A METHOD FOR AUTOMATIC PROGRAMMING OF SPECTRAL STIMULI USING A MONOCHROMATOR¹

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Although a number of investigators have studied color discrimination, generalization, and spectral sensitivity using operant conditioning procedures (Blough, 1957; Ganz, 1962; Guttman, 1959; Hansen, 1959; Honig, 1964; Mello and Peterson, 1964; Peterson, 1963), the technical difficulties associated with automatic selection and sequencing of narrow-band spectral stimuli have not been discussed. Of the four most commonly used devices for presenting spectral stimuli, (*i.e.*, color filters; transmission interference filters; quartz prism monochromator; diffraction grating monochromator) only some color filters can be readily adapted for automatic presentation. For example, color filters such as Kodak Wratten Filters, can be presented easily with a standard projector, modified to be compatible with operant conditioning equipment (Lubow and Stevens, 1964). However, color filters are usually broad band filters that transmit light over a range of 50 millimicrons ($m\mu$) or more.

Transmission type interference filters provide narrow band spectral stimuli (half-peak widths from 7 to 15 $m\mu$), but their physical thickness varies from 3 to 15 mm.² This precludes the use of standard size interference filters with most commercially available, automatic slide projectors.

A monochromator can provide spectral stimuli in band widths as narrow as 4.8 $m\mu$ across the visible spectrum. The peak wavelength is selected manually by turning a knob

which rotates a diffraction grating or a prism. Many monochromators can be equipped with a variable speed motor which allows a continuous scan between 350 and 800 $m\mu$. However, of the 11 monochromator manufacturers contacted, none could provide an attachment to permit programming a sequence of wavelengths from external circuitry.

A Bausch and Lomb, high intensity, grating monochromator (model 33-86-25) was used in the system described here. The wavelength selection knob on the monochromator was replaced with a timing belt pulley as shown in Fig. 1(A).³ This timing belt pulley was linked to a second pulley (Fig. 1 (B)) on the shaft of a bidirectional stepping motor⁴ by a flexible belt.⁵ An external circuit supplied pulses to the stepping motor. Each pulse to the stepping motor turns the modified wavelength selection dial a distance equivalent to 1.01 $m\mu$. Consequently, it is possible to determine the number of steps that the wavelength selection dial must turn in order to rotate the diffraction grating to any specified wavelength.

The modified wavelength selection knob is attached to an arm which contacts micro-switches (Fig. 1 (C)). These switches define the upper and lower limits of the selection dial excursion, *i.e.*, between 350 and 800 $m\mu$. The limit switches are a safety feature to prevent damage to the delicate mechanical linkage between the wavelength selection pulley and the diffraction grating.

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²These dimensions are based on information provided by each of the following companies: Bausch and Lomb; Photovolt Corp.; Fish-Schurman Co.

³The design and construction of this part of the system was done by Ralph Gerbrands and Company, 8 Beck Road, Arlington, Mass.

⁴Slo-syn Synchronous Motor (model SS 50) available from the Superior Electric Company, Bristol, Connecticut. (\$56)

⁵A US Timing Belt with 75 teeth available from Louis E. Tracey Company, Alewife Brook Parkway, Cambridge, Massachusetts.

Fig. 1. Monochromator and stepping motor mechanical linkage. (A) Wavelength and selection dial on the monochromator. This timing belt pulley is $2\frac{1}{2}$ in. diameter with 40 teeth. (B) Timing belt pulley on the shaft of the bi-directional stepping motor ($\frac{3}{4}$ in. diameter with 12 teeth). (C) Limit switches to prevent excursion of the wavelength selection dial beyond 350 and 800 millimicrons respectively.

A schematic diagram of the total system⁶ used to program the automatic selection of spectral stimuli is shown in Fig. 2. The number of steps that the stepping motor (S) must advance to drive the monochromator dial to a given wavelength is expressed as a binary number. A slide with the appropriate binary number is projected onto the photodecoder which sends the information to the control logic block. A schematic diagram of the control logic circuit is presented in Fig. 3. The control logic block translates the binary num-

ber from the photodecoder into an equivalent number of pulses which advance the stepping motor. The stepping motor (S) in turn, drives the wavelength selection dial to a specified position corresponding to the number of pulses from the control logic block.

For example, to reach $500\text{ m}\mu$, the stepping motor would have to advance 150 times, since the zero position on the wave-length dial is $350\text{ m}\mu$. The decimal number, 150, is the equivalent of 010010110 in the binary number system. The binary number can be expressed as a sequence of solid circles and holes (reading left to right) and punched into any opaque paper cut to fit a slide for a standard projector. In the example shown in the upper

⁶The many helpful suggestions of Frank Goodwin of BRS Electronics Inc. and Ralph Gerbrands of Ralph Gerbrands and Co. are gratefully acknowledged.

Fig. 2. Schematic diagram of the control system for automatic programming of wavelength selection. The system consists of a slide projector; a photodecoder; a control circuit and driver unit (1 + 2); a bi-directional stepping motor (S) and a monochromator (M).

right of Fig. 2, 150 is expressed in binary. Each blank space represents a zero and each open circle represents a 1.

When a slide is in position, the projector displays a pattern of lighted areas which correspond to the "one's" in the binary number. Each lighted area turns on a photocell in the photodecoder.⁷ The output of the photocells is a pattern of "ons" and "offs" which corresponds to the binary equivalent of 150. The photodecoder programs the control logic block 1 to allow 150 pulses to the stepping motor (S) via its driver package,⁸ shown as control logic block 2. Once the stepping motor has driven the monochromator wavelength dial to the specified position, *e.g.*, 500 $m\mu$, it remains there until the trial is terminated by a response or by the passage of a fixed interval of time. The event that terminated a trial resets the monochromator to the zero position. Then the control circuit (Fig. 3) advances the slide projector to its next position.

Therefore, in an experiment involving the presentation of each of several wavelengths for fixed periods of time, the stimuli can be pre-selected and automatically programmed ac-

cording to the sequence of binary coded slides in the projector. A two key situation such as sameness-difference matching (*cf.* Honig, 1964) would require a second monochromator and driver system.

The time required for a single excursion is determined by the frequency setting of the pulse generator shown in Fig. 3 and the distance of the excursion required. In the system described, the pulse generator is set for 25 impulses per sec since its output is simultaneously monitored by Sodeco counters which accept 25 impulses per sec. Therefore it takes 14 sec to go from the zero position (350 $m\mu$) to the limit of the visible spectrum (700 $m\mu$). The minimum inter-trial interval based on the reset time from 700 $m\mu$ (14 sec) plus the time required to return to 700 $m\mu$ is equal to 28 sec. A pulse rate of 10 per sec has been used for studies of color generalization in which the wavelength is continuously varied. However, a more rapid excursion would be possible since the bi-directional stepping motor is rated to accept a maximum of 400 pulses per sec.

At the time of this writing, five of these systems are in operation. The prototype circuit was run continuously for six weeks and proved to be stable and reliable. The range of error observed has been plus or minus 1 $m\mu$. The major construction problems have been adjustment of the photocells in the photodecoder and insuring adequate spark suppression of the stepping motor driver.

Total cost of the prototype system was less than \$2000. The Bausch and Lomb high intensity monochromator (Model 33-86-25) cost \$900. The circuitry in the control logic blocks 1 and 2 was \$430. The combined cost of the carousel projector (\$115), the photodecoder (\$300) and the bi-directional stepping motor (\$56) was \$471. The major advantage of this system is that it provides a flexible method of programming sequences of specifiable, narrow band spectral stimuli. The basic system can be adapted to virtually any operant conditioning procedure.

The development of this system was prompted by several considerations in addition to those previously described.

(1) The initial cost of a Bausch and Lomb high intensity monochromator (\$900) compares favorably with the cost of the interference filters required to span 300 $m\mu$ at 5 $m\mu$ intervals: about \$1200.

⁷The photo decoder is available from BRS Electronics, 5415 Holland Drive, Beltsville, Maryland. (about \$300)

⁸The package and power supply to drive the Slo-sym stepping motor are available from BRS Electronics, 5415 Holland Drive, Beltsville, Maryland.

(2) Any point across the visible spectrum can be repeatedly selected, in any sequence, by the described programming system used in conjunction with a monochromator. Comparable flexibility with a filter and projection system would require either duplication of many filters or a circuit to select a repeating sequence from a single set of filters.

(3) Presentation of sufficiently intense narrow-band spectral stimuli to permit attenuation with neutral density filters requires an efficient, high intensity light source. Variable attenuation of spectral discriminative stimuli is often necessary because of the recurrent problem of insuring that a discrimination is based upon hue differences, not brightness differences. Variation of the intensity of each spectral stimulus across a wide range is a common approach to this problem. (*cf.* Mello and Peterson, 1964)

A monochromator is equipped with a high intensity light source with a specified spectral distribution. A comparable light source could probably be incorporated into a system for presentation of interference filters. However, the average projector bulb is not adequate for

this purpose, since the percent transmission of interference filters varies with the wavelength and averages about 25%.

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