Demonstrating the Stimulus Strength-Duration Relationship Using the Cockroach Leg

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Abstract
The stimulus strength-duration (S-D) relationship is typically demonstrated in physiology labs using the frog sciatic nerve preparation. An invertebrate model can also be used to demonstrate the S-D relationship. The built-in 10V stimulator of the Biopac MP36 and needle electrodes are used to stimulate movement of the cockroach tibia and tarsus. Students determine the necessary voltages that produce threshold responses for a range of stimulus durations (0.1 to 1 msec). Classic hyperbolic S-D curves are generated and rheobase and chronaxie are determined. This experimental setup can also be used to demonstrate summation and tetanus.

Theory
The strength of a stimulus and its duration determine the threshold of excitable membranes. As stimulus strength increases, the time required to excite the membrane decreases, and vice versa. Because of membrane capacitance, the relationship between stimulus strength and duration is not a simple product of the two, but rather shows a hyperbolic relationship—below a certain stimulus strength (the "rheobase"), there is no stimulation duration long enough to bring a membrane to threshold. Chronaxie, the duration of a threshold stimulus at twice the rheobase, is used to demonstrate summation and tetanus. The built-in hyperbolic relationship between stimulus strength and duration is not a simple product of the two, but rather shows a hyperbolic relationship—below a certain stimulus strength (the "rheobase"), there is no stimulation duration long enough to bring a membrane to threshold.

Materials

- Biopac MP36 Data Acquisition Unit
- OUT3: Low Voltage Stimulator Adaptor
- ELSTM2 Needle Electrodes
- Cockroach leg and electrodes
- Cockroach leg with two stimulating electrodes placed in the femur

Introduction

- Introduction
- Procedure
- Advantages
- Disadvantages

Example Student Data

- Example Student Data
- Example Student Data

Computer with BSL 4.1 Software

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Stimulus Strength vs. Stimulus Duration

The stimulus S-D relationship is examined by determining the threshold voltage for stimuli of 0.1 to 1.0 msec durations. Threshold is defined as the first noticeable twitch of the tarsus. Rheobase and chronaxie are determined from data. If chronaxie is less than 0.1 msec, threshold voltage should be determined for durations between 0.05 and 0.1 msec. Example student results are shown on the left.

Twich Summation

Using the 2X rheobase voltage and the chronaxie determined in the stimulus-duration experiment, students test next the summation of muscle twitches. Beginning with a 200 msec pulse duration, two distinct twitches should be observed. Students then reduce the delay in increments of 5 msec until only one visible twitch is seen—the largest delay between two pulses that results in one twitch is considered complete summation—typically 60-80 msec.

Demonstrating Tetanus

With a stimulator set on continuous pulses, the frequency of stimulation is increased in 1 Hz steps from 1 Hz up to 20 Hz until tetanus is observed (typically 12-15 Hz).

Advantages

- Simple, low cost preparation that demonstrates a basic physiological concept.
- Reliable results: Most students generate usable data in a short amount of time.
- Allows simple mathematical modeling along with the generation and interpretation of graphs.
- Uses an invertebrate instead of a vertebrate animal.

Disadvantages

- Not amenable to experimental variables, e.g., effect of drugs.
- No record of responses other than visual observations.

HAPS Learning Outcomes Addressed

- #7: Demonstrate laboratory procedures used to examine anatomical structures and evaluate physiological functions of each organ system.
- #8: Interpret graphs of anatomical and physiological data.

References


Online Resource

The McGill Physiology Virtual Lab has an excellent overview of the strength-duration relationship in the context of the compound action potential. https://www.medicine.mcgill.ca/physio/vlab/CAP/S-D.htm

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Cockroach Image top of poster: https://peistocontrolcanada.com/cockroaches/