SIMPLE AND INEXPENSIVE ELECTRONIC DEVICE FOR AUTOMATIC RECORDING AND ANALYSIS OF INSECT ACOUSTICAL ACTIVITY

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Abstract

An apparatus has been developed for monitoring the timing and duration of cricket calling song, using a simple electronic device coupled to an Apple II microcomputer. The calling activity of up to three insects can automatically be recorded and stored to magnetic disc. An analysis program determines the percent of time spent calling for each half-hour block of a 24-hour recording period. A graphical representation of the temporal pattern of calling is also an available option. Other microcomputers can be used with minor modification of the connections, and the ancillary electronics required for this purpose are inexpensive and readily constructed.

Resumen

Presentamos un aparato electrónico para medir dos aspectos del canto de grillós: la distribuión temporal y la duración. El aparato es connectado al minicomputador "Apple II". Este montaje puede grabar hasta tres insectos y pone automáticamente en disco magnético los resultados. Un programa de análisis determina el porciento de tiempo en canto por cada media-hora en un período de 24-horas. También se puede representar gráficamente el patrón temporal del canto. Se puede adaptar el aparato para usarlo con otras marcas de minicomputadores usando electrónicas baratas y fáciles.

Although much is known of the mating behavior of crickets (Orthoptera: Gryllidae), few studies have been conducted on diel patterns of calling in this diverse insect group (Walker 1983). Male crickets call to attract sexually receptive females, and the timing and duration of acoustic signalling activity are crucial to male reproductive success. In many species, males appear to call throughout most of the night, placing practical limitations on the use of standard observational sampling methods (Altmann 1974) which can often be extremely laborious. Consequently, some researchers have employed electronic sound relay devices to monitor cricket calling (e.g., Cade 1981, Sakaluk et al. 1987, Rost & Honegger 1987). The construction of such instruments, however, can be prohibitively expensive or beyond the technical expertise of most researchers. Accordingly, we have developed an inexpensive electronic addition to the Apple[R] II series microcomputer which simultaneously records the calling of up to three insects and stores the data directly to disk. An associated analysis program determines the proportion of time spent calling by each male for each half-hour of recording time, and presents the results in a printed table. A graphics program permits the calling activity of each male to be plotted as a function of real time.

Hardware and Construction

The requirements are an Apple II+ computer with 48K of memory, a single disk drive, and a CRT monitor. If a printer is available, the programs can make use of it, but this feature is not essential. To record as a function of real time, the computer must be equipped with a clock. Finally, a simple electronic circuit is required to convert the electrical impulses from the three microphones into signals appropriate to the inputs available at the Apple's game port. This and the requisite programming complete the requirements for the system.

The electronic circuit required for interfacing the computer with the microphones is illustrated in Figure 1. There are three identical channels (n = 1, 2 and 3), each consisting of an audio amplifier Q_{n1}, a comparitor Q_{n2} and a timer Q_{n3}. Aside from a common audio amplifier bias adjustment (R_2) and power source, no other parts are shared by the channels. The audio amplifier and comparitor are packaged with four identical amplifiers to a chip, so only one chip is needed for all three channels. The timer (Q_{n3}) is a dual circuit, so two chips and sockets are needed, leaving one unused unit. The 10.2 x 10.3 cm prototype card (Radio Shack 276-154A) on which the circuit is connected, mates with a plug which is wired as shown in Figure 2. Each channel has an auditory sensitivity and time delay adjustment located on the front panel, along with an indicator light to show when the channel is active.

The microphones used are electret versions (Radio Shack) and require application of voltage. The use of a 1K resistor (R_{n1}) gives the highest electrical output for a given

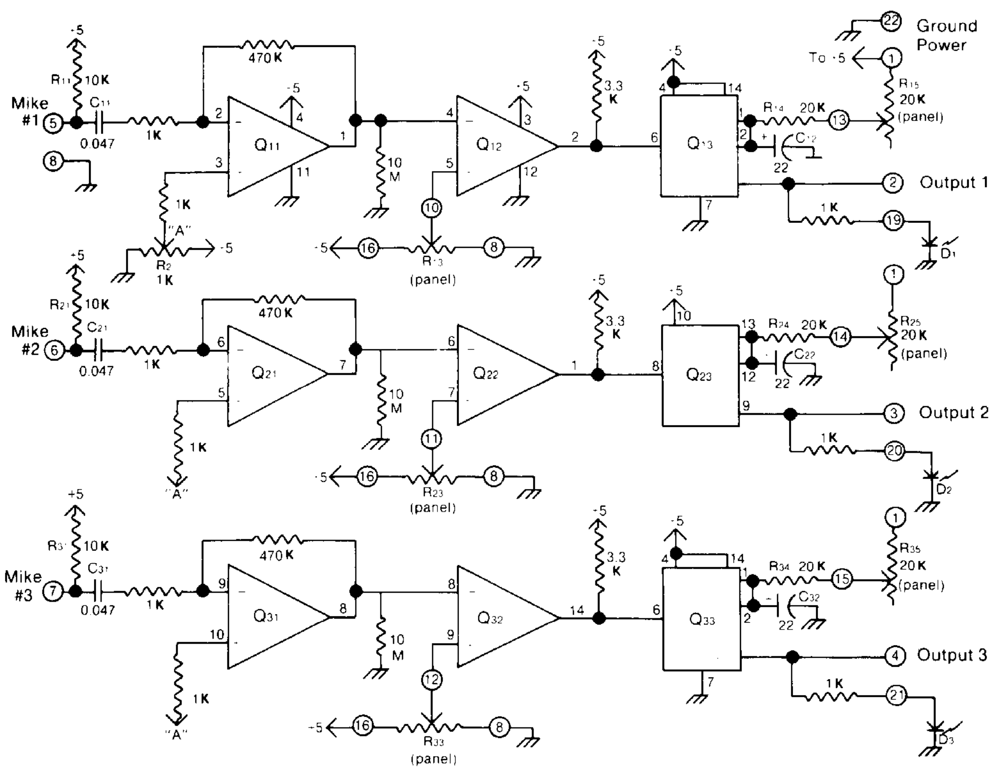

Fig. 1. A schematic diagram of the interface electronics, as constructed on a 44-pin edge-connector prototype card. Connection numbers (in circles) refer to the pins on the edge connector. All integrated circuits are commercial DIP versions and are mounted in sockets. Resistors are 1/4 W 5% tolerance and are given in ohms, kilohoms (K) and mehohms (M); capacitors are in microfarads. C_{n1} (C_{11}, C_{12}, C_{13}) is a disc ceramic, while C_{n2} is a tantalum (observe polarity); 15 V ratings are ample. Variable resistors are 10-turn ceramic trimmers; all but R_2 are mounted on the front panel and connected through the edge connector. Power is drawn from the computer via the games connector; about 40 mA is required at 5 volts.

sound input, which is maximized since distortion is of no concern to the present study. Q_{n1} is an audio amplifier with a gain of 470X. The positive excursions of the audio signal carry the input of the comparitor Q_{n2} across its threshold value (adjustable by panel-mounted R_{n3}), producing a negative-going pulse at the input of Q_{n3}. This is a timer which, when tripped, produces a positive 5 V signal at its output for a duration determined by R_{n5} (panel mounted) in series with R_{n4}. This timer is normally adjusted to produce a 1-second pulse. Increasing the values of R_{n4}, R_{n5} or C_{n2} will increase the time period should a greater range be desired. Light emitting diodes (LEDs) D_{n1} are used to visualize the operation of the circuit, and are valuable during initial adjustment and monitoring.

The interface circuits are mounted in a metal box (14.8 x 20.1 x 4.2 cm) with the adjustable resistors and LEDs mounted on the front panel and the microphone connectors and cable to the computer extending from the rear. The latter connections are made via a DB-19 connector which is wired in accordance with the joystick input of the Apple IIe and IIc computers; if one of these computers is used, the computer cable should be wired pin for pin to the corresponding DB-19 connector. The Apple II+ requires a connector which plugs into the game port on the main board and is routed out of a ventilation slot in the rear of the computer. This connector system can also be used with the Apple IIe, but not with the IIc or Laser. The interface box draws about 40 mA at 5 volts from the host computer, which is well within the design limits of the port.

The connections between the edge connector and the interface box are shown in Figure 2. J_1-J_3 are sub-miniature phone jacks which mate with corresponding plugs on the shielded microphone cables. J_4 is the 44-pin edge connector for the circuit board, of which only the 22 numbered pins are used. J_5 is a DB-9 female connector mounted on the interface box, mating to a corresponding male connector on the cable to the computer. J_6 is a 16-pin DIP header which mates with the games connector in the Apple II+ or IIe. The off-board components from Figure 1 are also indicated in this schematic diagram.

Programs

Since BASIC is the resident language in the Apple II series, it was chosen for these programs; the disk operating system is DOS 3.3. Programs are available to: 1) record events, 2) determine the proportion of time spent singing by each male for each half-hour block of recording, and 3) produce a graph of the temporal distribution of calling. In addition, a file transfer program and a program to read, display and set the clock are included. All of these programs can be accessed from the main menu which is displayed upon booting the disk, and all but the file management program return to this menu upon completion. The main menu is part of the HELLO program which is automatically run when the program disk is booted.

Upon entry to the data collection program EVENTS, the clock is read to the nearest second to obtain the time and date. The system collects data by examining the three inputs and recording the time at which a change in activity is detected at any one of them. The 1-second timers ensure that no "on" event is missed during the time required to read the clock and store a record to memory. The timers are not re-triggerable, however, and actually drop out for a brief period even in the presence of continuous audio activity (substitution of an N74123 retriggerable monostable multivibrator would eliminate the "drop out"). Thus the program loop that monitors the inputs takes about three readings per second, and these three must agree before a change of state is recorded. When a change in any of the three inputs occurs, the clock is read and the time (in seconds since midnight) and the values of each input (1 = on, 0 = off) are stored to an array in memory. This array has provisions for 1300 such records, and the program will terminate automatically before this limit is exceeded.

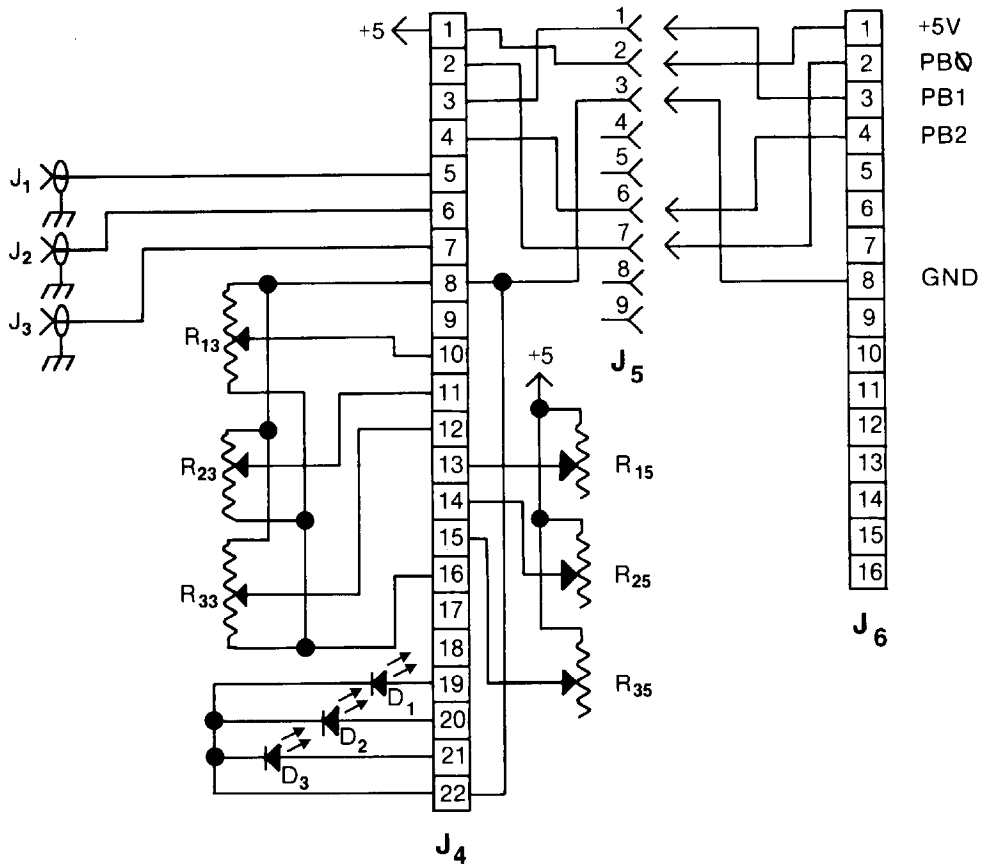

Fig. 2. Wiring diagram of the interface box. J_1-J_3 are subminiature phone jacks, J_4 is the card socket, J_5 is a DB-9 male connector for output to the computer, and J_6 is a 16-pin DIP header required for connection to the main board on the Apple II+. Also shown are the off-board components from Figure 1. The LEDs are mounted in Beckman 89B trimmer holders to provide shielding from ambient light.

The program normally terminates at the end of a user-defined recording interval. Alternatively, unlimited recording may be specified, or the program may be terminated by keyboard entry regardless of the preset values. When the program terminates, the data are automatically transferred to the disk if a file name is specified in advance, without operator intervention. A default filename is taken from the clock when the program initializes, in the form of the date and year. Thus a set of data which were obtained starting on April 15, 1988 will be stored to a file called APR15/88. The default file name can be modified to any legal name, or no selection entered, in which case the program waits for the operator to supply a name at termination or opt not to store the data at all. As a protection against storing new data over old, the program searches the data disk for a file with the proposed name. If one is found, the new file name has an "X" appended to it, such as APR15/88X. This process is repeated until the new name (with an appropriate number of X's) is unique. The only way to remove a data file from disk is by using the DELETE command from BASIC or from the filer.

Upon termination of the recording program, control is passed back to the main menu. Normally, the analysis program would be selected at this time. This program (LIST.EVENTS) is menu driven, with routines for listing the raw data to the screen or printer, determining the proportion of time spent singing by each male for each half-hour block, listing the array of 48 half-hour blocks to the screen or printer, and saving the array to disk for later display and/or graphical analysis. The analysis program discards any data recorded before the start of the first even half hour, analyzes data collected over the subsequent 24 hours, and discards any data after the 24-hour period. For this reason, the default time for data recording is set to 24.5 hours, ensuring a full 24 hours of usable data. In the analysis, the time at which singing begins is recorded and, when singing stops, the difference in time is added to the running total for that channel. At the end of the half-hour period, the time spent calling by each male is divided by 1800 seconds to determine the percent of time spent calling (rounded off to the nearest 0.1%) for that block. To enable analysis of files which contain less than 24 hours of data, the array is initially cleared to an impossible value (–1%) to distinguish "no singing" from "no data" in that period.

The analysed data are stored to disk with a file name consisting of the original raw data file name and an appended "#" sign, to assist in associating each results file with its raw data file. Upon terminating the program, the graphics program (GRAPH.EVENTS) is normally selected. This program accesses the results file, can list it to screen or printer in the same manner as the analysis program, and produces a high-resolution CRT bar graph which plots calling time (as a percent of time available) versus the time of day for each channel. Periods for which no data are available (flagged as –1%) are indicated on the graph.

Calibration

Before data collection, it is first necessary to calibrate the apparatus. As an initial adjustment, the threshold of the comparators is set with the microphones removed, shorting the inputs. R_{n3} is adjusted until the associated LED is just extinguished. When the microphone is replaced, ambient noise will usually trigger the circuit, so a further decrease in sensitivity is required until the LED is off except when deliberately stimulated. At this point, the timer duration can be set (R_{n5}); this is best done with a calibrated oscilloscope at the output of the timer, or at the positive terminal of the LED. We adjusted each of the timers to a duration of 0.9 seconds. The microphones are then installed in the recording chambers, which are rectangular plastic shoe boxes (29.5 X 15.0 cm at the base and 8.5 cm high), appropriately ventilated and with a microphone inserted through a hole.

The process of adjusting the sensitivities is simplified by having a standard sound source that can be placed in the recording chamber instead of an insect, and which generates the same sound level in every chamber. This is accomplished using a high-frequency speaker (Realistic[R] piezo tweeter 40-1383), that can be placed in the chamber and driven in parallel with the computer's internal speaker. Due to the high frequencies involved, a program in machine language (TONE) was used to produce pure tones of adjustable frequency, duration and interpulse delay; the latter two determine the pulse repetition rate. This program is called by a BASIC program, MAKE.TONES, which displays the default parameters, accepts changes and POKE's them to memory, and calls TONE. The modified parameters subsequently can be stored as part of TONE for future use. It should be possible to simulate a wide variety of insect calls with this program, although it is intended for calibration purposes, unlike the systems of Walker (1982) and Campbell & Forest (1987). To permit the signal amplitude to be varied, an 8-ohm potentiometer is used (Realistic[R] L-Pad 40-.980), wired such that one side of the L-Pad provides a constant impedance to the computer cable while the speaker is connected between the wiper and the grounded side.

Test Results

To test for uniformity of response across the three channels, an experiment was performed in which the three microphones were bundled together and placed in the same chamber with a single male cricket, *Gryllodes supplicans* Walker (Orthoptera: Gryllidae). Over a 24-hour recording period, there were several half-hour blocks during which singing was continuous (100%), many blocks in which there was no singing, amd many with intermediate values. Only 13 of the 48 half-hour periods showed any difference between channels, with the greatest error being a 0.6% (10.8-second) difference in a period of low activity (0.6, 1.0 and 0.4% for the three channels, respectively). Ten of the 13 periods had a difference of only 0.1-0.2% (1.8-3.6 seconds). Careful alignment of the circuits with respect to sensitivity and timer duration resulted in a second trial in which only 10 of the 48 half-hour periods showed any difference between channels, with the error never exceeding 0.2% (3.8 seconds).

Because the crickets frequently change their location within the recording chambers, sensitivities must be adjusted such that microphone response does not vary as a consequence of such movement. To determine if the placement of the microphone relative to the cricket had any influence on microphone response, the three microphones were placed in different locations in the same chamber and oriented in different directions. In a 24-hour recording period, 11 of the 48 sampling periods showed a difference between channels, with the error never exceeding 0.3% (5.4 seconds).

Finally, the apparatus was set up for an experiment employing three recording chambers, each containing a single male *G. supplicans* and provisioned with ample food, water and shelter. Microphone cables, approximately three meters in length, permitted the chambers to be widely separated, thereby preventing acoustical activity in one cage from being detected at adjacent microphones. The results of this experiment are shown in Figure 3. Although there was some variation between males, calling activity peaked shortly after "lights off", remained constant throughout most of the dark portion of the photoperiod, and ceased shortly before "lights on". These results conform closely to field observations of *G. supplicans* (Sakaluk 1987).

Discussion

The ease and accuracy of data collection using our apparatus make possible a range of experiments which would be extremely laborious or essentially impossible using standard observational sampling methods (Altmann 1974). Three crickets can be monitored for acoustical activity continuously over a 24-hour period, and the system measures not only the duration of activity, but its temporal distribution. The use of half-hour analysis periods was an arbitrary choice; appropriate program modifications can provide any appropriate interval.

For some studies, the restriction to three channels of input may be a limitation. The interface electronics will support a fourth channel involving no additional active components, since an unused section of each chip is available. The Apple II+ has a cassette input, similar to the pushbutton inputs, which is mapped to a specified memory location (49256, $C060) and could be specified as PB3. However, this input is capacitor coupled and will not respond to direct current, so that the Apple main circuit board would have to be modified to enable use of this input.

It should also be possible to use a parallel interface card such as the Apple Parallel Interface Card to access up to eight inputs, using one digit for each input. If used in conjunction with the three or four inputs available through the games/cassette inputs, a total of 12 event channels could be monitored, with a corresponding increase in the complexity of the interface circuit. Alternatively, by employing an appropriate multiplexing circuit, a single input line could be used to signal a change in activity (i.e., on or off) while three others would be sufficient to specify which channel of the eight was being monitored. In either scheme, a more efficient data storage system would be

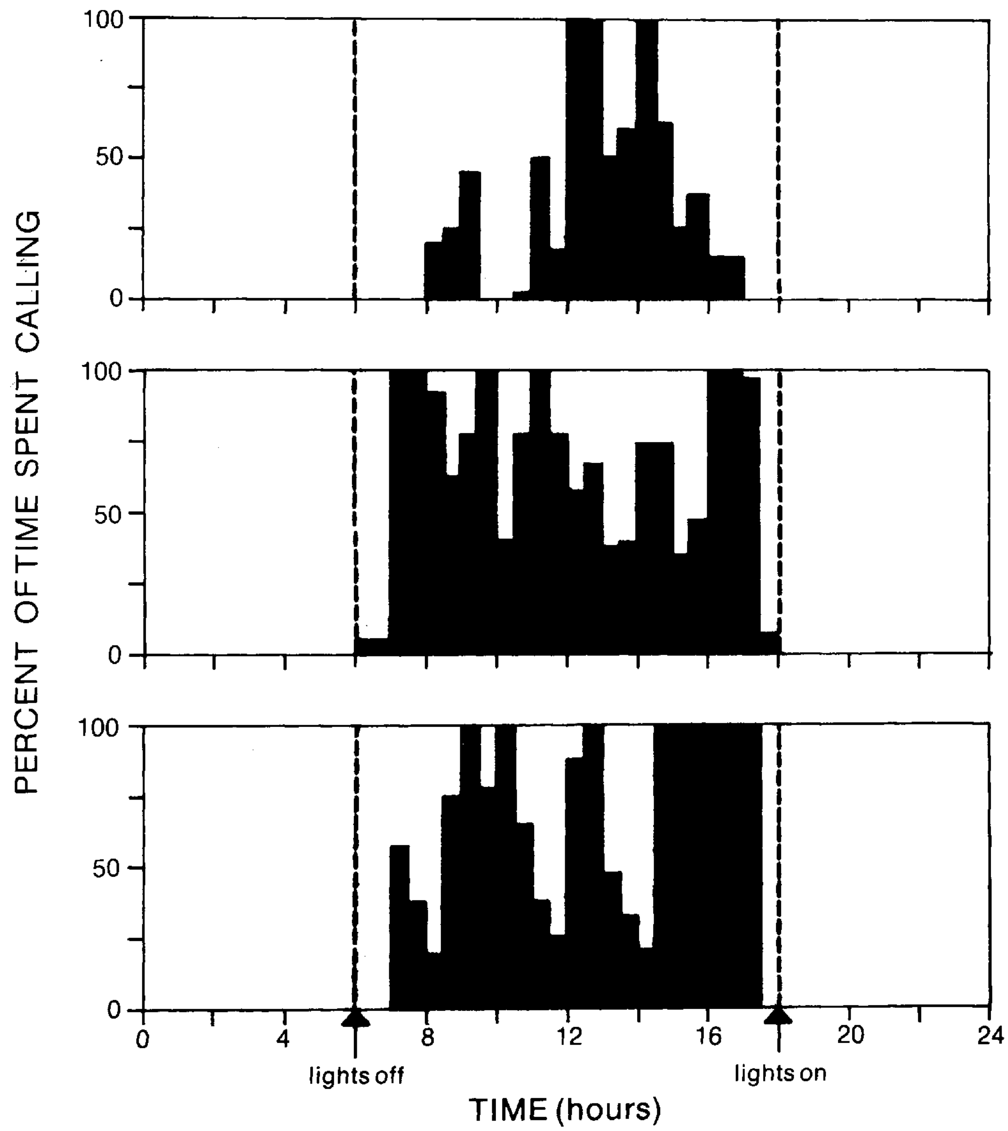

Fig. 3. Temporal pattern of calling of three decorated crickets, *Gryllodes supplicans*, monitored over a 24-hour period. Calling time is shown as a percent of the total time available for each half-hour block.

required. At present, the data are stored as an array of three integers, requiring six words per record. Since only one bit is required to specify the information for each channel, it would be possible with additional programming to compress 16 channels of data into a single integer representation (two 8-bit words).

Most of these modifications would, of course, be unnecessary with the purchase of a more powerful (and more expensive) computer. However, our selection of the Apple II+ was deliberate, since we sought to utilize a common and inexpensive computer that is often found in departmental stockrooms, having been retired from more demanding service. In fact, the existence of this computer and similar computers as surplus items, or at low cost on the used market, is an attractive feature of this apparatus. The authors would be pleased to correspond with others interested in the further development or implementation of this system. Since the programs are too long for publication, we would be happy to supply listings or copies of them on request.

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COMPARATIVE ENERGETICS OF TWO SPECIES OF *DROSOPHILA* IN FLORIDA

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ABSTRACT

The metabolic rates of wild-caught adult female *Drosophila melanogaster* measured at 22°C are significantly greater than those of sympatric *Drosophila simulans*. Similarly, the temperature-specific metabolic rates, measured at 18, 22, and 25°C, in laboratory-reared granddaughters of the wild-caught *D. melanogaster* are greater than those of the laboratory-reared granddaughters of the wild-caught *D. simulans* females. These genetically encoded differences in metabolic rate between the two species may be related to differences in fecundity and seasonality.

RESUMEN

La tasa de metabolismo de hembras salvajes atrapadas de *Drosophila melanogaster* medidas a 22°C fué significantemente mayor que aquellas de *Drosphila simulans* simpátricas. Similarmente, la tasa de metabolismo de temperatura específica, medidas a