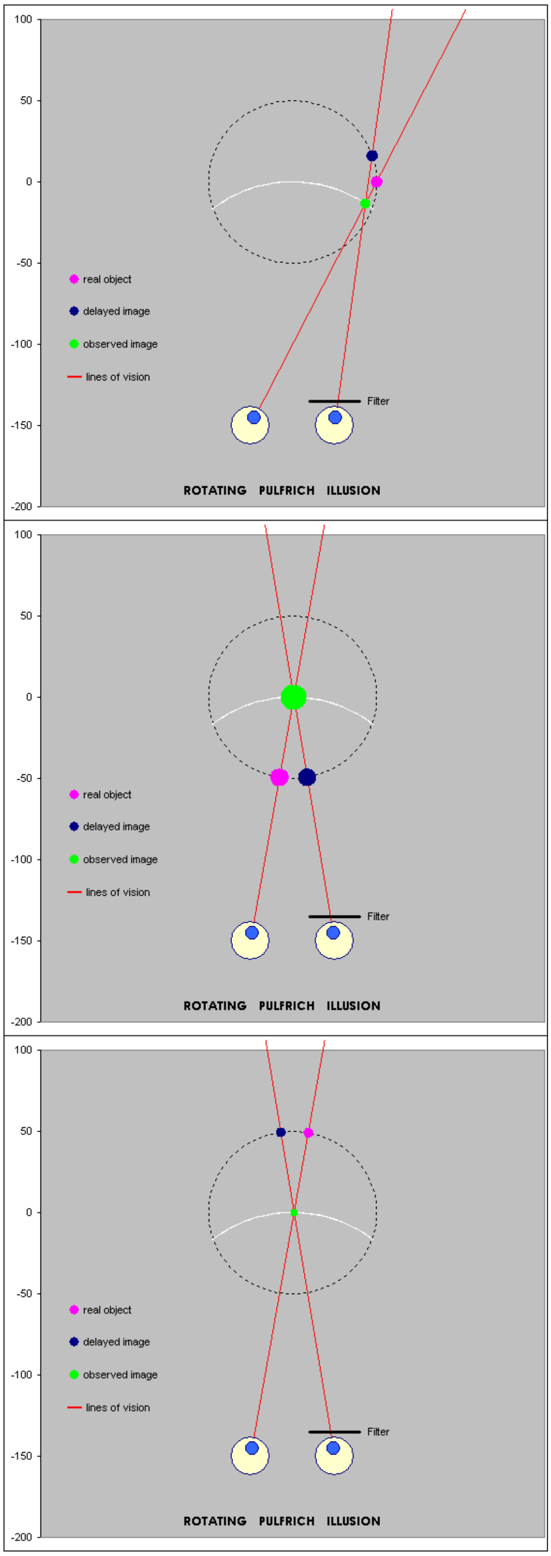

Figure 6: Screenshots of the computer animated RPE observation with the target in transition mode.

the target seems bigger when the real object travels closer to the viewer.

4 Conclusions

The students responded to these multi-disciplinary educational projects on the research of human reaction and perception, with an exceptional degree of involvement, enthusiasm, and persistence in experimental and computer studies. A series of creative suggestions and original observations were generated by the students. In particular, diverse configurations of the reaction time experiments were proposed and tested. A variety of unconventional dimmers of vision were used with success to produce the Pulfrich Effect. The dramatic violations of linear perspective observed in Rotating Pulfrich Effect were computer-modeled and explained. Activities addressing the background physiology, geometry and kinematics of the studied effects were undertaken by the class of Introductory Physics, to the obvious enjoyment of the students.

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