— INSTRUMENTATION & TECHNIQUES —

A computerized system for analyzing linear locomotion

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An accurate and reliable, yet simple and inexpensive electronic tracking device delivers voltages that denote changing positions of moving objects. In combination with an analog-to-digital converter, a microcomputer, and specific software, this device enables the depiction and analysis of linear or linearly represented locomotion. The system is particularly useful for laboratory analysis of animal movements. An application in preference-avoidance testing is described.

Many behavioral studies focus on locomotion. However, there is a lack of efficient, inexpensive methods to determine and process such basic parameters as velocity, direction, rate of turns, and frequency and duration of movements into or out of specific areas. By combining a previously developed viewing and tracking device (Scherer & Nowak, 1973) with a microcomputer and simple software, we have developed a highly reliable, efficient system that may be useful in various areas of research.

Hardware

The tracking device (Scherer & Nowak, 1973) was developed to overcome a lack of adequate recording techniques in preference-avoidance testing as conventionally carried out in otherwise well-proven types of choice chambers (Jones, 1947; Shelford & Allee, 1913; Sprague, 1964; see also Höglund, 1961; Jones, Hara, & Scherer, 1985). Figures 1 and 2 show the essential components of that recording system, and the core of the electronic module. The tracking device employs a gunsight-type viewer connected to a linear taper potentiometer, across which a regulated voltage is applied. Movements of the viewer by the observer produce varying voltage outputs on the wiper of the potentiometer; thus, a certain position of a reference point or "target" within the test area corresponds to a certain voltage value. The gunsight-type design of the viewer with a foresight and backsight eliminates the problem of parallax; that is, with the viewer properly sighted, the position of the experimenter will not

Figure 1. The apparatus: block diagram with essential elements of hardware assembly. (A) elements as previously used for analog recordings (Scherer & Nowak, 1973). (B₁-B₂) present upgrade with microcomputer and mainframe options.

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Figure 2. The apparatus: circuit diagram. (For list of parts and prices, see Appendix.)

change the voltage value of the target point. Targets should be clearly defined and focused on by the experimenter. They may be structures or markings on the animal's body; in our work, for example, we use the fishes' eyes as convenient reference points. The voltage analogs of the animal's linear movements are the primary parameters for on-line recording and subsequent analysis. Previously, these voltages were fed into strip chart recorders, producing instantaneous and accurate displays of the animal's movements (see, e.g., Hara & Thompson, 1978; Hidaka & Tatsukawa, 1985; Jones et al., 1985; Lawrence & Scherer, 1974; Scherer, 1975; Tatsukawa & Hidaka, 1978). Although the potential of this method for detailed analysis of locomotor characteristics such as velocity (degree and rate of its change) and rate of turns was recognized early (Lawrence & Scherer, 1974; Scherer & Nowak, 1973), it was never utilized. The obstacle was the very labor-intensive and error-prone method of digitizing tracings with conventional visuomechanical methods. The electronic digitizing and computing developments of the 1980s have made our tracking technique feasible.

The present system employs an Omega WB-31 White Box analog-to-digital (A/D) interface (see list of parts and prices). This unit accepts analog inputs with a standard range of 5 V dc; the resolution within this range is 1 part in 5,000, which equals 1 mV. Transmission rates up to 9600 baud are possible using a standard RS 232 serial interface. The A/D conversion rate is 7.5/sec, thus requiring 133 msec per conversion.

A simple, inexpensive microcomputer may be used for data collection and storage. Our prototype assembly

(Scherer, Hunt, & McNicol, 1989) employed a Commodore 64C with a 1541-II disk drive. Presently, we are using an IBM-compatible 386SX microcomputer with 1 MB RAM and an optional 40-MB hard drive that allows significantly faster disk access. A simple GW-BASIC program controls the rate and duration of collecting entries. Files can be transmitted quickly to an external computer (Figure 1, B₂) for storage and/or advanced statistical processing and graphing using software packages such as SAS.

Software

To collect, store, and process the data generated through the A/D converter, software must be tailored to the particular application. We developed a GW-BASIC program (Listing 1) specifically for two-way preference-avoidance testing with fish in a test chamber where the animal has a choice between left and right, the midline of the test area providing the reference (1.0 V). Aside from this specific feature (which can be easily modified), the program contains elements that are useful for any applications that require the recording and analysis of linear movements. For one particular application and test species, we chose a position sampling rate of 1 sec. This degree of temporal resolution produces clear tracings and informative digital data strings (Figure 3; Listings 2 and 3; McNicol & Scherer, 1991). Any coarser resolution could be set, up to a rate of one entry every 9 h. The WB-31 White Box A/D converter can also sample faster than once per second, but only in a continuous mode; control over the time interval between readings would require a modified control program.

LISTING 1

A GW-BASIC Program for Tracking an Animal (Collecting Position Data)
in a Left/Right Choice Situation; Centerline at 1.0

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10 REM Whitebox Data Collection Program
20 REM-----
30 VIEW PRINT
40 CLOSE: CLEAR
50 ON ERROR GOTO 1380
60 REM-----
70 DIM DAT$(2000),TIM(2000),NUM(2000)
80 CLS
90 VIEW PRINT 4 TO 6
100 CLS
110 LOCATE 5,5
120 PRINT "HOW MANY DATA POINTS DO YOU WISH TO COLLECT"
130 LOCATE 6,10
140 INPUT "(MAXIMUM 2000)_____";DP
150 IF DP>2000 THEN BEEP : GOTO 100
160 VIEW PRINT 7 TO 9
170 CLS
180 LOCATE 8,5
190 PRINT "HOW MANY SECONDS BETWEEN DATA POINTS"
200 LOCATE 9,10
210 INPUT "(MAXIMUM 32767)_____";G
220 G = INT(G+.5)
230 IF G>32767 THEN BEEP:GOTO 170
240 VIEW PRINT 10 TO 13
250 CLS
260 LOCATE 12,10
270 PRINT "WHEN YOU ARE READY TO START"
280 LOCATE 13,10
290 INPUT "ENTER S _____";S$
300 IF S$="s" OR S$="S" THEN 330
310 BEEP
320 GOTO 250
330 VIEW PRINT
340 REM This routine initializes the COM port.
350 OPEN "COM1:300,N,7,1" AS #1
360 PRINT#1,"T1";CHR$(13)
370 E=LOC(1)
380 IF E<1 THEN GOTO 370
390 ES=INPUT$(LOC(1),#1)
400 CLS
410 LOCATE 5,10
420 PRINT "COLLECTING";DP;"SAMPLES AT";G;"SECOND INTERVALS"
430 LOCATE 7,10
440 PRINT "          (PRESS Q TO STOP COLLECTION)          "
450 LOCATE 10,10
460 PRINT "SAMPLE #          TIME(Secs)          READING"
470 LOCATE 11,9
480 PRINT "_____ "
490 VIEW PRINT
500 PRINT#1,"T";G;CHR$(13)
510 VIEW PRINT 14 TO 24
520 N=0
530 B=LOC(1)
540 IF B<1 THEN GOTO 530
550 A$=INPUT$(LOC(1),#1)
560 D=ASC(A$)
570 IF D<> 7 THEN GOTO 530
580 PRINT #1,"R";CHR$(13)
590 X=LOC(1)
600 IF X<7 THEN 590
610 M$=INPUT$(LOC(1),#1)
620 N=N+1
630 PRINT SPC(13-LEN(STR$(N)));N;SPC(18-LEN(STR$(N*G)));N*G;SPC(13);M$
640 NUM(N)=N
650 TIM(N)=N*G
660 DAT$(N)=VAL(RIGHT$(M$,5))
670 Q$ = INKEY$:IF Q$="Q" OR Q$="q" THEN 10
680 IF N<DP THEN GOTO 530
690 PRINT#1,"Q";CHR$(13)
700 CLOSE #1
710 FOR X=1 TO 5
720 SOUND 440,1
730 SOUND 880,1
740 SOUND 440,1
750 NEXT X
760 VIEW PRINT
770 CLS
780 LOCATE 5,5
790 PRINT "DO YOU WANT TO VIEW THIS DATA"
800 LOCATE 6,5
810 INPUT "BEFORE YOU SAVE IT_____(Y/N)";N$
820 IF N$="N" OR N$="n" THEN 1030

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Listing 1 (Continued)

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830 IF N$="Y" OR N$="y" THEN 850
840 GOTO 770
850 T=1
860 CLS
870 LOCATE 1,10
880 PRINT "SAMPLE#           TIME(Secs)           READING"
890 FOR X=T TO (T+19)
900 PRINT SPC(13-LEN(STR$(NUM(X))));NUM(X);SPC(18-LEN(STR$(TIM(X))));TIM(X);
910 PRINT SPC(14);PRINT USING "#.###";DAT$(X)
920 IF X=DP THEN 940
930 NEXT X
940 VIEW PRINT 23 TO 24
950 CLS
960 LOCATE 23,10
970 PRINT "PRESS ANY KEY TO CONTINUE"
980 C$=INKEY$:IF LEN(C$)=0 THEN 980
990 VIEW PRINT
1000 IF X=DP THEN 1030
1010 T=T+20
1020 GOTO 860
1030 REM-----FILE STORAGE ROUTINE-----
1040 BEEP
1050 CLS
1060 LOCATE 5,5
1070 PRINT "DO YOU WANT SAVE THIS DATA IN"
1080 LOCATE 6,5
1090 INPUT "A PERMANENT FILE_____ (Y/N)";N$
1100 IF N$="N" OR N$="n" THEN 1260
1110 IF N$="Y" OR N$="y" THEN 1130
1120 GOTO 1050
1130 LOCATE 8,5
1140 PRINT "ENTER A FILE NAME (MAX. 8 LETTERS)"
1150 LOCATE 9,5
1160 PRINT "AND EXTENSION (3 LETTERS)"
1170 LOCATE 10,5
1180 INPUT "eg  EXPT12.DAT_____";F$
1190 OPEN F$ FOR OUTPUT AS #2
1200 FOR X=1 TO DP
1210 PRINT#2,NUM(X);" ";TIM(X);" ";DAT$(X)
1220 NEXT X
1230 CLOSE #2
1240 VIEW PRINT 14 TO 17
1250 CLS
1260 LOCATE 15,5
1270 PRINT "DO YOU WANT TO COLLECT ANOTHER"
1280 LOCATE 16,5
1290 INPUT "SET OF DATA_____ (Y/N)";W$
1300 IF W$="N" OR W$="n" THEN 1340
1310 IF W$="Y" OR W$="y" THEN 10
1320 GOTO 1240
1330 VIEW PRINT
1340 CLOSE
1350 VIEW PRINT
1360 END
1370 REM----- ERROR TRAPPING-----
1380 E = ERR
1390 IF E = 57 THEN 400
1400 IF E = 24 THEN 1420
1410 END
1420 CLS
1430 LOCATE 5,10
1440 BEEP
1450 PRINT "THE WHITEBOX IS NOT SWITCHED ON"
1460 LOCATE 7,10
1470 PRINT "OR THE SWITCH BOX IS IN THE"
1480 LOCATE 9,10
1490 PRINT "WRONG POSITION. PLEASE CORRECT"
1500 LOCATE 11,10
1510 INPUT "THE PROBLEM AND ENTER C TO CONTINUE";C$
1520 IF C$ = "C" OR C$ = "c" THEN 10

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Discussion

In applying our system to the analysis of preference-avoidance movements in a two-way choice tank, we could define and process more than 20 response parameters based on 5 basic elements of the locomotor behavior of lake whitefish (*Coregonus clupeaformis*). We found responses to cadmium solutions at concentrations as low as 0.2 µg/L (McNicol & Scherer, 1991). None of the previously avail-

able methods allowed a comparably thorough and conclusive response analysis. We see no reason, though, to restrict the application to this type of test. For example, levels and patterns of locomotor activity can be analyzed within the same or any similar kind of tank or cage.

Vertical movements or displacements can be as readily studied as horizontal ones. To do two-dimensional x,y analyses, one might mount two potentiometers perpen-

Figure 3. Examples of printouts derived from the system tracking a fathead minnow (*Pimephales promelas*) in a preference-avoidance tank. Top panel: both sides containing uncontaminated water. Bottom panel: right-hand side (Positions 0.6-1.0) containing 100 µg/L of cadmium. Position values denote a relative scale equivalent to 47.5 cm of trough length on either side of the 1.0 centerline.

dicularly to each other, converting the present viewing device (which only moves horizontally) to a kind of joystick (the second potentiometer being attached via a vertically moving joint). Specific software would be needed to gather these data.

The technique may be used to analyze filmed or videotaped material. In order to test the precision of the recordings, we tracked the same videotaped sequence of fish movements from a monitor screen several times; the resulting tracings were virtually identical (deviations less than 5%).

Accuracy and sensitivity appear to be essentially determined by the potentiometer used. The inexpensive unit used in our fish recordings (R2 in list of parts and prices) delivered position differences in the millimeter range (see Figure 3 and Listing 2). Before and after each test, we check (and if necessary, adjust) the proper alignment of the viewer with the centerline and endpoints of the observation area. This is easily done by reviewing target-position voltages on the computer's monitor screen.

Computerized video tracking systems are available that will automatically record the position of an animal in two or even three dimensions (Korver & Sprague, 1988; Videomex, Columbus Instruments, Columbus, OH). However, in addition to being expensive, these systems have several limitations. They cannot track individuals within groups, except under special conditions. They are restricted to monitoring animals in relatively simple, homogeneous environments. Our observer-driven system can be applied under variable lighting (including infrared); with heterogeneous substrates; when movement under as well as outside a shelter is to be monitored; or when other animals are present. Furthermore, the observer is able to note the occurrence of behavior that an automated system would not capture. We use a conveniently mounted microphone and tape deck for recording such observations. Any malfunctioning of the experimenter (e.g., accidental jiggling of the viewing device) or the apparatus (e.g., power failure) may also be documented in this way.

LISTING 2

Examples of Animal-Position Data Collected in 1-sec Intervals, Corresponding to Segments 1-4 in Figure 3

①			②			③			④		
300	.797	326 1.229	600	.871	626 1.03	300	1.326	326 1.069	600	.962	626 1.228
301	.789	327 1.204	601	.848	627 .966	301	1.303	327 1.071	601	.942	627 1.253
302	.786	328 1.186	602	.828	628 .934	302	1.328	328 1.126	602	.952	628 1.247
303	.785	329 1.181	603	.823	629 .914	303	1.316	329 1.157	603	1.021	629 1.234
304	.848	330 1.2	604	.822	630 .878	304	1.287	330 1.23	604	1.074	630 1.24
305	.881	331 1.201	605	.791	631 .864	305	1.291	331 1.272	605	1.168	631 1.218
306	.892	332 1.198	606	.802	632 .826	306	1.299	332 1.26	606	1.131	632 1.186
307	.896	333 1.2	607	.809	633 .797	307	1.305	333 1.298	607	1.159	633 1.209
308	.903	334 1.194	608	.823	634 .783	308	1.305	334 1.302	608	1.158	634 1.196
309	.938	335 1.196	609	.831	635 .767	309	1.31	335 1.298	609	1.197	635 1.226
310	.951	336 1.199	610	.83	636 .76	310	1.312	336 1.235	610	1.263	636 1.246
311	.977	336 1.199	611	.868	637 .758	311	1.312	337 1.266	611	1.282	637 1.25
312	.987	337 1.202	612	.942	638 .766	312	1.313	338 1.256	612	1.322	638 1.182
313	1.02	338 1.2	613	.993	639 .839	313	1.315	339 1.203	613	1.29	639 1.207
314	1.101	339 1.201	614	1.048	640 .854	314	1.314	340 1.207	614	1.276	640 1.213
315	1.182	340 1.2	615	1.11	641 .812	315	1.308	341 1.218	615	1.275	641 1.184
316	1.189	342 1.201	616	1.176	642 .808	316	1.26	342 1.242	616	1.274	642 1.185
317	1.237	343 1.195	617	1.238	643 .814	317	1.195	343 1.293	617	1.274	643 1.162
318	1.226	344 1.18	618	1.276	644 .899	318	1.058	344 1.288	618	1.267	644 1.161
319	1.186	345 1.176	619	1.287	645 1.012	319	1.035	345 1.297	619	1.269	645 1.152
320	1.257	346 1.134	620	1.259	646 1.066	320	1.047	346 1.292	620	1.267	646 1.153
321	1.291	347 1.109	621	1.237	647 1.077	321	1.017	347 1.33	621	1.269	647 1.076
322	1.287	348 1.083	622	1.221	648 1.109	322	.951	348 1.348	622	1.267	648 1.048
323	1.285	349 1.097	623	1.178	649 1.105	323	.897	349 1.326	623	1.267	649 1.04
324	1.276	350 1.096	624	1.113	650 1.104	324	.94	350 1.305	624	1.268	650 1.035
325	1.231		625	1.069		325	.967		625	1.267	

LISTING 3

Some Parameters and Statistics Derived from Data Points Plotted in Figure 3 (Top and Bottom Panels, Respectively)

TOTAL TIME ON LEFT SIDE	436
NO. OF LEFT SIDE TRIPS	21
PERCENT TIME ON LEFT	48.498331479
MEAN LEFT-SIDE TRIP TIME	20.285714286
MEAN DEPTH OF PENETRATION, LEFT	270.76190476
MEAN VELOCITY OUT LEFT/IN RIGHT	108.47619048
MEAN RATIO OUT:IN, LEFT	1.5169271594
MEAN TOT RATIO OUT:IN, LEFT	1.21875
MEAN VELOCITY ON LEFT SIDE	29.936619718
MEAN DISTANCE TRAVELLED LEFT	607.28571429

TOTAL TIME RIGHT SIDE	463
NO. OF RIGHT SIDE TRIPS	21
PERCENT TIME ON RIGHT	51.501668521
MEAN RIGHT-SIDE TRIP TIME	21.904761905
MEAN DEPTH OF PENETRATION, RIGHT	236.47619048
MEAN VELOCITY OUT RIGHT/IN LEFT	78.714285714
MEAN RATIO OUT:IN, RIGHT	1.4242494451
MEAN TOT RATIO OUT:IN, RIGHT	0.9574468085
MEAN VELOCITY ON RIGHT SIDE	30.819565217
MEAN DISTANCE TRAVELLED RIGHT	675.0952381

TOTAL TIME ON LEFT SIDE	693
NO. OF LEFT SIDE TRIPS	19
PERCENT TIME ON LEFT	77.085650723
MEAN LEFT-SIDE TRIP TIME	34.736842105
MEAN DEPTH OF PENETRATION, LEFT	228.31578947
MEAN VELOCITY OUT LEFT/IN RIGHT	69.263157895
MEAN RATIO OUT:IN, LEFT	2.4431563734
MEAN TOT RATIO OUT:IN, LEFT	2.0136986301
MEAN VELOCITY ON LEFT SIDE	20.659090909
MEAN DISTANCE TRAVELLED LEFT	717.63157895

TOTAL TIME RIGHT SIDE	206
NO. OF RIGHT SIDE TRIPS	20
PERCENT TIME ON RIGHT	22.914349277
MEAN RIGHT-SIDE TRIP TIME	10.3
MEAN DEPTH OF PENETRATION, RIGHT	156.05
MEAN VELOCITY OUT RIGHT/IN LEFT	83.95
MEAN RATIO OUT:IN, RIGHT	0.7268995405
MEAN TOT RATIO OUT:IN, RIGHT	0.5606060606
MEAN VELOCITY ON RIGHT SIDE	35.412621359
MEAN DISTANCE TRAVELLED RIGHT	364.75

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APPENDIX

Parts and Approximate Prices

1. Power Supply

F1	fuse, 1 A fast blow	\$.50
S1	switch, single-pole	\$ 2.50
NE-1	neon pilot lamp	\$ 4.00
T1	12.6 V transformer (Hammond 262 F12)	\$ 15.00
D1	1N 4005 diode (Motorola)	\$.80
D2	1N 4739A zener (Motorola)	\$.80
C1	1000 μ fd 25 VDC capacitor	\$ 3.00
R1	270 $\Omega \pm 10\%$ 1 W resistor	\$ 0.10

2. Viewer Potentiometer

R2	250 Ω 2 W linear potentiometer (Bourns)	\$ 4.50
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3. Attenuator

R3	25 k Ω 2 W linear potentiometer	\$ 4.50
R4	8.2 k Ω $\pm 10\%$ 1/2 W resistor	\$ 0.10
R5	820 Ω $\pm 10\%$ 1/2 W resistor	\$ 0.10
R6	100 Ω $\pm 10\%$ 1/2 W resistor	\$ 0.10
C2	100 μ fd 16 VDC capacitor	\$ 0.85
4. Analog-to-Digital Converter

WB-31	White Box (Omega Engineering)	\$400.00
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5. Strip chart recorder, microcomputer, and printer, from approximately \$250.00 each.

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