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**SAFETY STUDY OF OSHA'S EXPERIMENTAL
VARIANCE ON SELF-TRIPPING OF POWER PRESSES:
PHASE I - Volume 2**

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Gavriel Salvendy
Principal Investigator

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Program Manager - John Etherton

Principal Investigator:

Gavriel Salvendy, Professor
Chairman of Human Factors Program
School of Industrial Engineering
Purdue University

Co-Principal Investigators:

Moshe M. Barash, Professor
Joseph ElGomayel, Associate Professor
In charge of Michael Golden Labs
Both of School of Industrial Engineering
Purdue University

Faculty Associates:

Leslie A. Geddes, Showalter Distinguished Professor
Director of Biomedical Engineering, Purdue
Virgil L. Anderson, Professor of Statistics, Purdue

Technical Associate:

Randy Gardner, Electronics Specialist

Research Assistants:

All research assistants were from the School of
Industrial Engineering, Purdue. The first two
were also associated with the Human Factors Program.
Sogand Shodja; Joe Sharit; Byoung K. Choi

Appendix A. Fault Tree Analysis

A thorough Fault Tree Analysis was made for the Light-Curtain system, and the analysis procedure and the resulting fault trees are presented in this Appendix. Two types of safety are differentiated and analyzed separately. Assuming a single-stroke press operation, the press operator puts his/her hand into the dangerous area at every press cycle to change the workpiece. Here, we are interested in the probability of the press coming down while the operator is changing the workpiece. The probability of this event not happening is termed Self-Tripping Safety. It is also possible that the press operator or anyone else might (unintentionally) put his/her hand into the dangerous area during the down stroke of a press cycle, and in this case, the light-curtain unit is supposed to give a command signal to the press control unit to stop the press. The probability of stopping the press in this situation is defined as Guard Safety.

The Appendix consists of four sections. Section 1 describes the overall fault tree analysis procedure, and a press operation cycle analysis is made in the section that follows. Detailed analyses for the self-tripping safety and the guard safety are made in the last two sections.

1. Overall Fault Tree Analysis.

The light curtain system consists of the Optical Head, the Electronic Circuitry, the Control Unit, the Solenoid Air-Valve Unit, and the Brake/Clutch Unit of the press. For the analysis of the system safety, the overall light-curtain system is depicted as a functional block diagram in Fig.A-1. The first block (Optical Head) detects the interruption of the light-curtain, and the last block (Brake/Clutch

System) activates the brake to stop the press.

The Top Fault Event in the Light-Curtain System could be defined to be an event which allows the press to run when the light curtain is under obstruction. From the functional characteristics of the light-curtain system, a set of component fault events has been identified which will, jointly or individually, cause the top event to occur. The initial fault tree developed as such is shown in Fig.A-2.

There are eleven component fault events which are conceptually possible, but some of them were found to be infeasible or meaningless.

An explanation of the component fault events is given below:

1. False Light Input to the Photo-cells: Should the photo-cells receive light other than the one passing through the normal light path, the system may not detect the presence of an object in the guarded area.
2. Photo-Cells Produce Fault Output: If the photo-cells produce electrical output without light input, the system will not be able to detect the obstruction of the light.
3. Multi-Vibrator (block #2) Primary Failure: This fault event is defined as any failures in the Multi-Vibrator circuit which would cause a reduction of the scanning width. If the scanning width is reduced, the dangerous area of the press will not be fully guarded.
4. Pulse-Shaper (block #1) Primary Failure: The primary failure of the pulse-shaper is defined as any failure in the circuit which will cause the pulse-shaper to produce a normal-signal output for an obstruction signal input (output from Photo-cell P1).
5. Low Scanning Frequency: The scanning frequency is determined by the rotation speed of the Rotating Mirror Wheel. If the frequency becomes too low, say 20/sec (200/sec is normal), the system response time (i.e., stopping time) will be increased. This is a dangerous condition for the Guard-Safety.

6. Multi-Vibrator Secondary Failure: The secondary failure of the multi-vibrator is the fault condition in the circuit which causes the multi-vibrator to produce a zero-voltage DC output. If this fault event is not detected by the subsequent monitoring circuits (blocks #8, #10 and #12), the light-curtain system will lose its function.
7. Pulse-Shaper Secondary Failure: The event "the pulse-shaper produces a zero-voltage DC output" is defined to be the secondary failure of the pulse-shaper. As with the multi-vibrator, a monitoring circuit (blocks 5, 9 and 11) is provided to detect this failure.
8. Digital Logic Circuit Failure: The digital logic circuit contains two functionally identical circuits named A-Path and B-Path in Fig.A-1. Each path consists of an AND-gate, a rectifier, an amplifier and a relay control circuit. Normally, when the light-curtain is interrupted, the digital logic circuit receives an obstruction signal from the pulse-shaper (block #1) and then energizes B-Relay and de-energizes A-Relay. If the digital logic circuit de-energizes B-Relay and energizes A-Relay for an obstruction input, the press will run with the Light-curtain being interrupted.
9. Failures in Switch Contacts: A series of contact switches is connected serially to provide power to the solenoid air-valve. There are 15 switch contacts, and if they all fail short, an accident may occur.
10. Air-Valve Failure: A Parallel-Flow Double-Value Unit with LIFE GUARD Lockout (by ROSS Valve Co.) is used to activate/deactivate the brake/clutch unit. If both valves become "jammed" at the same time, we have a fault condition.
11. Brake System Failure: The brake system consists of a brake/clutch assembly and four limit switches (and a motion detector relay). Worn-out brake-linings or broken springs may cause the brake assembly to fail, while a limit-switch failure requires that the motion detector relay fails and the limit-switch chain is broken.

A thorough analysis of the system design showed that only the component fault events #6, #7, #8, #10, and #11 had a practically meaningful possibility. We chose not to elaborate on the eliminated fault events except giving brief explanations about the reason(s) why they were eliminated.

1. The physical arrangement of the Optical Head does not allow

any false light input.

2. All the photo-cells are photo-voltaic, which means that they cannot produce an output energy (voltage) without an input energy (light).
3. The fixed arrangement of the rotating mirror wheel and the auxiliary photo-cells P2 and P3 would not allow the scanning width to change.
4. The main photo-cell P1 produces an artificial obstruction signal at the end of each scanning cycle, and a real obstruction signal is produced when the light-curtain is interrupted. As far as the pulse-shaper is concerned, they are identical, and as a result, it is not possible for the circuit to selectively neglect the real obstruction signals only.
5. The scanning frequency is controlled by the electric motor in the Optical Head, and is monitored by the Resonance Amplifier circuit (block #8). The joint probability that "motor speed drops, say, to 10/sec from 30/sec during a press cycle" and "the monitoring function fails" was found to be practically negligible.
6. Simultaneous failures (fail short) in the serially connected contacts were found to have no practical likelihood.

Now, going back to the meaningful fault events, detailed fault trees have been developed. Fig.A-3 and Fig.A-4 show the fault trees for the secondary failures of the Multi-Vibrator (event #6) and the Pulse-Shaper (event #7), respectively. The fault tree for the Digital Logic Circuit (event #8) is shown in Fig.A-5. These three fault events are related to the Light-Curtain Unit itself, and the remaining two fault events (#10 & #11) are the responsibility of the press unit (with or without a light-curtain unit attached to it). A combined fault tree for the Air-Valve Failure and Brake System Failure is given in Fig.A-6.

The failures in the Air-Valve and Brake systems are of mechanical kind, while those in the Light-Curtain Unit are of electronic kind. Lack of data about the mechanical failures of the Air-Valve and Brake

systems prevented us from any quantitative analysis. Note, however, that the mechanical failures are not affected by the introduction of the Light-Curtain Unit.

The fault trees in Figures A-3, A-4, A-5, and A-6 are combined in the fault tree in Fig.A-7. Since the mechanical failures in the press unit (Air-Valve and Brake) are not to be evaluated quantitatively, an undeveloped event symbol (diamond) is used. Note also that the fault trees for the secondary failures (Fig.A-3 & A-4) have been simplified somewhat, because there are no unsafe failures in the Resonance Amplifier circuit and Check-Stage circuit (block #5 in Fig.A-1).

2. Analysis of Press Operation Cycle.

A press operation with self-tripping involves four elements; an operator, a light-curtain unit, an electrical control unit, and the press itself. If the press stops at each cycle, it is called a single-stroke mode. To initiate the next cycle, the "RUN-BUTTONS" have to be depressed. In self-tripping, however, a breakage of the light-curtain restarts the press. Fig. A-8 describes the operation cycle of the press in a single-break single-stroke mode.

At time t_0 , the light-curtain is cleared, and then, after a short time period the light-curtain unit goes to "green" (meaning ready), which will activate a series of relays to start the press at time t_1 . This time delay ($t_1 - t_0$) is mainly due to the response times of the relays involved and air valve actuation time and is termed Starting Delay (SD). For the Light-curtain system installed in Interlake Stamping Co., SD is about 60 msec.

The ram slide reaches the bottom at t_3 , and stops at the top at time t_5 . For the type of presses used in Interlake, both the Down Stroke ($DS = t_3 - t_1$) and the Up Stroke ($US = t_5 - t_3$) were estimated to be around 300 msec. It takes a while for a human hand to travel the safety distance (a distance between the light-curtain and the press die), and we call it the Reach Time (RT). RT is about 200 msec which must be slightly longer than the Stopping Time (ST). A stopping time is determined by measuring the time delay from the instant the light-curtain is interrupted to the moment when the ram slide is completely stopped ($ST = 200$ msec.). The control unit gives a self-test signal to the light-curtain unit right after t_3 , and at time t_4 , the control unit activates the brake to stop the press at the top.

Now, at time t_6 , the operator is ready for another press operation (during the part preparation time the operator puts aside the finished workpiece and picks up a new one), and the operator's hand gets to the press die at time t_7 . Then, at time t_8 , the operator's hand leaves the dangerous area. Once the light-curtain is cleared at time t_9 , the press begins the next operation cycle.

If, for some reason, the light-curtain is interrupted during the time interval (t_0, t_2), the press will stop during the down stroke. This is the guard function of the light-curtain system. The time period between t_0 and t_2 is called the Dangerous Period, and the length of the dangerous period in a press cycle may be calculated as follows;

$$\begin{aligned} \text{Dangerous Period} &= SD + DS - RT \text{ -----(A-1)} \\ &= 60 + 300 - 200 = 160 \text{ msec.} \end{aligned}$$

where;

SD = Starting Delay Length.

DS = Down Stroke Length.

RT = Reach Time.

Note in Fig.A-8 that a press operation cycle time is determined by the operation speed of the operator. That is:

$$\text{Cycle Time} = \text{PPT} + 2 \cdot \text{RT} + \text{PCT} \text{ ----- (A-2)}$$

where;

PPT = Part Preparation Time.

RT = Reach Time (200 msec).

PCT = Part Change Time.

Let's assume that PPT is 800msec and PCT is 300 msec, then the press cycle time will become 1.5 sec (or a production rate of 40 pieces per minute). The Reach Time (RT) is the ratio of the safety distance to the hand moving speed, and should be greater than the press stopping time.

63 inches/sec is the OSHA standard for hand speed and is the same as 1.6m/sec in Germany and Sweden. 2.5m/sec, however, is used in Sweden for small presses.

During the time interval (t_3, t_4) , the light-curtain unit receives a self-test signal from the control unit, which will de-energize a relay (D-Relay) in the light-curtain unit. The relay will be energized again only if the light-curtain is interrupted (in Fig. A-8 at time t_6). Note, however, that the interruption time (t_6) can be placed any time after t_2 . If the light-curtain is completely cleared at time t_9 , the press will start the next cycle. Assuming that the press has been successfully stopped at the top (this is the responsibility of the press unit) and that the light-curtain unit has received the self-test signal,

and then the light-curtain unit becomes "go green" while the operator is changing the workpiece, an accident may occur. To have an accident, this fault event must occur during the time interval (t_g, t_g-DS) . Let's call this time period the Self-Tripping Period which may be roughly equal to:

$$\text{Self-Tripping Period} = RT + PCT - DS \text{-----(A-3)}$$

where:

RT = Reach Time (200 msec).

PCT = Part Change Time.

DS = Down Stroke Time (300 msec).

3. Guard Safety

Since we are mainly concerned about the light-curtain failure, the fault tree in Fig.A-7 is reproduced in Fig.A-9 with the press unit failures being neglected. In the fault tree the following variables are defined;

X = Multi-Vibrator Secondary Failure.

Y = Pulse-Shaper Secondary Failure.

U = Amp-A(w.r.t. V4) or Relay-A Circuit Failure.

V = Amp-B(w.r.t. V2) or Relay-B Circuit Failure.

A = A-Path Failure.

B = B-Path Failure.

Here, we want to define the exact form of the TOP EVENT in the fault tree in Fig.A-9 with regard to the guard safety. For this purpose, additional variables are defined;

g = Length of the Dangerous Period to be guarded (see Eq. A-1).

T = Time of obstruction during the dangerous period.

Then, the TOP-EVENT (guard failure) becomes:

$$\text{TOP-EVENT (guard)} = E1 \cup E2 \cup E3 \text{ -----(A-4)}$$

$$E1 = (0 < X, U < T ; U < X+r ; 0 < T < g) ,$$

$$E2 = (0 < Y, B < T ; V < Y+r ; 0 < T < g) ,$$

$$E3 = (0 < A, B < T ; 0 < T < g) .$$

Where, r = relay response time (20 msec).

Note in Eq.A-4 that the events E1 and E2 have additional joint event terms because the monitoring functions (U & V) must fail before the secondary failures (X & Y).

4. Self-Tripping Safety.

If the self-testing function is working properly (this means that the relay-synchronization monitoring function is also working), the pair of component fault events in each AND-logic gate in Fig.A-9 must occur simultaneously in order to have the top fault event. The TOP-EVENT (self-tripping) in this case would become:

$$\text{TOP-EVENT (self-tripping)} = E1 \cup E2 \cup E3 \text{ -----(A-5)}$$

$$E1 = (0 < X, U < s ; |X-U| < r)$$

$$E2 = (0 < Y, V < s ; |Y-V| < r)$$

$$E3 = (0 < A, B < s ; |A-B| < r)$$

Where, r = relay response time (20 msec).

s = self-tripping period (Eq.A-3).

The self-test function will fail if "the self-test contact of ZCR-Relay fails short" or "the self-test relay, D-Relay, remains energized without power". If the self-test is unsuccessful, the press will

restart the next cycle by itself.

In the case of the 2CR-Relay failure, the TOP-EVENT (2CR self-test) becomes;

$$\text{TOP-EVENT (2CR self-test)} = E1 \cup E2 \cup E3 \text{ ----- (A-6)}$$

$$\begin{aligned} E1 &= (0 < X, U < p ; U < X + r) \\ E2 &= (0 < Y, V < p ; V < Y + r) \\ E3 &= (0 < A, B < p). \end{aligned}$$

Where, r = relay response time (20msec).
 p = part preparation time (see Fig.A-8).

If the self-test failure is due to the D-Relay failure (in this case, the A,B-Relay synchronization monitoring function may also fail), the TOP-EVENT (D self-test) would become;

$$\text{TOP-EVENT (D self-test)} = E1 \cup E2 \cup E3 \text{ ----- (A-7)}$$

$$\begin{aligned} E1 &= (0 < X, U < p) \\ E2 &= (0 < Y, V < p) \\ E3 &= (0 < A, B < p). \end{aligned}$$

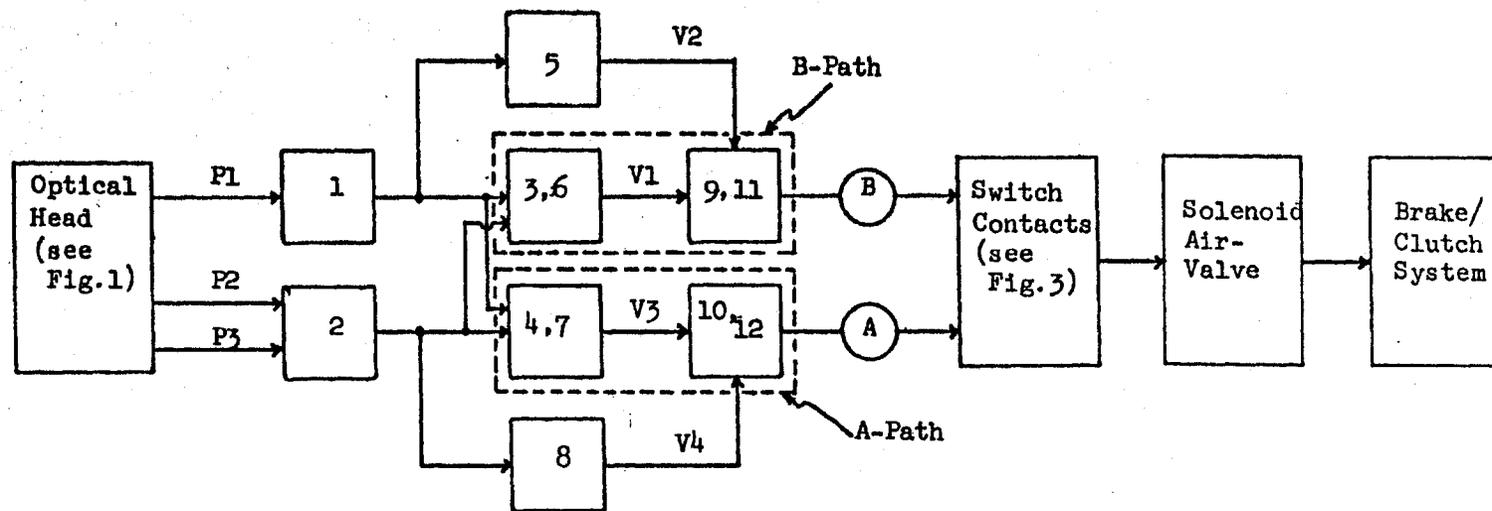
Where, p = part preparation time (Fig.A-8).

Observe that the event spaces in Equations A-6 and A-7 are larger than the actual ones. In other words, the unreliability values obtained will be an upper bound. A fault-tree representation of the self-tripping safety is given in Fig.A-10.

A summary of the variables and parameters (and their typical values) is given below;

X	= Multi-Vibrator Secondary Failure.
Y	= Pulse-Shaper Secondary Failure.
U	= Amp-A (w.r.t. V4) or Relay-B Circuit Failure.
V	= Amp-B (w.r.t. V2) or Relay-A Circuit Failure.
A	= A-Path Failure.
B	= B-Path Failure
T	= Time of Obstruction of the Light-Curtain during a Dangerous Period (to be guarded).
D	= Failure in D-Relay so that it remains energized

- without power.
- 2CR = The self-test contact of 2CR-Relay fail short.
- c = press operation cycle time (1.5 sec.).
- g = dangerous period in a press cycle requiring guard (.16 sec.).
- p = part preparation time (.80 sec.).
- s = self-tripping time in a press cycle (.20 sec.).
- r = relay response time (.02.).



(Blocks 1 thru 12 as defined in Fig.2 of the Reliability Main Report)

P1, P2, P3 : Outputs from the Photo-cells.

A, B : Relays.

A, B-Paths : Digital Logic Circuits consisting of
AND-Gate(3,4), Rectifier(6,7), Amplifier(9,10),
and Relay Switch(11,12).

Fig.A-1, Functional Block Diagram of the Light-Curtain System.

FIGURE C
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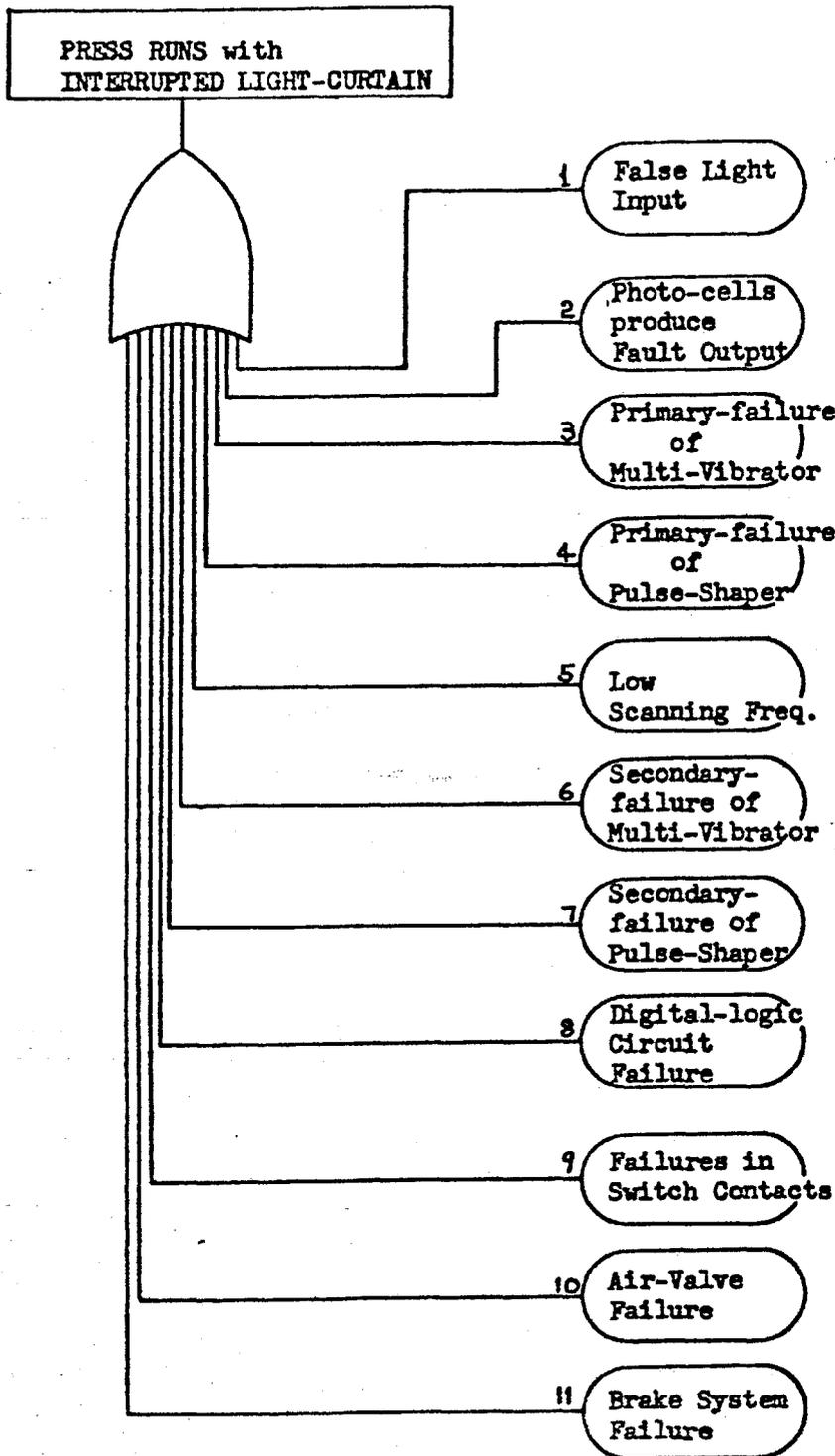


Fig.A-2, Initial Fault Tree for the Light-Curtain System.

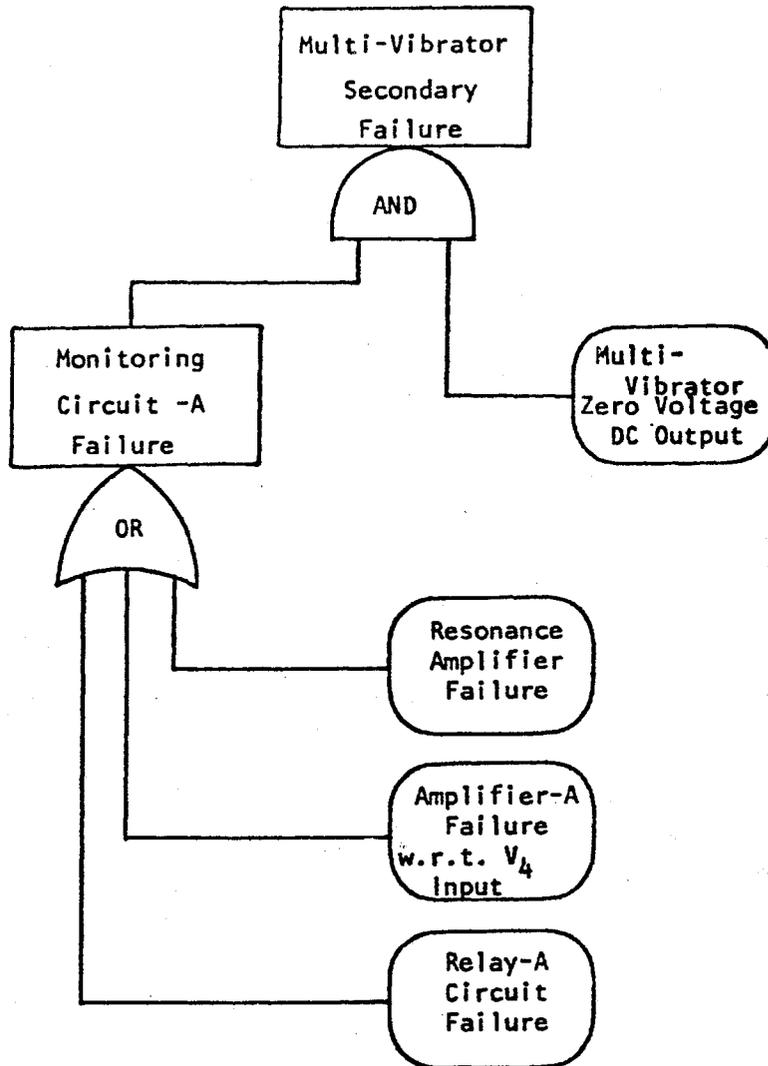


Figure A-3. Initial Fault Tree for Multi-Vibrator Secondary Failure.

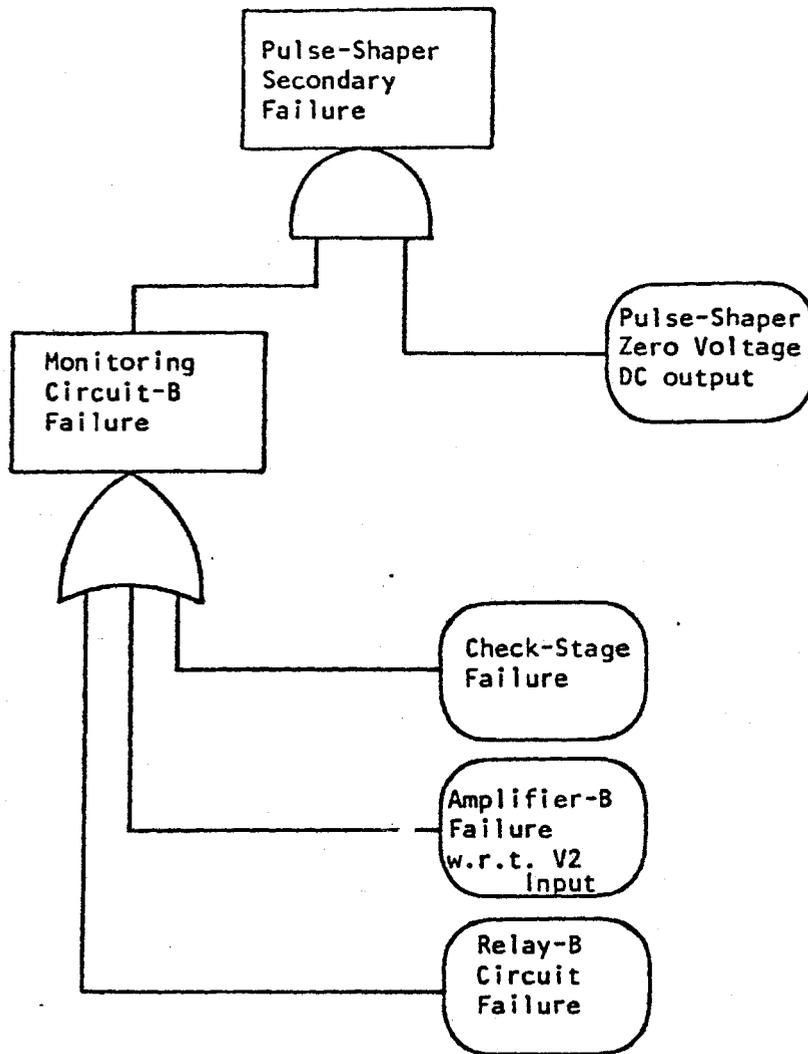


Fig. A-4, Initial Fault Tree for Pulse-Shaper Secondary Failure.

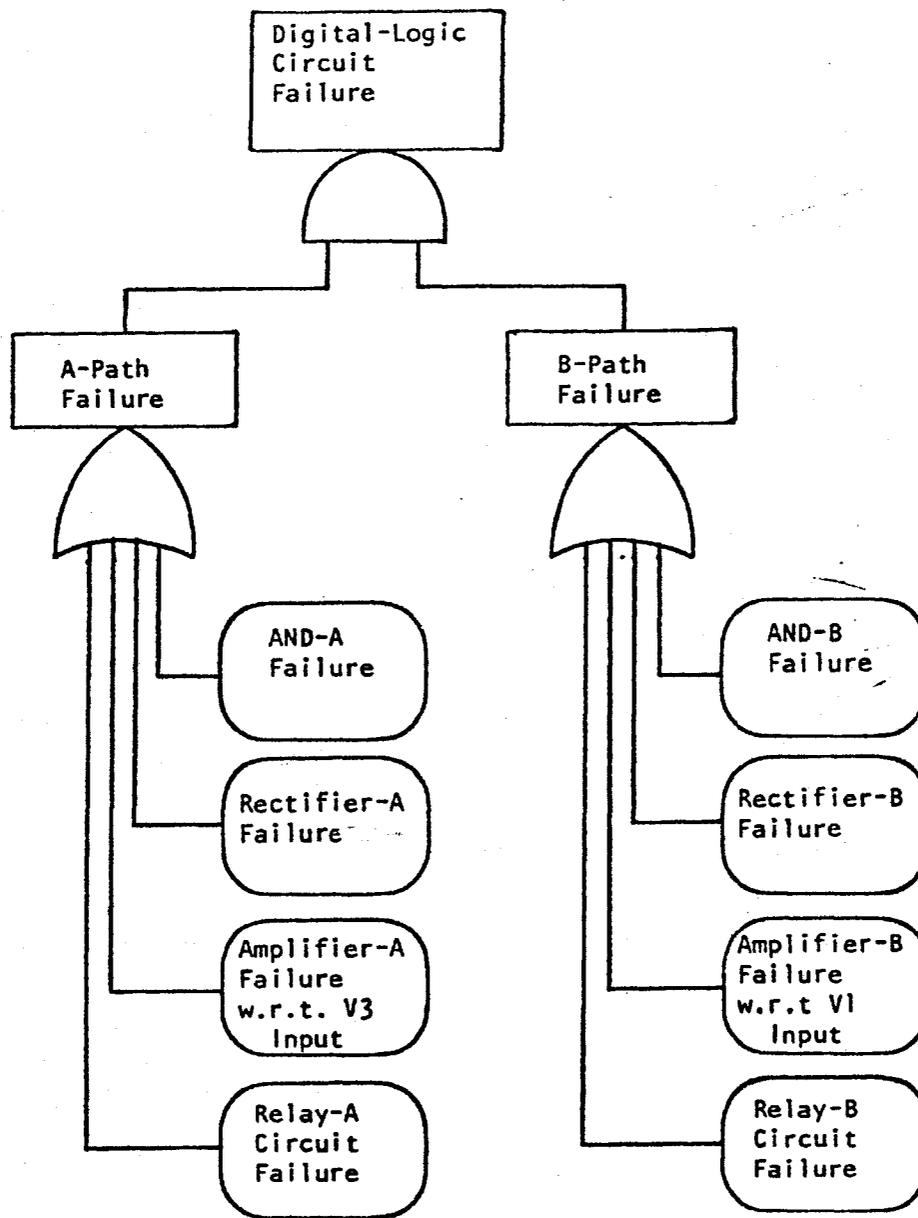


Fig. A-5, Fault Tree for Digital Logic Circuit Failure.

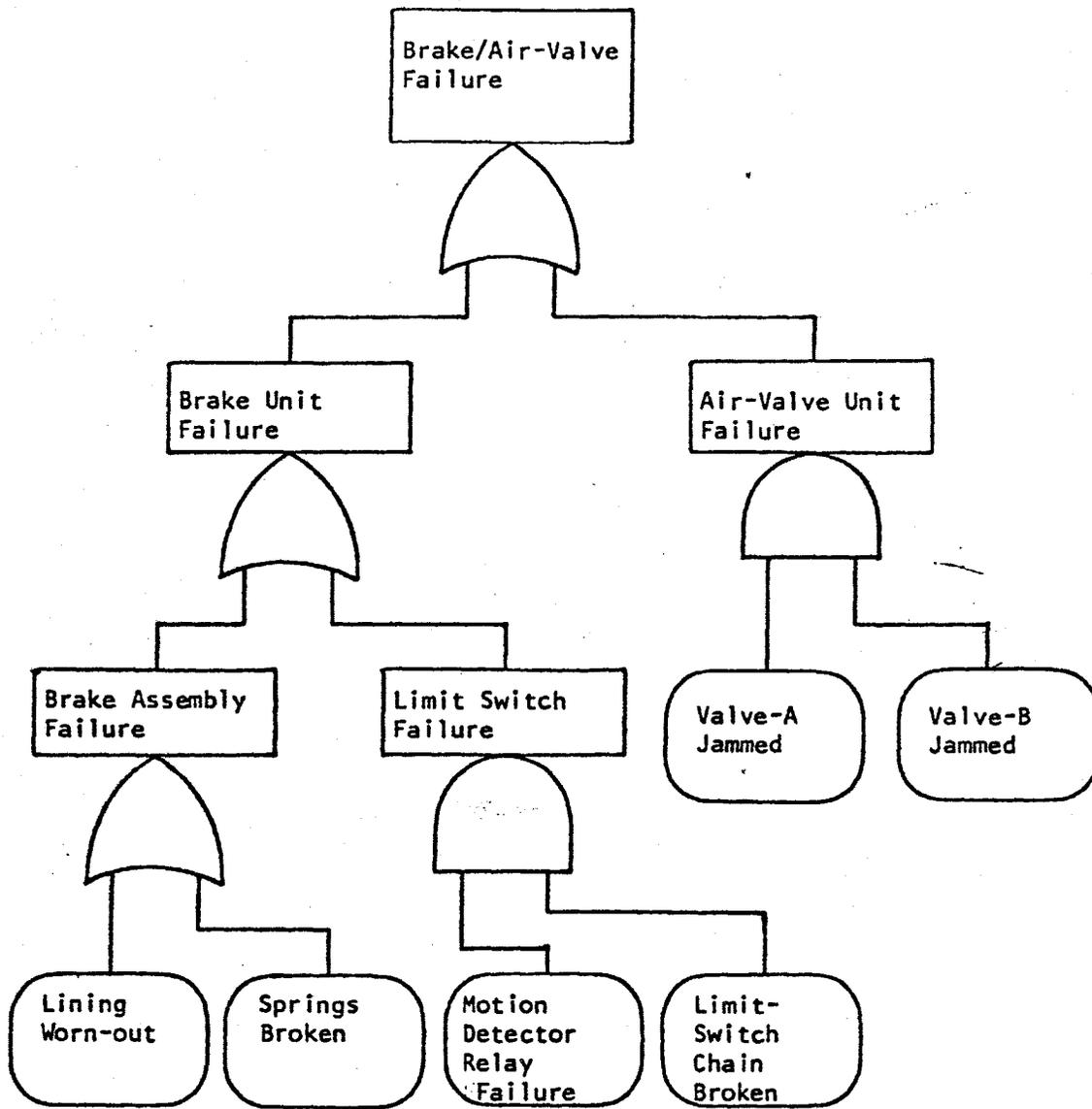


Fig. A-6, Fault Tree for Brake/Valve Failure.

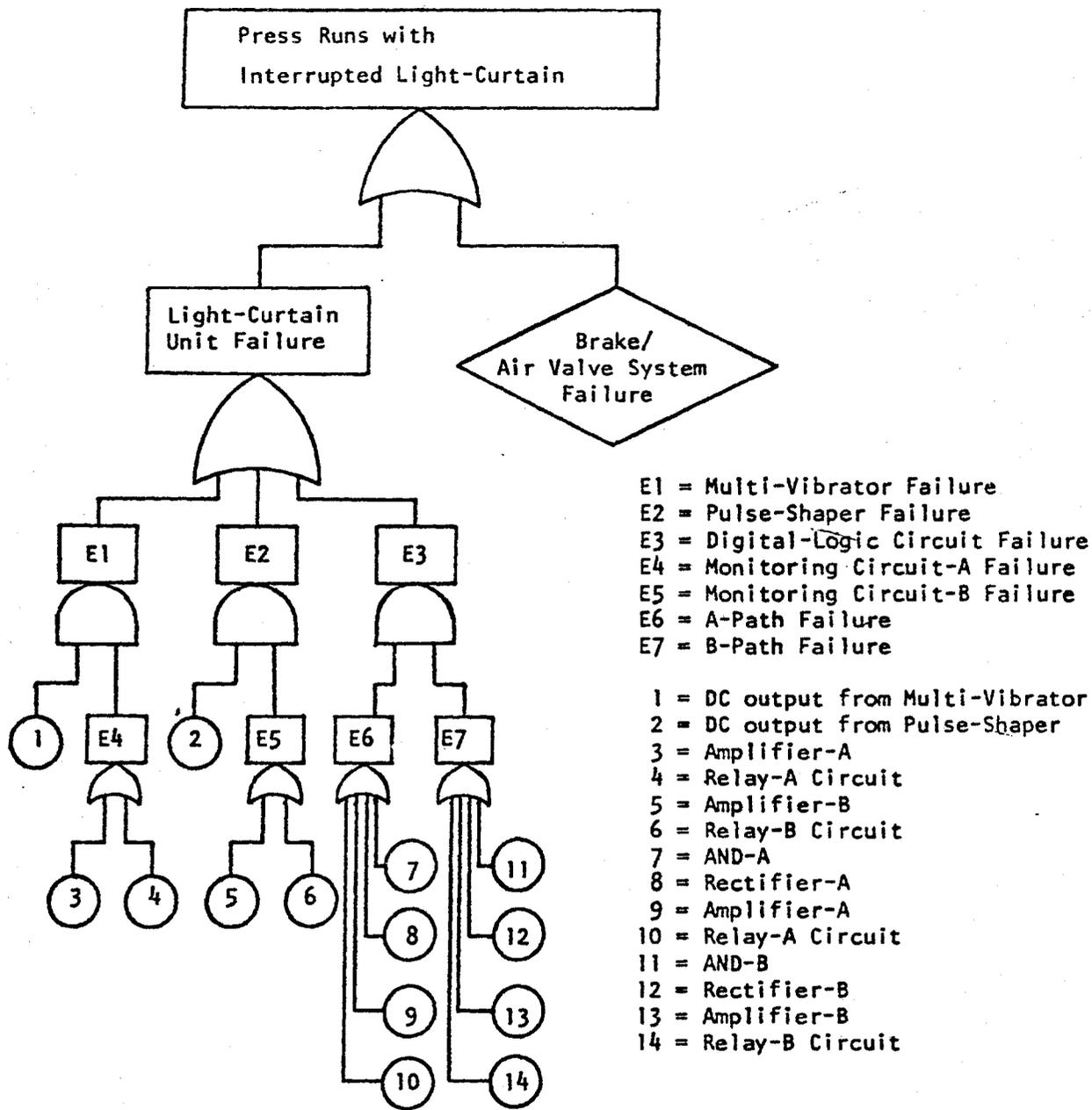
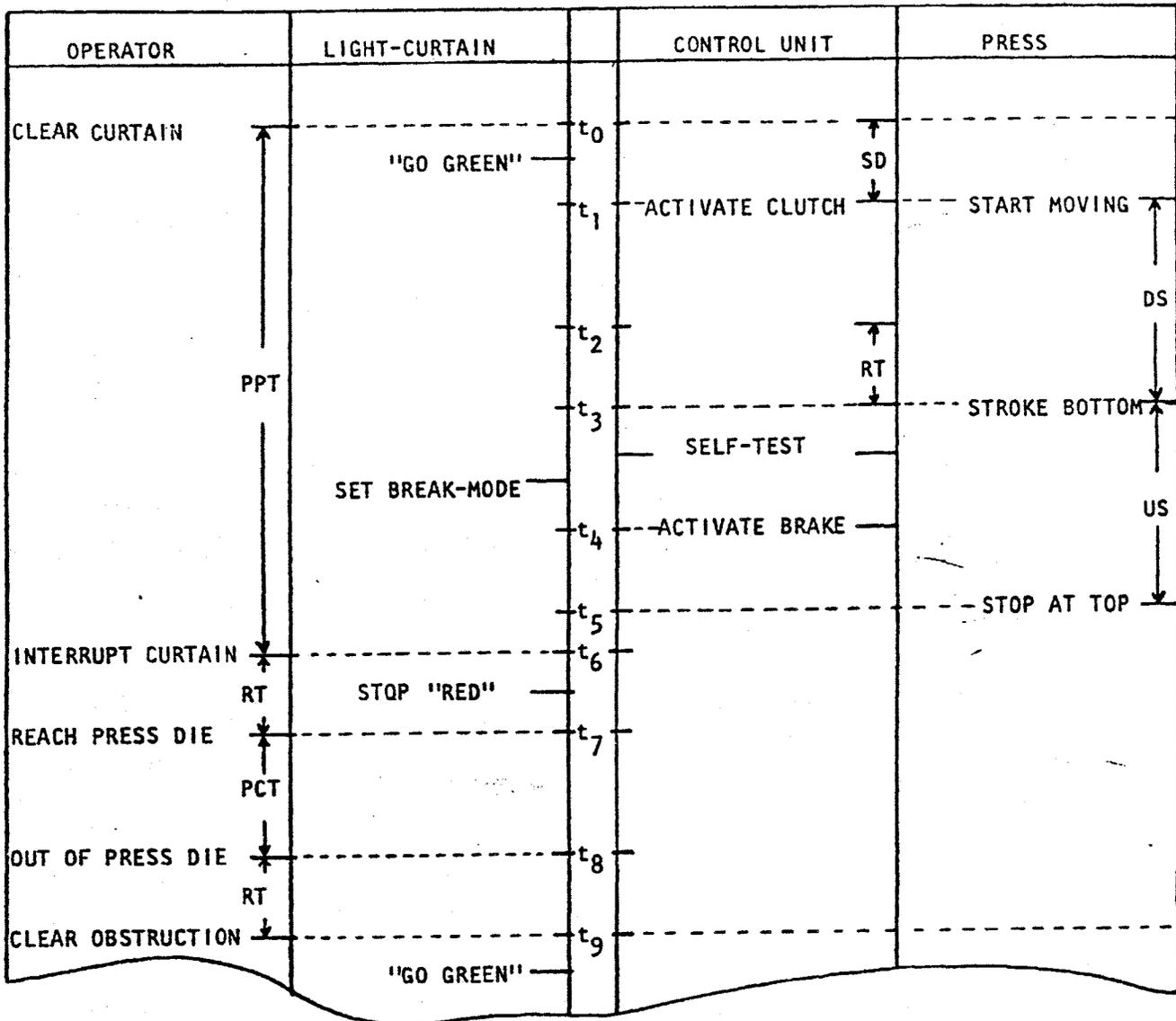
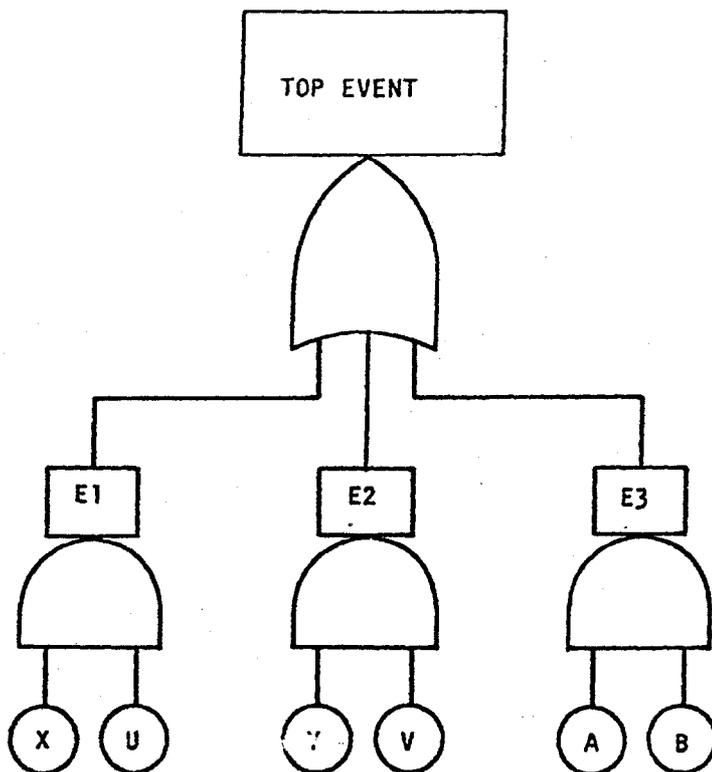


Figure A-7. Refined Fault Tree for Light-Curtain System



PPT = PART PREPARATION TIME
 PCT = PART CHANGE TIME
 RT = REACH TIME
 SD = STARTING DELAY
 DS = DOWN STROKE
 US = UP STROKE

Figure A-8. Operation Cycle in Single-Break Single-Stroke Mode.



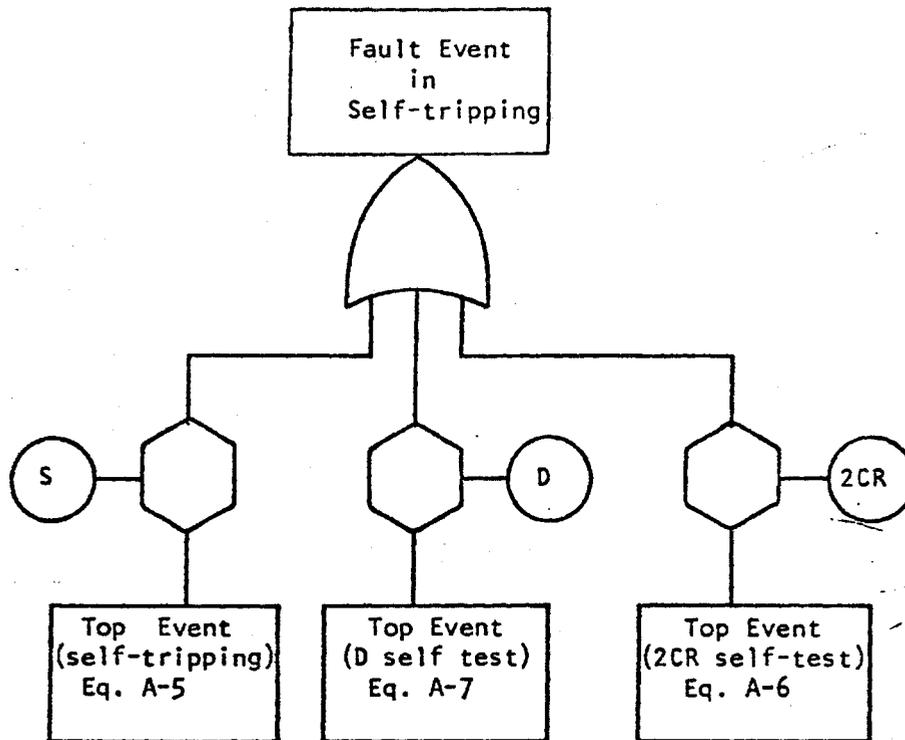
X = Multi-Vibrator

Y = Pulse-Shaper

U = Amp-A (with respect to V4) and Relay-A

V = Amp-B (with respect to V2) and Relay-B

Figure A-9. Fault Tree for Light Curtain Unit Failure



S = Self-test successful

D = D-Relay remains energized without Power to the Relay

2CR = The self-test contact switch fails short (2CR-Relay in Control Unit).

Figure A-10. Fault Tree for Self-Tripping Safety

APPENDIX B, FAILURE MODE ANALYSIS

The result of components failure mode analysis is presented in this Appendix. Section 1 describes basic failure modes of electronic components in the light-curtain unit, and different failure modes for the relays are separately described in Section 2. Section 3 gives the failure rate data for each functional block.

1. Electronic Component Failure.

A transistor can fail short or fail open. In our case, fail-short or fail-open of a transistor is defined as a short or open between the Collector and Emitter, and it is assumed that the chances of failure in either mode are equal. The chance of a diode fail-short is assumed to be equal to that of fail-open. A resistor failure is mostly due to a burn-out of the Carbon, and as a result, only the fail-open mode is considered. Similarly, only the fail-short mode is considered for the capacitor failure.

2. Relay Failure Modes.

As far as safety is concerned, four relays were found to be important. As discussed in Appendix A of this reliability report, the final output from the light-curtain unit is the state of Relay-A and Relay-B. Relay-D and Relay-ZCR are used as self-test relays. Relevant failure modes for these relays are as follows;

- RF1 : Relay remains energized after power is turned off.
- RF2 : Relay remains de-energized after power is turned on.
- RF3 : Relay suddenly de-energizes itself while power is on.
- RF4 : Relay suddenly energizes itself while power is off.
- RF5 : Only a specific contact becomes shorted and the rest of the relay operates normally.

Table B-1, Failure Rates of Electronic Components.

Component	Failure-rate	Individual Mode(%)	Individual Failure-rate
Transistor	0.615	open(50%) short(50%)	0.308 0.308
Diode	0.43	open(50%) short(50%)	0.215 0.215
Resistor	0.027	open(100%)	0.027
Capacitor	0.59	short(100%)	0.59

- c.f. 1. Source: MIL-HDBK-217C, the values are the same as those used in the Boeing Report (NIOSH CONT. 310-78-0124).
2. Failure rate per 10^6 hours.

If there is little possibility of contact welding, the failure modes RF1 and RF4 are highly unlikely (a probable cause for these types of failure could be due to the aging fatigue of the springs in the relay unit). Assuming a relay unit will be replaced before the fatigue failure of the springs, failure rates for these modes (RF1 and RF4) were not considered.

For RF2, RF3, and RF5, we assigned (to each of them) 1% of the total failure rate of the relay which is found to be 403.2 per 10^6 hours (Source; MIL-HDBK-217C, Inductive type 40% load; Environment condition GM; DPDT contact and 1 cycle/sec; 5-amp general purpose Armature type).

Thus, we have;

RF1 failure rate : not significant.
 RF2 failure rate : 4.03.
 RF3 failure rate : 4.03.
 RF4 failure rate : not significant.
 RF5 failure rate : 4.03.

The mode of "Relay-D self-test failure" is RF1, and "Relay-2CR self-test failure" corresponds to RF5. For the "self-tripping TOP-EVENT" (see Eq. A-5), RF4 is the failure mode of Relay-A and RF3 corresponds to the failure of Relay-B, and so on.

Table B-2, Relay Failure Modes and Rates.

Type of Top Fault Event	Relays	Mode of Failure	Failure Rate	Remarks
Guard	A	RF1	-	Eq. A-4 in Appendix A
	B	RF2	4.03	
Self-Tripping	A	RF4	-	Eq. A-5 in Appendix A
	B	RF3	4.03	
Self-Test	A	RF1	-	Eq. A-6, Eq. A-7, and Fig. A-10 in Appendix A
	B	RF2	4.03	
	D	RF1	-	
	2CR	RF5	4.03	

Summarized in Table B-2 are the failure modes and rates of the relays for different types of the top fault (i.e., accident conditions during the "guard", "self-tripping", and "self-test failure"). Note that the failure modes of the electronic components in the previous section were identical in all three types of the top fault event.

3. Block Failure Rates.

A functional block diagram of the light-curtain system is shown in Fig. B-1 (which is the same one as in the main report). For each functional block, a comprehensive failure mode analysis has been made as can be seen in the figures B-2 to B-10. Eventually, we want to find the probability of the top event in Fig. A-9 for both the Guard Safety and Self-Tripping Safety. In evaluating the fault conditions for a block,

only single component failures were considered.

Referring to Fig. B-1, the main command signal generated by the photo-cell P1 passes through the pulse-shaper (block #1), and is distributed to A-Path and B-Path. The signals denoted above the command-line represent "normal input" to the next block, and below the line are the "obstruction signals". Fault conditions for each block are as follows;

Fault Conditions For Each Block;

1. Pulse-Shaper : 0-voltage DC output regardless input condition.
2. Multi-Vibrator : 0-voltage DC output.
3. AND-B : Normal output V5 for obstruction input V7.
4. AND-A : " " V6 " " " V8.
5. Check-Stage : High-voltage output V2 for DC input V7.
6. Resonance-Amp: " " V4 " " " V8.
7. Rectifier-B : Normal output V1 for obstruction input V5.
8. Rectifier-A : " " V3 " " " V6.
9. Amp-B(w.r.t.V1) : Normal Vb for obstruction input V1.
Amp-B(w.r.t.V2) : Normal Vb for 0-voltage V2.
10. Amp-A(w.r.t.V3) : Normal Va for obstruction input V3.
Amp-A(w.r.t.V4) : Normal Va for 0-voltage V4.
11. Rel-B(excluding relay itself) : no power to relay for obstruction input Vb.
12. Rel-A(excluding relay itself) : power to relay for obstruction input Va.

Possible failure modes for the entire components in the circuit have been enumerated, and the components failures satisfying the above fault conditions were identified as listed in Table B-3. Other component failures not listed in the Table were found to be fail-safe. The failure modes for the Pulse-Shaper and the Multi-Vibrator were identified by examining the original circuit diagrams, Drawing no. 4-000-525 and 4-000-526.

To evaluate the probability of the top fault event defined in Appendix A, we need to find the failure rates related to the following

Table B-3, Block Failure Rate.

Block No.	Block Name	Component Failures	Failure Rate
1	Pulse-Shaper	T3-S, T101-S, T102-0 T104-S, R103-0, R104-0, R105-0.	4T + 3R
2.	Multi-Vibrator	T503-S, T504-0, T505-S (B-E), T506-S, D501-0, D502-0, R520, R526, C514, C107.	4T + 2D + 2R + 2C
3.	AND-B	R117.	R
4.	AND-A	R116.	R
5.	Check-Stage	none.	-
6.	Rectifier-B	T108-0, D109-0, C702.	T + D + C
7.	Rectifier-A	T107-0, D106-0, C602.	T + D + C
8.	Resonance-Amp	none.	-
9.	Amp-B (w.r.t.V1)	T702-0, T703-S, R701, R705, C701, C703.	2T + 2R + 2C
	Amp-B (w.r.t.V2)	T702-0, T703-S, R705, C701.	2T + R + C
10.	Amp-A (w.r.t.V3)	T601-0, T602-S, T603-0, R601, R605, R606, C603.	3T + 3R + C.
	Amp-b (w.r.t.V4)	T602-S, T603-C, R605, R606.	2T + 2R
11.	Relay-B	T704-0, R707.	T + R
12.	Relay-A	T604-S.	T

C.F., 1. T : transistor failure rate(0.308)
D : diode failure rate(0.215)
R : resistor failure rate(0.027)
C : capacitor failure rate(0.59).

2. Relay-A and Relay-B blocks do not include the failures in the relay units.

variables;

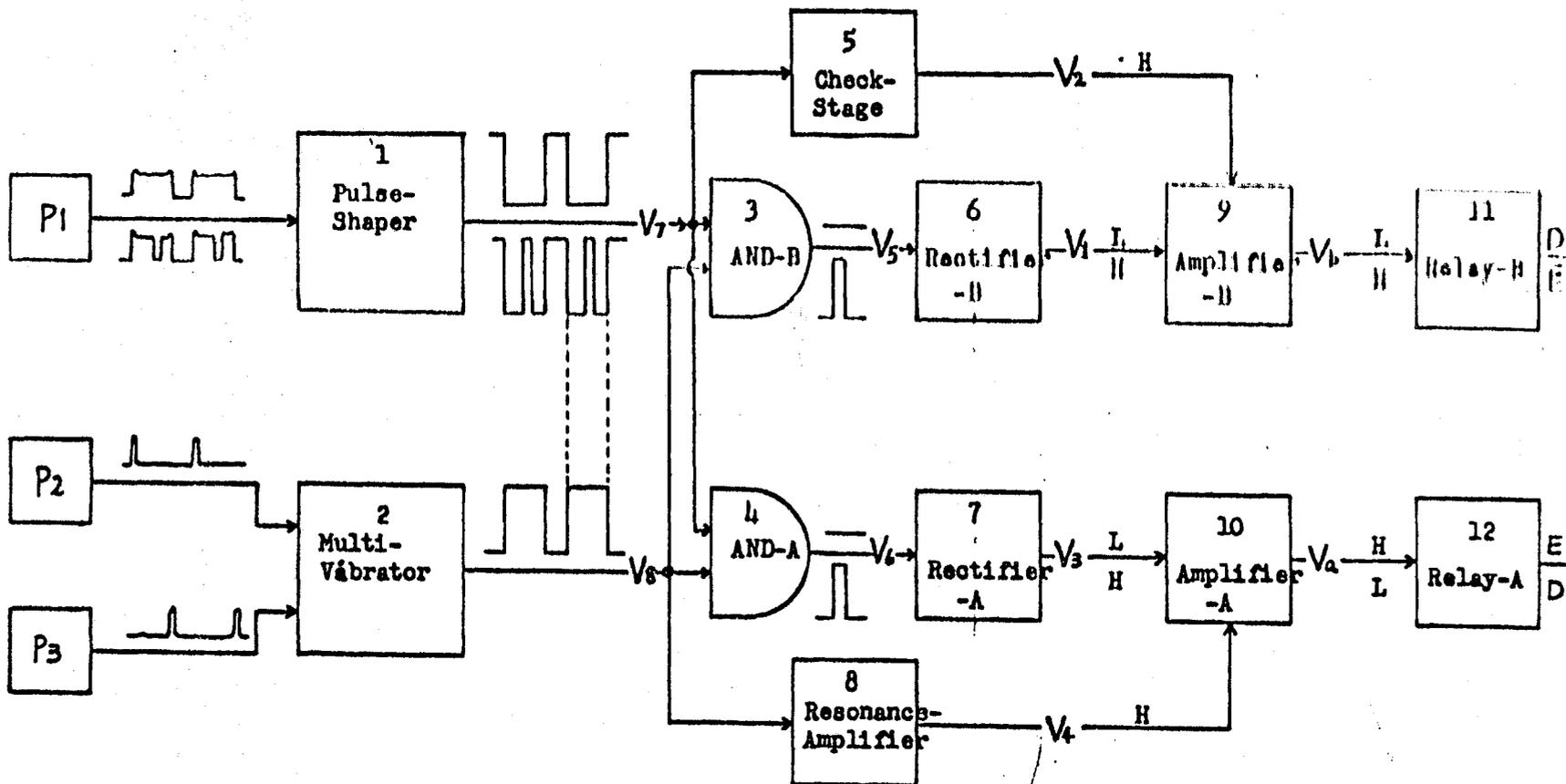
X : Multi-Vibrator Failure,
 Y : Pulse-Shaper Failure,
 U : Amp-A(w.r.t.V4) or Relay-A Failure,
 V : Amp-B(w.r.t.V2) or Relay-B Failure,
 A : A-Path(AND-A, Rect-A, Amp-A, or Rel-A) Failure,
 B : B-Path(AND-B, Rect-B, Amp-B, or Rel-B) Failure,
 D(self-test) : Relay-D self-test function failure,
 ZCR(self-test) : Relay-ZCR self-test function failure.

From the results obtained in Table B-2 and Table B-3, it is straightforward to find the necessary failure rates, and the final results are summarized in Table B-4.

Table B-4, Failure Rate for the Base Fault Events.

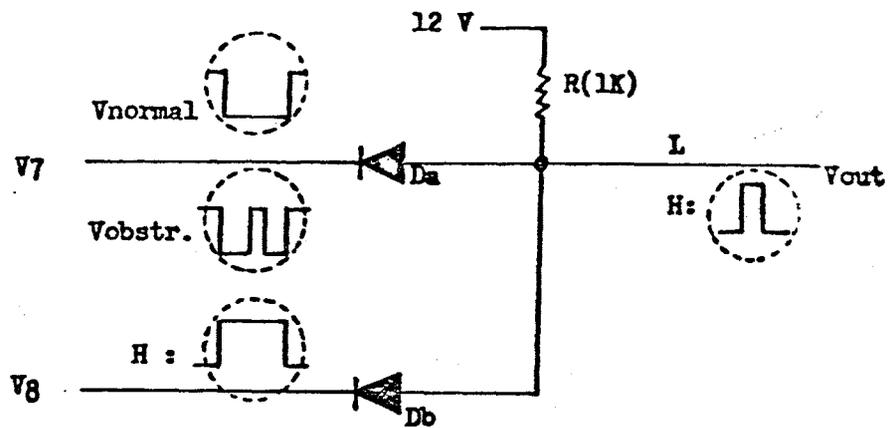
Variable related to the Fault Event	Electronic Components Failures	Failure Rate
X : Multi-Vibrator	$4T + 2D + 2R + 2C$	2.90
Y : Pulse-Shaper	$4T + 3R$	1.31
U : Amp-A, Rel-A	$3T + 2R + RFa^*$	0.98
V : Amp-B, Rel-B	$3T + 2R + C + RFb$	5.60
A : A-Path	$3T + D + 2R + 2C + RFa$	2.37
B : B-Path	$2T + D + 3R + 2C + RFb$	6.12
DR : Relay-D self-test	RF1	-
ZCR: Relay-ZCR self-test	RF5	4.03

C.F.(*) ; 1. RFa becomes RF1 for "Guard" and "Self-test", RF4 for "Self-tripping" (but the failure rate is neglected).
 2. RFb equals RF2 for "Guard" and "Self-test", RF3 for "Self-tripping"(in all cases, the rate is 4.03).



H : high voltage; L : low voltage;
 E : relay energized; D : relay de-energized.
 P1,P2,P3 ; photo-cells.

Fig. B-1, ELECTRONIC PRINCIPLE OF THE LIGHT CURTAIN.



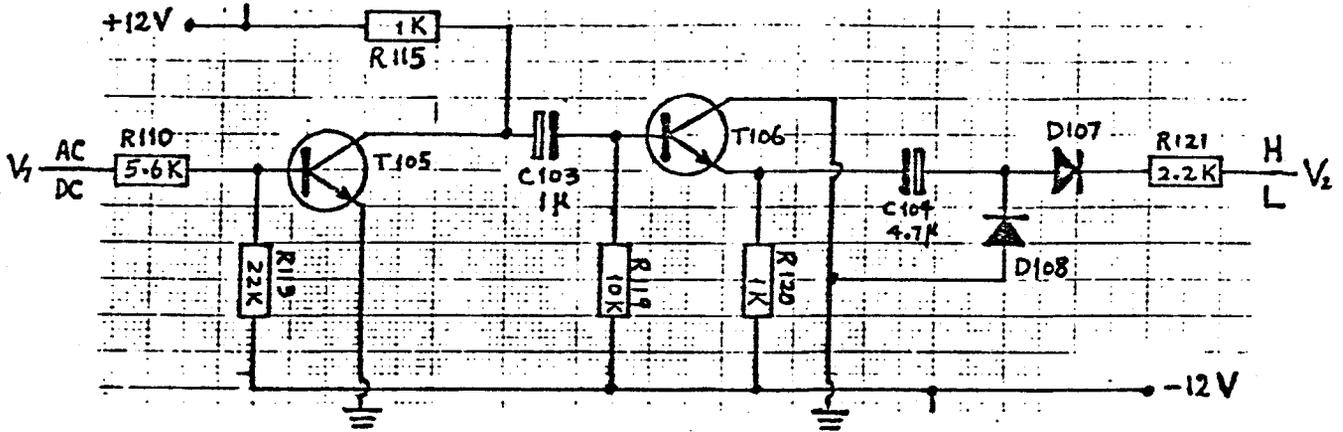
No.	Failure Mode	Output (V-out)		Fault Type
		V7: Obstruct.	Normal	
0	no failure	H	L	-
1	Da open	H	H	safe
2	Da short	H	L	long-term effect (overshoot)
3	Db open	H	H	safe
4	Db short	H	L	long-term effect
5	R open	L	L	unsafe

Fig. B-2, Passive AND-Gate (blocks 3 and 4).

a) R = R117, Da = D101, Db = D104 for AND-B.

b) R = R116, Da = D102, Db = D105 for AND-A.

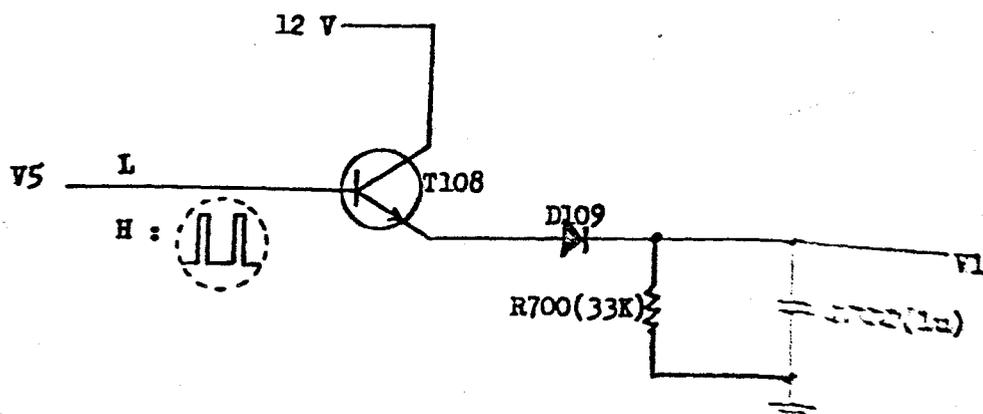
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No.	Failure Mode	Output (V2)		Fault Type
		V7: DC	AC	
0	no failure	L	H	-
1		There is no fault event. That is, it is not possible to get V2 = H, for a DC input, due to a component failure.		

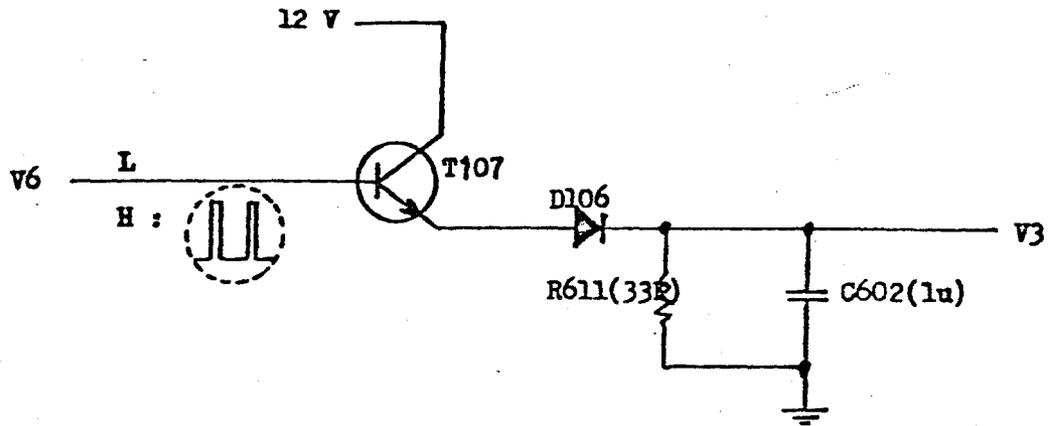
Fig. B-3, Check-Stage (block 5)

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No.	Failure Mode	Output (V1)		Fault Type
		V5: H	L	
0	no failure	H	L	-
1	T108 open	L	L	unsafe
2	T108 short	H	H	safe
3	D109 open	L	L	unsafe
4	D109 short	H	L	long-term effect
5	R700 open	H	L	long-term effect
6	C702 short	L	L	unsafe

Fig. B-4, Rectifier-B (block 6)



No.	Failure Mode	Output (V3)		Fault Type
		V6: H	L	
0	no failure	H	L	-
1	T107 open	L	L	unsafe
2	T107 short	H	H	safe
3	D106 open	L	L	unsafe
4	D106 short	H	L	long-term effect
5	R611 open	H	L	long-term effect
6	C602 short	L	L	unsafe

Fig. B-5, Rectifier-A (block 7).

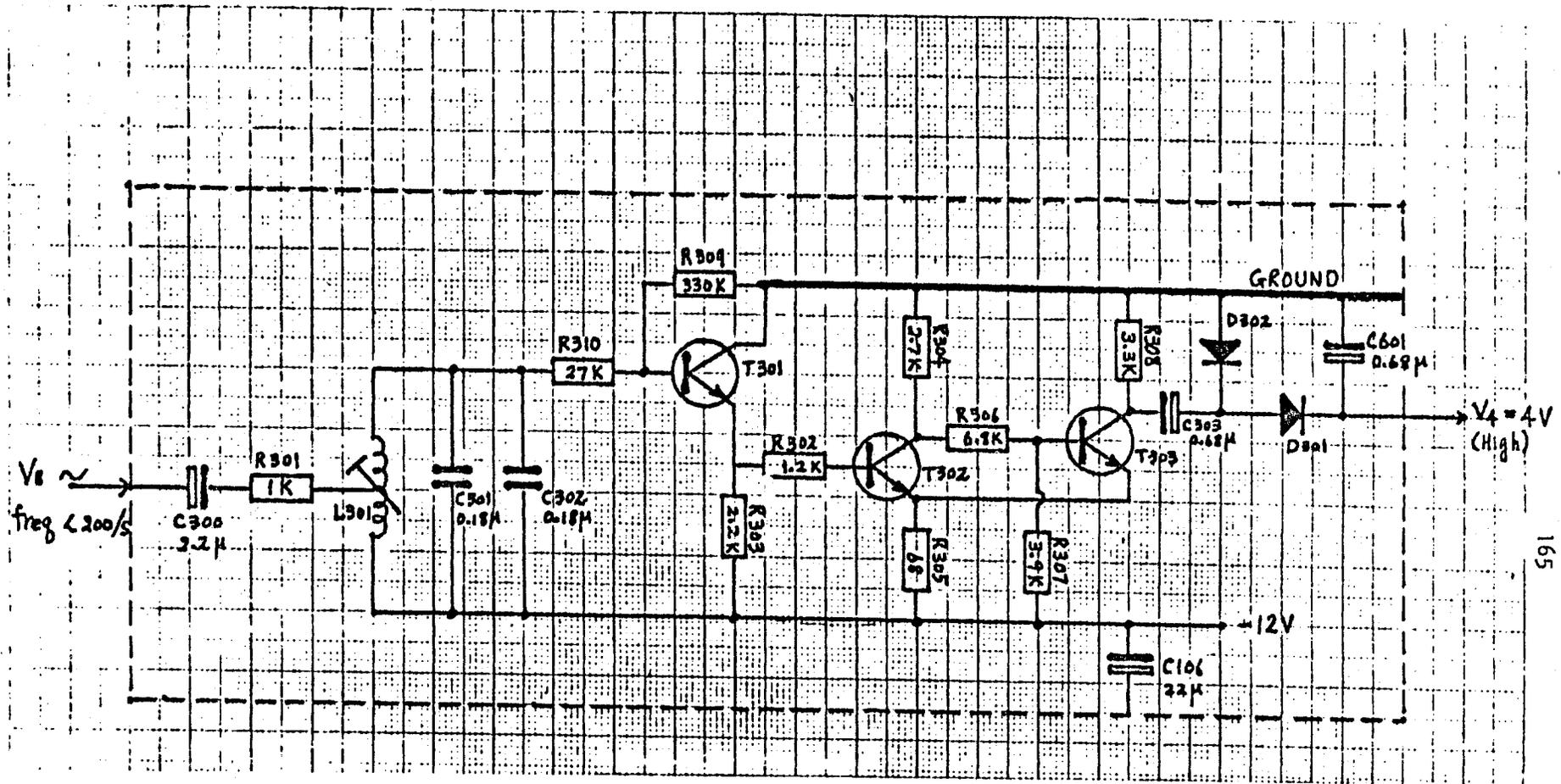
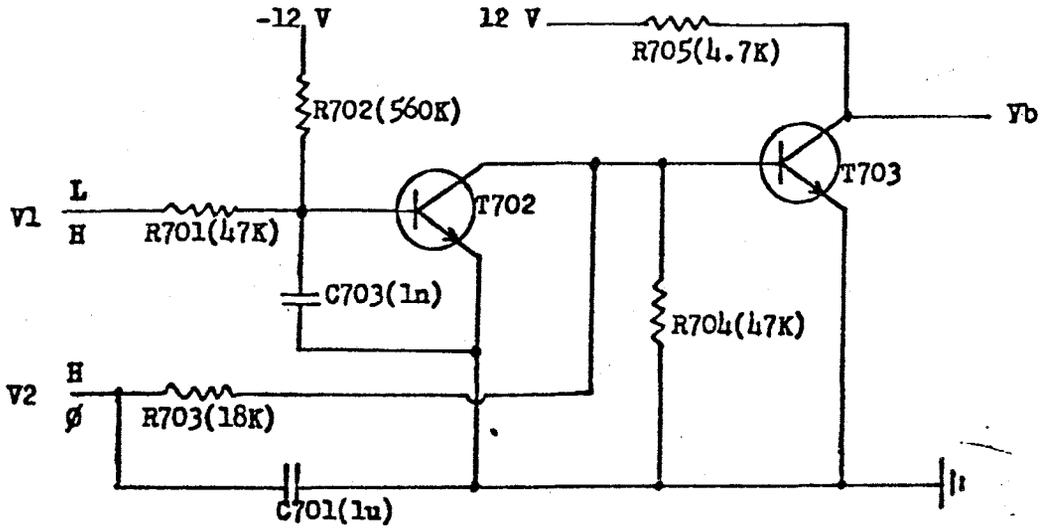


Fig. B-6, Resonance Amplifier Circuit (Block #8).

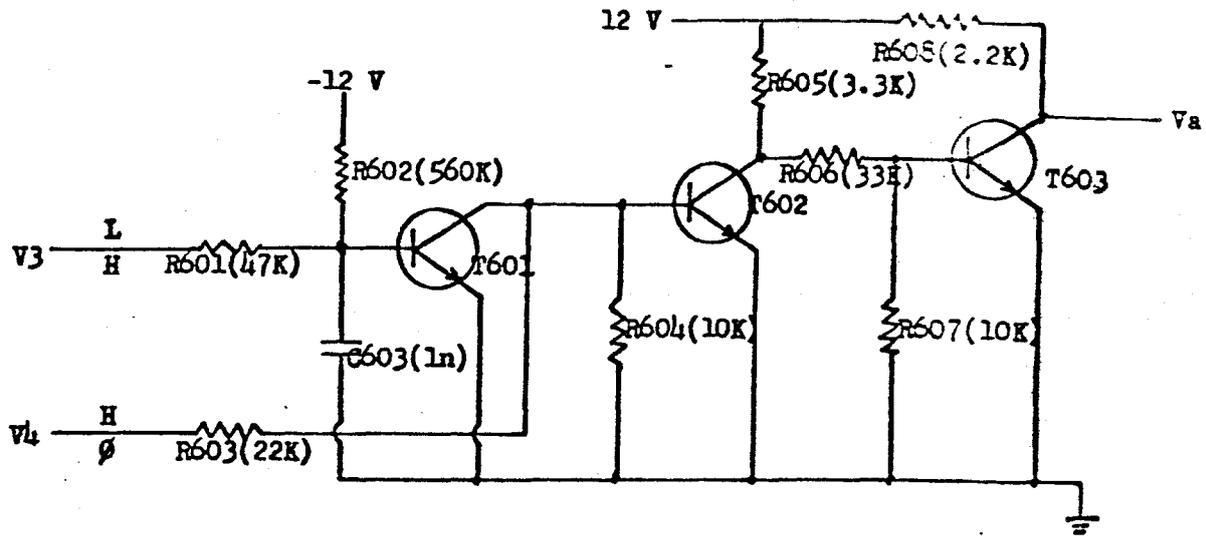
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Fault Condition for this circuit is any component failure which will cause the circuit to produce a high-voltage (V_4) for a low-frequency input (or DC input). There is, however, no meaningful fault events in the circuit.



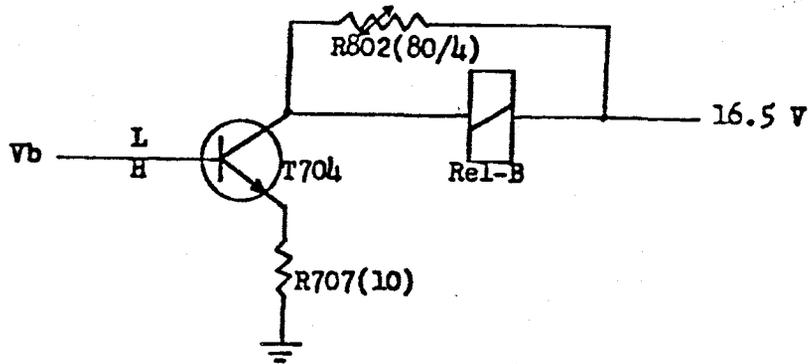
No.	Failure Mode	Output: (Vb)				Fault Type
		V1/V2: H/H	H/O	L/H	L/O	
0	no failure	H	H	L	H	-
1	T703 open	H	H	L	L	safe
2	T703 short	L	L	L	L	unsafe
3	T702 open	L	L	L	L	unsafe
4	R705 open	L	L	L	L	unsafe
5	R704 open	H	H	L	H	safe
6	R703 open	H	H	H	H	safe
7	R702 open	H	H	L	H	safe
8	R701 open	L	H	L	H	unsafe (w.r.t. V1 only)
9	C703 short	L	H	L	H	unsafe (w.r.t. V1 only)
10	C701 short	L	L	L	L	unsafe
11	T702 short	H	H	H	H	safe

Figure B-7. Amplifier - B (block 9)



No.	Failure Mode	Output (Va)				Fault Type
		V3/V4: H/H	H/O	L/H	L/O	
0	no failure	L	L	H	L	-
1	T603 open	H	H	H	H	unsafe
2	T603 short	L	L	L	L	safe
3	T602 open	L	L	L	L	safe
4	T602 short	H	H	H	H	unsafe
5	T601 open	H	L	H	L	unsafe (w.r.t. V3 only)
6	T601 short	L	L	L	L	safe
7	R608 open	L	L	L	L	safe
8	R607 open	L	L	H	L	safe
9	R606 open	H	H	H	H	unsafe
10	R605 open	H	H	H	H	unsafe
11	R604 open	L	L	H	L	safe
12	R603 open	L	L	L	L	safe
13	R602 open	L	L	H	L	safe
14	R601 open	H	L	H	L	unsafe (w.r.t. V3 only)
15	C603 short	H	L	H	L	unsafe (w.r.t. V3 only)

Figure B-8. Amplifier - A (block 10)

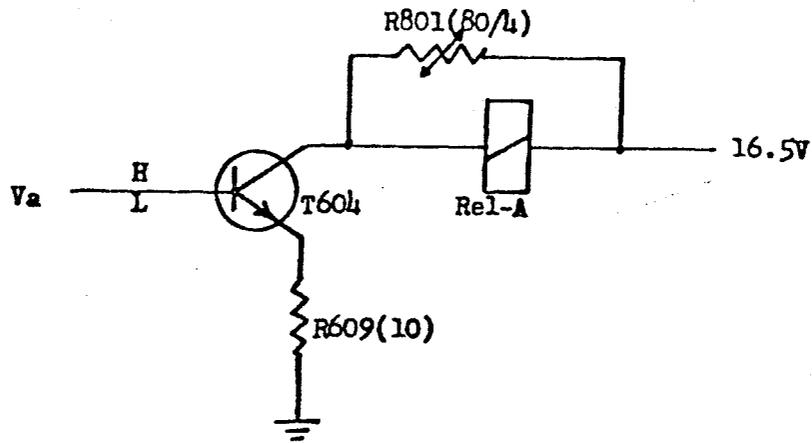


No.	Failure Mode	Output (Rel-B)		Fault Type
		Vb: H	L	
0	no failure	Energize	De-energ.	-
1	T704 open	D	D	unsafe
2	T704 short	E	E	safe
3	R707 open	D	D	unsafe
4	R802 open	E	D	long-term effect

* Relay itself failure is not included.

Figure B-9. Relay - B Circuit (block 11)

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No.	Failure Mode	Output (rel-A)		Type of Fault
		Va:L	H	
0	no failure	De-energize	Energize	-
1	T604 open	D	D	safe
2	T604 short	E	E	unsafe
3	R609 open	D	D	safe
4	R801 open	D	E	effect on other parts

Figure B-10. Relay - A Circuit (block 12)

APPENDIX C, RELIABILITY FORMULAE AND PROBABILITIES

In this Appendix, actual probability values for the "Self-Tripping Safety" and "Guard Safety" are calculated, based on the results obtained in Appendix A and Appendix B. Some of the variables and parameters defined earlier are re-introduced here;

c : press cycle length.
 g : length of the dangerous period to be guarded.
 s : self-tripping period length.
 p : length of a part-preparation period.
 r : relay response time length.

A : A-Path Failure (with rate a).
 B : B-Path Failure (with rate b).
 X : Multi-Vibrator Failure (with rate x).
 Y : Pulse-Shaper Failure (with rate y).
 U : Amp-A or Rel-A Failure (with rate u).
 V : Amp-B or Rel-B Failure (with rate v).
 ZCR: ZCR Relay Failure (with rate 4.03).
 T : Time of obstruction.

1. Self-Tripping Safety.

As discussed in Appendix A, there are three cases in which an accident may occur during the self-tripping period due to the light-curtain unit failure. For each case, we want to find the probability of a (possible) accident in a single press cycle. The three cases are;

- (1) Successful self-test.
- (2) Unsuccessful self-test due to Relay-2CR failure.
- (3) Unsuccessful self-test due to Relay-D failure.

In Appendix B, however, the type of failure in Relay-D was found to be insignificant. As a result, we have only two cases to consider. When the self-test has been successful, the accident probability can be calculated by finding the probability for the top fault-event defined in Eq. A-5 in Appendix A. For an unsuccessful self-test, Eq. A-6 is used.

Probability of Accident with Successful Self-test (PASS)

$$\begin{aligned} \text{PASS} &= \text{Pr}(E1 \cup E2 \cup E3) \\ &= \text{Pr}(E1) + \text{Pr}(E2) + \text{Pr}(E3) \end{aligned}$$

$$\begin{aligned}
&= \Pr[0 < X, U < s ; |X-U| < r] + \Pr[0 < Y, V < s ; |Y-V| < r] + \\
&\quad \Pr[0 < A, B < s ; |A-B| < r] \\
&= H1(s, r, x, u) + H1(s, r, y, v) + H1(s, r, a, b) \text{ ----- (C-1)}.
\end{aligned}$$

Where, $H1(.)$: Formula 1 (in Section 3).

Probability of Accident with Unsuccessful Self-test (PAUS)

$$\begin{aligned}
\text{PAUS} &= \Pr(E1) + \Pr(E2) + \Pr(E3) \\
&= \Pr[0 < X, U < p ; U < X+r] + \Pr[0 < Y, V < p ; V < Y+r] + \\
&\quad \Pr[0 < A, B < p] \\
&= H2(p, r, x, u) + H2(p, r, y, v) + H3(p, a, b) \text{ ----- (C-2)}.
\end{aligned}$$

Where, $H2(.)$, $H3(.)$: Formulae 2 and 3, respectively.

Probability of Self-test Failure (PSF) due to Relay-2CR

$$\begin{aligned}
\text{PSF} &= \Pr(2\text{CR} < c) \\
&= 4.03 \times 10^{-6} x_c \text{ ----- (C-3)}.
\end{aligned}$$

Thus, the probability of the self-tripping accident in a press cycle becomes;

$$\Pr(\text{self-tripping accident}) = \text{PASS} + \text{PSF} * \text{PAUS} \text{ ----- (C-4)}.$$

Note that the probability in Eq. (C-4) is an upper bound.

2. Guard Safety

Here, we are interested in the probability that, when the light-curtain is interrupted during the dangerous period, the press will not stop due to the failure (or fault event) of the light-curtain unit. The top fault event is as defined in Eq. A-4 in Appendix A. Given that the light-curtain is interrupted during the dangerous period, the probability can be calculated as follows;

Probability of Guard Malfunction (PGM)

$$\begin{aligned}
 \text{PGM} &= \text{Pr}(E1) + \text{Pr}(E2) + \text{Pr}(E3) \\
 &= \text{Pr}(0 < X, U < T ; U < X+r ; 0 < T < g) \\
 &+ \text{Pr}(0 < Y, V < T ; V < Y+r ; 0 < T < g) \\
 &+ \text{Pr}(0 < A, B < T ; 0 < T < g) \\
 &= G1(g, r, x, u) + G1(g, r, y, v) + G2(g, a, b) \text{ ----- (C-5)}.
 \end{aligned}$$

Where, $G1(\cdot)$ and $G2(\cdot)$: formulae 4 and 5, respectively.

3. Probability Formulae

In the formulae below, X and Y are exponential random variables with parameters λ and μ respectively, and T is uniformly distributed between 0 and t . d is a small real number relative to t .

FORMULA 1

$$H1(t, d, \lambda, \mu) \equiv \Pr[0 < X, Y < t; |X - Y| < d]$$

$$\doteq (\lambda^2 + \mu^2 - \lambda^2 e^{-\mu d} - \mu^2 e^{-\lambda d}) (1 - e^{-(\lambda + \mu)t}) / (\lambda + \mu)^2$$

Derivation;

$$\Pr[0 < X, Y < T; |X - Y| < d]$$

$$= P(X > Y) \cdot P(0 < X, Y < t; Y < X + d) + P(X < Y) \cdot P(0 < X, Y < t; X < Y + d)$$

$$\doteq P(X > Y) \cdot P(Y < X + d; X < t) + P(X < Y) \cdot P(X < Y + d; 0 < X < t)$$

$$= \frac{\mu}{\lambda + \mu} \int_0^t (F_x(y+d) - F_x(y)) \cdot f_y(y) dy + \frac{\lambda}{\lambda + \mu} \int_0^t (F_y(x+d) - F_y(x)) \cdot f_x(x) dx$$

$$= \frac{\mu}{\lambda + \mu} \int_0^t (e^{-\lambda y} - e^{-\lambda(y+d)}) \cdot \mu e^{-\mu y} dy + \frac{\lambda}{\lambda + \mu} \int_0^t (e^{-\mu x} - e^{-\mu(x+d)}) \cdot \lambda e^{-\lambda x} dx$$

$$= \frac{\mu^2}{\lambda + \mu} (1 - e^{-\lambda d}) \int_0^t e^{-(\lambda + \mu)y} dy + \frac{\lambda^2}{\lambda + \mu} (1 - e^{-\mu d}) \int_0^t e^{-(\lambda + \mu)x} dx$$

$$\begin{aligned}
&= \frac{1}{\lambda+\mu} \cdot [\mu^2(1-e^{-\lambda d}) + \lambda^2(1-e^{-\mu d})] \cdot \frac{1}{\lambda+\mu}(1-e^{-(\lambda+\mu)t}) \\
&= \frac{1}{(\lambda+\mu)^2} (\lambda^2 + \mu^2 - \lambda^2 e^{-\mu d} - \mu^2 e^{-\lambda d}) (1-e^{-(\lambda+\mu)t})
\end{aligned}$$

FORMULA 2

$$H_2(t, d, \lambda, \mu) \equiv \Pr[0 < X, Y < t ; X < Y + d]$$

$$\doteq (1-e^{-\mu t}) - \mu \frac{e^{-\lambda d}}{\lambda+\mu} (1-e^{-(\lambda+\mu)t})$$

Derivation;

$$\Pr[0 < X, Y < t ; X < Y + d] \doteq \Pr[X < Y + d ; Y < t]$$

$$= \int_0^t F_X(y+d) \cdot f_Y(y) dy$$

$$= \int_0^t (1-e^{-\lambda(y+d)}) \cdot \mu e^{-\mu y} dy$$

$$= \int_0^t [\mu e^{-\mu y} - \mu e^{-\lambda d} \cdot e^{-(\lambda+\mu)y}] dy$$

$$= (1-e^{-\mu t}) - \mu \frac{e^{-\lambda d}}{\lambda+\mu} (1-e^{-(\lambda+\mu)t})$$

FORMULA 3

$$H3(t, \lambda, \mu) \equiv \Pr[0 < x, y < t]$$

$$= (1 - e^{-\lambda t}) (1 - e^{-\mu t})$$

FORMULA 4

$$G1(t, d, \lambda, \mu) \equiv \Pr[0 < X, Y < t ; X < Y + d ; T < t]$$

$$\doteq \left[1 - \frac{1}{\mu t} (1 - e^{-(\mu t)}) \right] - \frac{\mu e^{-\lambda d}}{\lambda + \mu} \left[1 - \frac{1}{(\lambda + \mu)t} (1 - e^{-(\lambda + \mu)t}) \right]$$

Derivation;

$$\Pr[0 < X, Y < t ; X < Y + d ; T < t]$$

$$= \int_0^t \Pr[0 < X, Y < u ; X < Y + d | T = u] dP[T < t]$$

$$\doteq \int_0^t \Pr[X < Y + d, 0 < Y < u] \cdot \frac{1}{t} du$$

$$= \int_0^t \left[\int_0^u F_X(y+d) \cdot f(y) \cdot dy \right] \cdot \frac{1}{t} du$$

$$= \frac{1}{t} \int_0^t \left[\int_0^u (1 - e^{-\lambda(y+d)}) \cdot \mu e^{-\mu y} dy \right] du$$

$$\begin{aligned}
&= \frac{1}{t} \int_0^t \left[\int_0^u (\mu e^{-\mu y} - \mu e^{-\lambda d} e^{-(\lambda+\mu)y}) dy \right] du \\
&= \frac{1}{t} \int_0^t \left[(1 - e^{-\mu u}) - \frac{\mu e^{-\lambda d}}{\lambda + \mu} (1 - e^{-(\lambda+\mu)u}) \right] du \\
&= \frac{1}{t} \left[t - \frac{1}{\mu} (1 - e^{-\mu t}) - \frac{\mu e^{-\lambda d}}{\lambda + \mu} t + \frac{\mu e^{-\lambda d}}{(\lambda + \mu)^2} (1 - e^{-(\lambda+\mu)t}) \right]
\end{aligned}$$

FORMULA 5

$$G_2(t, \lambda, \mu) \equiv \Pr[0 < X, Y < T ; T < t]$$

$$= 1 - \frac{1}{\lambda t} (1 - e^{-\lambda t}) - \frac{1}{\mu t} (1 - e^{-\mu t}) + \frac{1}{(\lambda + \mu)t} (1 - e^{-(\lambda + \mu)t})$$

Derivation;

$$\Pr[0 < X, Y < T ; T < t]$$

$$= \int_0^t P(0 < X, Y < u) \cdot \frac{1}{t} du$$

$$= \frac{1}{t} \int_0^t F_X(u) \cdot F_Y(u) du$$

$$= \frac{1}{t} \int_0^t (1 - e^{-\lambda u}) (1 - e^{-\mu u}) du$$

$$= \frac{1}{t} \int_0^t [1 - e^{-\lambda u} - e^{-\mu u} + e^{-(\lambda+\mu)u}] du$$

$$= \frac{1}{t} \left[t - \frac{1}{\lambda}(1 - e^{-\lambda t}) - \frac{1}{\mu}(1 - e^{-\mu t}) + \frac{1}{\lambda+\mu}(1 - e^{-(\lambda+\mu)t}) \right]$$

4. Approximation of the Safety Formulae and Mean Time Between Accidents.

To calculate the MTBA (mean time between accident) values, we have to evaluate the functions H1, H2, H3, G1, G2. It is straightforward to evaluate the functions, but some numerical problem may result because the exponent values are expected to be extremely small. This fact suggests that approximation calculations (by using Taylor's expansion) can be successfully employed.

$$\begin{aligned}
 H1(t, d, \lambda, \mu) &= (\lambda^2 + \mu^2 - \lambda^2 e^{-\mu d} - \mu^2 e^{-\lambda d}) (1 - e^{-(\lambda + \mu)t}) / (\lambda + \mu)^2 \\
 &= [\lambda^2 (1 - e^{-\mu d}) + \mu^2 (1 - e^{-\lambda d})] (1 - e^{-(\lambda + \mu)t}) / (\lambda + \mu)^2 \\
 &\doteq \{ \lambda^2 (\mu d - (\mu d)^2 / 2 + \dots) + \mu^2 (\lambda d - (\lambda d)^2 / 2 + \dots) \} \\
 &\quad \{ (\lambda + \mu)t - (\lambda + \mu)^2 t^2 / 2 + \dots \} / (\lambda + \mu)^2 \\
 &= d \cdot \lambda \cdot \mu \{ \lambda (1 - \mu d / 2) + \mu (1 - \lambda d / 2) \} \cdot \{ 1 - (\lambda + \mu) \cdot t / 2 \} \cdot t / (\lambda + \mu) \\
 &\doteq d \cdot \lambda \cdot \mu \cdot (\lambda + \mu) \cdot t / (\lambda + \mu) = t \cdot d \cdot \lambda \cdot \mu
 \end{aligned}$$

$$\begin{aligned}
 H2(t, d, \lambda, \mu) &= (1 - e^{-\mu t}) - \frac{\mu}{\lambda + \mu} \cdot e^{-\lambda d} \cdot (1 - e^{-(\lambda + \mu)t}) \\
 &\doteq (\mu t - (\mu t)^2 / 2) - \frac{\mu}{\lambda + \mu} \cdot (1 - \lambda d) \cdot ((\lambda + \mu)t - (\lambda + \mu)^2 t^2 / 2)
 \end{aligned}$$

$$= \mu t(1 - \mu t/2) - \mu t(1 - \lambda d)(1 - (\lambda + \mu)t/2)$$

$$= \mu t[1 - \mu t/2 - 1 + \lambda d + (\lambda + \mu)t/2 - \lambda d(\lambda + \mu)t/2]$$

$$\doteq \mu t(\lambda d + \frac{1}{2}\lambda t)$$

$$= \mu \cdot t \cdot \lambda \cdot (d + t/2)$$

$$H3(t, \lambda, \mu) = (1 - e^{-\lambda t})(1 - e^{-\mu t})$$

$$= (\lambda t)(\mu t)$$

$$G1(t, d, \lambda, \mu) = \{1 - \frac{1}{\mu t}(1 - e^{-\mu t})\} - \frac{\mu}{(\lambda + \mu)} e^{-\lambda d} \{1 - \frac{1}{(\lambda + \mu)t}(1 - e^{-(\lambda + \mu)t})\}$$

$$\doteq \{1 - \frac{1}{\mu t}(\mu t - (\mu t)^2/2 + (\mu t)^3/6)\} - \frac{\mu e^{-\lambda d}}{(\lambda + \mu)} \{1 - \frac{1}{(\lambda + \mu)t}[(\lambda + \mu)t - (\lambda + \mu)^2 t^2/2$$

$$+ (\lambda + \mu)^3 t^3/6]\}$$

$$= \{(\mu t)/2 - (\mu t)^2/6\} - \frac{\mu e^{-\lambda d}}{(\lambda + \mu)} \{(\lambda + \mu)t/2 - (\lambda + \mu)^2 t^2/6\}$$

$$= \{(\mu t)/2 - (\mu t)^2/6\} - \{(\mu t) \cdot e^{-\lambda d}/2 - (\mu t)(\lambda + \mu)t \cdot e^{-\lambda d}/6\}$$

$$= \frac{1}{2}(\mu t) \cdot (1 - e^{-\lambda d}) - \frac{1}{6}(\mu t)^2(1 - e^{-\lambda d}) + \frac{1}{6}(\mu t)(\lambda t) \cdot e^{-\lambda d}$$

$$\begin{aligned}
& \doteq \frac{1}{2} (\mu_t) \cdot (\lambda_d - \frac{(\lambda_d)^3}{6}) - \frac{1}{6} (\mu_t)^2 (\lambda_d)^2 / 2 \\
& \quad + \frac{1}{6} (\lambda_t) (\mu_t) (1 - \lambda_d + (\lambda_d)^2 / 2) \\
& = \frac{1}{2} (\mu_t) (\lambda_d) \{ (1 - (\lambda_d) / 2 - (\mu_t) / 3 + (\lambda_d)^2 / 6 + (\mu_t) (\lambda_d) / 6) \} + \\
& \quad \frac{1}{6} (\lambda_t) (\mu_t) \{ (1 - \lambda_d + (\lambda_d)^2 / 2) \} \\
& \doteq \frac{1}{2} (\lambda_d) (\mu_t) + \frac{1}{6} (\lambda_t) (\mu_t)
\end{aligned}$$

$$G_2(t, \lambda, \mu) = 1 - (1 - e^{-\lambda t}) / \lambda t - (1 - e^{-\mu t}) / \mu t + (1 - e^{-(\lambda + \mu)t}) / (\lambda + \mu)t$$

$$\doteq 1 - (1 - (\lambda t) / 2 + (\lambda t)^2 / 6) - (1 - (\mu t) / 2 + (\mu t)^2 / 6) +$$

$$(1 - (\lambda + \mu)t / 2 + (\lambda + \mu)^2 t^2 / 6)$$

$$= (\lambda t) / 2 + (\mu t) / 2 - (\lambda + \mu)t / 2 - (\lambda t)^2 / 6 - (\mu t)^2 / 6 + (\lambda + \mu)^2 t^2 / 6$$

$$= (\lambda t) (\mu t) / 3$$

With these approximation results, it would be easier to evaluate the probability equations. From Appendix B, we also know the following values;

x = 2.90	(multi-vibrator failure rate),
y = 1.31	(pulse-shaper failure rate),
u = 0.98	(amp-A, rel-A failure rate),
v = 5.60	(amp-B, rel-B failure rate),
a = 2.37	(A-path failure rate),
b = 6.12	(B-path failure rate),

$r = 20$ msec. (relay response time, from Appendix A).

Now, the Probability of Accident with a Successful Self-test (PASS) in Eq.C-1 becomes;

$$\begin{aligned} \text{PASS} &= H1(s,r,x,u) + H1(s,r,y,v) + H1(s,r,a,b) \\ &= s*r*x*u + s*r*y*v + s*r*a*b \\ &= (1.4 * 10^{-16})_s \text{-----} \text{(C-6)}. \end{aligned}$$

Where, s : length of a self-tripping period.

Eq.C-2 becomes;

$$\begin{aligned} \text{PAUS} &= H2(p,r,x,u) + H2(p,r,y,v) + H3(p,a,b) \\ &= p*x*u*(r+p/2) + p*y*v*(r+p/2) + p*p*a*b \\ &= (5.7 * 10^{-17})_p + (2.0 * 10^{-11})_p^2 \text{-----} \text{(C-7)}. \end{aligned}$$

Where, p is the length of part preparation time.

In Appendix A, typical values for the parameters related to press operation cycle were given as follows;

c = length of a press operation cycle (1.5 sec.),
 s = length of a self-tripping period (0.2 sec.),
 p = length of part preparation time (0.8 sec.),
 g = length of a dangerous period (0.16 sec.).

Using these values, we can find a typical value for the probability of self-tripping accident in a press cycle by evaluating Eq.C-4.

Plugging in the values into the equations C-3, C-6, and C-7, we have;

$$\begin{aligned} \text{PSF} &= (4.03 * 10^{-6})_c = 2.0 * 10^{-9} \\ \text{PASS} &= (1.4 * 10^{-16})_s = 8.0 * 10^{-21} \\ \text{PAUS} &= (5.7 * 10^{-17})_p + (2.0 * 10^{-11})_p^2 = 1.0 * 10^{-18}. \end{aligned}$$

Note, in the above calculations, that the unit of the parameters is hours. For example, c is 1.5 seconds and is equivalent to $4.2 * 10^{-4}$

hours. Thus, finally we have;

$$\begin{aligned} \text{Pr}(\text{self-tripping accident}) &= \text{PASS} + (\text{PSF} * \text{PAUS}) \\ &= 8.0 * 10^{-21}. \end{aligned}$$

In practice, we are more interested in the mean time between accidents (MTBA), the value of which can be determined as;

$$\begin{aligned} \text{MTBA}(\text{self-tripping}) &= c/\text{Pr}(\text{self-tripping accident}) \\ &= (4.2 * 10^{-4}) / (8.0 * 10^{-21}) \\ &= 5 * 10^{16} \text{ hours} \text{-----} (C-8). \end{aligned}$$

For the guard safety, the probability of guard malfunction (PGM) in a single press cycle can also be evaluated as follows (Eq. C-5);

$$\begin{aligned} \text{PGM} &= G1(g,r,x,u) + G1(g,r,y,v) + G2(g,a,b) \\ &= (g*r*x*u/2 + g^2*x*u/6) + (g*r*y*v/2 + g^2*y*v/6) + (g^2*a*b/3) \\ &= g*r*(u*x + v*y)/2 + g^2*(u*x + v*y + 2*a*b)/6 \\ &= (1.3 * 10^{-21}) + (1.4 * 10^{-20}) \\ &= 1.5 * 10^{-20} \text{-----} (C-9). \end{aligned}$$

The values in Eq. C-8 and Eq. C-9 gives overall reliability measures of the system (light-curtain unit only). Then, how much "reliable" are the reliability values? The accuracy of a final value can not be better than that of the input data. From the approximation equations, we can see that the errors in the component failure rates are squared. In other words, for example, if the actual failure rates of the electronic components (transistors, diodes, resistors, capacitors, relays) were 10 times higher than the ones used in our calculations,

then the accident probabilities would become 100 times higher than the ones given in Eq. C-8 and Eq. C-9. Thus, if we use these conservative values, the mean-time-between accident during self-tripping, MTBA (self-tripping), would become $5 * 10^{14}$ hours. Similarly, the probability of guard malfunction in a single press cycle will be changed to $1.5 * 10^{-18}$.

APPENDIX D, OPERATION SEQUENCE OF CONTROL RELAYS.

Appendix D describes the sequences of operations in various modes, and all the references are made to the circuit diagram (Drawing No. 7A-000-77).^{*} As listed in Table 1 of this appendix, there are 14 relays and 4 limit switches. Described here are three operation modes, 1) Guard-only Single-stroke Mode using two-hand push-buttons, 2) Single-break Single-stroke self-tripping mode, and 3) Double-break Single-stroke self-tripping mode.

Guard-Only Single-Stroke Mode.

1. Selector Switch Position;

SS1 at "RUN", SS2 at "SINGLE STROKE", and SS3 at "HAND".

2. Start-up Sequence.

Power is applied to the circuit through the motor forward contact (MF-Relay) on line 6 after the MOTOR-START button has been depressed. With the press at top-stop (0 degree rotation), LC2-Relay energizes on line 35. Since limit-switch 1LSa is closed and the relays 3CR, MD and 2CR are de-energized, 1CR-Relay will pull in.

With 1CR energized, the closed contacts of MD (line 20), 1CR (line 19) and 4CR (line 19) will make 2CR-Relay energize. When 2CR pulls in, the self-test contact (line 38) to the light curtain terminals 11 & 12 are closed, and the self-test function starts its cycle. If there were no obstruction in the light curtain, the light curtain would "go green", de-energizing LC2 and closing the contacts between terminals 5 & 8 (lines 30 & 32). Now the light curtain is ready for a press cycle. This start-up sequence is summarized in Table 2.

^{*}This drawing is proprietary of Sick Optic-Elektronik. Persons wishing to obtain it should contact Sick Optic-Elektronik directly.

3. Cycling Sequence.

If the RUN-buttons are pressed, power is applied to 3CR through the closed contacts between terminals 5 & 8, normally closed LC2-contact (line 30), and 2CR contact on line 30. When 3CR-Relay energizes, power is applied to the AIR-VALVE solenoids through the contacts of 1CR (line 31) which has already been de-energized (after the RUN-buttons depressed) and of 3CR. The press now goes in motion, energizing the motion detector relay MD. 2CR-Relay remains energized, through the normally open contact of 3CR (line 19), when the press continues to operate.

Limit Switch 1LS changes position shortly after start-up, and 4LS changes position shortly before the bottom. 2CR was held in via the contact of LC2 and the 2CR self-holding contact (line 21) through the limit switch contacts, 2LSb and 3LSb. This is a stop-off-bottom feature. Still, if there is no obstruction, the limit switches 2LSa and 3LSb (line 33) close at 180° and the press returns to the top until either 2LSa or 3LSb opens, giving the top-stop. If, for some reason, the chain on the cam limit switch had broken during this time (then 2LSa and 3LSb remain closed), the MD-Relay would detect this failure and drop out, stopping the press. During the up-stroke (at around 270°), 4LSa and 1LSb open up, de-energizing 2CR which will give a self-test signal to the light curtain through the terminals 11 & 12 (line 38). The whole cycling sequence is described in detail in Table 3.

If there were any obstructions during the down-stroke, the light curtain would tell the press to stop by opening contacts between terminals 5 & 8, and by closing contacts between terminals 3 & 4 which

in turn will energize LC2, opening the LC2 contact on line 30 (i.e., contacts A4 and B5 open, and A5 and B4 close, and then LC2 contact opens).

Single-Break Single-Stroke Mode.

1. Selector Switch Positions.

SS1 at "RUN"; SS2 at "SINGLE STROKE"; SS3 at "SINGLE BREAK".

2. Start-up Sequence.

Power is applied to the circuit by depressing the MOTOR-START button, but the light curtain must be obstructed to initiate the unit (see the sequence no. 4 thru 8 in Table 4). Now depress the CONT. AUTO PRESET button to temporarily energize 4CR-Relay whose time contact (line 28) remains pulled in and holds in 5CR-Relay. 2CR has already been pulled out by depressing the button.

So the power is to be applied to the light curtain (terminal 5) thru the 4CR timer contact (line 28), thru 5CR contact (line 30), and thru SS3 switch (line 31). At the time of 2CR de-energized, the self-test command was given to the light curtain (to de-energize D-Relay in the light curtain) thru the self-test terminals on line 38. The states of the relays at the end of start-up sequence is as shown in Table 4 (step no. 13).

3. Cycling Sequence.

Now the press is ready to run. So if the timer (4CR on line 28) has not timed out and the light curtain is broken once (see the 3rd step in Table 5), the relays in the light curtain (by connecting between

terminals 5 & 8 and opening 3 & 4) will tell the press to run by de-energizing LC2 and energizing 3CR. The only power line to the AIR VALVE solenoid is thru the contacts between terminals 5 & 8, until the press ram reaches 180° from which point the auto-return (line 33) takes over and returns it for a top stop.

During the return cycle, 2CR-Relay is de-energized, setting the relay logic in the light curtain again (de-energizing D-Relay). Relay 4CR is pulsed via 3CR (at each start of a press cycle), resetting the 4CR timer contact for a new time period (around 10 - 20 seconds).

If the light curtain is interrupted during the down-stroke period, the RESET push button must be depressed to energize 1CR to start the sequence all over again, because 1LSa is open and 1CR has been de-energized. The interruption initiates the same sequence of relay operations as before (i.e., A4 & B5 open and A5 & B4 close to open the LC2 contact) to stop the press.

After a normal completion of a press cycle, the states of the relays are as shown in Table 5 (step 0). That is, A and C relays energized and B and D relays de-energized; LC2, 1CR, 2CR and 5CR energized, and 3CR, 4CR and MD de-energized. If the operator puts his hand(s) into the guarded area to change the work, A-Relay becomes de-energized and B-Relay energized, causing D-Relay to energize. If, for some reason, the relays A and B change their states simultaneously while the hand (s) is still under the press die, an accident may occur.

Double-Break Single-Stroke Mode.

The sequence of operation is exactly the same as in the Single-break mode except the contact between terminals 9 & 10 of the selector

switch (SS3) is open, requiring two breakages of the light curtain to initiate the press cycle. All other controls and functions act the same.

Table D-1, List of Relays and Limit Switches.

No.	Symbol	Description	No. of Contacts	Effect ^{#1} on Safety	Drawing No.
1	A	Light Curtain Output Relay	5	Critical	4000526
2	B	Light Curtain Output Relay	5	Critical	"
3	C	A, B Relays Monitoring Relay	6	Important	4000733
4	D	Self-Test Starting Relay	7	Very Important	"
5	E	Double-Break Relay	6	No	"
6	Rel1(S) ^{#2}	Self-Test Signal Relay	1	No	4000525
7	MF	Motor Starter Relay	5	No	7A00077
8	MD(M)	Motion Detector Relay	4	Indirect	"
9	1CR(R1)	Interrupted Stroked Relay	4	No	"
10	2CR(R2)	Anti-Repeat Relay	4	Very Important	"
11	3CR(R3)	Valve Relay	5	No	"
12	4CR(R3)	Auto Time-Out Relay	3	Indirect	"
13	5CR(R5)	Auto Relay	3	No	"
14	LC2(L)	Stop Channel Relay	4	Indirect	"
15	1LS	Brake Monitor Anti-Repeat Limit Switch	3	Indirect	"
16	2LS	Auto-Return Limit Switch	2	Important	"
17	3LS	" " " "	4	Important	"
18	4LS	Stop Off-Bottom Anti-Repeat	2	No	"

(c.f.) ^{#1} "Effect of Safety" with respect to the use of light curtains.

^{#2} The "Symbols" within the parentheses are the ones used in the Relay Sequence Tables.

Table D-2, "Guard-Only Single Stroke" Start-Up Sequence
 Terminals 9 - 10 closed, 20 - 21 open)

No.	LVU 200 Relays	Control Relays	State Changes or Input
0	A B C D S	L R1 R2 R3 M	"Power-Up" energizes B, S, L
1	A (B)* C D (S)	(L) R1 R2 R3 M	On R1 thru L - contact on line #23
2		(L) (R1) R2 R3 M	On R2 thru R1 - contact #21 (see 7A00077)
3		(L) (R1) (R2) R3 M	Close terminals <u>11</u> - <u>12</u> thru R2 - contact #38 "MOTOR SPEED-UP" in LVU200 (on A, off B)
4	(A) B C D (S)		On C thru contacts a ₁ , b ₁ (see 4000733)
5	(A) B (C) D (S)		Off S by opening contact c ₁
6	(A) B (C) D S		Self-test obstruction signal (on B, off A)
7	A (B) (C) D S		On D thru contacts a ₂ , b ₂ , c ₃
8	A (B) (C) (D) S		On S thru contact d ₃
9	A (B) (C) (D) (S)		End of self-test (normal signal on A, off B)
10	(A) B (C) (D) (S)		Close <u>5</u> - <u>6</u> , open <u>1</u> - <u>4</u> (off L)
11	(A) B (C) (D) (S)	L (R1) (R2) R3 M	READY FOR PRESS OPERATION

(c.f.) 1. Relays E, R4, R5 are not used in this mode.

2. (B) means Relay B energized.

Table D-3, "Guard-Only Single-Stroke" Cycling Sequence

1) Two Hand Control Relay Sequence

Ram Slide	Control Relays					State Change or Input
0°	L	(R1)	(R2)	R3	M	Depress "Run-Buttons" (on R3, off R1).
0°	L	R1	(R2)	(R3)	M	Power to clutch; cam movement (on M).
0°~180°	L	R1	(R2)	(R3)	M	Down-stroke; at 180°, auto-return limit switches change.
180°~270°	L	R1	(R2)	(R3)	(M)	Up-stroke; at 270°, on L, off R2.
270°~300°	(L)	R1	R2	(R3)	(M)	At 300°, off R3 and "BRAKE".
200°~360°	(L)	R1	R2	R3	(M)	At 360°, stop motion (off M).
360°	(L)	R1	R2	R3	M	Power to R1 on line #23 (on R1).
360°	(L)	(R1)	R2	R3	M	Off L (line #36), on R2 (line #19).
360°	L	(R1)	(R2)	R3	M	End of cycle.

2) Self-Test in LVU200 (During 270°~360° RAM-SLIDE).

No.	LVU200 Relays					State Change or Input
0	(A)	B	(C)	(D)	(S)	Terminals <u>11</u> - <u>12</u> open (off D) at 270°
1	(A)	B	(C)	D	(S)	d ₃ -contact open (off S)
2	(A)	b	(C)	D	S	Self-test obstruction pulse (on B, off A).
3	A	(B)	(C)	D	S	<u>11</u> - <u>12</u> closed at 360° (on D).
4	A	(B)	(C)	(D)	S	d ₃ -contact closed (on S)
5	A	(B)	(C)	(D)	(S)	End of self-test; normal signal (on A, off B)
6	(A)	B	(C)	(D)	(S)	

Table D-4, "Single-Break Single-Stroke" Start-Up Sequence

No.	LVU200 Relays	Control Relays	State Change or "Input"
1	A (B) C D	(L) R1 R2 R3 R4 R5 M	<u>"POWER-UP"</u> (on L, on B)
2		(L) (R1) R2 R3 R4 R5 M	Close R1-contact #19 (on R2)
3		(L) (R1) (R2) R3 R4 R5 M	<u>"LVU200 Motor Speed-up"</u> (on A, off B)
4	(A) B C D		Close contact a ₁ (on C)
5	(A) B (C) D		<u>"OBSTRUCTION OF LIGHT"</u> (off A, on B)
6	A (B) (C) D		Close contacts a ₂ , b ₂ (on D)
7	A (B) (C) (D)		<u>"OBSTRUCTION REMOVED"</u> (on A, off B)
8	(A) B (C) (D)		Close "MAKE" (5 - 8), open 3 - 4 (off L)
9		L (R1) (R2) R3 R4 R5 M	<u>"depress AUTO-PRESET"</u> (off R2, on R4)
10		L (R1) R2 R3 (R4) R5 M	Close timer-contact R4 #28 (on R5) open R2-contact #38 (self-test, off D)
11	(A) B (C) D	L (R1) R2 R3 (R4) (R5) M	<u>"return AUTO-PRESET"</u> (off R4) open 5 - 8, close 3 - 4 (on L)
12		(L) (R1) R2 R3 R4 M	Close R4-contact #19 (on R2)
13		(L) (R1) (R2) R3 R4 (R5) M	

(c.f.) 1. Relays E and S are not used.

2. Terminals 9 - 10 closed, 20 - 21 closed.

Table D-5, "Single-Break Single-Stroke" Cycling Sequence

No.	LVU200 Relays	Control Relays	State Change or "Input"
0	(A) B (C) D	(L) (R1) (R2) R3 R4 (R5) M	"OBSTRUCTION OF LIGHT" (off A, on B)
1	A (B) (C) D		close contacts a ₂ , b ₂ (on D)
2	A (B) (C) (D)		"REMOVE OBSTRUCTION" (on A, off B)
3	(A) B (C) (D)		close 5 - 8 , open 3 - 4 (off L)
4		L (R1) (R2) R3 R4 (R5) M	close L-contact #30 (on R3)
5		L (R1) (R2) (R3) R4 (R5) M	close R3-contact #25 (on R4), open #23 (off R1)
6		L R1 (R2) (R3) (R4) (R5) M	power to clutch; CAM movement (on M)
7		L R1 (R2) (R3) (R4) (R5) (M)	DOWN-STROKE (0°~180°); at 180° auto-return.
8			UP-STROKE (180°~270°); at 270° (on L, off R2)
9		(L) R1 R2 (R3) (R4) (R5) (M)	(270°~300°); open R2-contact #14 (off D)
10	(A) B (C) D		At 300°, open #33 (off R3) and BRAKE
11		(L) R1 R2 R3 (R4) (R5) (M)	(300°~360°); open R3-contact #27 off (R4)
12		(L) R1 R2 R3 R4 (R5) (M)	complete stop at 360° (off M)
13		(L) R1 R2 R3 R4 (R5) M	close M-contact #23 (on R1)
14		(L) (R1) R2 R3 R4 (R5) M	close R1-contact #19 (on R2)
15		(L) (R1) (R2) R3 R4 (R5) M	end of cycle

APPENDIX E

TABLES OF RAW PRODUCTION DATA

1st Shift

INTERLAKE STAMPING CO.

Production Data

Date: 6/1/81 Day: MONDAY	Machine No. 28 Subject No. 1						Machine No. 24 Subject No. 2						Machine No. 27 Subject No. 3					
	Two hand control			Self-tripping			Two hand control			Self-tripping			Two hand control			Self-tripping		
	Job #	Hits	Duration	Job #	Hits	(min.) Duration	Job #	Hits	Duration	Job #	Hits	(min.) Duration	Job #	Hits	Duration	Job #	Hits	Duration
7:00-8:00				7859	175	15				10048	152	15				7224	0	0
8:00-9:00				7859	124	50				11	1050	55				11	0	0
9:00-10:00				11	204	43				11	1825	46				11	0	0
10:00-11:00				11	366	58				11	2747	56				11	68	37
11:00-12:00				11	412	55				11	3817	55				11	1549	55
12:30-1:30				11	5078	55				11	4407	60				11	2382	60
1:30-2:30				11	6089	47				11	581	50				11	3286	45
2:30-3:30				11	6805	38				11	5790	40				11	3969	40

194.2

2nd Shift

INTERLAKE STAMPING CO.

Production Data

Date: <u>6/1/81</u>	Machine No.						Machine No.						Machine No.					
	Subject No. <u>1</u>						Subject No. <u>2</u>						Subject No. <u>3</u>					
	Two hand control			Self-tripping			Two hand control			Self-tripping			Two hand control			Self-tripping		
Day: <u>Monday</u>	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
4:00-5:00		221	15					200	13					148	10			
5:00-6:00		1286	66					1235	66					1046	66			
6:00-7:00		1912	43					1926	43					1589	43			
7:00-8:00		2664	60					2812	60					2418	58			
8:00-9:00		3425	55					3749	55					3145	55			
9:30-10:30		4057	60					4682	60					3911	57			
10:30-11:30		4549	50					5524	50					4640	50			
11:30-12:30		5050	5					6071	35					5144	35			

5/17/81
12:05

1st Shift

INTERLAKE STAMPING CO.

Production Data

Date: <u>6/2/82</u>	Machine No.						Machine No.						Machine No.					
	Subject No. <u>1</u>						Subject No. <u>2</u>						Subject No. <u>3</u>					
	<u>Two hand control</u>			Self-tripping			<u>Two hand control</u>			Self-tripping			<u>Two hand control</u>			Self-tripping		
Day: <u>Tuesday</u>	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
7:00-8:00		506	35					577	40					535	35			
8:00-9:00		1240	60					1342	60					1623	60			
9:00-10:00		1796	47					1977	47					2466	45			
10:00-11:00		2503	56					2840	60					3500	57			
11:00-12:00		3205	55					3555	55					4501	50			
12:30-1:30		3861	55					4291	55					5530	55			
1:30-2:30		4412	43					4920	48					6210	35			
2:30-3:30		4861	37					5490	40					6981	40			

2nd Shift

INTERLAKE STAMPING CO.

Production Data

Date: <u>6/2/81</u> <hr/>	Machine No.						Machine No.						Machine No.					
	Subject No. <u>1</u>						Subject No. <u>2</u>						Subject No. <u>3</u>					
	Two hand control			Self-tripping			Two hand control			Self-tripping			Two hand control			Self-tripping		
Day: <u>TUESDAY</u> <hr/>	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
4:00-5:00					1101	50			110		861	46					751	42
5:00-6:00					2461	61			51		2125	61					1728	60
6:00-7:00					3416	46					3019	46					2461	46
7:00-8:00					4656	60					4076	60					3344	60
8:00- 8:30					6076	83					5522	82					4751	
10:00-10:30					7158	30					6503	28					5670	30
10:30-12:00					8167	90					7379	90					6542	90
11:30-12:20																		

197

INTERLAKE STAMPING CO.

Production Data

Date: <u>6/3/81</u>	Machine No. Subject No. <u>1</u>						Machine No. Subject No. <u>2</u>						Machine No. Subject No. <u>3</u>					
	Two hand control			Self-tripping			Two hand control			Self-tripping			Two hand control			Self-tripping		
	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
7:00-8:00					758	39					590	39				9946	123	15
8:00-9:00					1879	57					1430	55				11	194	5
9:00-10:00					2978	54					2221	57				11	0	0
10:00-11:00					3858	48					2928	50				8771	366	32
11:00-12:00					4890	55					3770	55				8771	405	18
12:30-1:30					5973	52					4503	50				3352	540	26
1:30-2:30					6829	47					5120	48				11	1120	45
2:30-3:10					7385	41					5645	48				11	1480	42

198

→ machine
break
down.

← he
jo

← he
jok

INTERLAKE STAMPING CO.

Production Data

Date: <u>6/3/81</u>	Machine No. 28						Machine No. 24 Job # 9946-5						Machine No. 27 Job # 3352-11					
	Subject No. 1						Subject No. 2						Subject No. 3					
	Two hand control			Self-tripping			Two hand control			Self-tripping			Two hand control			Self-tripping		
Day: <u>Wednesday</u>	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
4:00-5:00		557	52					574	50					270	22			
5:00-6:00		1222	61					1313	62					910	61			
6:00-7:00		1691	55					1902	57					1452	57			
7:00-8:00		2253	57					2532	58					2164	60			
8:00-8:55		2772	55					3166	51					2790	55			
9:30-10:30		3331	58					3841	56					3559	58			
10:30-11:30		3719	47					4454	48					⊕ 3885 waiting	31			
11:30-12:20		4049	32					4890	34					⊕ 352	23			

11/12:04

⊕ job # 3352-11 completed
 ⊗ job # 7221-48

1st Shift

INTERLAKE STAMPING CO.

Production Data

Date: <u>6/4/81</u>	Machine No. <u>28</u>						Machine No. <u>24</u>						Machine No. <u>27</u>					
	Subject No. <u>1</u>						Subject No. <u>2</u>						Subject No. <u>3</u>					
	Two hand control			Self-tripping			Two hand control			Self-tripping			Two hand control			Self-tripping		
Day: <u>Thursday</u>	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
7:00-8:00	7859 -25	562	44				9946 -5	382	40				7224 -48	171	10			
8:00-9:00	"	1322	56				"	967	56				"	1190	55			
9:00-10:00	"	1910	47				"	1420	47				"	1602	22			
10:00-11:00	"	2698	60				"	2149	60				7809 -22	505	55			
11:00-12:00	"	3300	51				"	2670	55				"	861	50			
12:30-1:30	"	3995	54				"	3321	57				"	1286	46			
1:30-2:30	"	4545	45				"	3830	47				"	1651	40			
2:30-3:30	"	5084	40				"	4264	40				"	2000	35			

200

← new
195

note: job 7809-22 was relatively big in size compared to previous jobs. (8" x 6")

INTERLAKE STAMPING CO.

Machine 3
Job # 2803

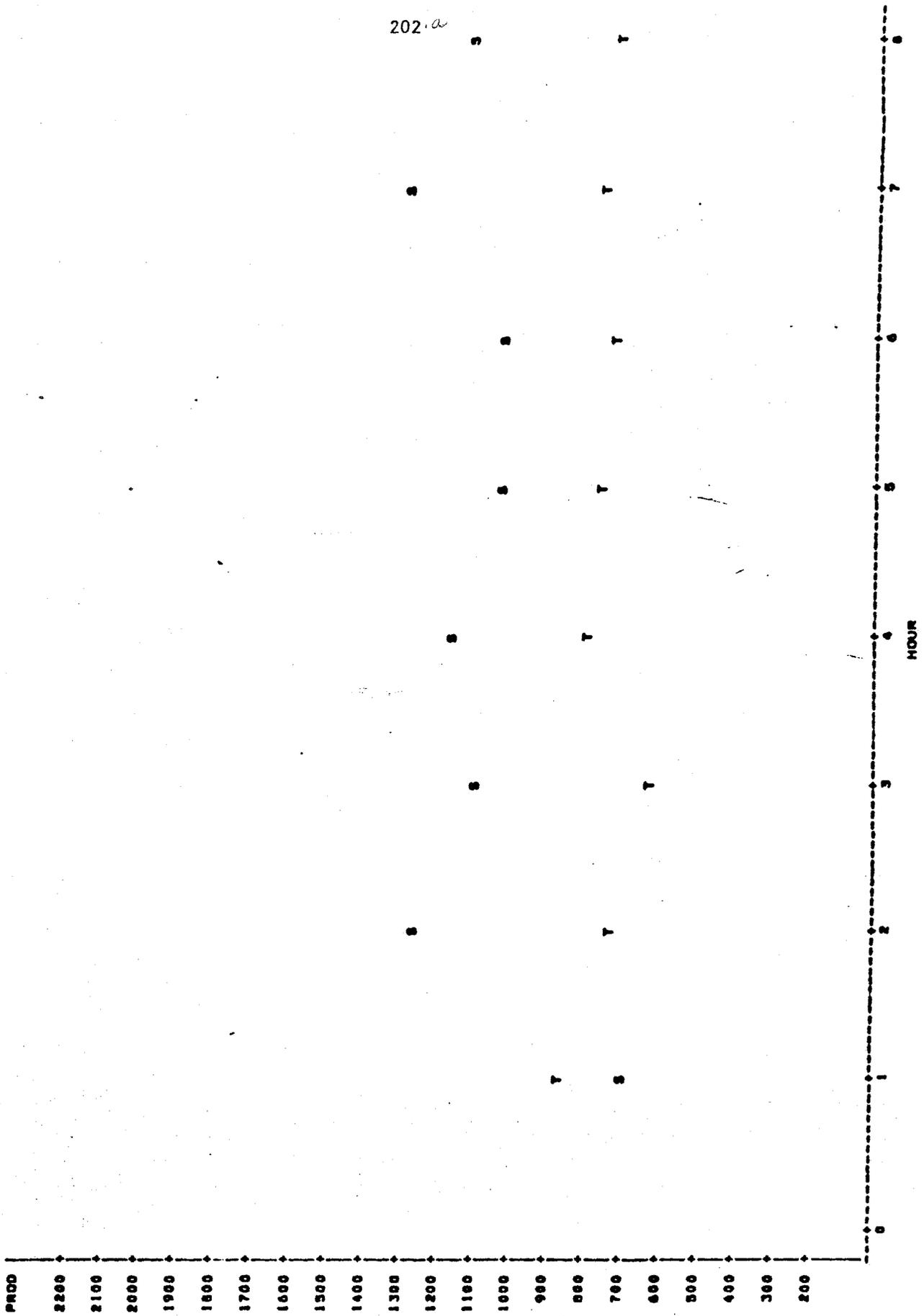
Production Data
same job as previous days

Date: <u>6/4/81</u>	Machine No.					Machine No.					Machine No.							
	Subject No. 1					Subject No. 2					Subject No. 3							
	Two hand control			Self-tripping		Two hand control			Self-tripping		Two hand control			Self-tripping				
Day: <u>Thursday</u>	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration	Job #	Hits	Duration
4:00-5:00			48		830	48					577	38					315	42
5:00-6:00					1880	60					1520	60					746	60
6:00-7:00					2695	45					2207	46					1050	46
7:00-8:00					3780	57					2977	54					1432	56
8:00-8:55					4632	52					3646	49					1817	55
9:30-10:35					579	60					4560	60					249	63
10:35-12:00					7170	69					5705	73					2714	71
12:15-12:30																		

APPENDIX F
Productivity Data Plots

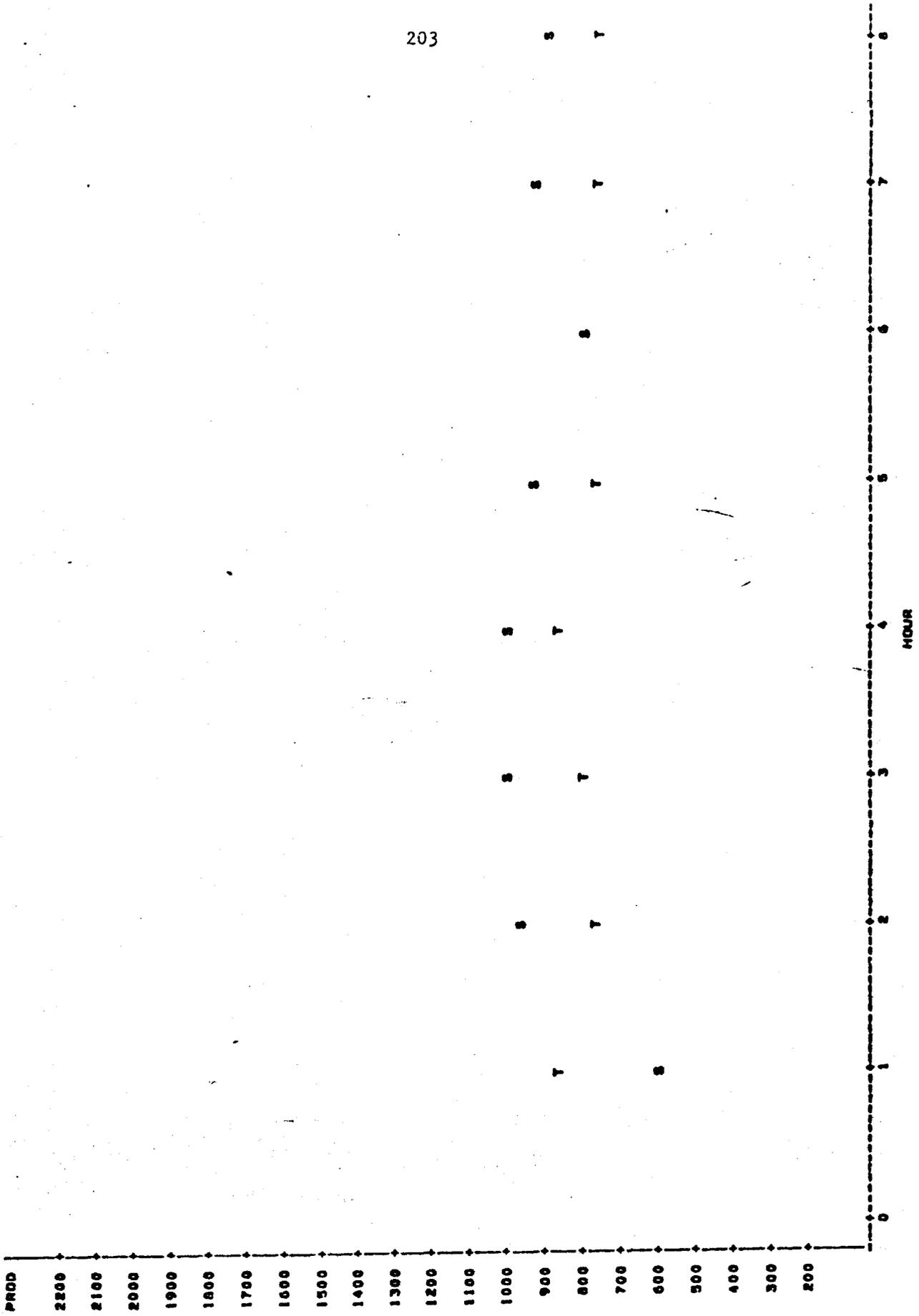
FIGURE II.3

SUBJECT 1 - DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



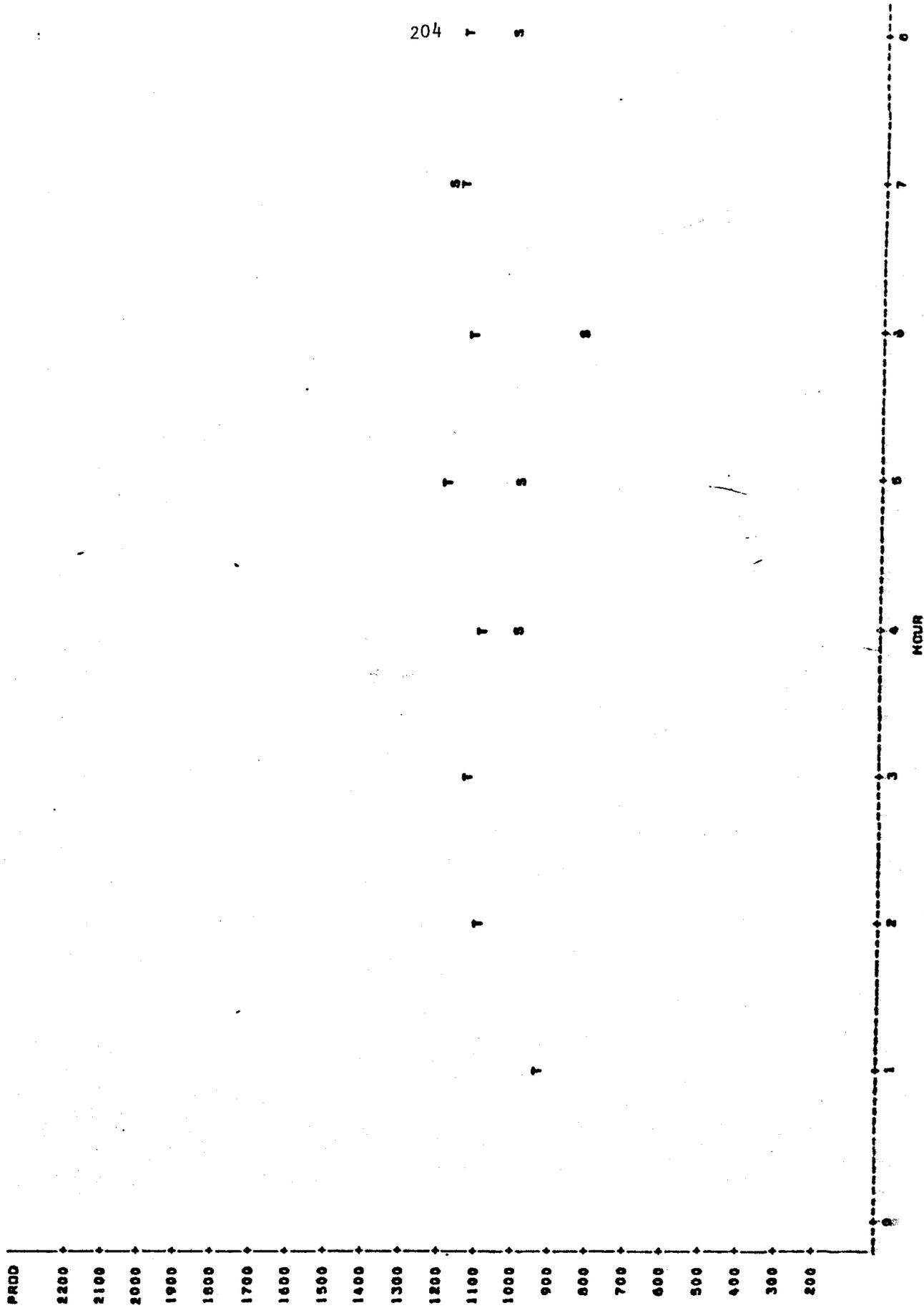
SUBJECT 2 - DAYS 1 AND 2
 S=SELF TRIPPING
 T=TED HAND CONTROL

FIGURE II.4



SUBJECT 3 - DAYS 1 AND 2
 S=SELF TRIPPING
 T=TWO HAND CONTROL

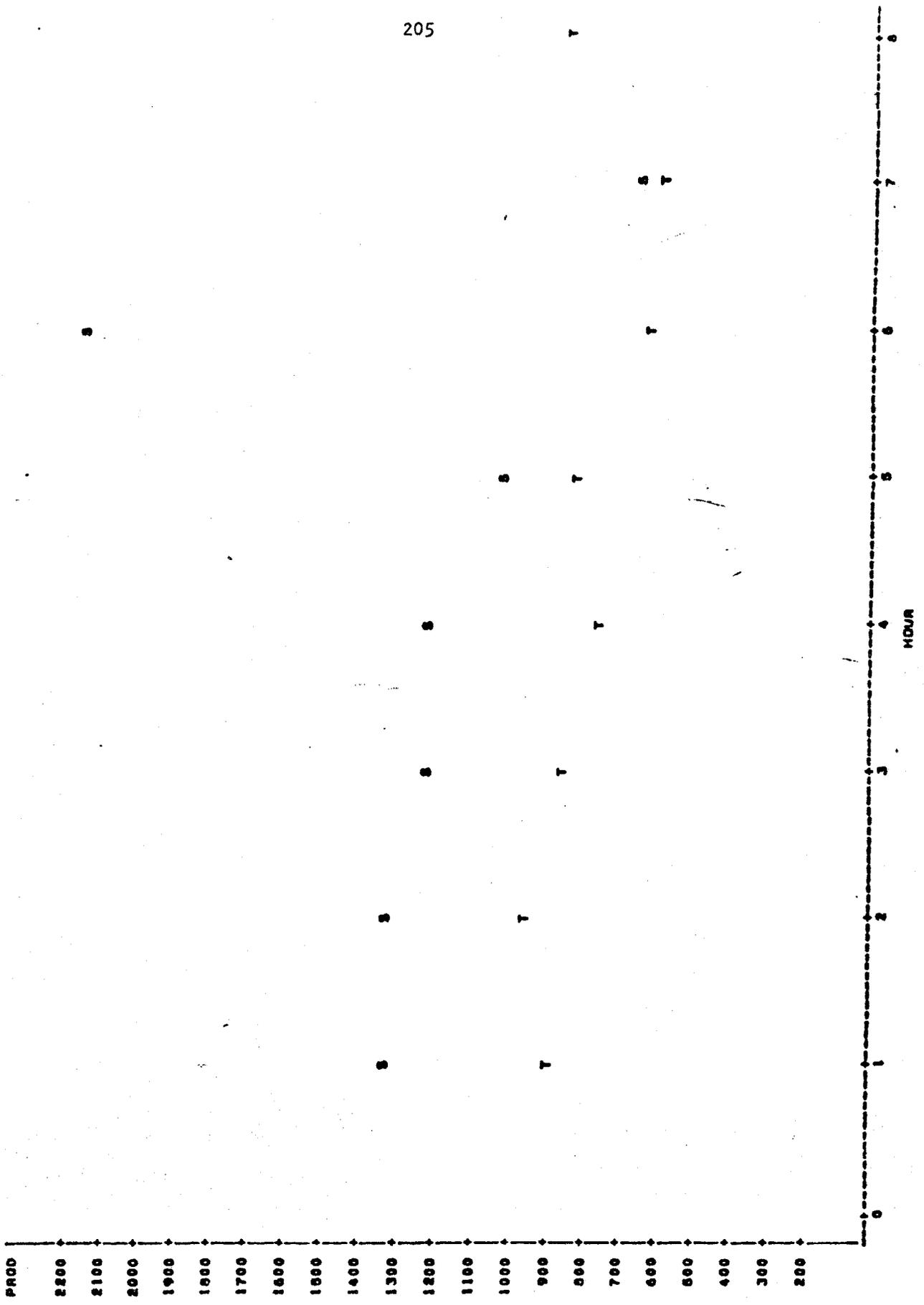
FIGURE II.5



NOTE: 3 OBS HAD MISSING VALUES

FIGURE II.6

SUBJECT A . DAYS 1 AND 2
S=SELF TRIPPING
T=TOO HAND CONTROL



SUBJECT B - DAYS 1 AND 2
3-SELF TRIPPING
T-180 HAND CONTROL

FIGURE II.7

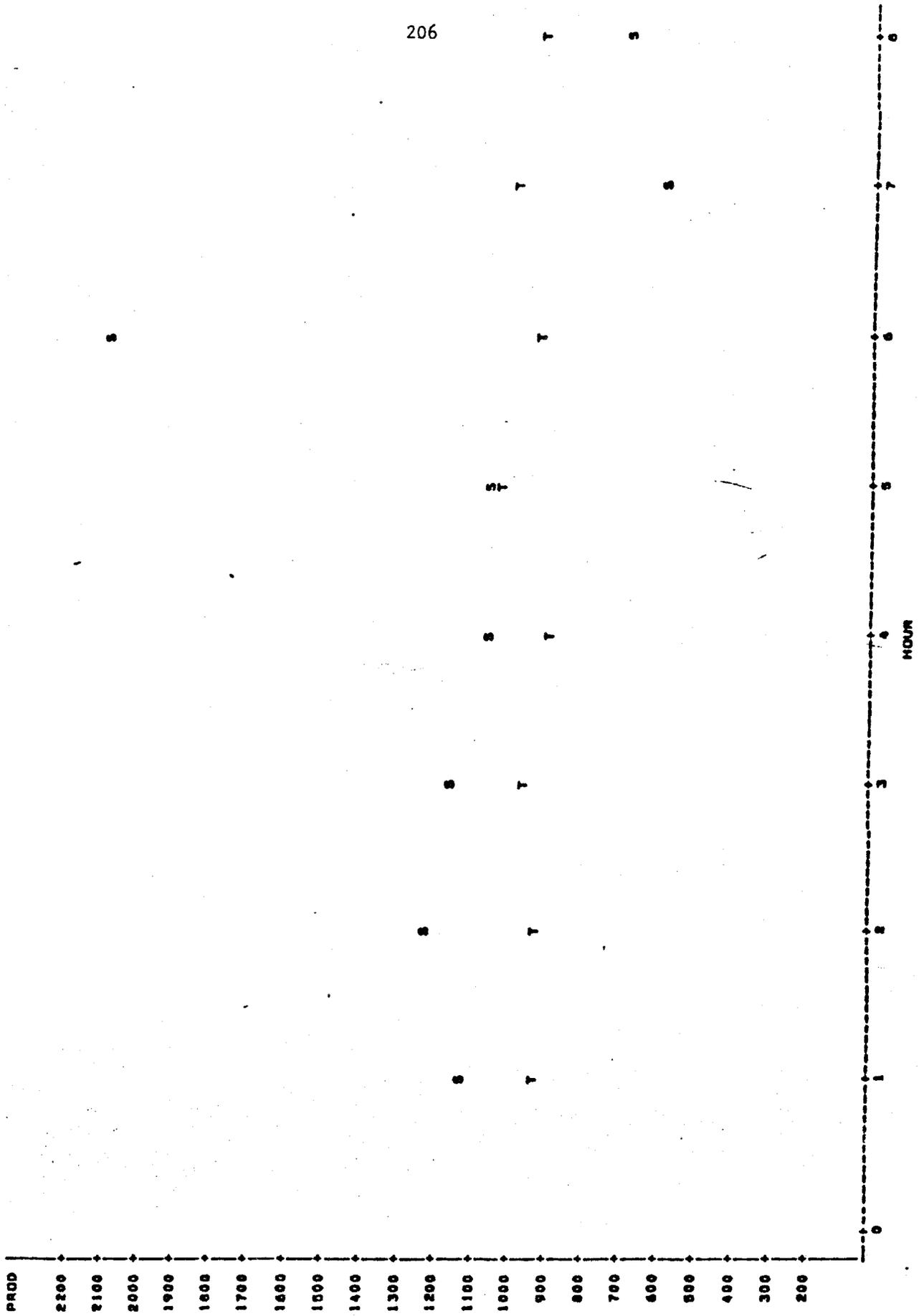
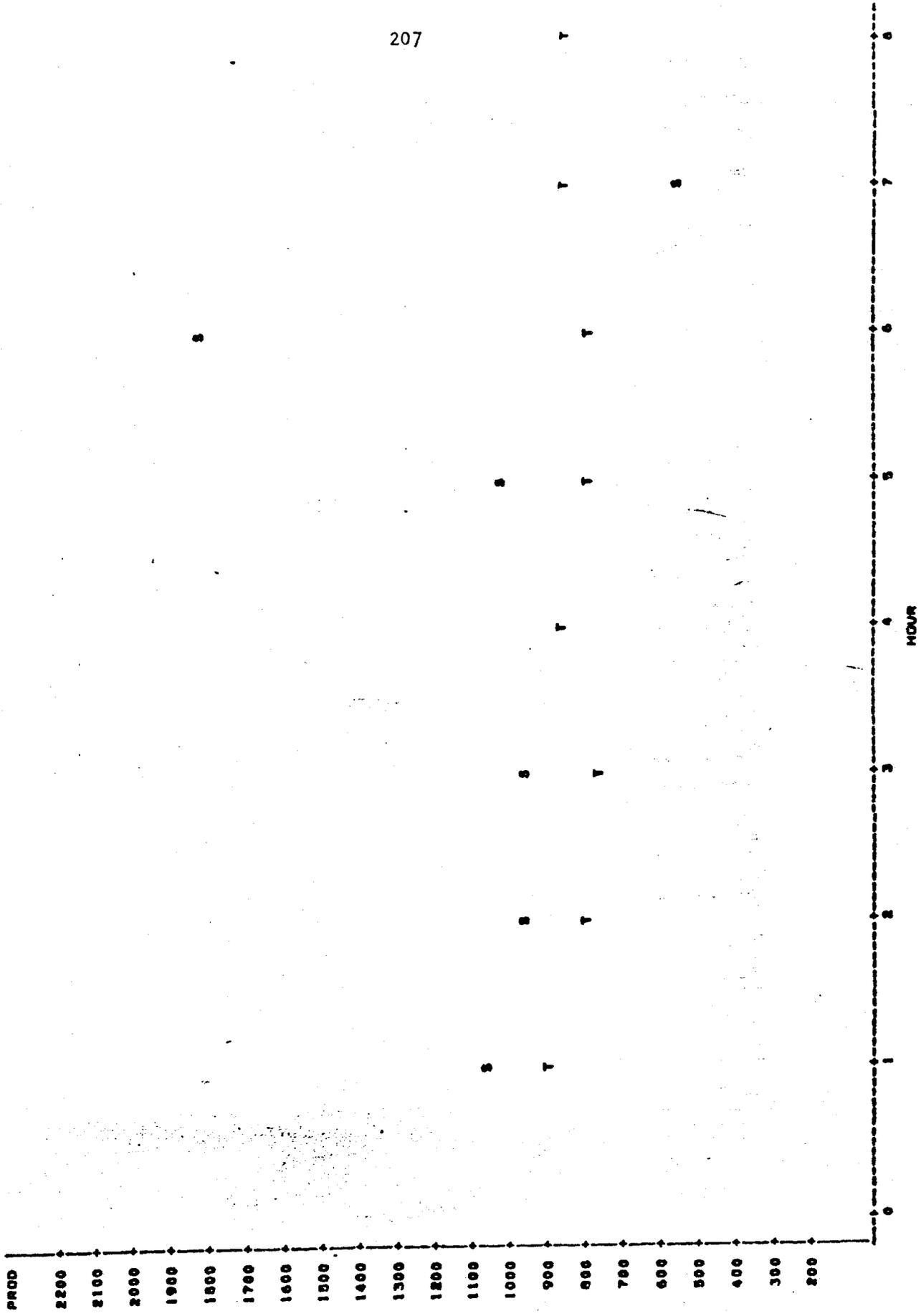


FIGURE II.8

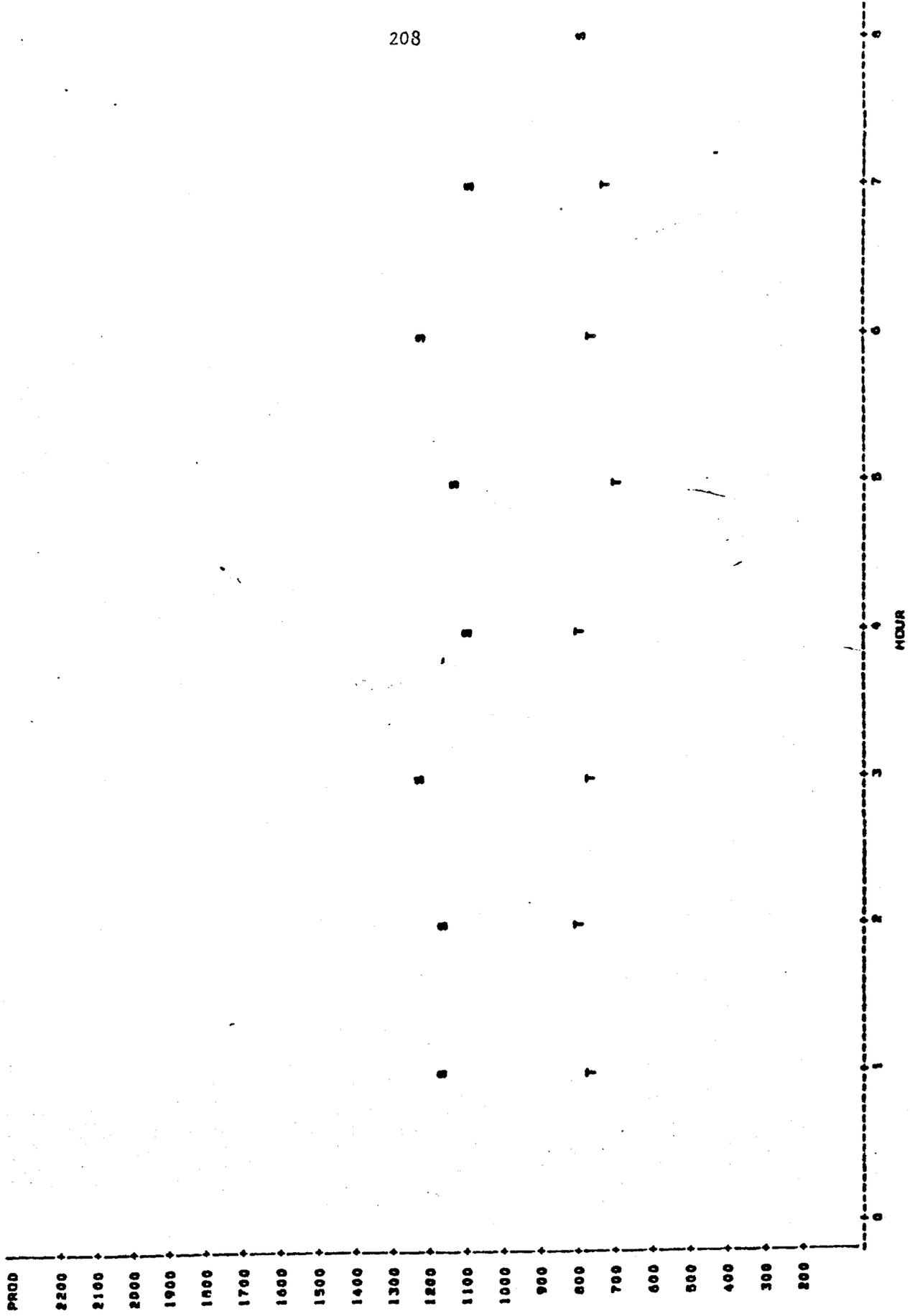
SUBJECT 6 - DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTES: 1. OBS HIDDEN

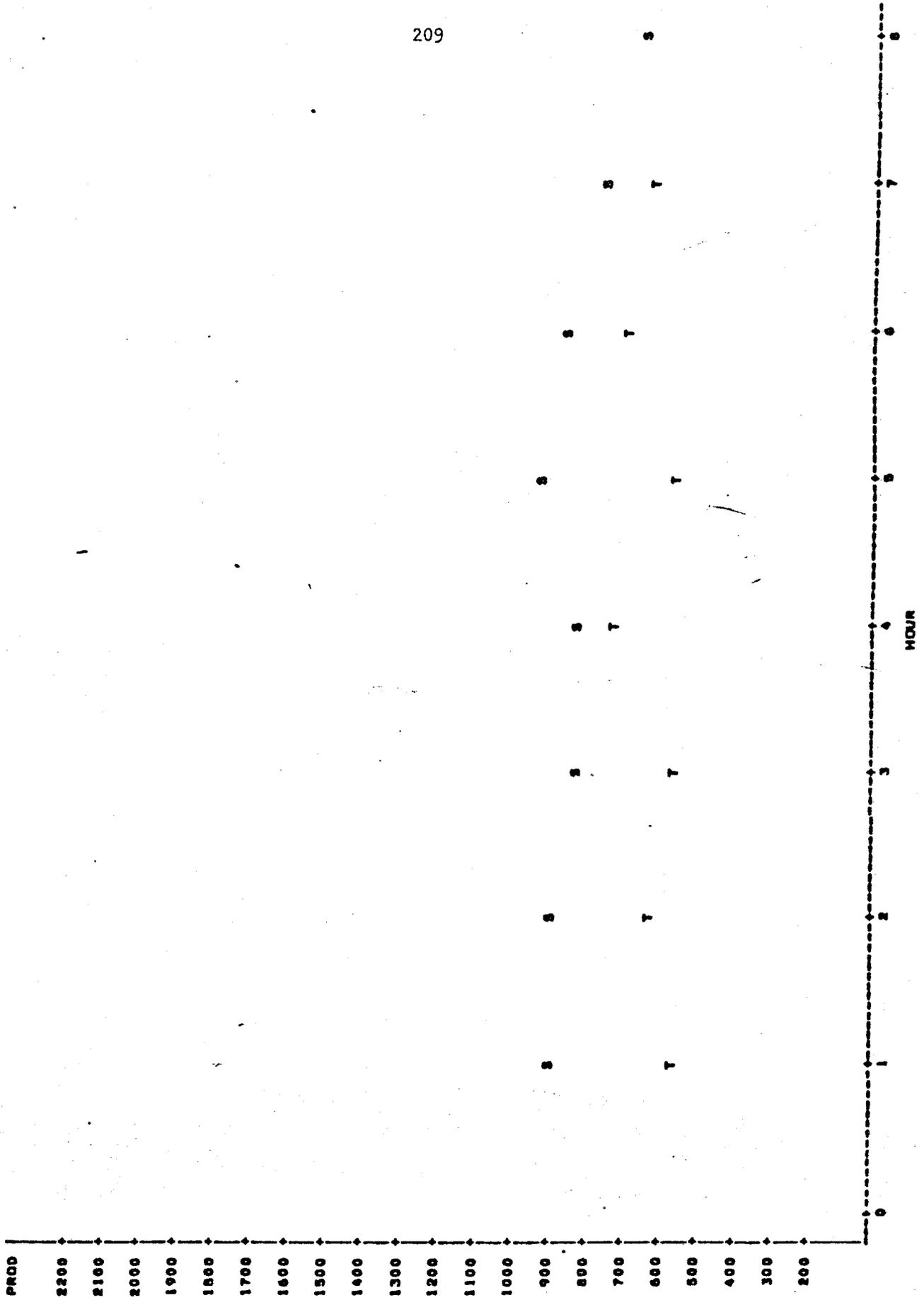
FIGURE II.9

SUBJECT 1 . DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



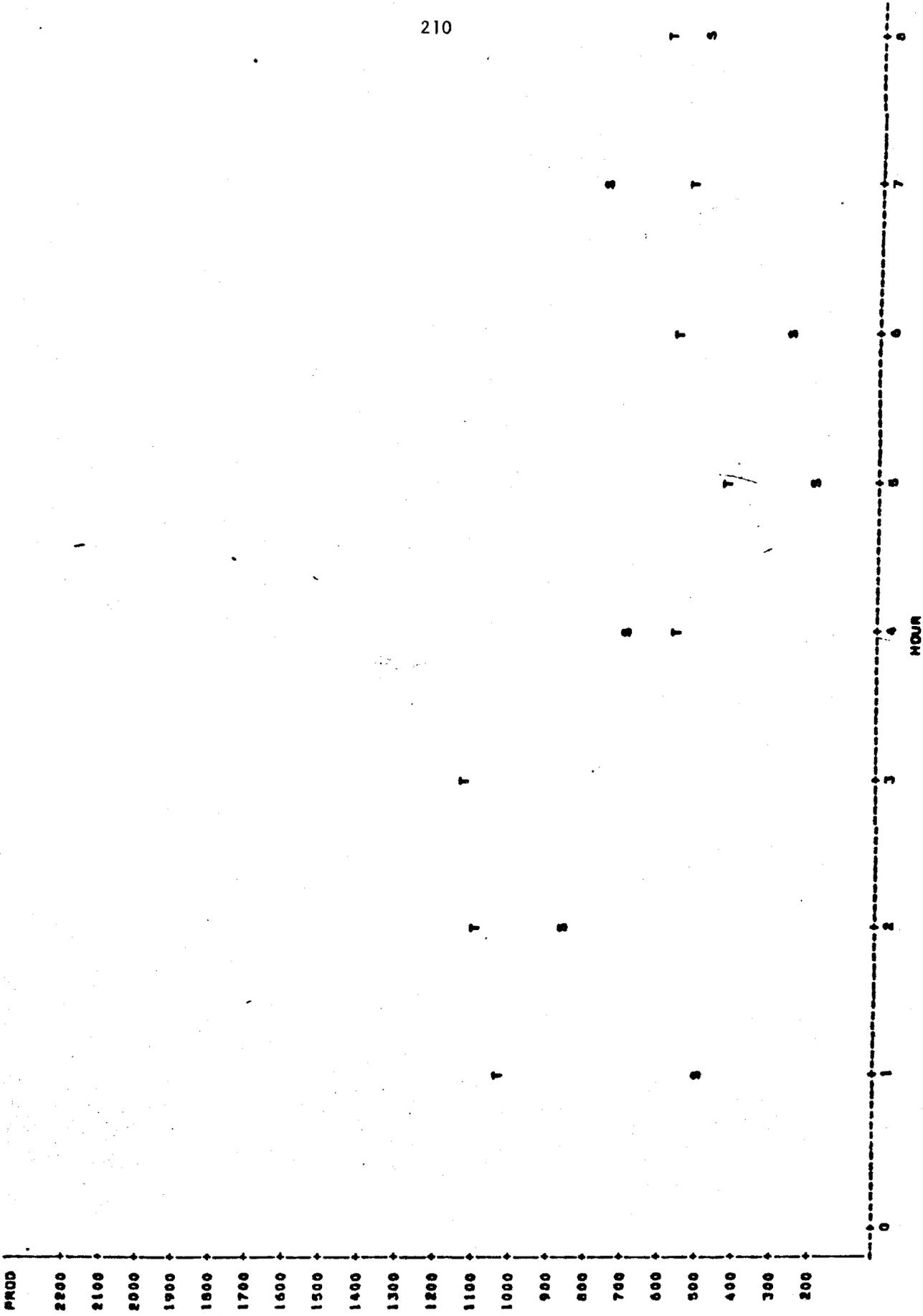
SUBJECT 2 • DAYS 3 AND 4
S-SELF TRIPPING
T-TWO HAND CONTROL

FIGURE II.10



SUBJECT 3 - DAYS 3 AND 4
 S-SELF TRIPPING
 T-TWO HAND CONTROL

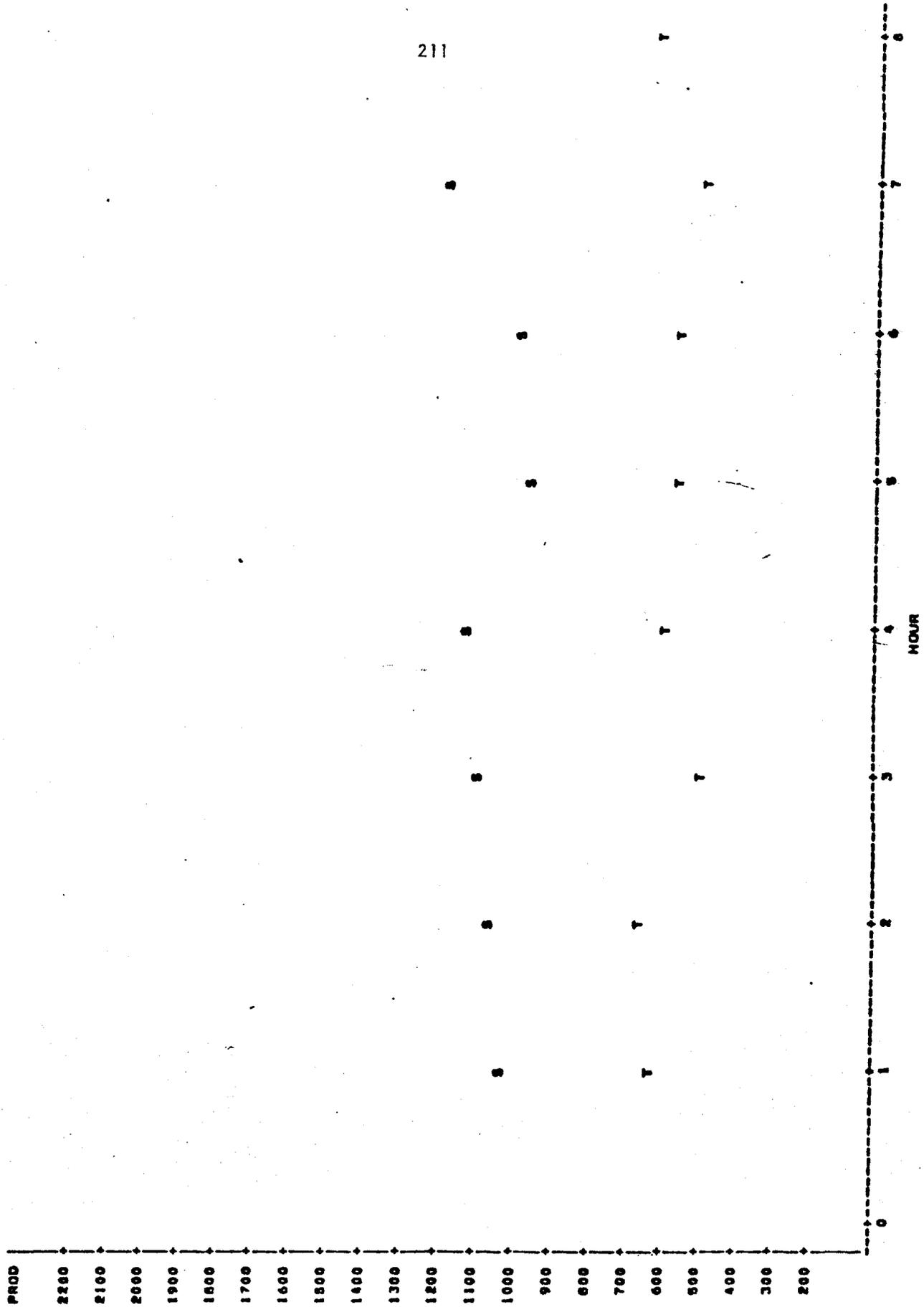
FIGURE II.11



NOTE: 1 OBS HAD MISSING VALUE

SUBJECT 4 - DAYS 3 AND 4
S-SELF TRIPPING
T-TWO HAND CONTROL

FIGURE II.12



SUBJECT 5 - DAYS 3 AND 4
S-SELF TRIPPING
T-TWO HAND CONTROL

FIGURE II.13

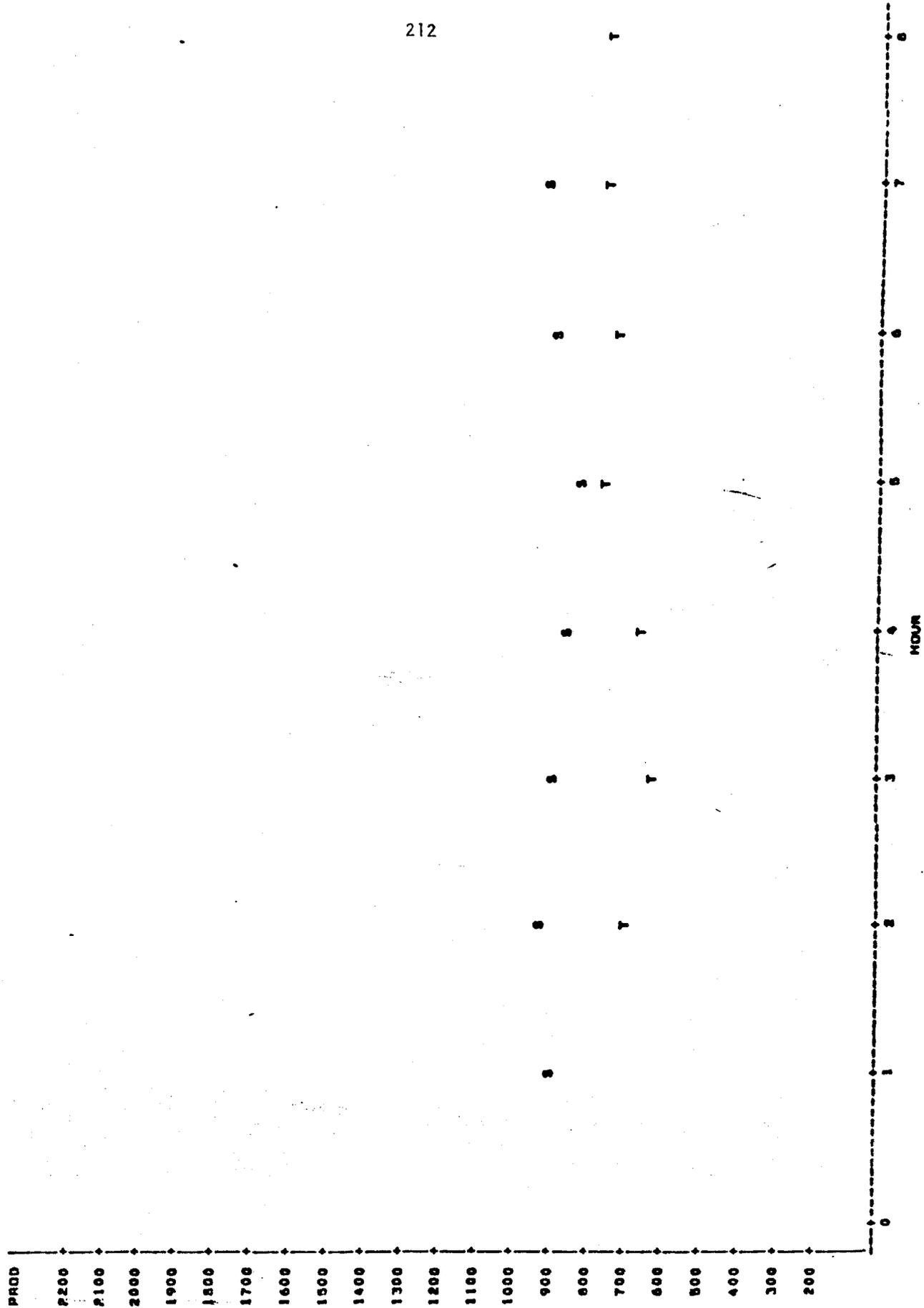
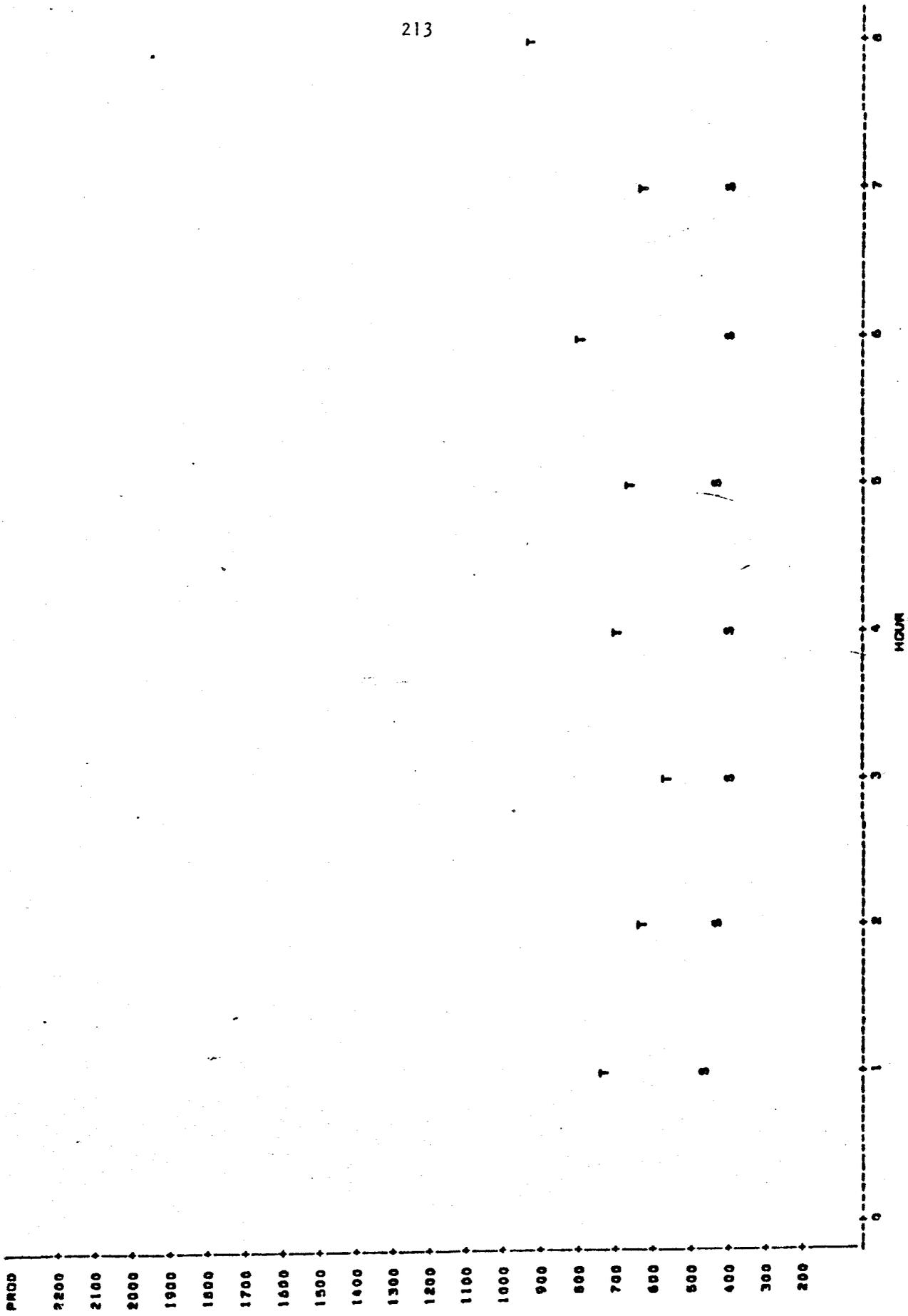


FIGURE II.14

SUBJECT 6 . DAYS 3 AND 4

S=SELF TRIPPING
T=TYO HAND CONTROL



14.2

APPENDIX G: Computer Program for Monitoring
and Recording Physiological Data

- G.1. Computer Program
- G.2. A sample of program output of recorded physiological data.

TYPE JS3TEST

```

CHANTASK 16,4
EXTERNAL VARS,MONTR,FAIL
COMMON/PLACE/IFIN,KAT,MBP,SYS,DIAS,HR
COMMON SUMRY(1,8),ISTOP
COMMON/SENSE/IRSMP,INUM
DIMENSION IAR(3)
INTEGER SUMRY
INTEGER SYS,DIAS,HR
CALL INIT('MTO',0,IER)
TYPE* *
TYPE*DATA TAPE SHOULD BE LOADED; INDICATOR SET TO ON-LINE.*
TYPE* *
TYPE*AFTER PAUSE, TO EACH REQUEST REGARDING TIME,*
TYPE*INPUT APPROPRIATE NUMBER AND HIT RETURN.*
TYPE* *
TYPE* *
PAUSE
TYPE* *
TYPE* *
80 ACCEPT*TIME IN HOURS=',IAR(1)
ACCEPT*TIME IN MINUTES=',IAR(2)
ACCEPT*TIME IN SECONDS=',IAR(3)
TYPE* *
TYPE* *
TYPE*MISTAKE? ENTER THE NUMBER ONE AND THE ABOVE REQUESTS*
TYPE*WILL BE REPEATED. OTHERWISE, STRIKE ANY OTHER KEY*
TYPE*FOR PAUSE. AFTER PAUSE, CONSOLE WILL REQUEST MTO FILE#.*
TYPE* *
TYPE* *
CALL HGTCHR(0,ICHAR,IER)
IF(ICHAR.EQ.49) GO TO 80
CALL STIME(IAR,IER)
PAUSE
81 TYPE* *
TYPE* *
TYPE*WHEN ASKED, ENTER THE MTO FILE# AND HIT RETURN.*
TYPE*NOTE: FILE# RANGE EQUALS 0-14.*
TYPE* *
TYPE* *
ACCEPT*FILE# ON MTO TO BE OPENED=',IFNUM
TYPE* *
TYPE* *
TYPE*MISTAKE? ENTER THE NUMBER ONE. OTHERWISE, STRIKE*

```

TYPE REQUEST THE NUMBER OF SUBJECTS TO BE SAMPLED. ENTER
TYPE APPROPRIATE NUMBER BUT DO NOT HIT RETURN.

CALL HGICHR(0,ICHR,IER)

IF(ICHR.EQ.49) GO TO 81

215

TYPE *

TYPE *

IF(IFNUM.EQ.0) GO TO 82

GO TO(83,84,85,86,87,88,89,90,91,92,93,94,95,96)IFNUM

GO TO 81

82 CALL OPEN(2,"MT0:0",3,IER)

GO TO 100

83 CALL OPEN(2,"MT0:1",3,IER)

GO TO 100

84 CALL OPEN(2,"MT0:2",3,IER)

GO TO 100

85 CALL OPEN(2,"MT0:3",3,IER)

GO TO 100

86 CALL OPEN(2,"MT0:4",3,IER)

GO TO 100

87 CALL OPEN(2,"MT0:5",3,IER)

GO TO 100

88 CALL OPEN(2,"MT0:6",3,IER)

GO TO 100

89 CALL OPEN(2,"MT0:7",3,IER)

GO TO 100

90 CALL OPEN(2,"MT0:8",3,IER)

GO TO 100

91 CALL OPEN(2,"MT0:9",3,IER)

GO TO 100

92 CALL OPEN(2,"MT0:10",3,IER)

GO TO 100

93 CALL OPEN(2,"MT0:11",3,IER)

GO TO 100

94 CALL OPEN(2,"MT0:12",3,IER)

GO TO 100

95 CALL OPEN(2,"MT0:13",3,IER)

GO TO 100

96 CALL OPEN(2,"MT0:14",3,IER)

100 CALL DGOT(1,1,IER)

C

***LS BIT=DYNAMAP RESET/ENABLE

C BIT=1;DYNAMAP IS RESET

C BIT=0;DYNAMAP FUNCTIONS ACCORDING TO PANEL SPECIFICATION

C BITS 1 THROUGH 5;SOLENOID RESET/ENABLE

C IF BIT=1;SOLENOID IS ENABLED AND MUST BE DISENGAGED

C PRIOR TO ANY NEW SAMPLING

C

C

C ***IFIN=1; HEADER NOT FOUND

C IFIN=2; 27-11 NQR 48-48-58-32-46 SEQ FOUND

C IFIN=3; M-S-D DATA FOUND BUT NOT HR

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best available copy.



IFIN=4; NEITHER M-S-D NOR HR DATA FOUND
IFIN=5; HR DATA FOUND BUT NOT M-S-D
IFIN=6; ALL DATA FOUND BUT ZEROS PRESENT
IFIN=7; ALL DATA FOUND AND NON-ZERO

216

FAUSE

TYPE* *

TYPE* *

TYPE*HOW MANY SUBJECTS WILL BE SAMPLED?*

***ASSUMING SUBJECT NO.1 CORRESPONDS TO IVAL1, SUBJECT
NO.2 TO IVAL2, AND SUBJECT NO.3 TO IVAL3, WHERE THE
VALUES 2,4,8,16,32 ARE POSSIBLE AND CORRESPOND TO
SOLENOIDS 1,2,3,4 AND 5 RESPECTIVELY.

ISTOP=0

IRSMP=0

IWAIT=0

CALL HGTCHR(0,ICHR,IER)

IF(ICHR.EQ.49) GO TO 1

IF(ICHR.EQ.50) GO TO 2

IF(ICHR.EQ.51) GO TO 3

GO TO 99

TYPE* *

TYPE*MISTAKE? ENTER THE NUMBER ONE.*

TYPE*OTHERWISE, STRIKE ANY OTHER KEY.*

TYPE* *

TYPE*CONSOLE WILL VERIFY THAT NUMBER, AND THEN ASK FOR <VALUE>*

TYPE*OF SOLENOID FOR THAT SUBJECT. RESPOND BY ENTERING THE*

TYPE*APPROPRIATE NUMBER(2,4,8,16, OR 32) AND HIT RETURN.*

CALL HGTCHR(0,ICHR,IER)

IF(ICHR.EQ.49) GO TO 99

TYPE* *

TYPE*ONE SUBJECT WILL BE SAMPLED.*

INUM=1

TYPE* *

TYPE* *

ACCEPT*SOLENOID VALUE TO BE USED FOR SUBJECT ONE=*,IVAL1

TYPE* *

TYPE*MISTAKE? ENTER THE NUMBER ONE.*

TYPE*OTHERWISE, STRIKE ANY OTHER KEY.*

CALL HGTCHR(0,ICHR,IER)

IF(ICHR.EQ.49) GO TO 101

GO TO 6

TYPE* *

TYPE*MISTAKE? ENTER THE NUMBER ONE.*

TYPE*OTHERWISE, STRIKE ANY OTHER KEY.*

TYPE* *

TYPE*CONSOLE WILL VERIFY THAT NUMBER, AND THEN ASK FOR <VALUES>*

TYPE*OF SOLENOIDS FOR THOSE SUBJECTS. RESPOND BY ENTERING THE*

TYPE*APPROPRIATE NUMBERS(2,4,8,16, OR 32) AND HIT RETURN.*

CALL HGTCHR(0, ICHAR, IER)
IF(ICHAR.EQ.49) GO TO 99
TYPE* *
TYPE*TWO SUBJECTS WILL BE SAMPLED.* 217

102

INUM=2
TYPE* *
TYPE* *
ACCEPT*SOLENOID VALUE TO BE USED FOR SUBJECT ONE=*,IVAL1
ACCEPT*SOLENOID VALUE TO BE USED FOR SUBJECT TWO=*,IVAL2
TYPE* *
TYPE*MISTAKE? ENTER THE NUMBER ONE.*
TYPE*OTHERWISE, STRIKE ANY OTHER KEY.*
CALL HGTCHR(0, ICHAR, IER)
IF(ICHAR.EQ.49) GO TO 102

3

GO TO 6
TYPE* *
TYPE*MISTAKE? ENTER THE NUMBER ONE.*
TYPE*OTHERWISE, STRIKE ANY OTHER KEY.*
TYPE* *
TYPE*CONSOLE WILL VERIFY THAT NUMBER, AND THEN ASK FOR <VALUES>
TYPE*OF SOLENOIDS FOR THOSE SUBJECTS. RESPOND BY ENTERING THE
TYPE*APPROPRIATE NUMBERS(2,4,8,16, OR 32) AND HIT RETURN.*
CALL HGTCHR(0, ICHAR, IER)
IF(ICHAR.EQ.49) GO TO 99

103

TYPE* *
TYPE*THREE SUBJECTS WILL BE SAMPLED.*
INUM=3
TYPE* *
TYPE* *
ACCEPT*SOLENOID VALUE TO BE USED FOR SUBJECT ONE=*,IVAL1
ACCEPT*SOLENOID VALUE TO BE USED FOR SUBJECT TWO=*,IVAL2
ACCEPT*SOLENOID VALUE TO BE USED FOR SUBJECT THREE=*,IVAL3
TYPE* *
TYPE*MISTAKE? ENTER THE NUMBER ONE.*
TYPE*OTHERWISE, STRIKE ANY OTHER KEY.*
CALL HGTCHR(0, ICHAR, IER)
IF(ICHAR.EQ.49) GO TO 103

6

TYPE* *
TYPE* *
TYPE*FOLLOWING THE NEXT PAUSE, THE EXPERIMENT WILL
TYPE*BEGIN(OR RESUME). CHECK POWER FOR DINAMAP AND SOLENOIDS.*
TYPE* *
PAUSE

8

CALL FTASK(FAIL, \$60, 4)
IVAL=IVAL1
ISUB=1
K=0

10

CALL FTASK(VALS, \$50, 2)
KAT=0
CALL DGOT(1, IVAL, IER)
CALL RES(KAT, ICONTINUE)

```

      CALL HGT(1,1,IER)
IF(IFIN.EQ.7) GO TO 14          218
N=N+1
IF(N.GT.1) GO TO 14
IF(IFIN.LE.5) GO TO 11
IF(IFIN.EQ.6) GO TO 12
11  TYPE* *
    TYPE*PROBLEM WITH DATA TRANSMISSION.*
    TYPE*ANOTHER SAMPLE WILL BE ATTEMPTED.*
    IRSMP=1
    CALL WAIT(40,2,IER)
    GO TO 10
12  TYPE* *
    TYPE*ZERO READINGS; CHECK CUFF PLACEMENT AND CONNECTIONS.*
    TYPE*ANOTHER SAMPLE WILL BE ATTEMPTED.*
    IRSMP=1
    CALL WAIT(40,2,IER)
    GO TO 10
14  IF(ISUB.EQ.1) GO TO 15
    IF(ISUB.EQ.2) GO TO 18
    IF(ISUB.EQ.3) GO TO 24
15  SUMRY(1,1)=MBP
    SUMRY(1,2)=SYS
    SUMRY(1,3)=DIAS
    SUMRY(1,4)=HR
    SUMRY(1,5)=IFIN
    SUMRY(1,6)=ISUB
    CALL FGTIM(IHR,IMIN,ISEC)
    SUMRY(1,7)=IHR
    SUMRY(1,8)=IMIN
    CALL FTASK(MONTR,$55,3)
    CALL DELAY(IWAIT)
    CALL WAIT(IWAIT,2,IER)
    IF(ISTOP.EQ.1) GO TO 16
    IF(ISTOP.EQ.2) GO TO 75
    IF(INUM.GE.2) GO TO 17
    GO TO 8
16  PAUSE
    TYPE* *
    TYPE* *
    TYPE*IF A CHANGE IN THE NUMBER OF SUBJECTS/(SOLENOIDS) IS NEC-
    TYPE*ESSARY, ENTER A ONE. OTHERWISE, STRIKE ANY OTHER KEY FOR
    TYPE*PAUSE. RESPONSE MEANS BREAK IS OVER.*
    CALL HGTCHR(0,ICHAR,IER)
    IF(ICHAR.EQ.49) GO TO 99
    TYPE* *
    PAUSE
    ISTOP=0
    IF(INUM.GE.2) GO TO 17

```

```

GO TO 8
ISUB=2
IVAL=IVAL2
GO TO 8
SUMRY(1,1)=MBP
SUMRY(1,2)=SYS
SUMRY(1,3)=DIAS
SUMRY(1,4)=HR
SUMRY(1,5)=IFIN
SUMRY(1,6)=ISUB
CALL FGTIM(IHR,IMIN,ISEC)
SUMRY(1,7)=IHR
SUMRY(1,8)=IMIN
CALL FTASK(MONTR,$55,3)
CALL DELAY(IWAIT)
CALL WAIT(IWAIT,2,IER)
IF(ISTOP.EQ.1) GO TO 19
IF(ISTOP.EQ.2) GO TO 75
IF(INUM.GE.3) GO TO 20
ISUB=1
IVAL=IVAL1
GO TO 8
PAUSE
TYPE* *
TYPE* *
TYPE*IF A CHANGE IN THE NUMBER OF SUBJECTS/(SOLENOIDS) IS NEC-
TYPE*ESSARY, ENTER A ONE. OTHERWISE, STRIKE ANY OTHER KEY FOR
TYPE*PAUSE. RESPONSE MEANS BREAK IS OVER.*
CALL HGTCHR(0,ICHAR,IER)
IF(ICHAR.EQ.49) GO TO 99
TYPE* *
PAUSE
ISTOP=0
IF(INUM.GE.3) GO TO 20
ISUB=1
IVAL=IVAL1
GO TO 8
ISUB=3
IVAL=IVAL3
GO TO 8
SUMRY(1,1)=MBP
SUMRY(1,2)=SYS
SUMRY(1,3)=DIAS
SUMRY(1,4)=HR
SUMRY(1,5)=IFIN
SUMRY(1,6)=ISUB
CALL FGTIM(IHR,IMIN,ISEC)
SUMRY(1,7)=IHR
SUMRY(1,8)=IMIN
CALL FTASK(MONTR,$55,3)
CALL DELAY(IWAIT)
CALL WAIT(IWAIT,2,IER)

```

```

CALL REGRNTYTCOURTIRCE?
UNLES=WHI? \AWDIT?ALN/
IF(ISTOP.EQ.1) GO TO 25
IF(ISTOP.EQ.2) GO TO 75
ISUB=1
IVAL=IVAL1
GO TO 8
25 PAUSE
TYPE* *
TYPE* *
TYPE*IF A CHANGE IN THE NUMBER OF SUBJECTS/(SOLENOIDS) IS NEC-
TYPE*ESSARY, ENTER A ONE. OTHERWISE, STRIKE ANY OTHER KEY FOR
TYPE*PAUSE. RESPONSE MEANS BREAK IS OVER.*
CALL HGTCHR(0,ICHR,IER)
IF(ICHR.EQ.49) GO TO 99
TYPE* *
PAUSE
ISTOP=0
ISUB=1
IVAL=IVAL1
GO TO 8
50 TYPE*NOT ENOUGH VARS TCBS*
55 TYPE*NOT ENOUGH MONTR TCBS*
60 TYPE*NOT ENOUGH FAIL TCBS*
75 PAUSE
DO 76 J=1,8
SUMRY(1,J)=1
76 CONTINUE
WRITE(2,77)(SUMRY(1,J),J=1,8)
77 FORMAT(1X,I3,2X,I3,2X,I3,2X,I3,3X,I1,3X,I1,2X,I3,2X,I3)
CALL AKILL(4)
CALL CLOSE(2,IER)
CALL RLSE("MTO",IER)
TYPE* *
TYPE* *
TYPE*MAGTAPE FILE CLOSED AND MTO RELEASED.*
TYPE*TOGGLE STOP/RESET.*
TYPE*HIT ON-LINE AND REWIND.*
TYPE*NOTE WHICH MAGTAPE FILE GETS OPENED NEXT.*
TYPE*RESET SWITCHES TO 10022.*
TYPE*TURN OFF POWER TO DINAMAP AND SOLENOIDS.*
STOP
END

```

TYPE TEST2

```
TASK VARS
COMMON/PLACE/IFIN,KAT,MBP,SYSD,DIAS,HR
DIMENSION II(120)
DIMENSION III(60)
INTEGER SYSD,DIAS,HR
MSDS=0
DO 3 J=1,18
CALL HGTCHR(1,ICHR,IER)
TYPE*ICHR=" ",ICHR
III(J)=ICHR
CONTINUE
ISUM=III(J)+III(J-1)+III(J-2)
IF(ISUM.EQ.30) GO TO 5
J=J+1
IF(J.GT.50) GO TO 997
CALL HGTCHR(1,ICHR,IER)
III(J)=ICHR
TYPE*ICHRB=" ",ICHR
GO TO 4
CALL HGTCHR(1,ICHR,IER)
TYPE*ICHR=" ",ICHR
IF(ICHR.NE.27) GO TO 5
II(1)=ICHR
DO 8 J=2,58
CALL HGTCHR(1,ICHR,IER)
II(J)=ICHR
TYPE*ICHR1=" ",ICHR
CONTINUE
N=0
DO 10 J=1,5,2
IF(II(J).EQ.II(J+2)) N=N+1
CONTINUE
IF(N.EQ.3)GO TO 50
CONTINUE
DO 20 J=5,9
ICOMB=II(J)+II(J+1)+II(J+2)+II(J+3)+II(J+4)
IF(ICOMB.EQ.232) GO TO 30
CONTINUE
GO TO 998
IMARK=J
TYPE*IMARK=" ",J
GO TO 70
CONTINUE
```

CALL HGTCHR(1, ICHAR, IER)

***FOUR '2711' SEQUENCES HAVE BEEN FOUND

K=47

MBP=100*(II(K)-48)+10*(II(K+1)-48)+II(K+2)-48

IF((MBP.GE.0).AND.(MBP.LT.200.)) GO TO 55

K=K-1

ICOUNT=ICOUNT+1

IF(ICOUNT.EQ.5) GO TO 999

GO TO 52

ISPACE=II(K+3)

SYS=100*(II(K+4)-48)+10*(II(K+5)-48)+II(K+6)-48

ISLASH=II(K+7)

DIAS=100*(II(K+8)-48)+10*(II(K+9)-48)+II(K+10)-48

ILF=II(K+11)

CONTINUE

IF(ISPACE.NE.32) GO TO 999

IF((SYS.LT.0).AND.(SYS.GT.250.)) GO TO 999

IF(ISLASH.NE.47) GO TO 999

IF(ILF.NE.10) GO TO 999

TYPE'MBP=',MBP

TYPE'SYS=',SYS

TYPE'DIAS=',DIAS

GO TO 80

ICOUNT=1

K=IMARK+38

GO TO 52

***ASSUMING REMAINING OUTPUT(CHARACTERS) HAVE
REMAINED IN BUFFER

DO 85 K=59,61

CALL HGTCHR(1, ICHAR, IER)

II(K)=ICHR

TYPE'K=',K

TYPE'ICHR2=',ICHR

CONTINUE

K=62

CALL HGTCHR(1, ICHAR, IER)

II(K)=ICHR

TYPE'ICHR2=',ICHR

TYPE'K=',K

TYPE'II(80)=',II(80)

ICOMB=II(K-2)+II(K-1)+II(K)

IF(ICOMB.EQ.30) GO TO 90

K=K+1

CALL HGTCHR(1, ICHAR, IER)

TYPE'ICHR2=',ICHR

II(K)=ICHR

GO TO 88

ICOUNT=1

MBP=100*(II(K)-48)+10*(II(K+1)-48)+II(K+2)-48

```

IF((HR.GE.0).AND.(HR.LT.200.)) GO TO 95
HR=10*(II(K-4)-48)+II(K-3)-48
IF((HR.GE.0).AND.(HR.LT.100.)) GO TO 95
K=K-1
ICOUNT=ICOUNT+1
IF(ICOUNT.EQ.7) GO TO 1000
GO TO 92
95 CONTINUE
X TYPE*HR=",HR
IF(MSDS.EQ.1) GO TO 994
GO TO 995
994 IFIN=5
GO TO 1002
995 IF(MBP.EQ.0) GO TO 996
IF(SYS.EQ.0) GO TO 996
IF(DIAS.EQ.0) GO TO 996
IF(HR.EQ.0) GO TO 996
IFIN=7
GO TO 1002
996 IFIN=6
GO TO 1002
997 TYPE*"COULD NOT FIND PROPER HEADER."
IFIN=1
GO TO 1003
998 TYPE*"COULD NOT FIND 27-11 NOR 48-48-58-32-46 SEQUENCES."
GO TO 1001
999 TYPE*"COULD NOT FIND COMPLETE MBP-SYS-DIAS SEQUENCE."
MSDS=1
GO TO 80
1000 TYPE*"COULD NOT FIND HR."
IF(MSDS.NE.1) IFIN=3
IF(MSDS.EQ.1) IFIN=4
GO TO 1002
1001 IFIN=2
1002 CONTINUE
X WRITE(10) II
GO TO 1004
1003 CONTINUE
1004 CALL XMT(KAT,IFIN,$9999)
9999 TYPE*"KAT ALREADY SET"
END

```

R

E TEST3

```

TASK MONTR
COMMON SUMRY(1,8),ISTOP
INTEGER SUMRY
TYPE* *
TYPE*MBF  SYS  DIAS  HR  IFIN  SUB  IHR  IMIN*
WRITE(2,70)(SUMRY(1,J),J=1,8)
WRITE(10,70)(SUMRY(1,J),J=1,8)
FORMAT(1X,I3,2X,I3,2X,I3,2X,I3,3X,I1,3X,I1,2X,I3,2X,I3)
CALL RDS(IVAL)
IMASK=000022K
IVAL=IVAL.AND.IMASK
IF(IVAL.EQ.16) GO TO 100
IF(IVAL.EQ.0) GO TO 120
GO TO 150
TYPE* *
TYPE*LUNCH BREAK OR OTHER TEMPORARY DELAY ENCOUNTERED.*
TYPE*MAGTAPE FILE WILL NOT BE CLOSED.*
TYPE*RESET SWITCHES TO 100022.*
TYPE*LEAVE POWER ON TO DINAMAP AND SOLENOIDS.*
TYPE* *
TYPE*A PAUSE STATEMENT WILL ARRIVE FOLLOWING THE RETURN*
TYPE*TO THE MAIN PROGRAM. RESPONDING TO THIS PAUSE*
TYPE*WILL CAUSE THE CONSOLE TO INQUIRE WHETHER A WORK-*
TYPE*BREAK IS IN EFFECT, OR WHETHER A CHANGE IN*
TYPE*SUBJECTS AND/OR SOLENOIDS IS NECESSARY.*
ISTOP=1
TYPE* *
TYPE* *
GO TO 150
TYPE* *
TYPE*END OF DAY OR OTHER PERMANENT SHUTDOWN ENCOUNTERED.*
TYPE*MAGTAPE FILE WILL BE CLOSED AND MTO RELEASED.*
TYPE* *
TYPE*A PAUSE STATEMENT WILL ARRIVE FOLLOWING THE RETURN*
TYPE*TO MAIN PROGRAM. RESPONSE WILL INITIATE SHUTDOWN.*
ISTOP=2
TYPE* *
TYPE* *
CALL AKILL(3)
STOP
END

```

JSFAIL

```
TASK FAIL
COMMON SUMRY(1,8),ISTOP
INTEGER SUMRY
CALL RDS(IVAL)
IMASK=000077K
IVAL=IVAL.AND.IMASK
IF(IVAL.EQ.63) GO TO 10
GO TO 5
DO 20 J=1,8
SUMRY(1,J)=1
CONTINUE
WRITE(2,30)(SUMRY(1,J),J=1,8)
FORMAT(1X,I3,2X,I3,2X,I3,2X,I3,3X,I1,3X,I1,2X,I3,2X,I3)
CALL DGOT(1,1,IER)
CALL CLOSE(2,IER)
CALL RLSE('MTO',IER)
TYPE* *
TYPE* *
TYPE*PROBLEM ENCOUNTERED. TOGGLE STOP/RESET.*
TYPE*TURN OFF POWER TO DINAMAP AND SOLENOIDS.*
TYPE*HIT ON-LINE AND REWIND.*
TYPE*NOTE WHICH FILE GETS OPENED NEXT OR USE NEW TAPE.*
TYPE*<USE A DIFFERENT SOLENOID> IF IT IS A SOLENOID PROBLEM.*
TYPE*RESET SWITCHES TO 100022.*
STOP
END
```

TYPE JS1DELAY

```
SUBROUTINE DELAY(IWAIT)
COMMON/SENSE/IRSMP,INUM
IF((IRSMP.EQ.0).AND.(INUM.EQ.3)) GO TO 10
IF((IRSMP.EQ.1).AND.(INUM.EQ.3)) GO TO 12
IF((IRSMP.EQ.0).AND.(INUM.EQ.2)) GO TO 14
IF((IRSMP.EQ.1).AND.(INUM.EQ.2)) GO TO 16
IF((IRSMP.EQ.0).AND.(INUM.EQ.1)) GO TO 18
IF((IRSMP.EQ.1).AND.(INUM.EQ.1)) GO TO 20
10  IWAIT=100
    GO TO 50
12  IWAIT=15
    GO TO 50
14  IWAIT=180
    GO TO 50
16  IWAIT=90
    GO TO 50
18  IWAIT=410
    GO TO 50
20  IWAIT=320
50  IRSMP=0
    RETURN
    END
```

R

G.2
DATA TAPE SHOULD BE LOADED; INDICATOR SET TO ON-LINE.

227

AFTER PAUSE, TO EACH REQUEST REGARDING TIME,
INPUT APPROPRIATE NUMBER AND HIT RETURN.

PAUSE
STRIKE ANY KEY TO CONTINUE.

TIME IN HOURS=15
TIME IN MINUTES=56
TIME IN SECONDS=10

MISTAKE? ENTER THE NUMBER ONE AND THE ABOVE REQUESTS
WILL BE REPEATED. OTHERWISE, STRIKE ANY OTHER KEY
FOR PAUSE. AFTER PAUSE, CONSOLE WILL REQUEST MTO FILE=.

PAUSE
STRIKE ANY KEY TO CONTINUE.

WHEN ASKED, ENTER THE MTO FILE= AND HIT RETURN.
NOTE: FILE= RANGE EQUALS 0-14.

FILE= ON MTO TO BE OPENED=0

MISTAKE? ENTER THE NUMBER ONE. OTHERWISE, STRIKE
ANY OTHER KEY FOR PAUSE. AFTER PAUSE, CONSOLE WILL
REQUEST THE NUMBER OF SUBJECTS TO BE SAMPLED. ENTER
APPROPRIATE NUMBER BUT DO NOT HIT RETURN.

PAUSE
STRIKE ANY KEY TO CONTINUE.

HOW MANY SUBJECTS WILL BE SAMPLED?

MISTAKE? ENTER THE NUMBER ONE.
OTHERWISE, STRIKE ANY OTHER KEY.

CONSOLE WILL VERIFY THAT NUMBER, AND THEN ASK FOR <VALUES>
OF SOLENOIDS FOR THOSE SUBJECTS. RESPOND BY ENTERING THE
APPROPRIATE NUMBERS (2, 4, 8, 16, OR 32) AND HIT RETURN.

THREE SUBJECTS WILL BE SAMPLED.

SOLENOID VALUE TO BE USED FOR SUBJECT ONE=2
SOLENOID VALUE TO BE USED FOR SUBJECT TWO=4
SOLENOID VALUE TO BE USED FOR SUBJECT THREE=8

MISTAKE? ENTER THE NUMBER ONE.
OTHERWISE, STRIKE ANY OTHER KEY.

FOLLOWING THE NEXT PAUSE, THE EXPERIMENT WILL
CHECK FOR DYNAMO AND SOLENOIDS.

APPENDIX H: QUESTIONNAIRES

DATE: 6/3/81DAY Wednesday

NAME : _____

SUBJECT NO : 1POWER PRESS TYPE : SELF TRIPPINGPUSH BUTTON

If you feel about the same as the statement, place an "X" in the "same as" column.

If you feel worse than the statement, place an "X" in the "worse than" column.

Remember, answer each question with regard to how you feel at this instant.

No.	Better than	Same as	Worse than	Statement
1.	()	()	(✓)	very lively
2.	(✓)	()	()	extremely tired
3.	()	()	(✓)	quite fresh
4.	()	(✓)	()	slightly pooped
5.	()	()	(✓)	extremely peppy
6.	()	(✓)	()	somewhat fresh
7.	()	(✓)	()	petered out
8.	()	()	(✓)	very refreshed
9.	()	(✓)	()	fairly well pooped
10.	(✓)	()	()	ready to drop

DATE: 6/3/DAY WED~~NAME~~ : _____

SUBJECT NO : _____ | _____

POWER PRESS TYPE : SELF TRIPPING ✓PUSH BUTTON _____

If you feel about the same as the statement, place an "X" in the "same as" column.

If you feel worse than the statement, place an "X" in the "worse than" column.

Remember, answer each question with regard to how you feel at this instant.

No.	Better than	Same as	Worse than	Statement
1.	()	(X)	()	very lively
2.	(X)	()	()	extremely tired
3.	()	(X)	()	quite fresh
4.	()	(X)	()	slightly pooped
5.	()	(X)	()	extremely peppy
6.	()	(X)	()	somewhat fresh
7.	(X)	()	()	petered out
8.	()	(X)	()	very refreshed
9.	(X)	()	()	fairly well pooped
10.	(X)	()	()	ready to drop

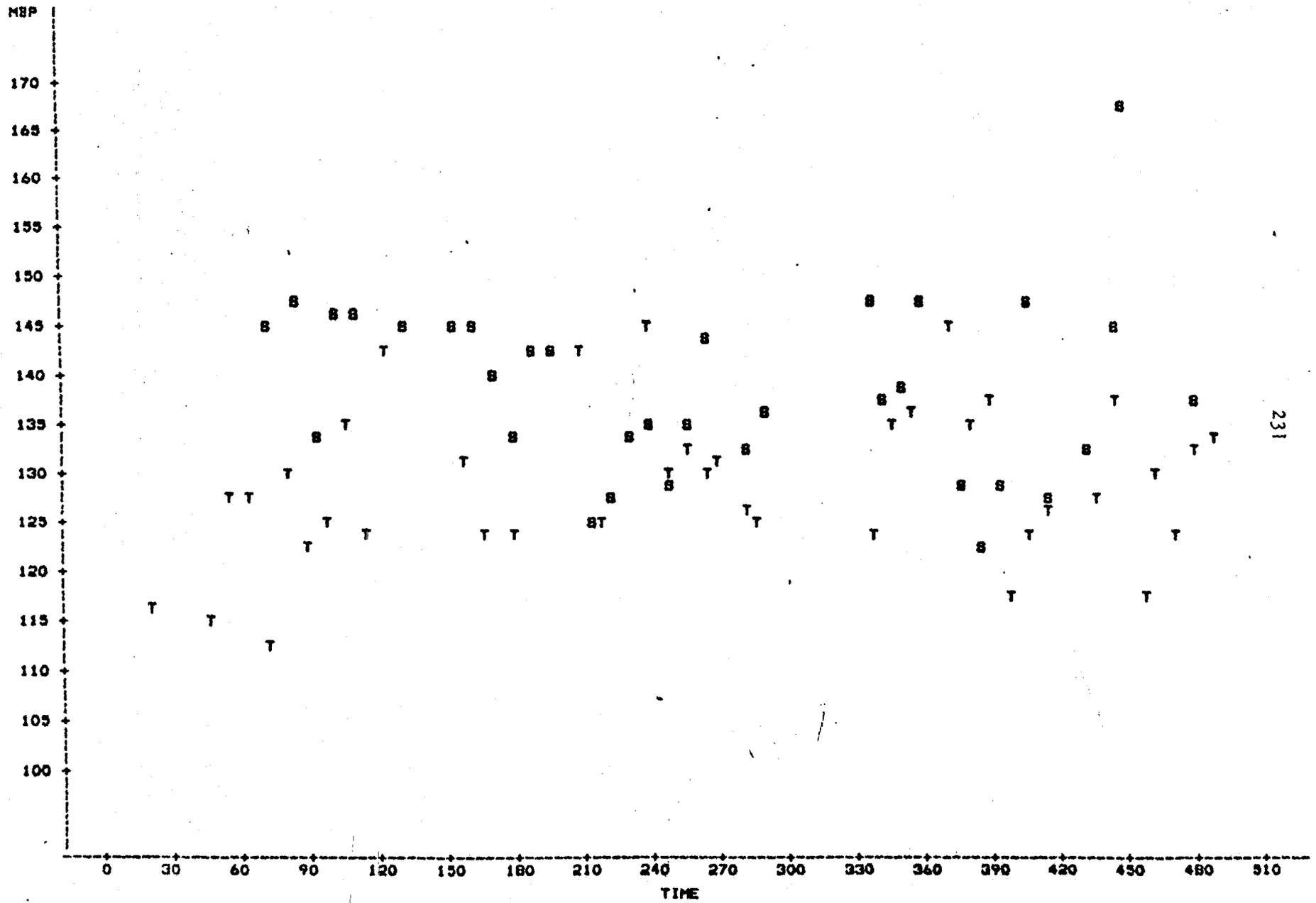
APPENDIX I: PHYSIOLOGICAL DATA PLOTS

Please Note:

1. Time values in all figures are in minutes.
2. "OBS" refers to the number of observations in the plots which have missing data.
3. Blood pressure units are in mm Hg.
4. Heart rate units are in beats/minutes.

Figure 1.1.

MSP VS TIME
SUBJECT 1, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

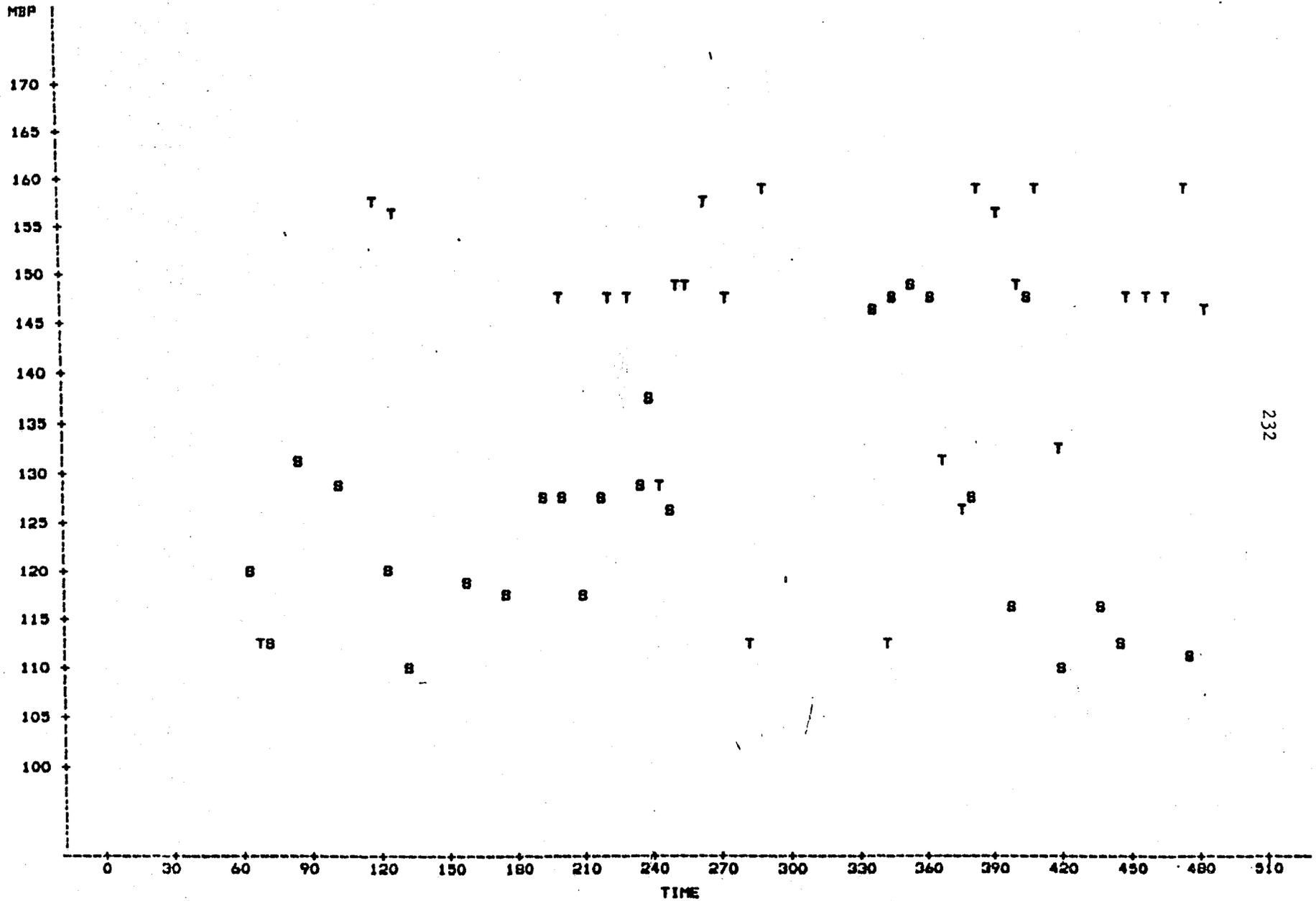


231

NOTE: 13 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

Figure 1.2.

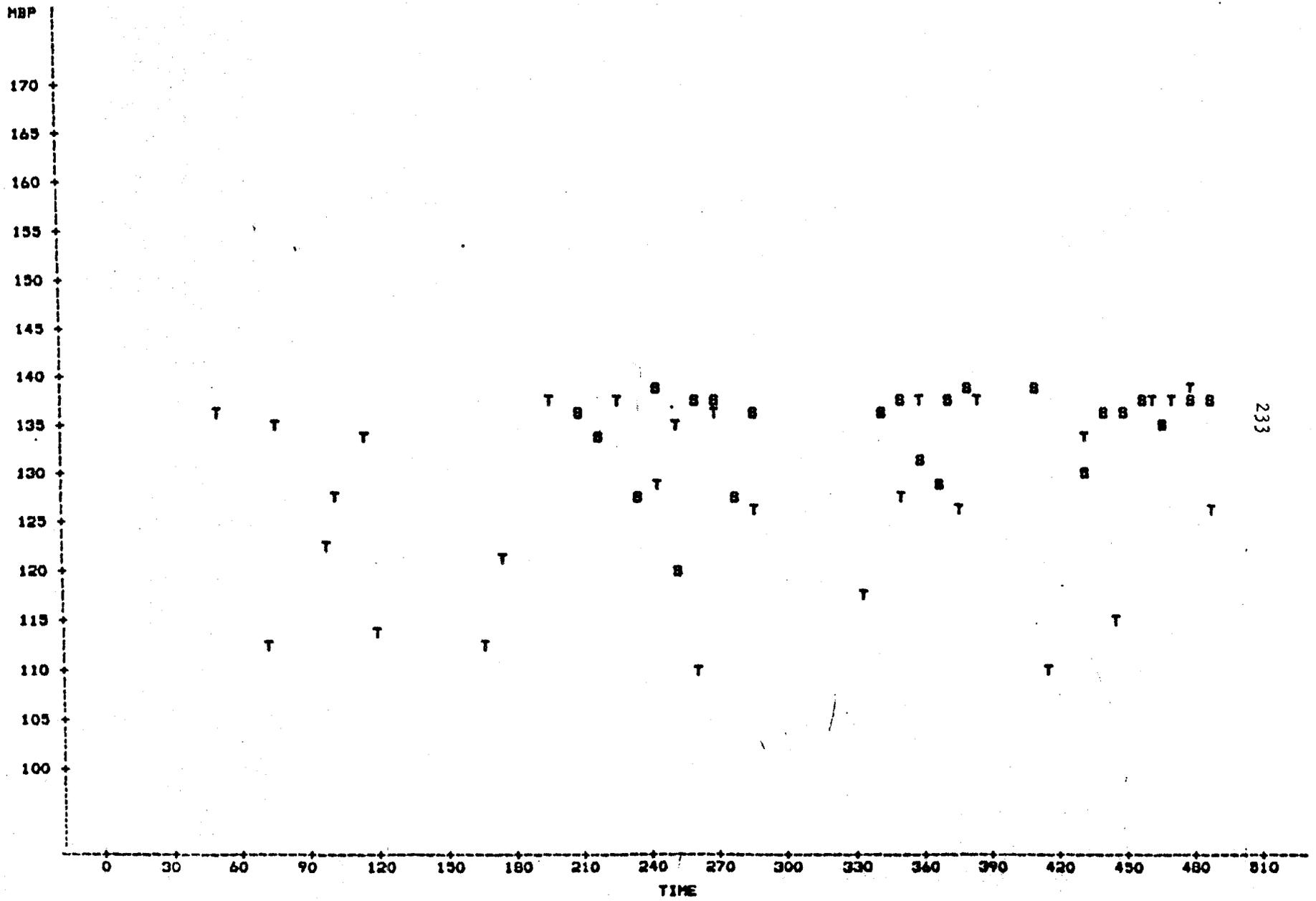
MBP VS TIME
SUBJECT 2, DAYS 1 AND 2
B=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 31 OBS HAD MISSING VALUES

Figure 1.3.

MBP VS TIME
SUBJECT 3, DAYS 1 AND 2
S=BELT TRIPPING
T=TWO HAND CONTROL

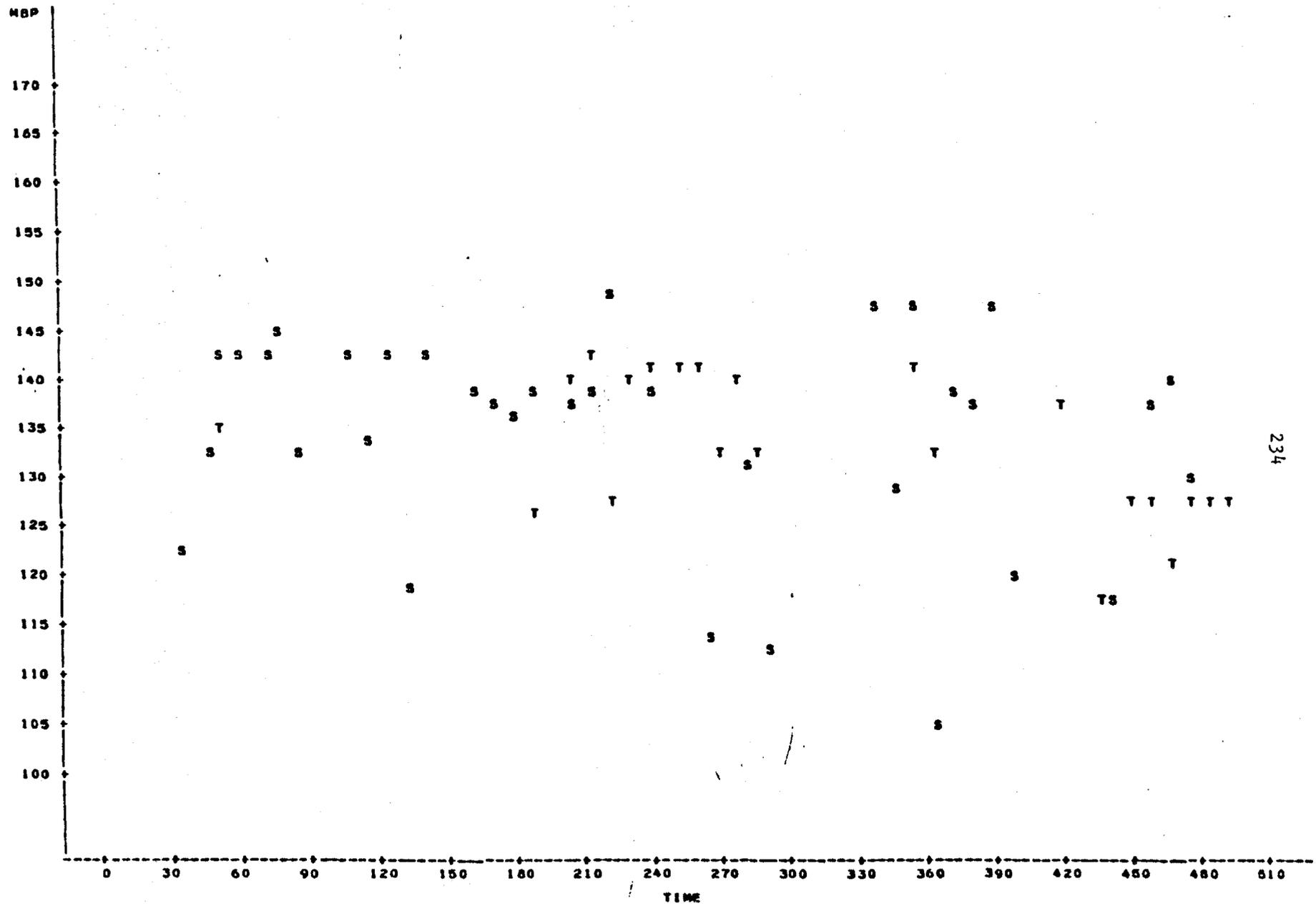


233

NOTE: 12 OBS HAD MISSING VALUES !

Figure 1.4.

HBP VS TIME
SUBJECT 4, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

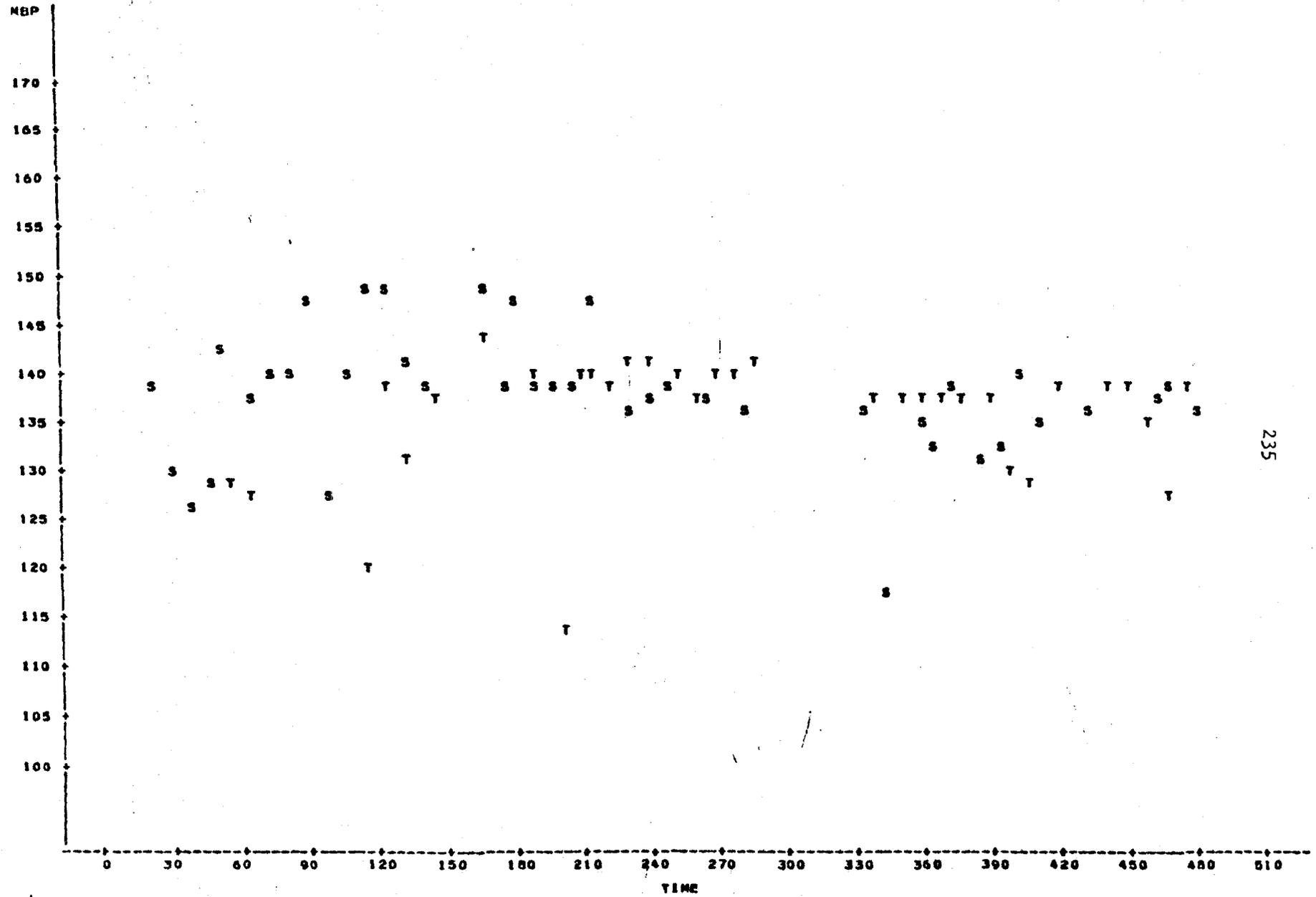


NOTE: 17 OBS HAD MISSING VALUES

234

Figure 1.5.

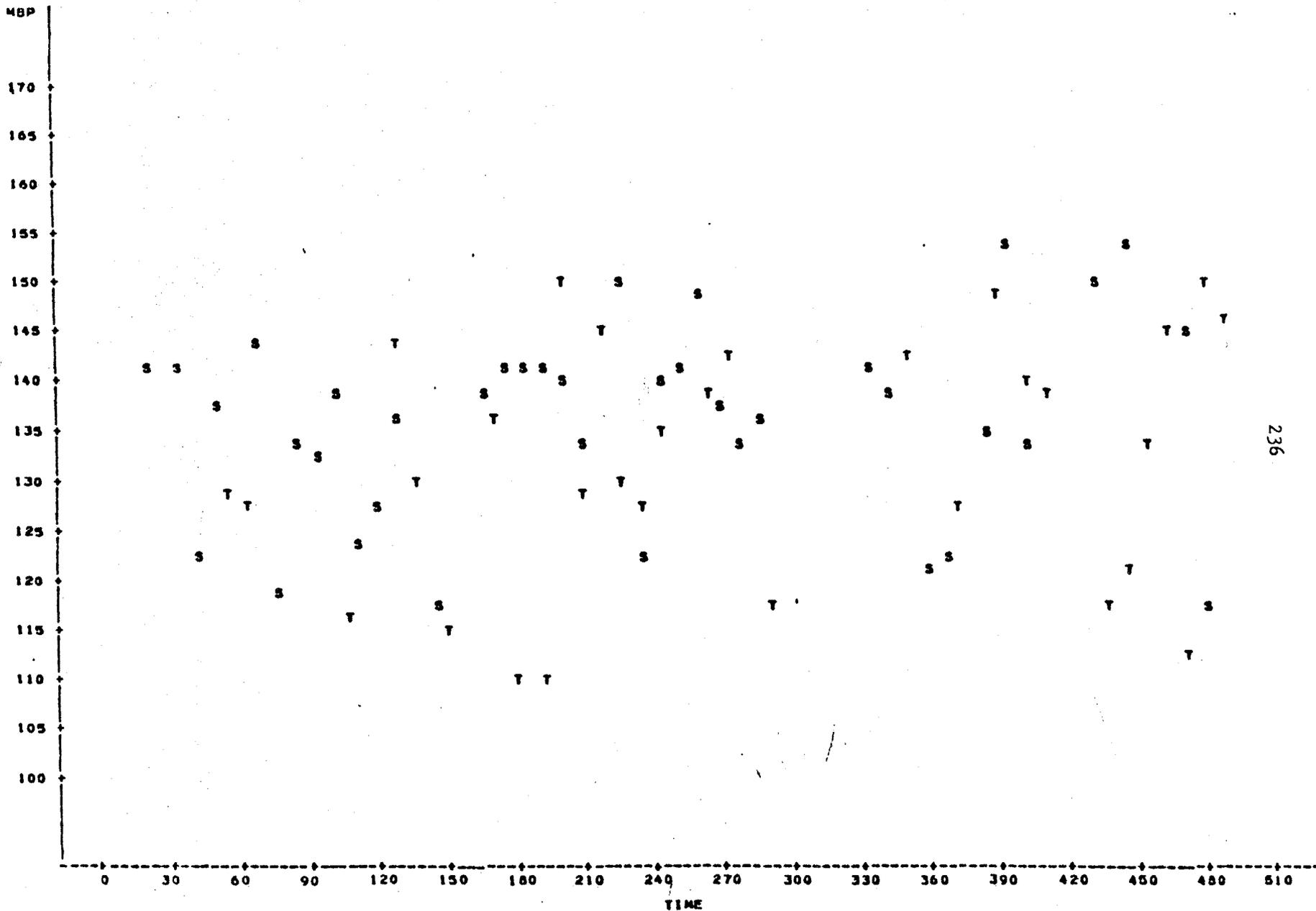
NBP VS TIME
SUBJECT S, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 6 OBS HAD MISSING VALUES

Figure 1.6.

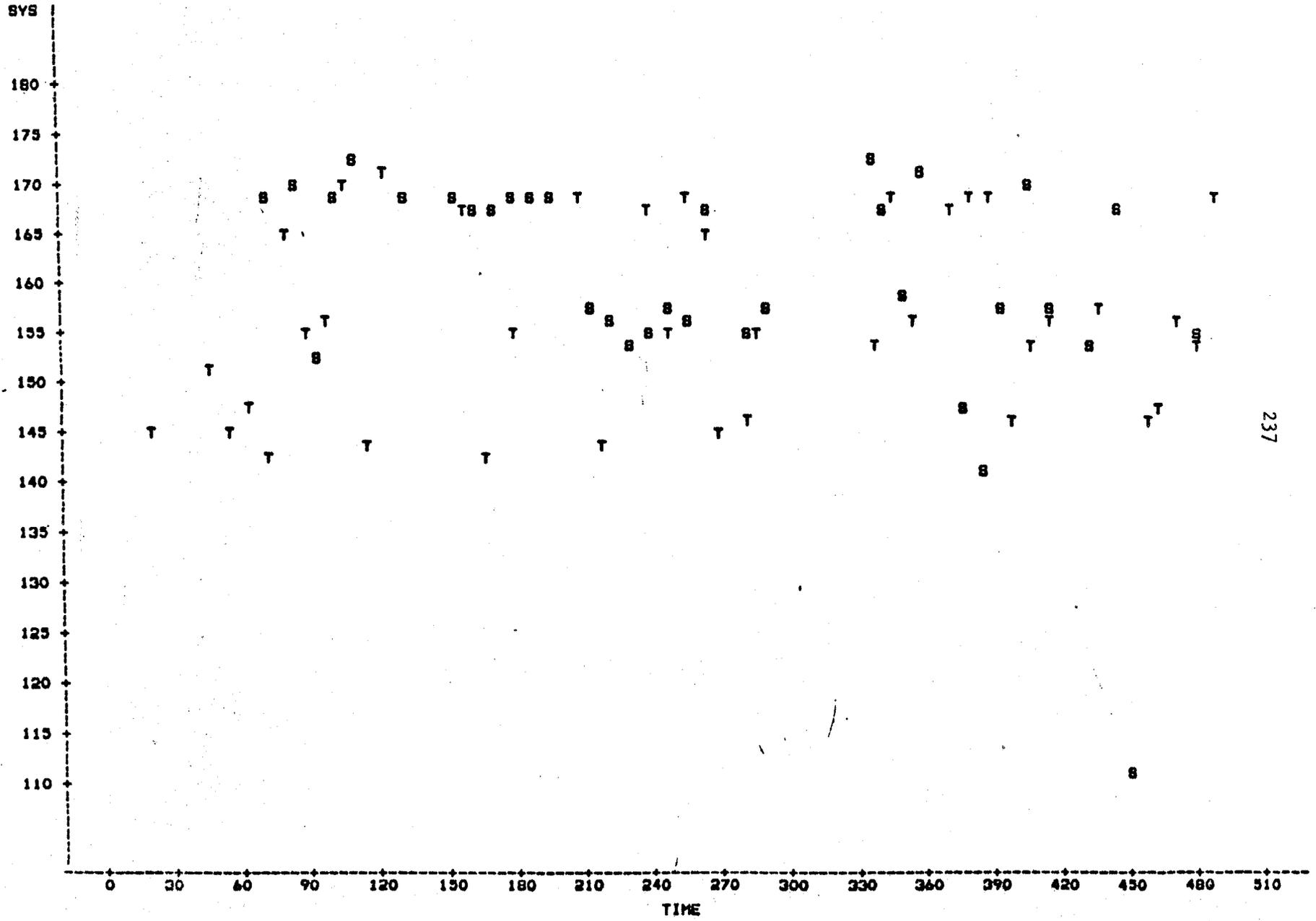
MBP VS TIME
SUBJECT 6, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



236

NOTE: 11 OBS HAD MISSING VALUES

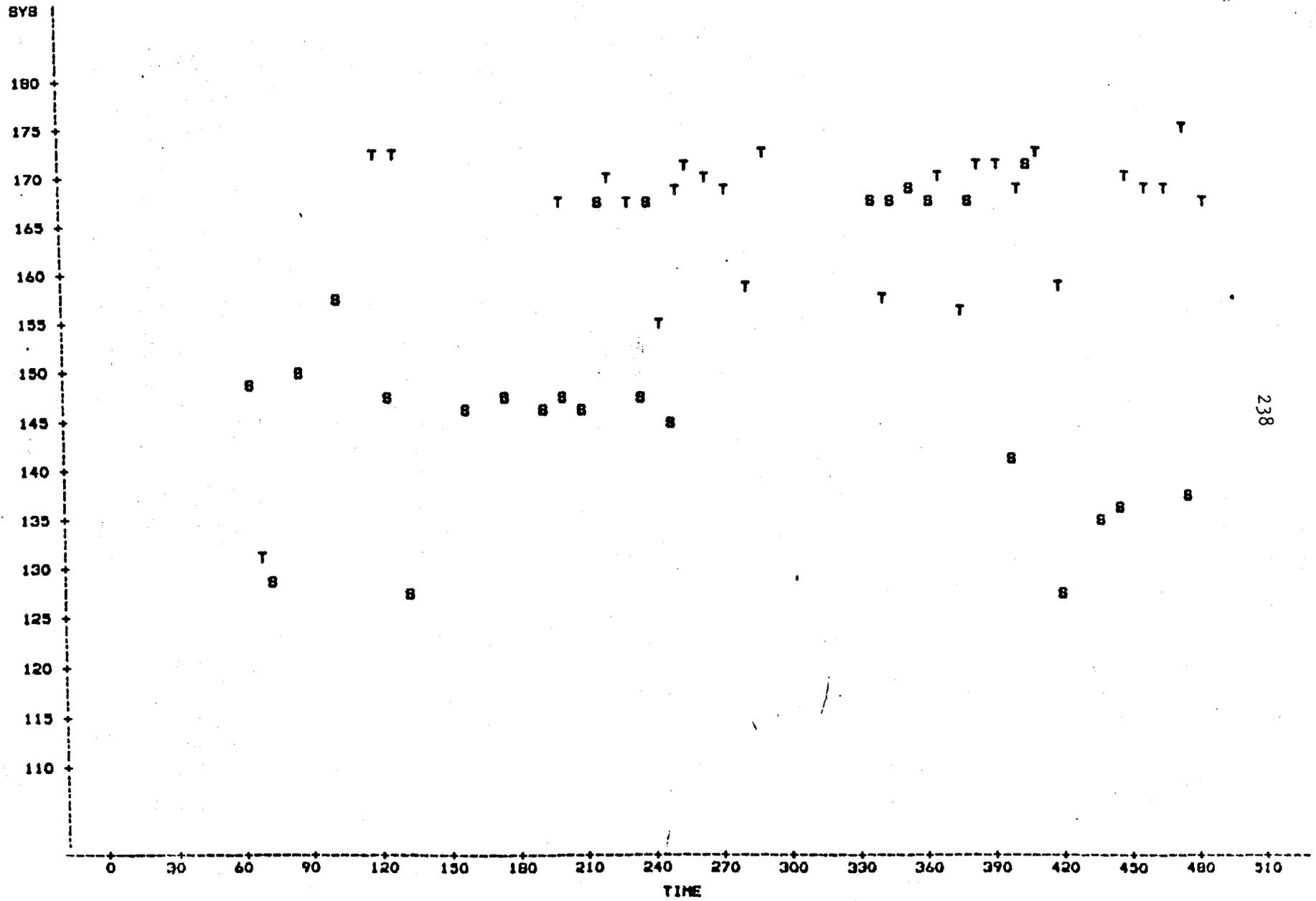
Figure 1.7. **SYSTOLIC VS TIME**
SUBJECT 1, DAYS 1 AND 2
B=BELT TRIPPING
T=TWO HAND CONTROL



NOTE: 13 OBS HAD MISSING VALUES

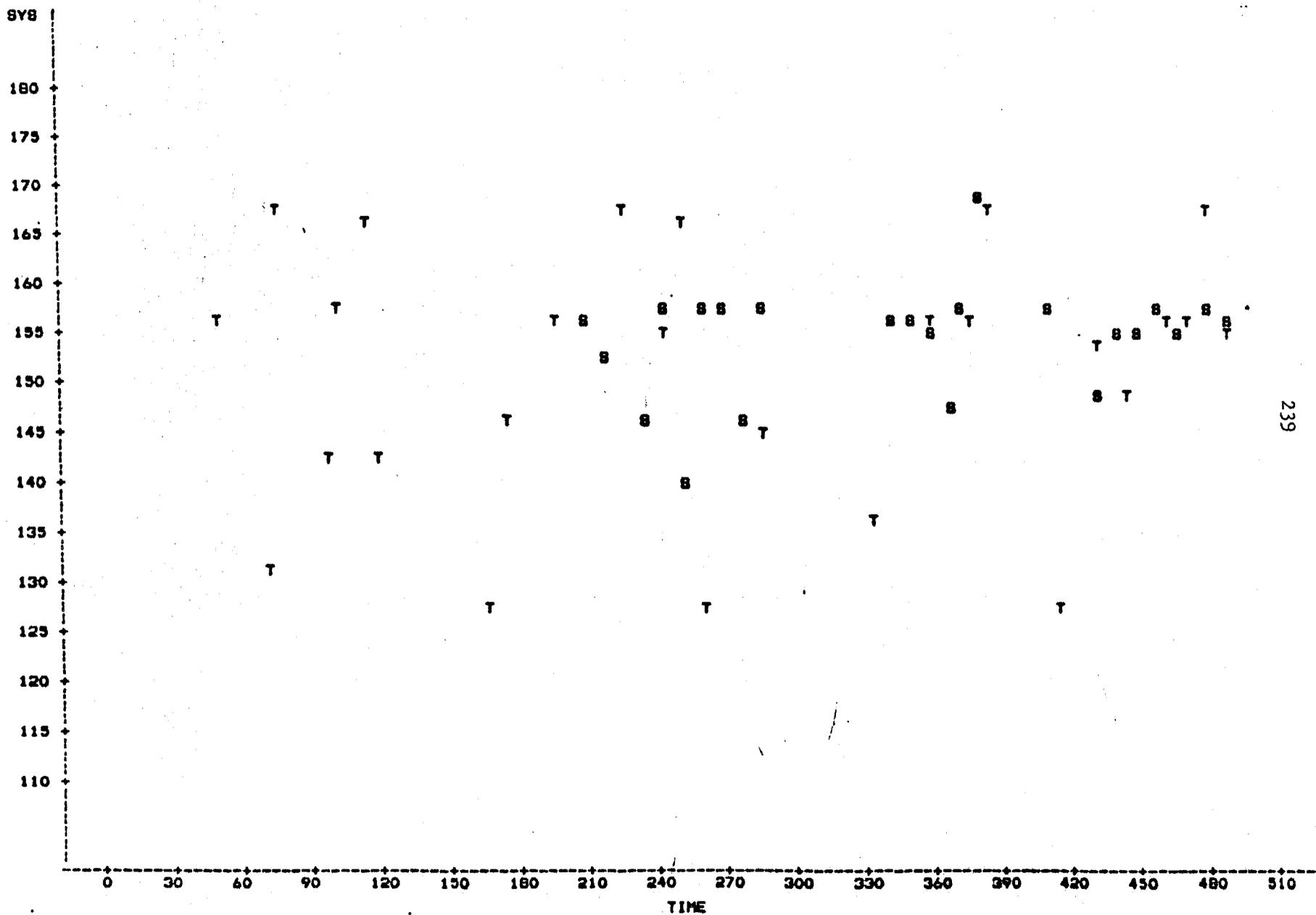
Figure 1.8.

SYSTOLIC VS TIME
SUBJECT 2, DAYS 1 AND 2
B-BELT TRIPPING
T-TWO HAND CONTROL



NOTE: 31 OBS HAD MISSING VALUES

Figure 1.9. SYSTOLIC VS TIME
 SUBJECT 3, DAYS 1 AND 2
 B=SELF TRIPPING
 T=TWO HAND CONTROL

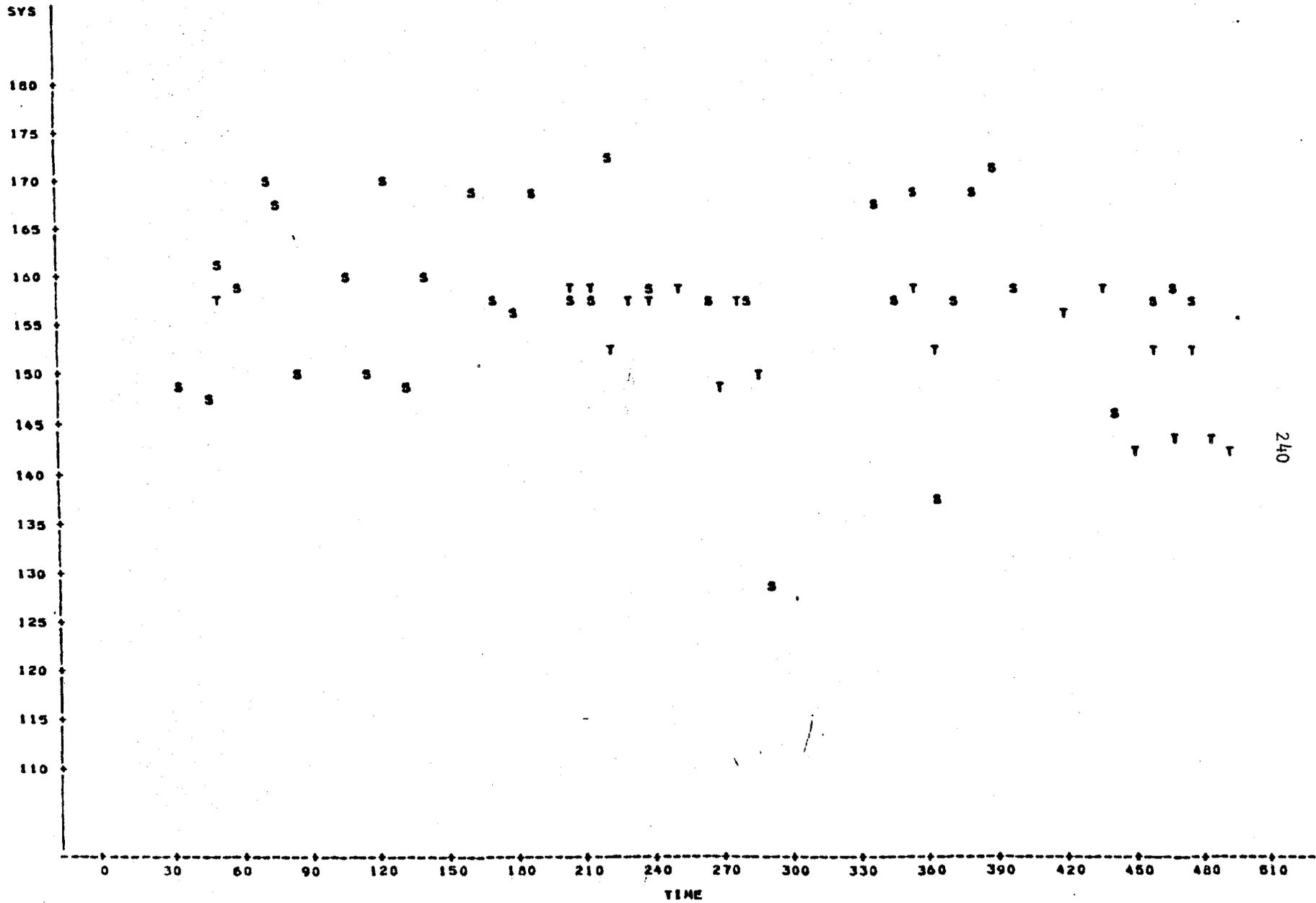


239

NOTE: 12 OBS HAD MISSING VALUES

Figure 1.10.

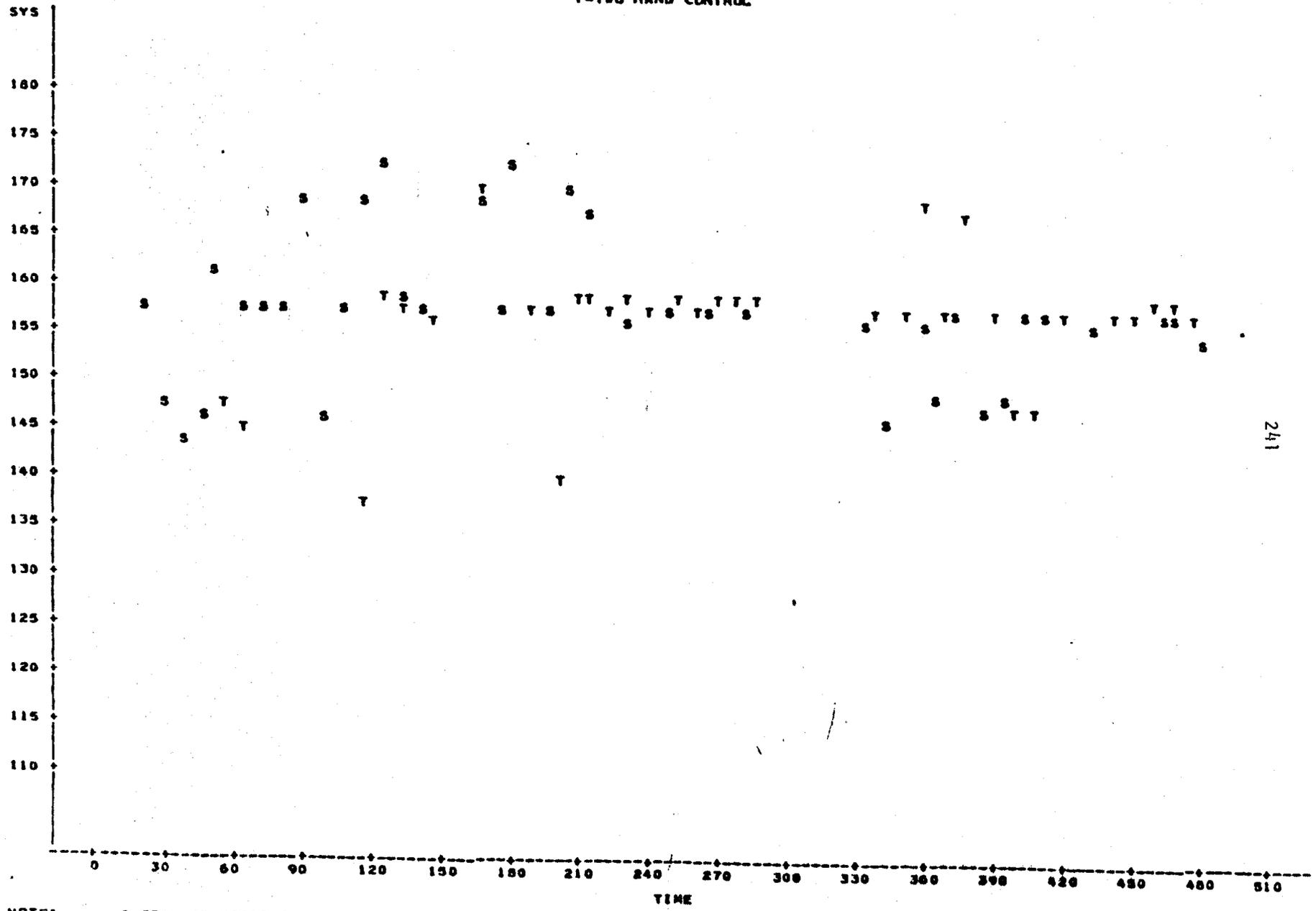
SYSTOLIC VS TIME
SUBJECT 4 - DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 19 OBS HAD MISSING VALUES

Figure 1.11.

SYSTOLIC VS TIME
SUBJECT S, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

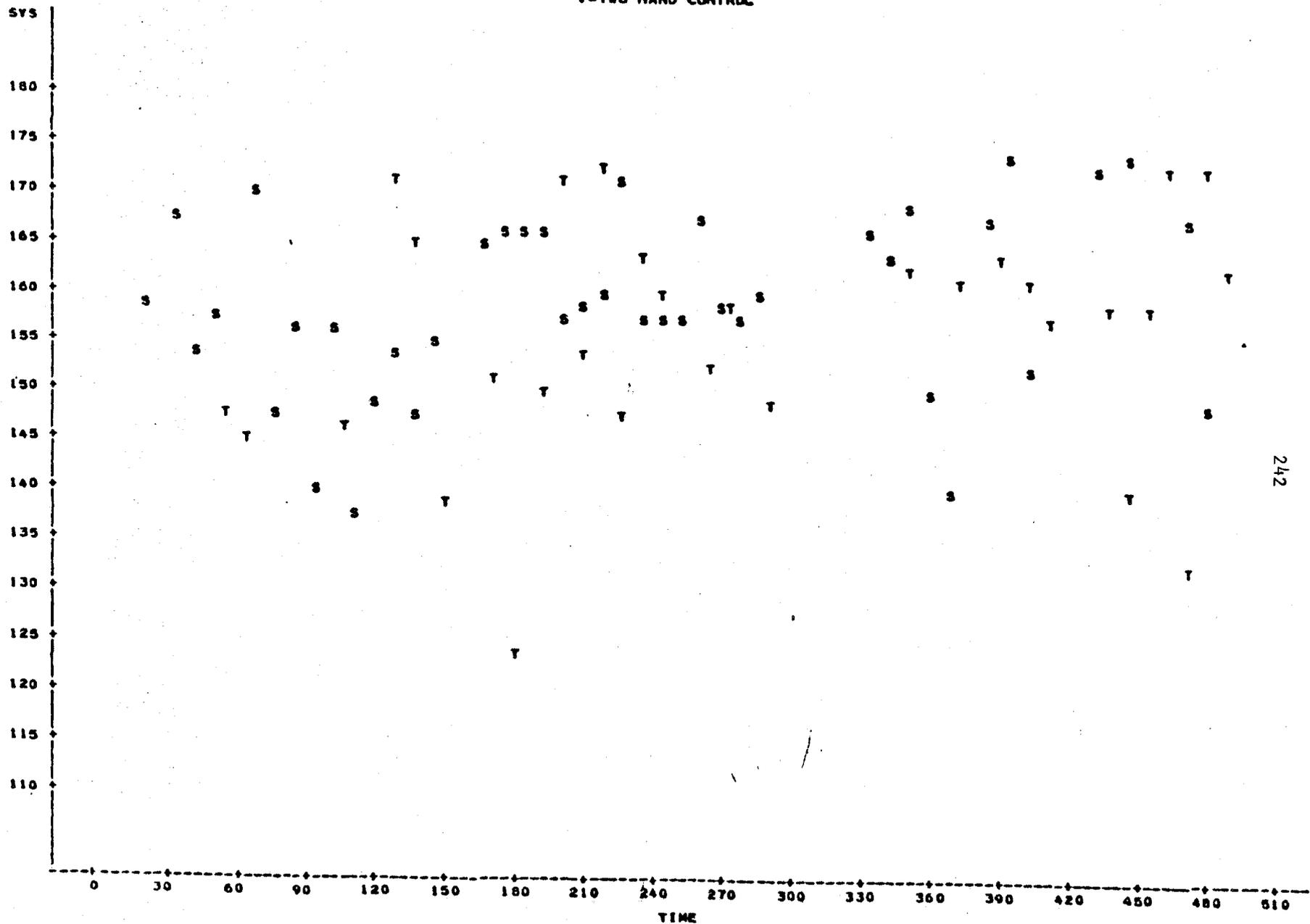


NOTE: 6 OBS HAD MISSING VALUES

241

Figure 1.12.

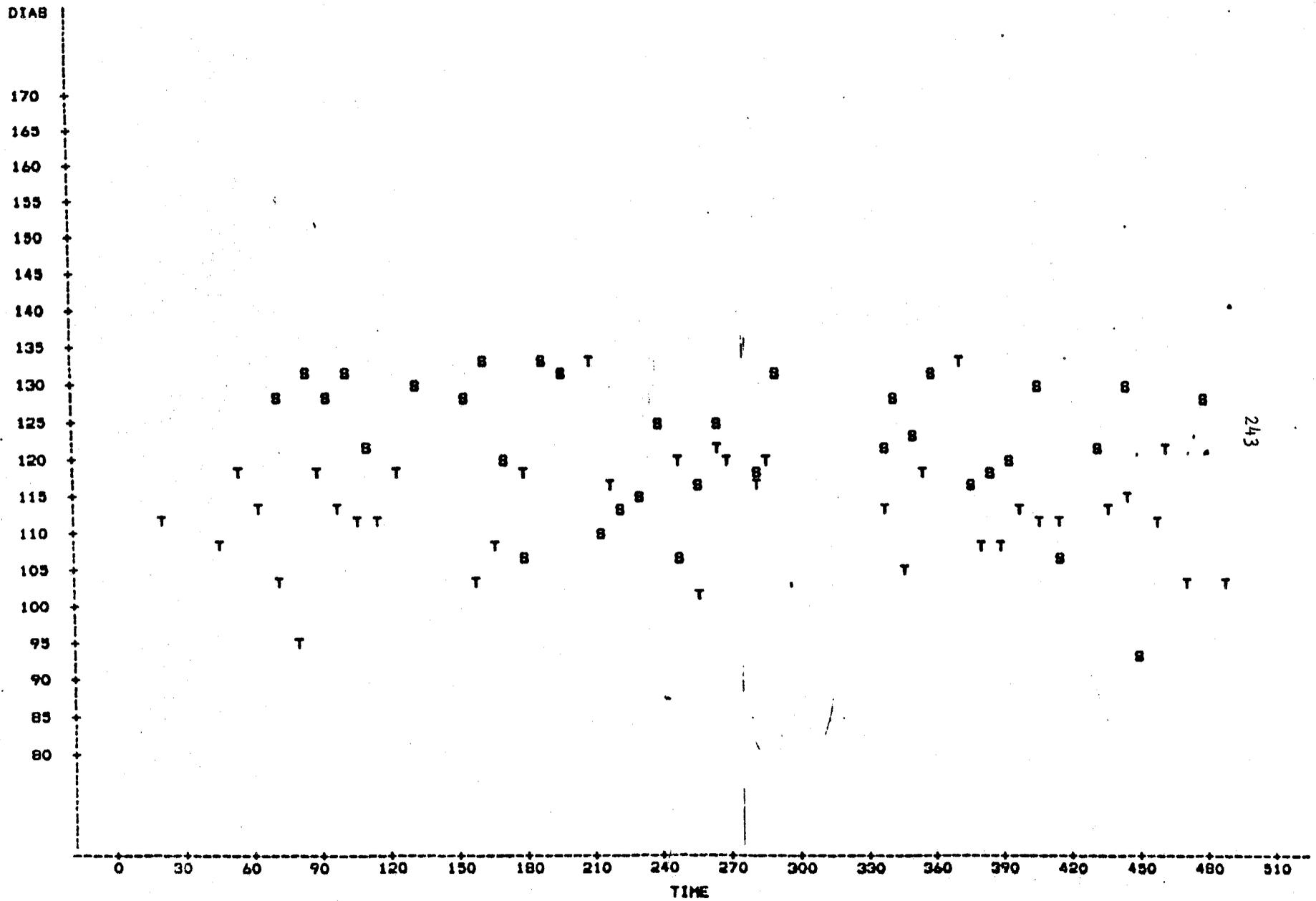
SYSTOLIC VS TIME
SUBJECT 6, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 11 OBS HAD MISSING VALUES

Figure 1.13.

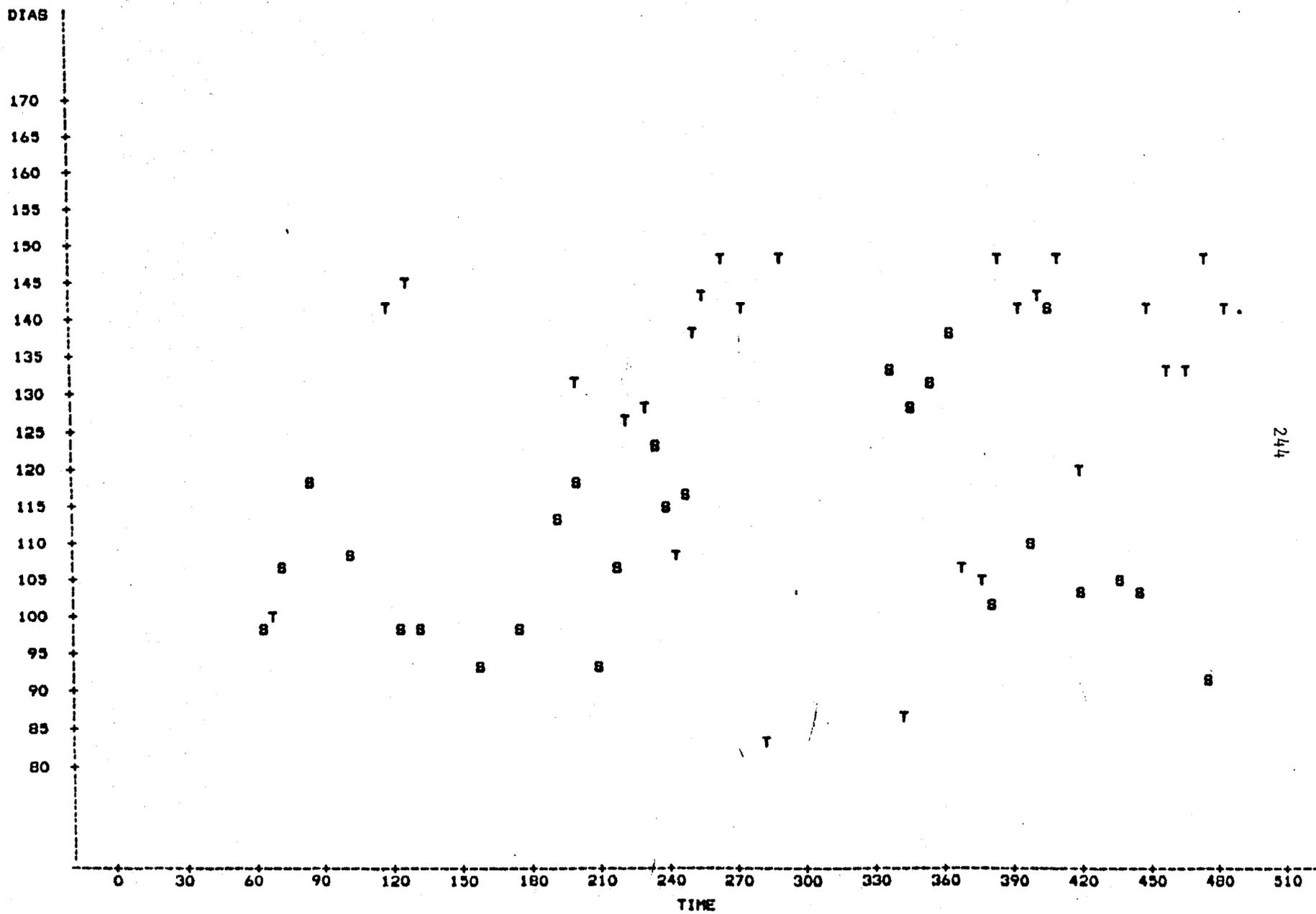
DIABTOLIC VS TIME
SUBJECT 1, DAYS 1 AND 2
S-BELP TRIPPING
T-TWO HAND CONTROL



NOTE: 13 OBS HAD MISSING VALUES

Figure 1.14.

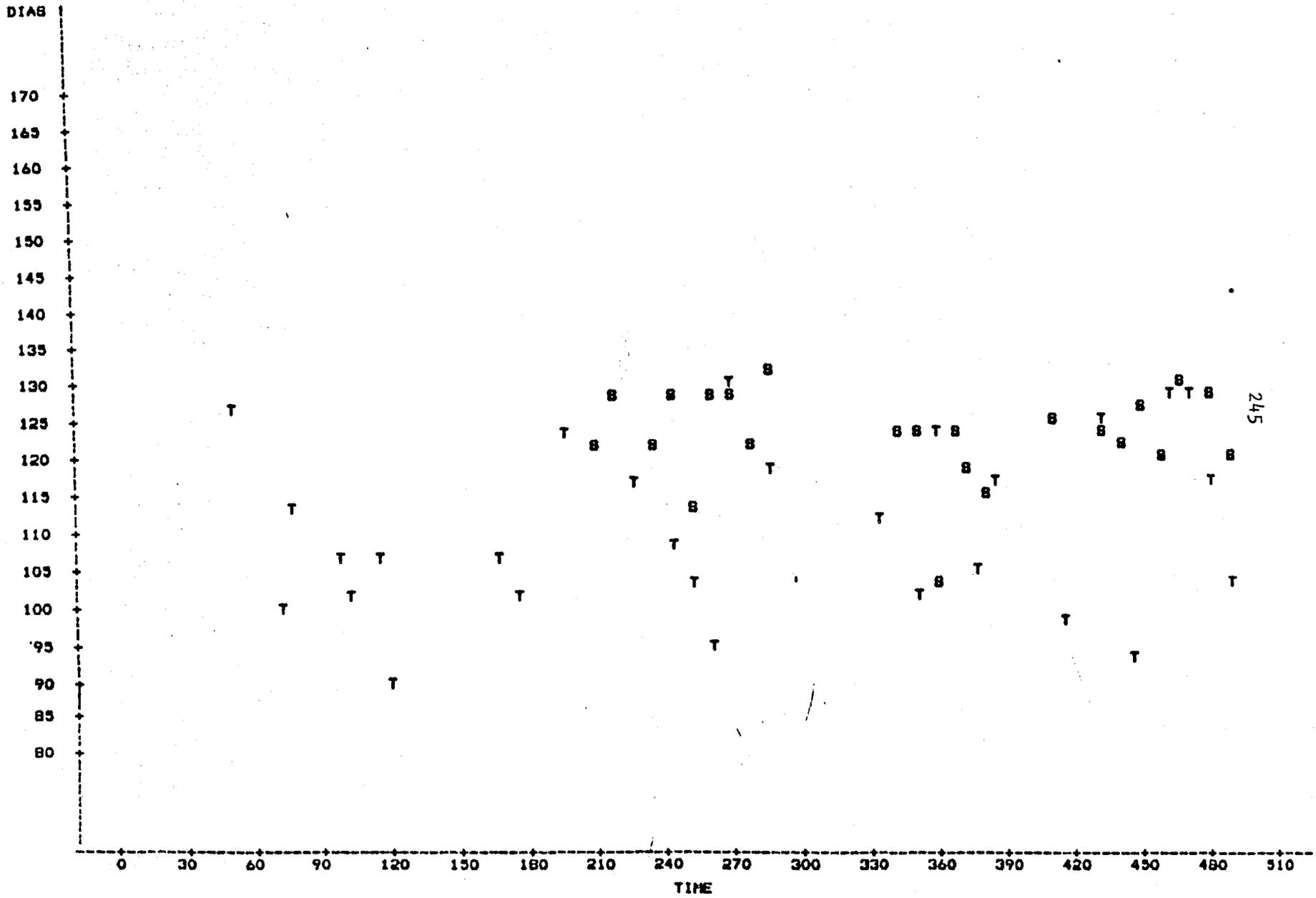
DIASTOLIC VS TIME
SUBJECT 2, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 31 OBS HAD MISSING VALUES

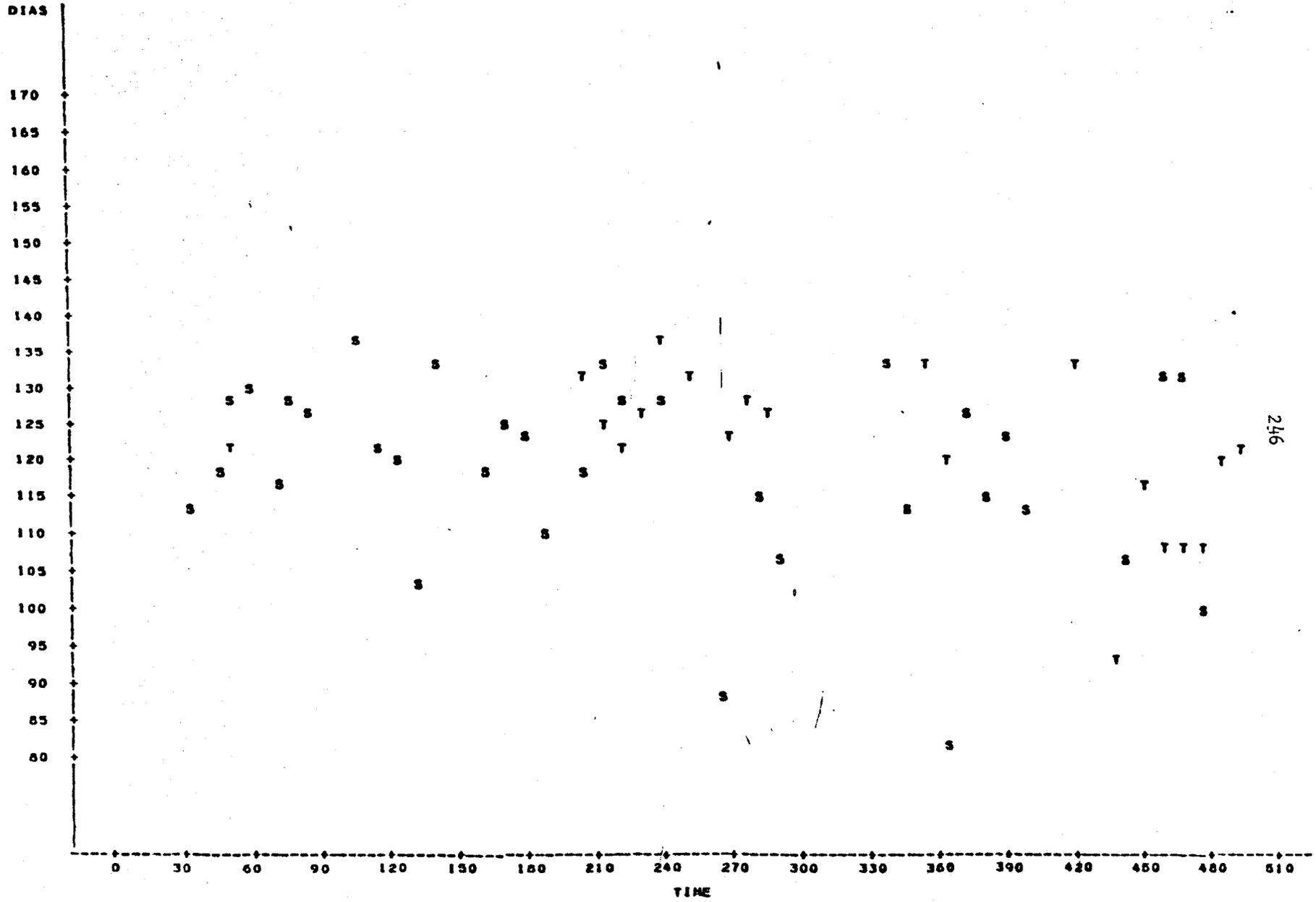
Figure 1.15.

DIABTOLIC VS TIME
SUBJECT 3, DAYS 1 AND 2
B-BELT TRIPPING
T-TWO HAND CONTROL



NOTE: 12 OBS HAD MISSING VALUES

Figure 1.16. DIASTOLIC VS TIME
 SUBJECT 4, DAYS 1 AND 2
 S=SELF TRIPPING
 T=TWO HAND CONTROL

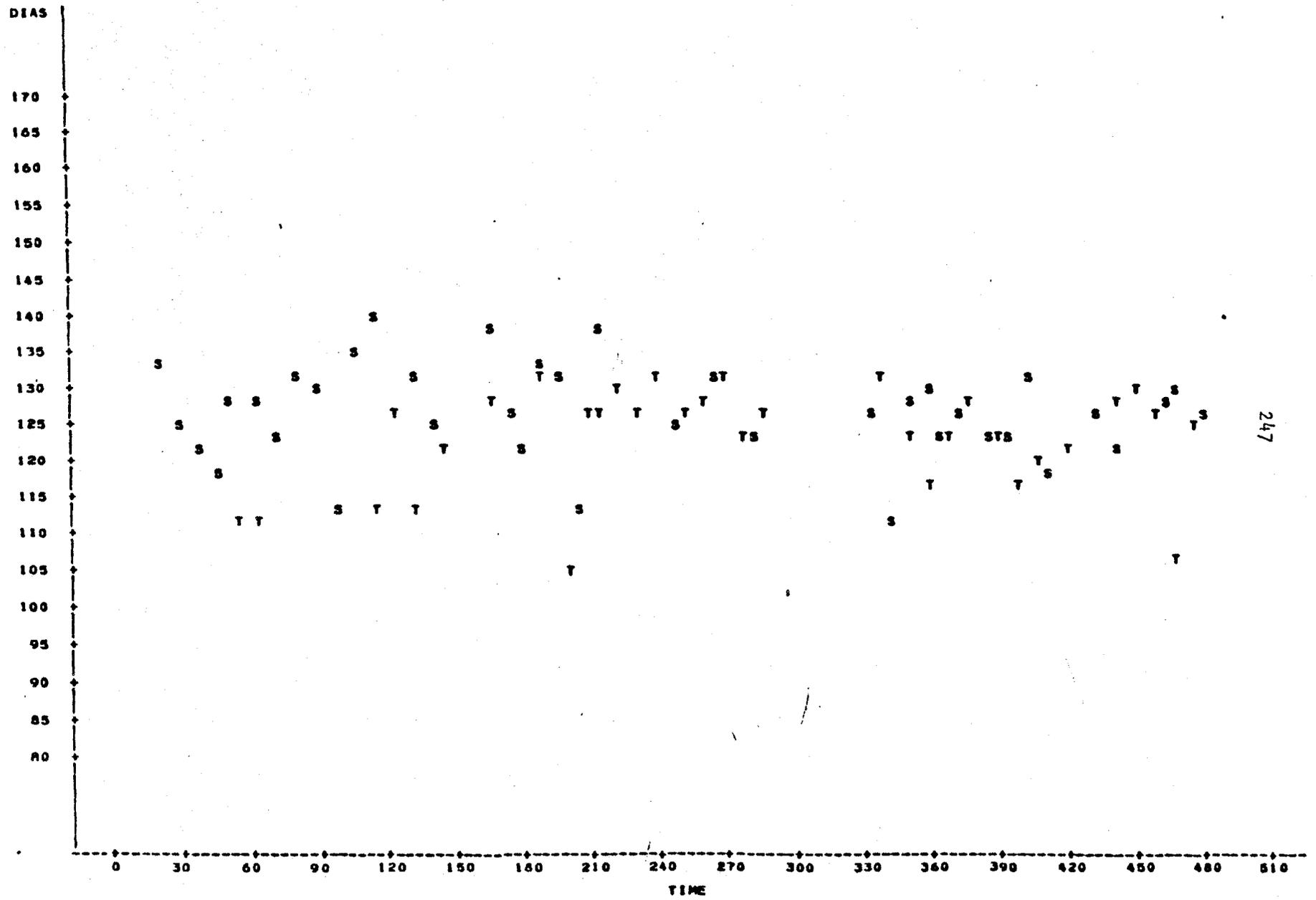


246

NOTE: 19 OBS HAD MISSING VALUES

Figure 1.17.

DIASTOLIC VS TIME
SUBJECT 5, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

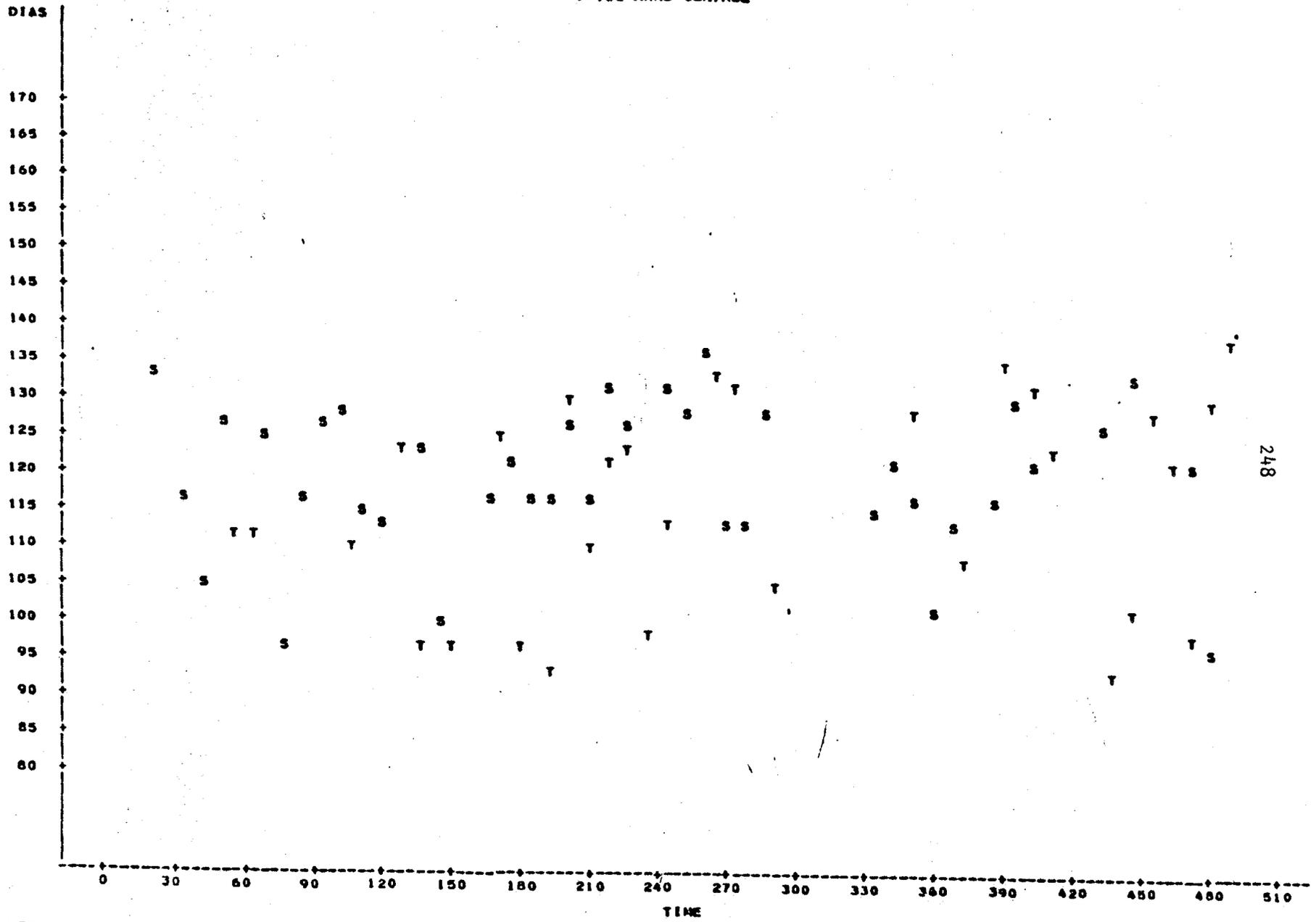


NOTE: 6 OBS HAD MISSING VALUES

247

Figure 1.18.

DIASTOLIC VS TIME
SUBJECT 6, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

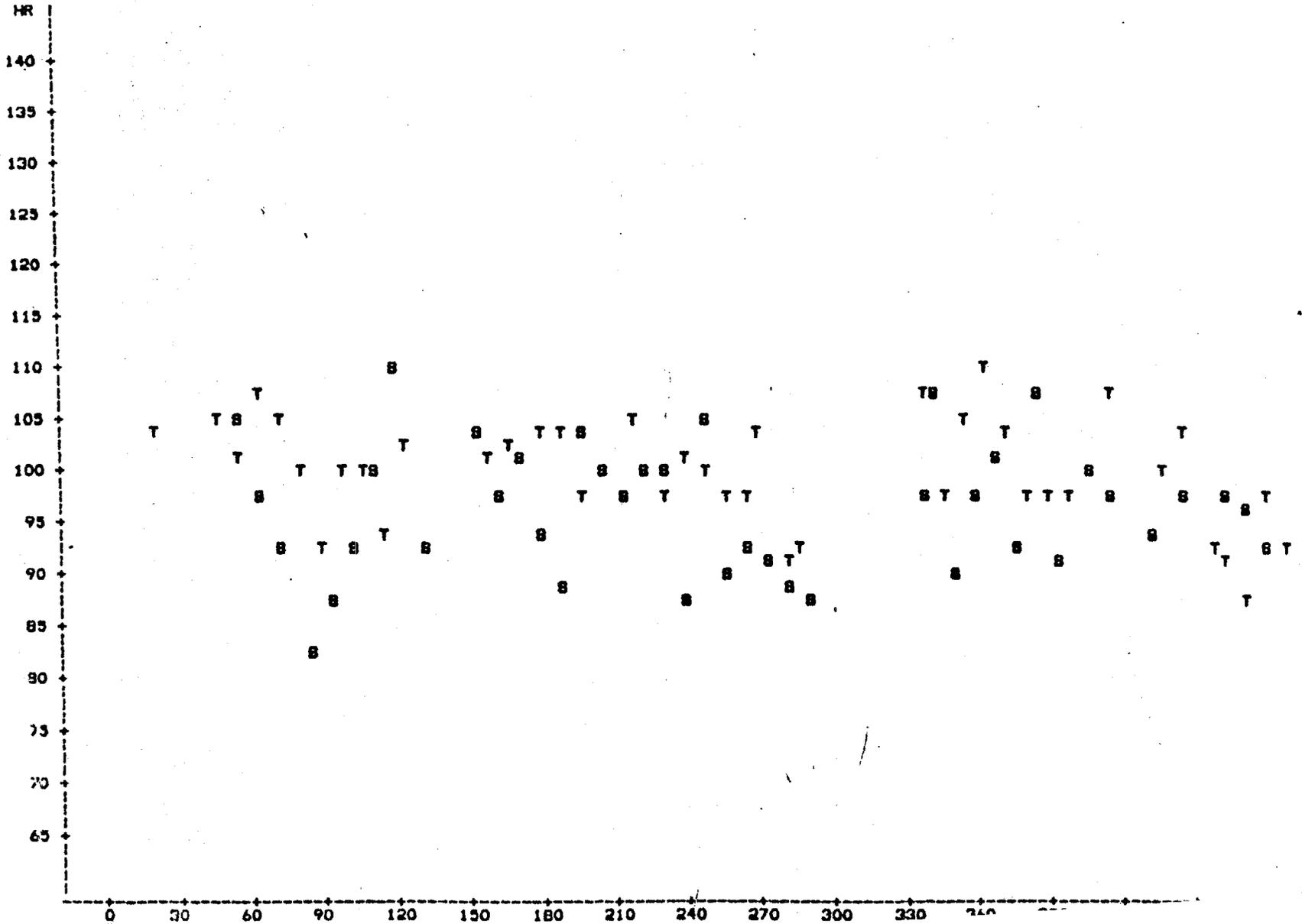


248

NOTE: 11 OBS HAD MISSING VALUES

Figure 1.19.

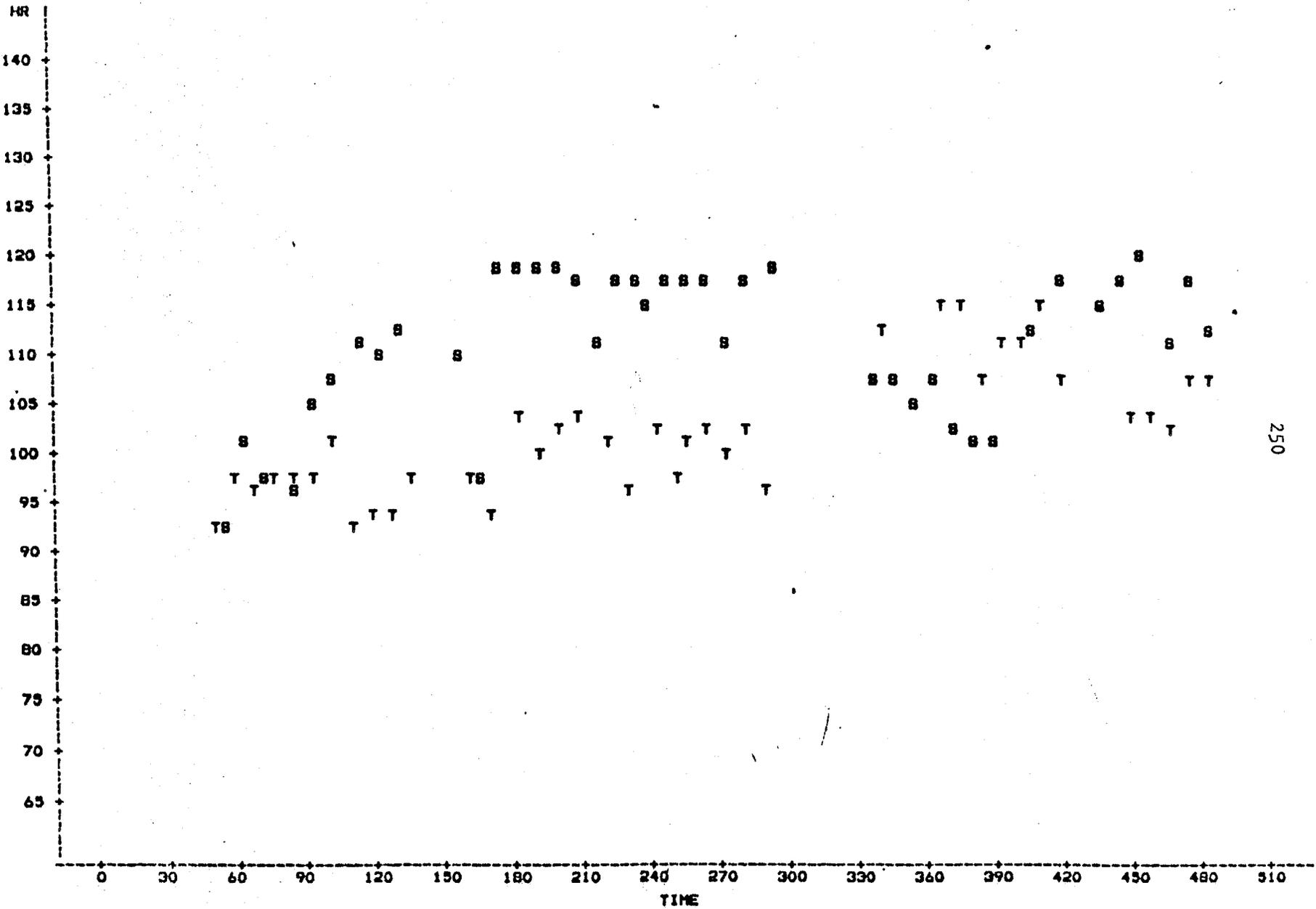
HR VS TIME
 SUBJECT 1, DAYS 1 AND 2
 B=SELF TRIPPING
 T=TWO HAND CONTROL



NOTE: 2 DAY MAX

Figure 1.20.

HR VS TIME
SUBJECT 2, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

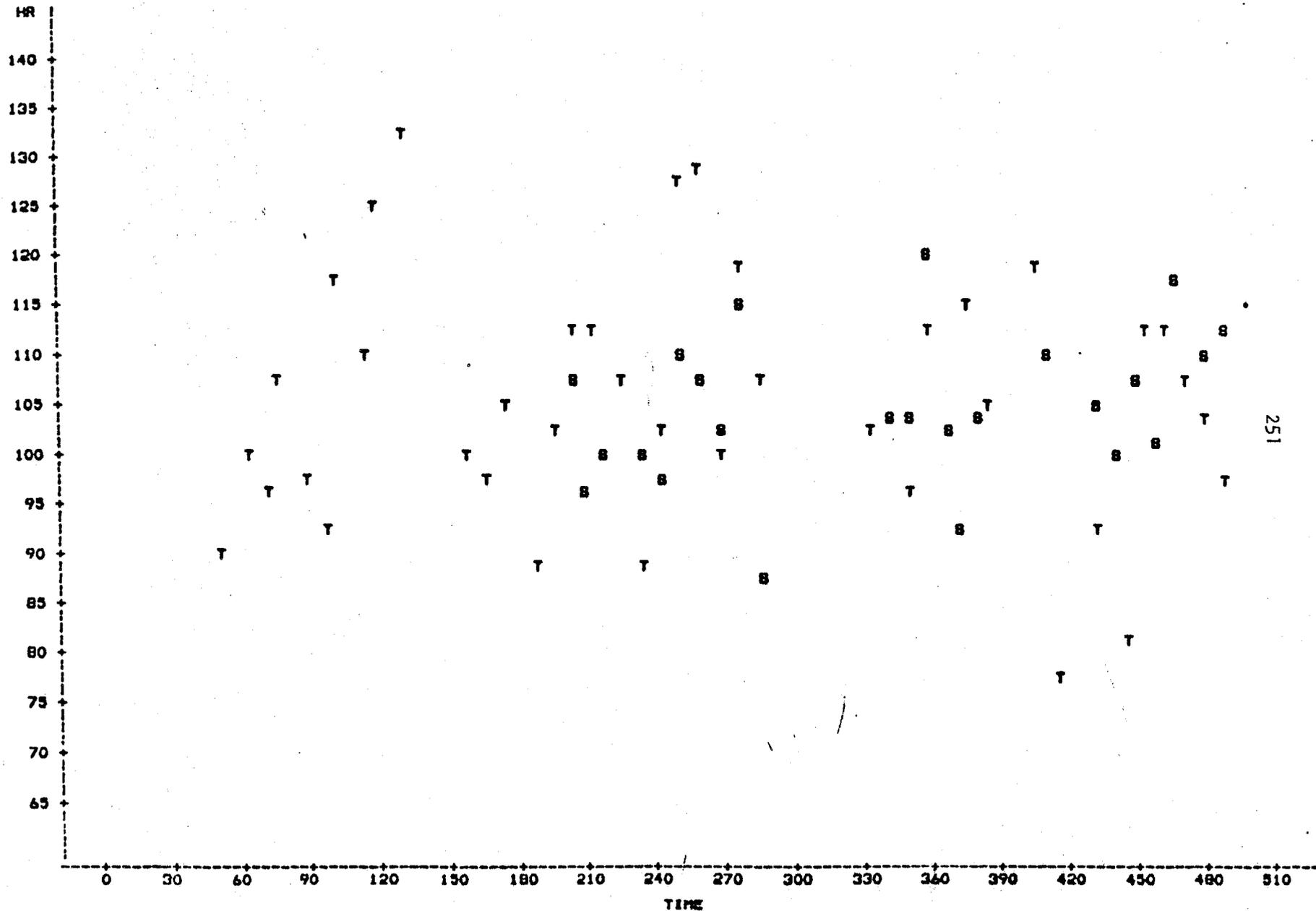


250

NOTE: 2 OBS HAD MISSING VALUES

Figure 1.21.

HR VS TIME
SUBJECT 3, DAYS 1 AND 2
S-SELF TRIPPING
T-TWO HAND CONTROL

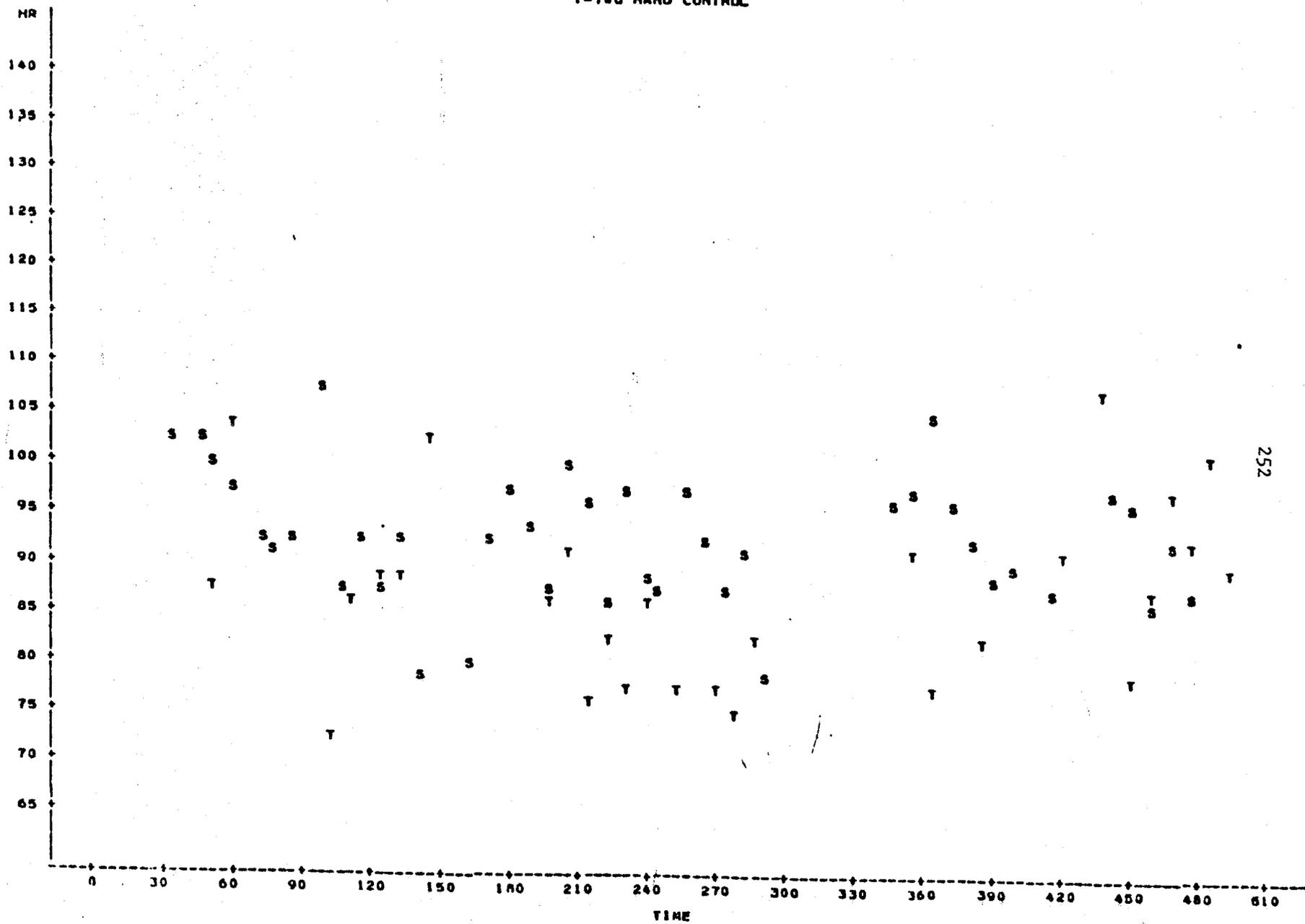


251

Figure 1.22.

HR VS TIME
SUBJECT 4, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

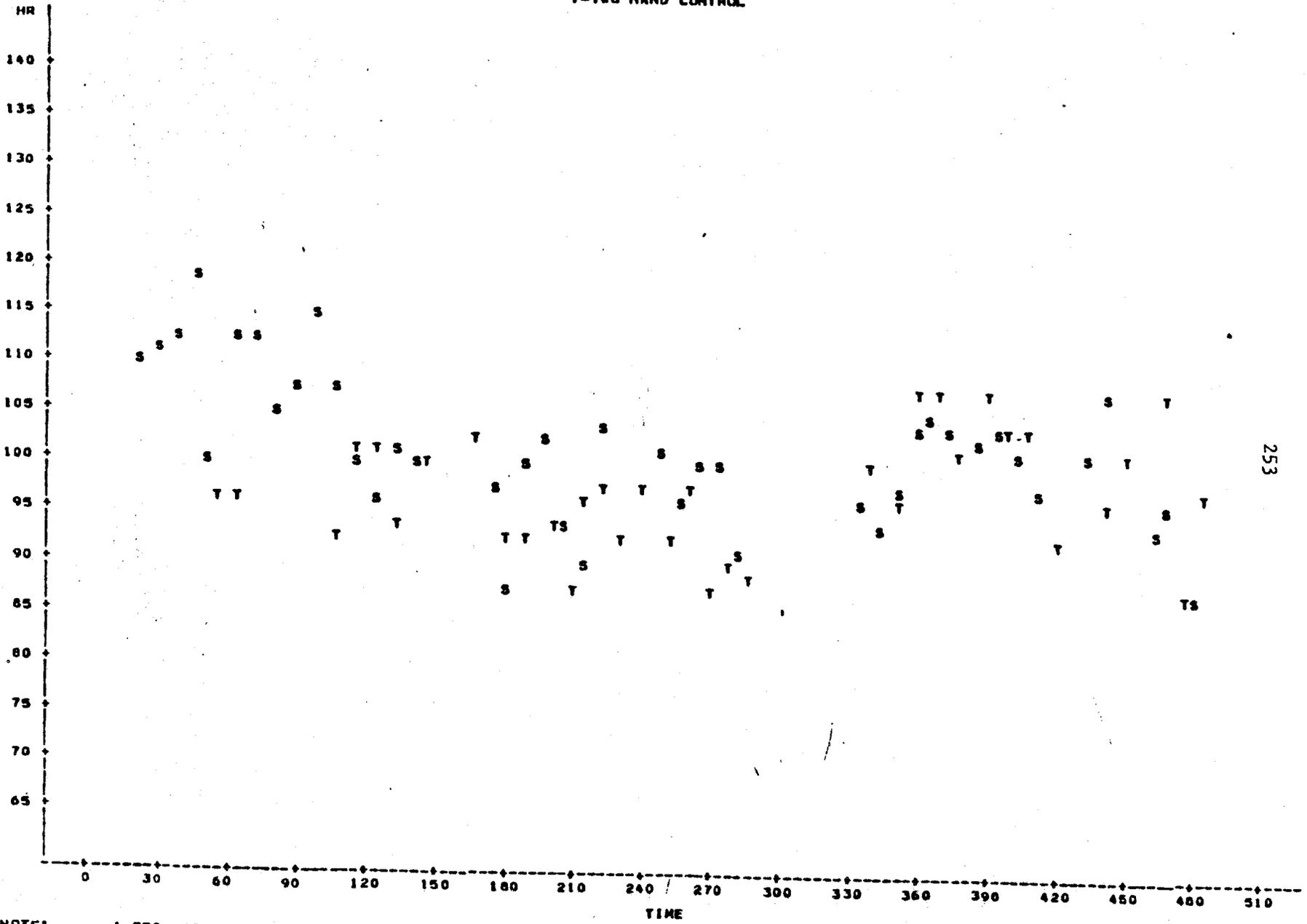
252



NOTE: 4 OBS HAD MISSING VALUES

Figure 1.23.

HR VS TIME
SUBJECT S, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

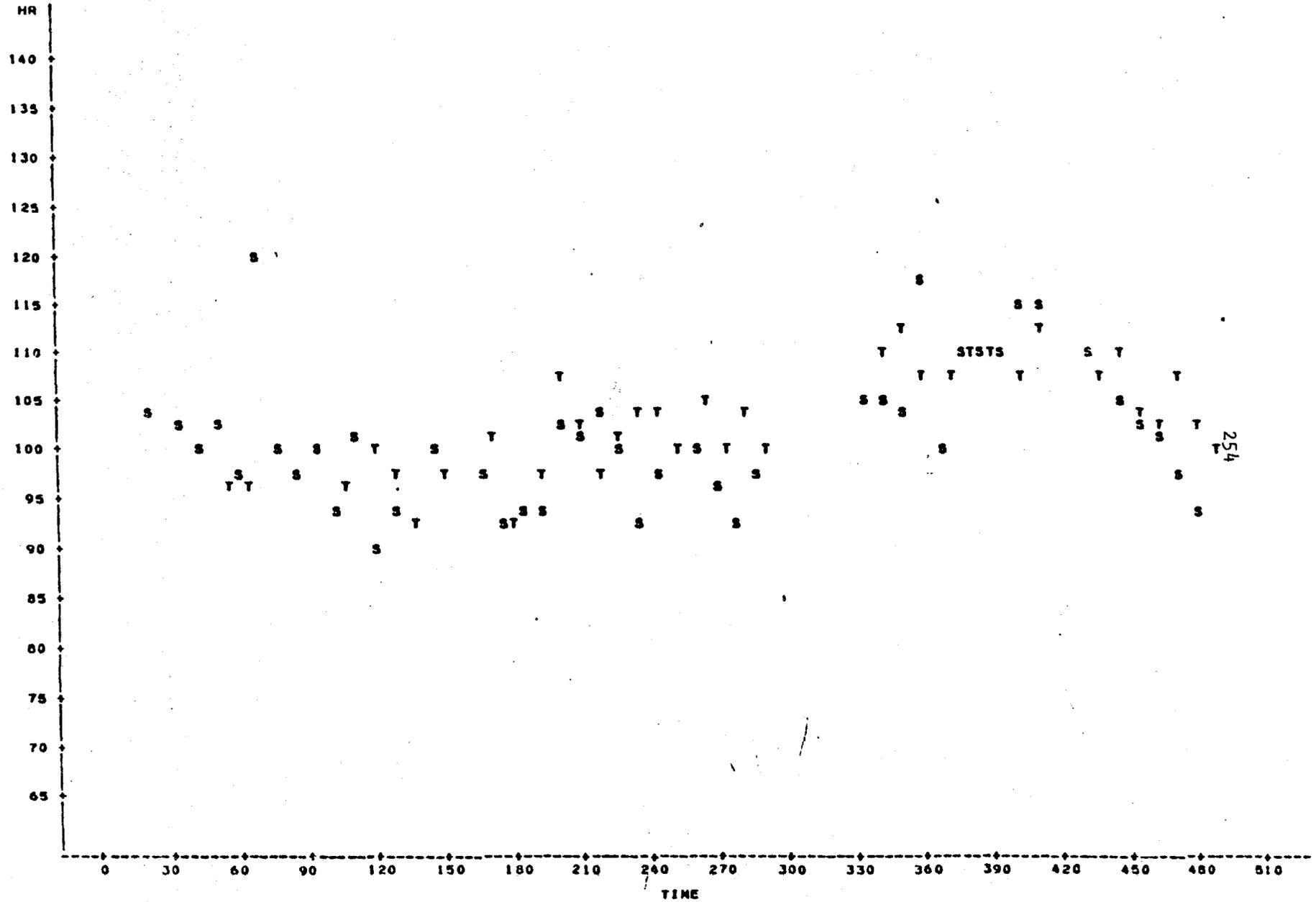


253

NOTE: 1 OBS HAD MISSING VALUES

Figure 1.24.

HR VS TIME
SUBJECT 6, DAYS 1 AND 2
S=SELF TRIPPING
T=TWO HAND CONTROL

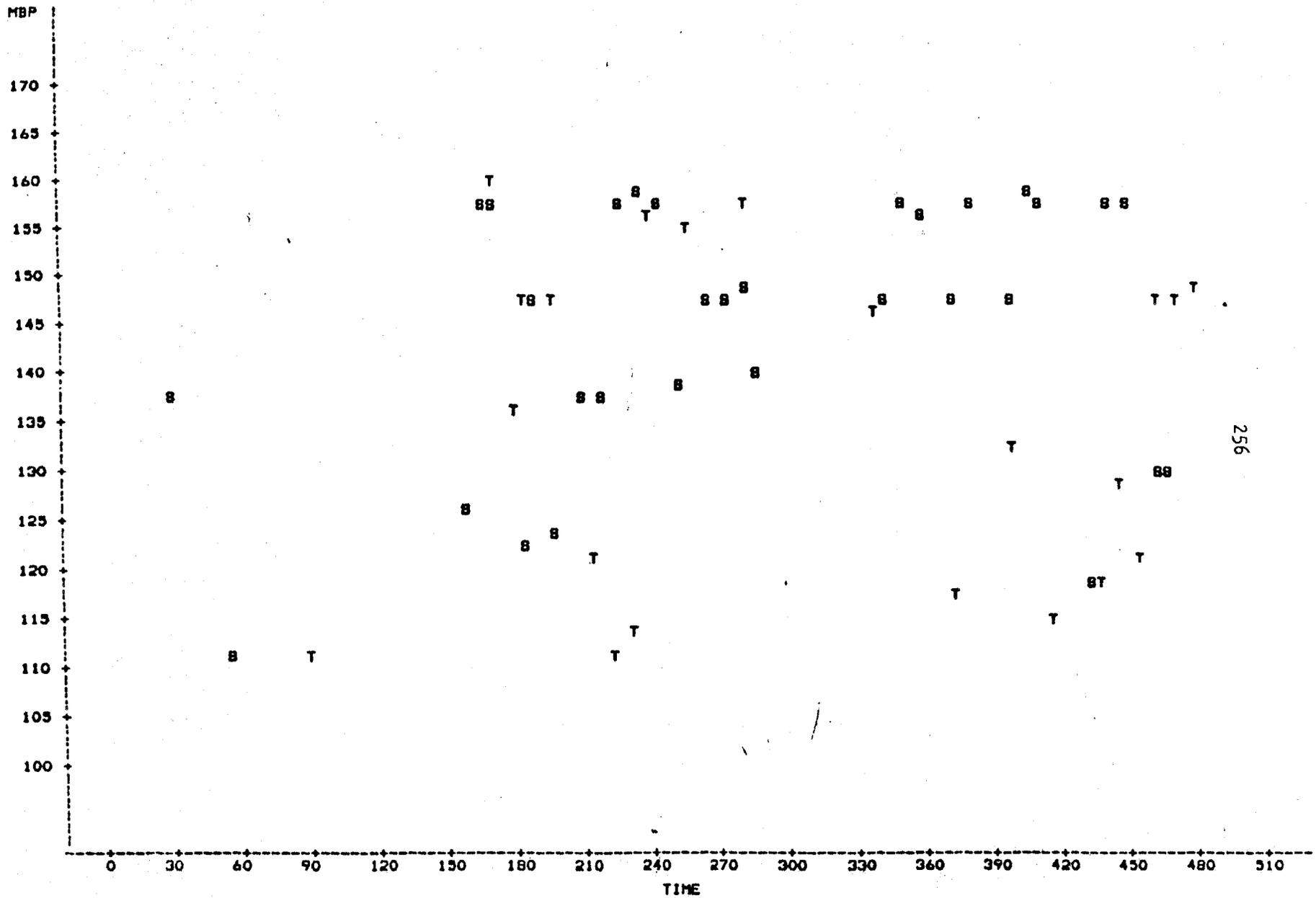


NOTE: 2 OBS HIDDEN

254

Figure 1.26.

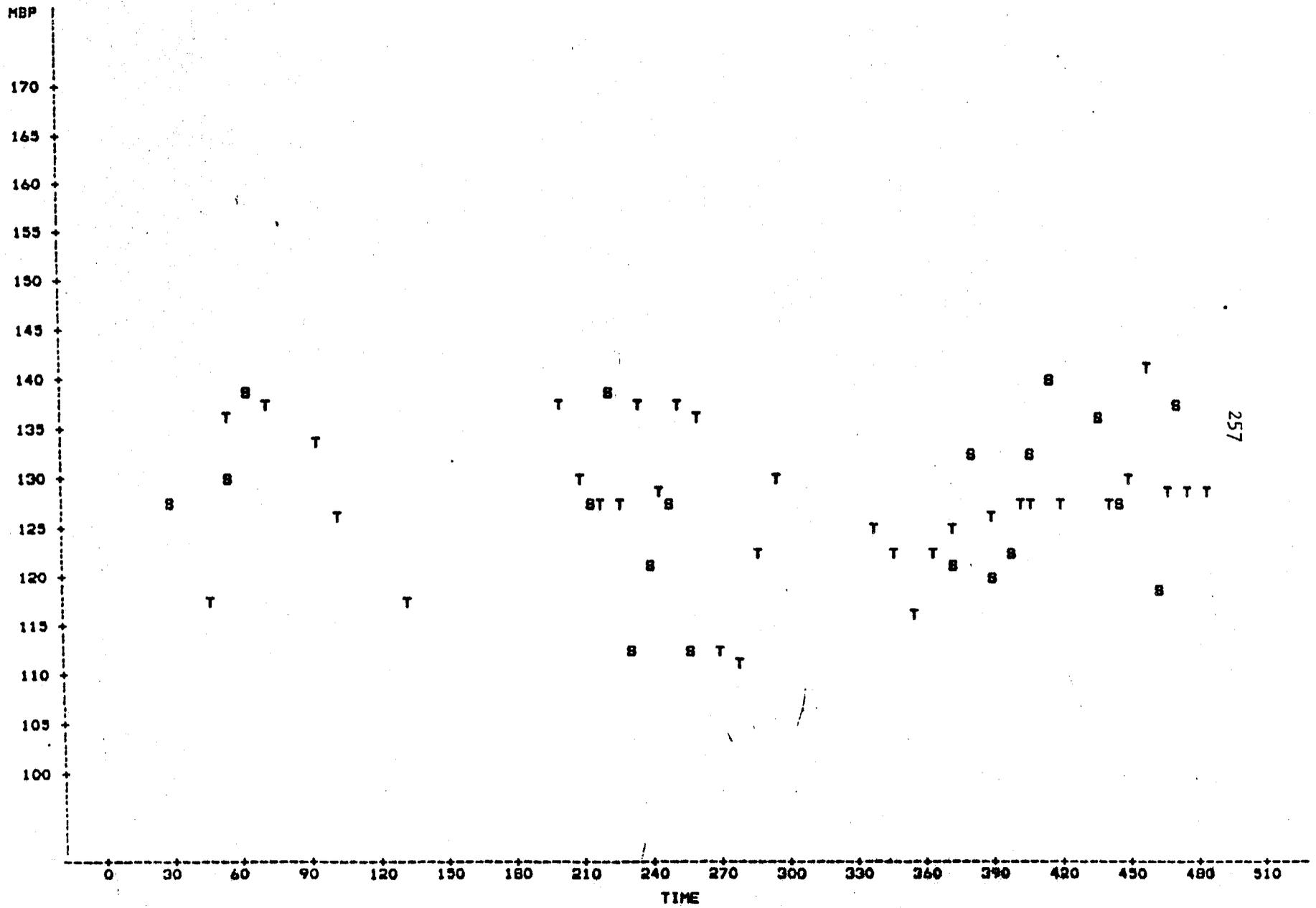
MBP VS TIME
SUBJECT 2, DAYS 3 AND 4
B-BELT TRIPPING
T-TWO HAND CONTROL



NOTE: 31 OBS HAD MISSING VALUES

Figure 1.27.

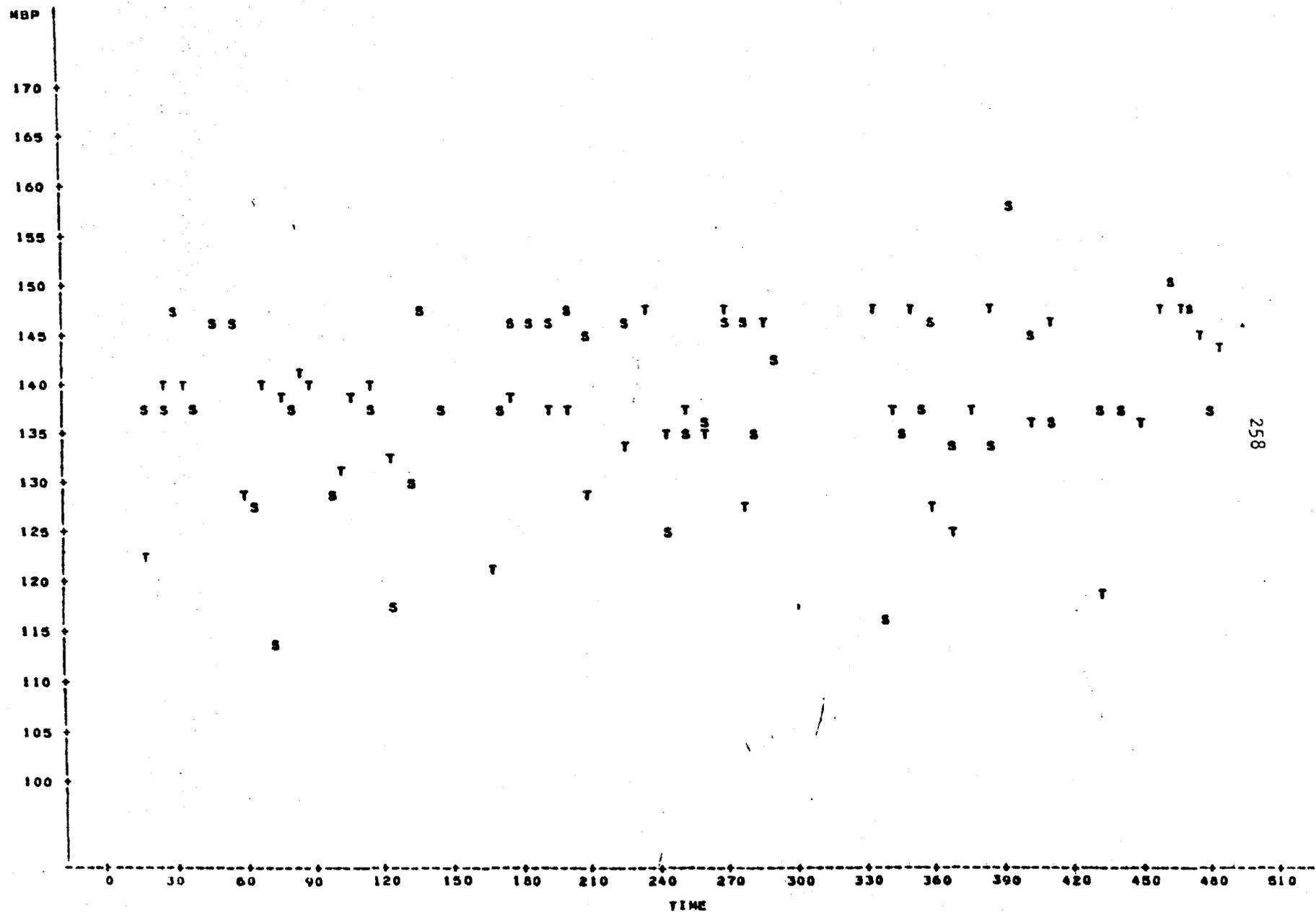
MBP VS TIME
SUBJECT 3, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 0 OBS HAD MISSING VALUES

Figure 1.28.

MBP VS TIME
SUBJECT 4, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 10 OBS HAD MISSING VALUES

Figure 1.29.

NBP VS TIME
SUBJECT S, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

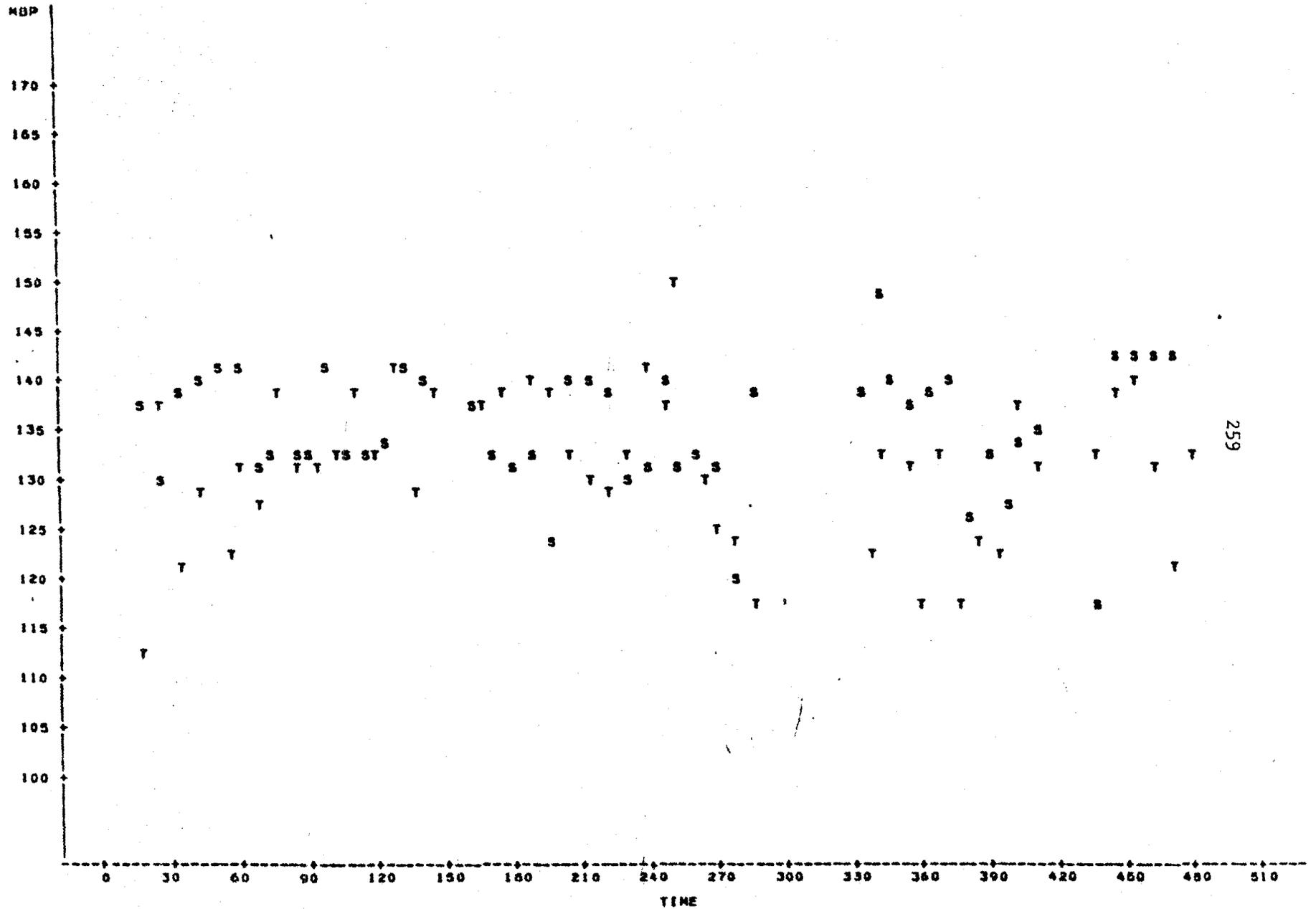


Figure 1.30.

MBP VS TIME
SUBJECT 6, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

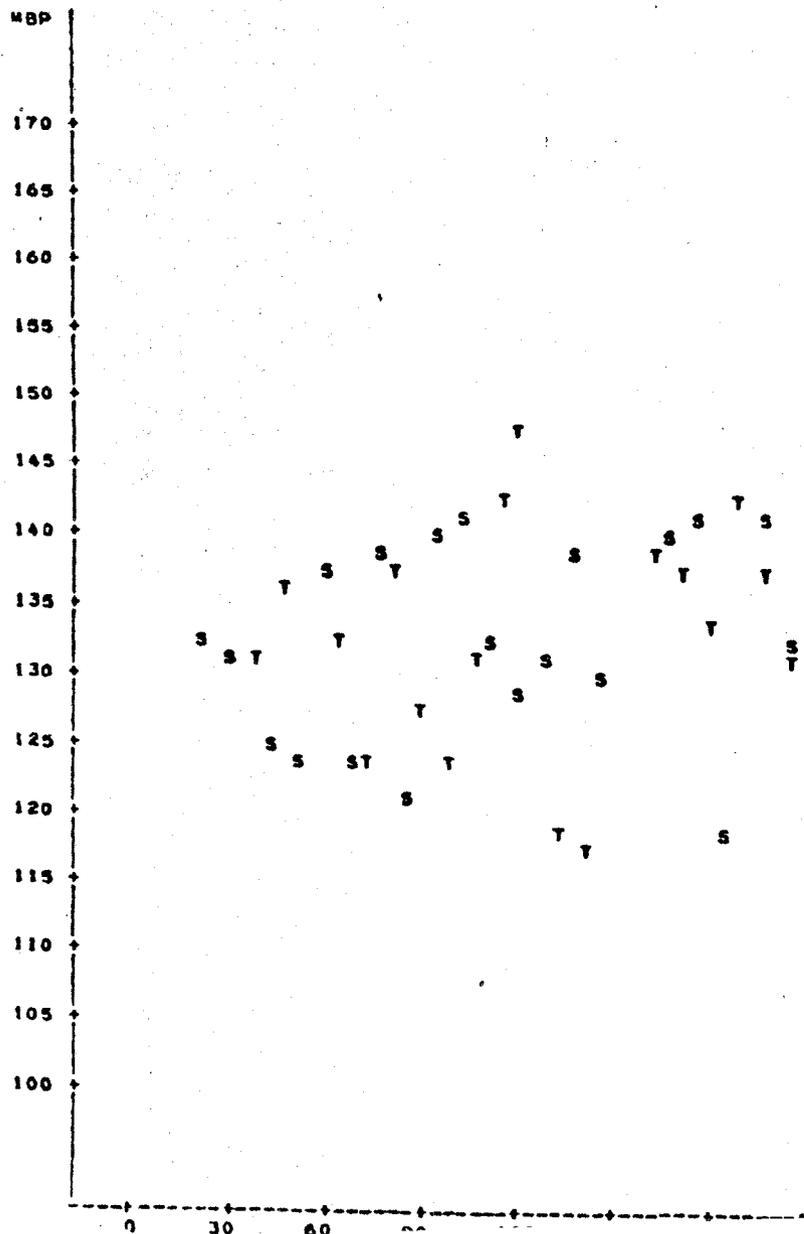
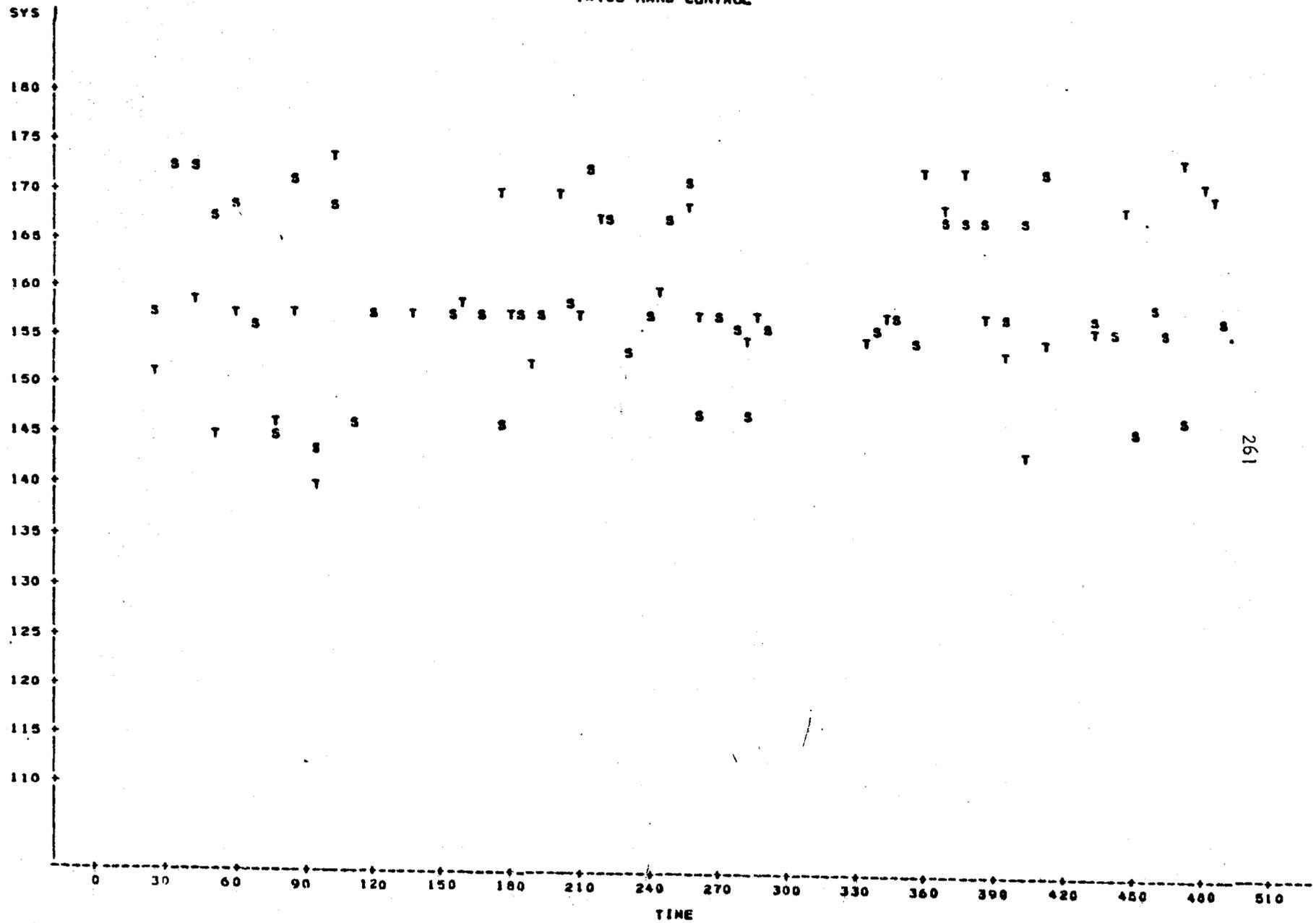


Figure 1.31.

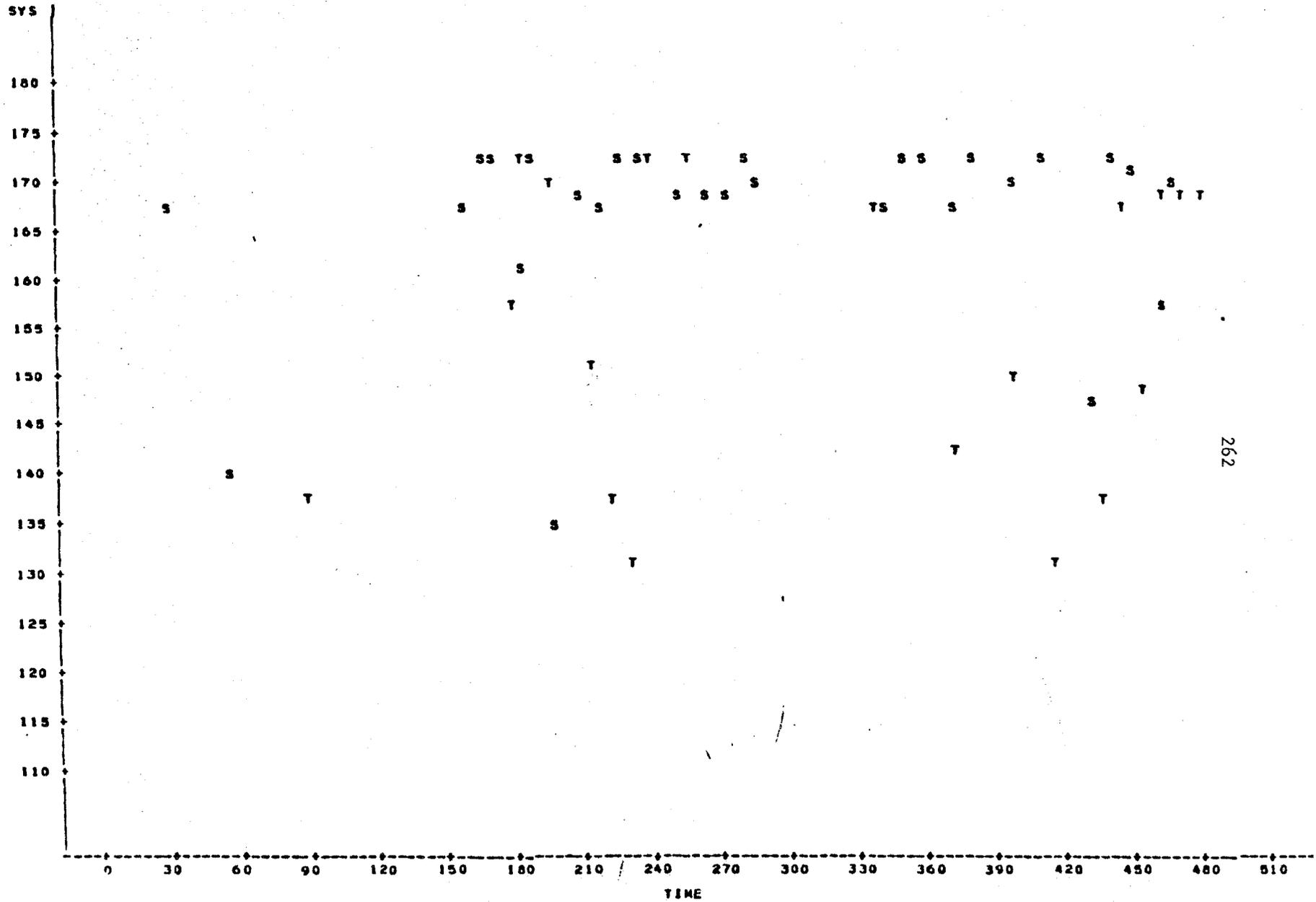
SYSTOLIC VS TIME
SUBJECT 1, DAYS 3 AND 4
S=SELF TRIPPING
T=TWD HAND CONTROL



NOTE: 11 OBS HAD MISSING VALUES

Figure 1.32.

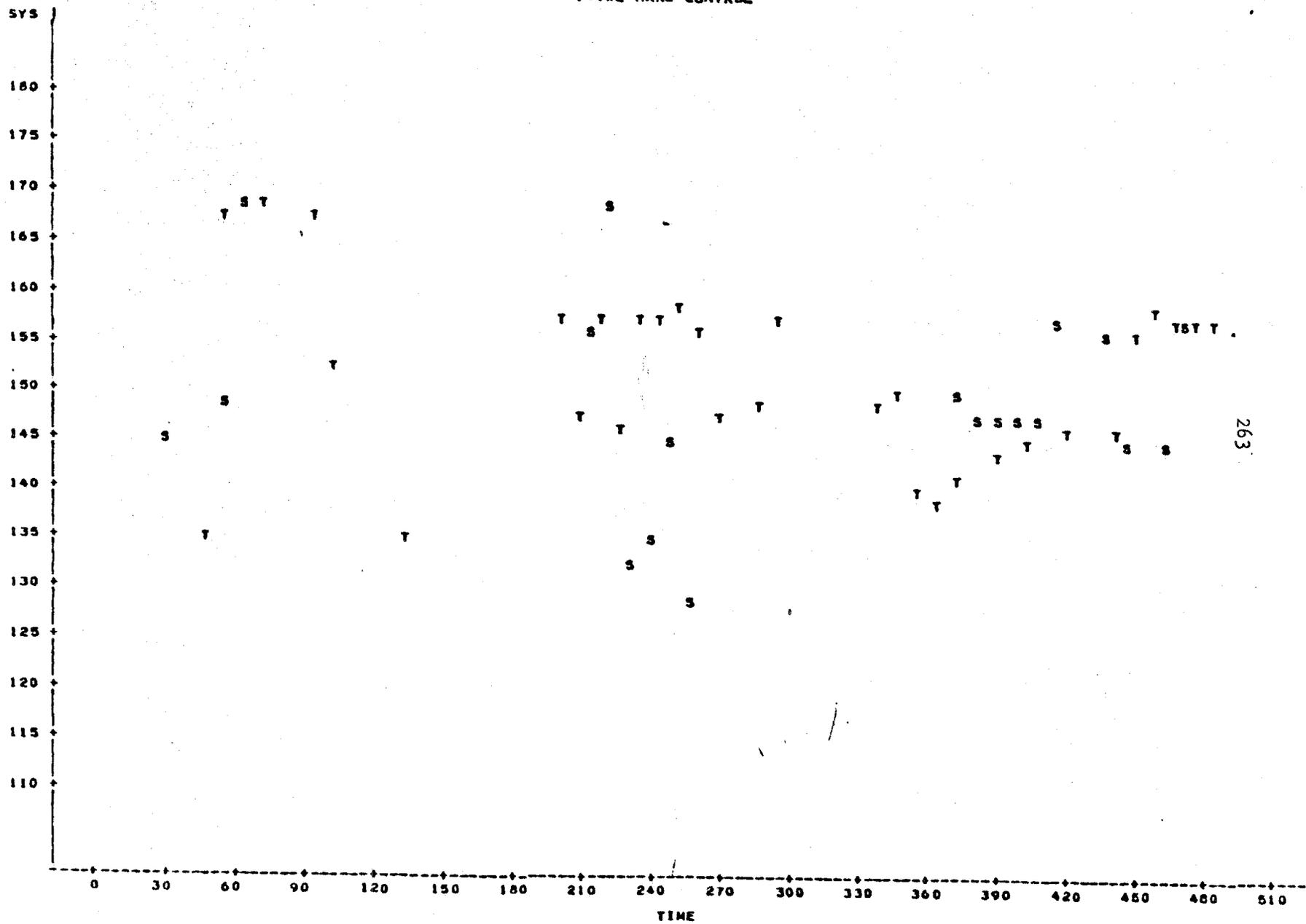
SYSTOLIC VS TIME
SUBJECT 2, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 34 OBS HAD MISSING VALUES

Figure 1.33.

SYSTOLIC VS TIME
SUBJECT 3, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

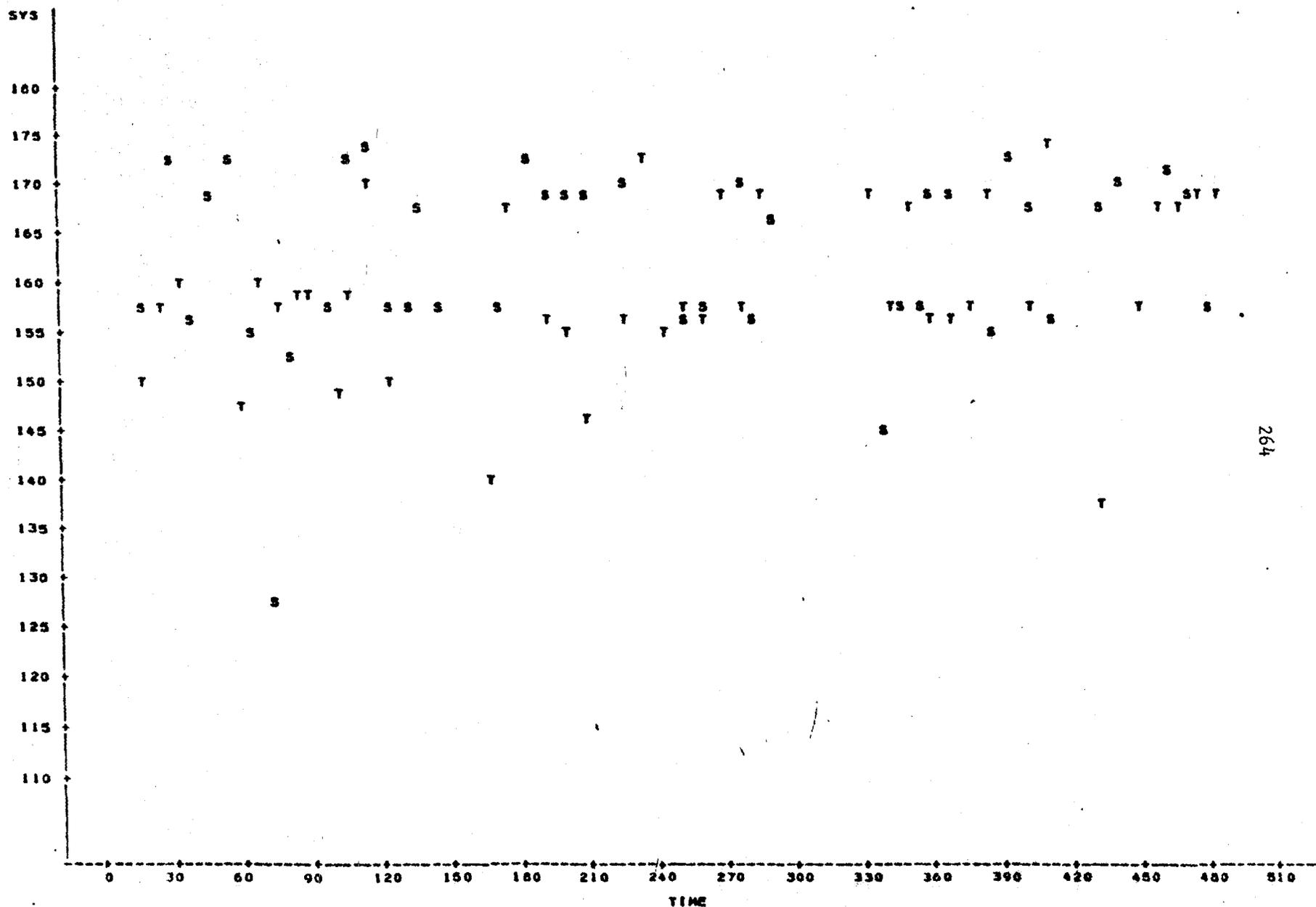


263

NOTE: 6 OBS HAD MISSING VALUES

Figure 1.34.

SYSTOLIC VS TIME
SUBJECT 4 - DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 9 OBS HAD MISSING VALUES

Figure 1.35.

SYSTOLIC VS TIME
SUBJECT 5, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

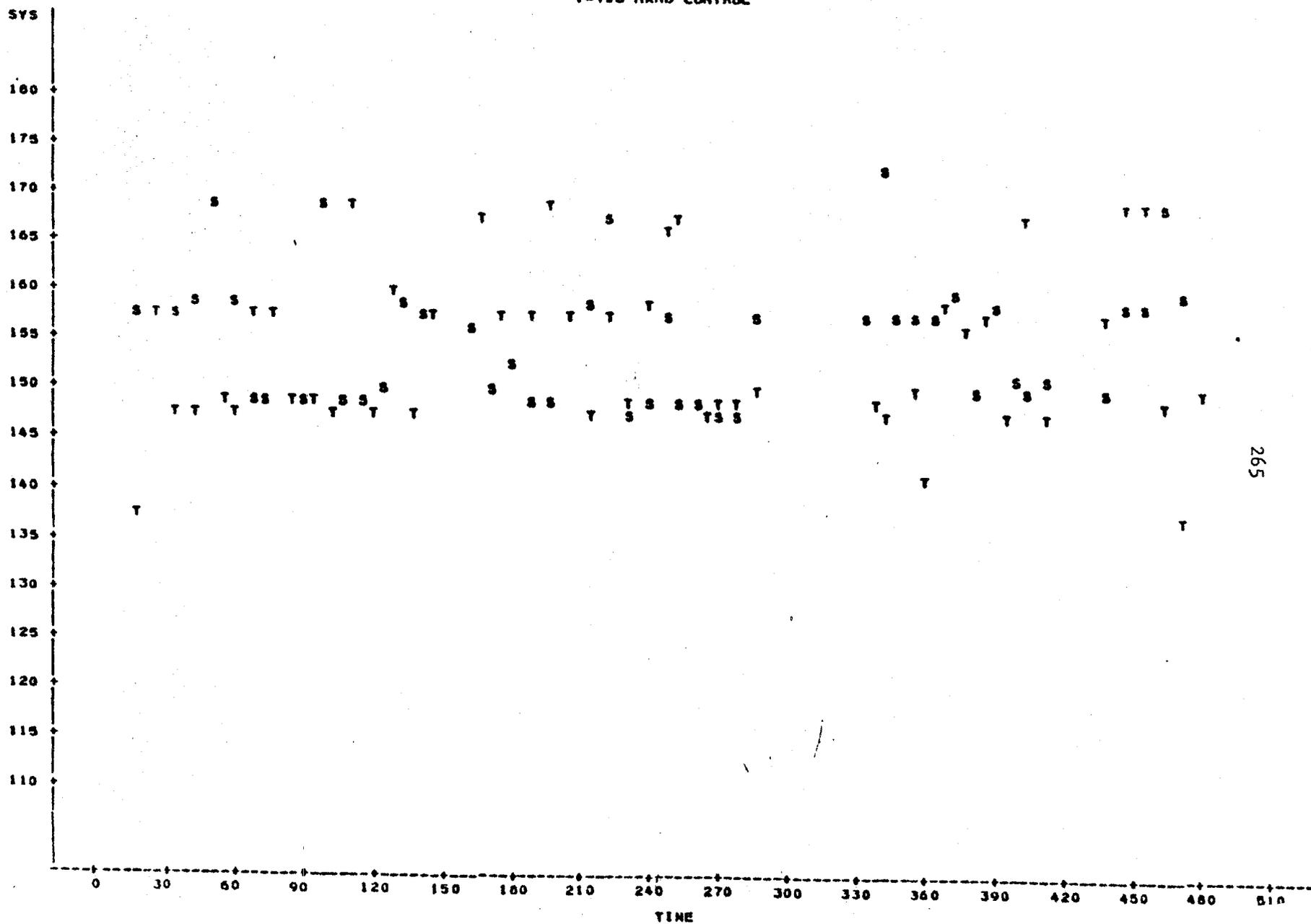
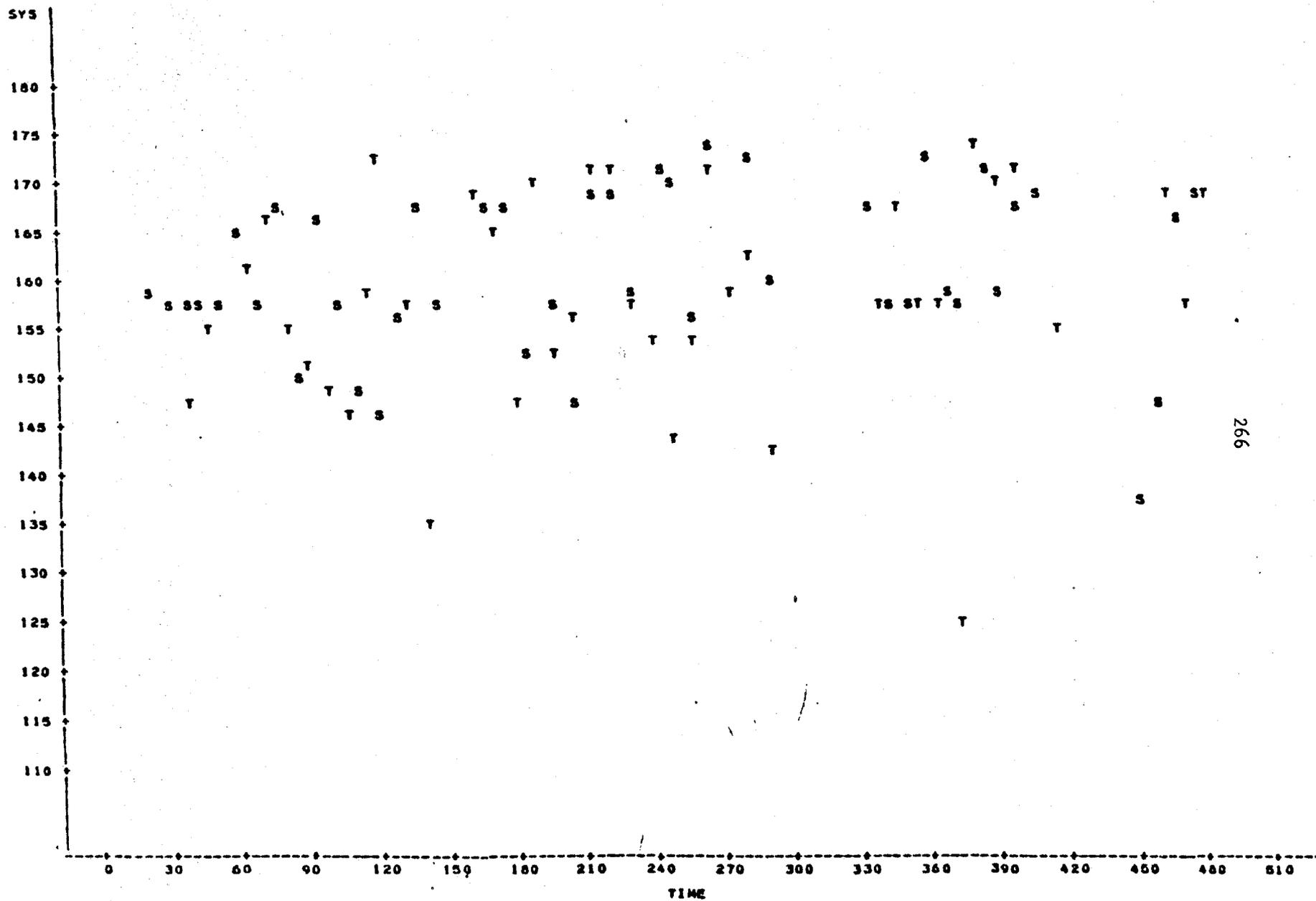


Figure 1.36.

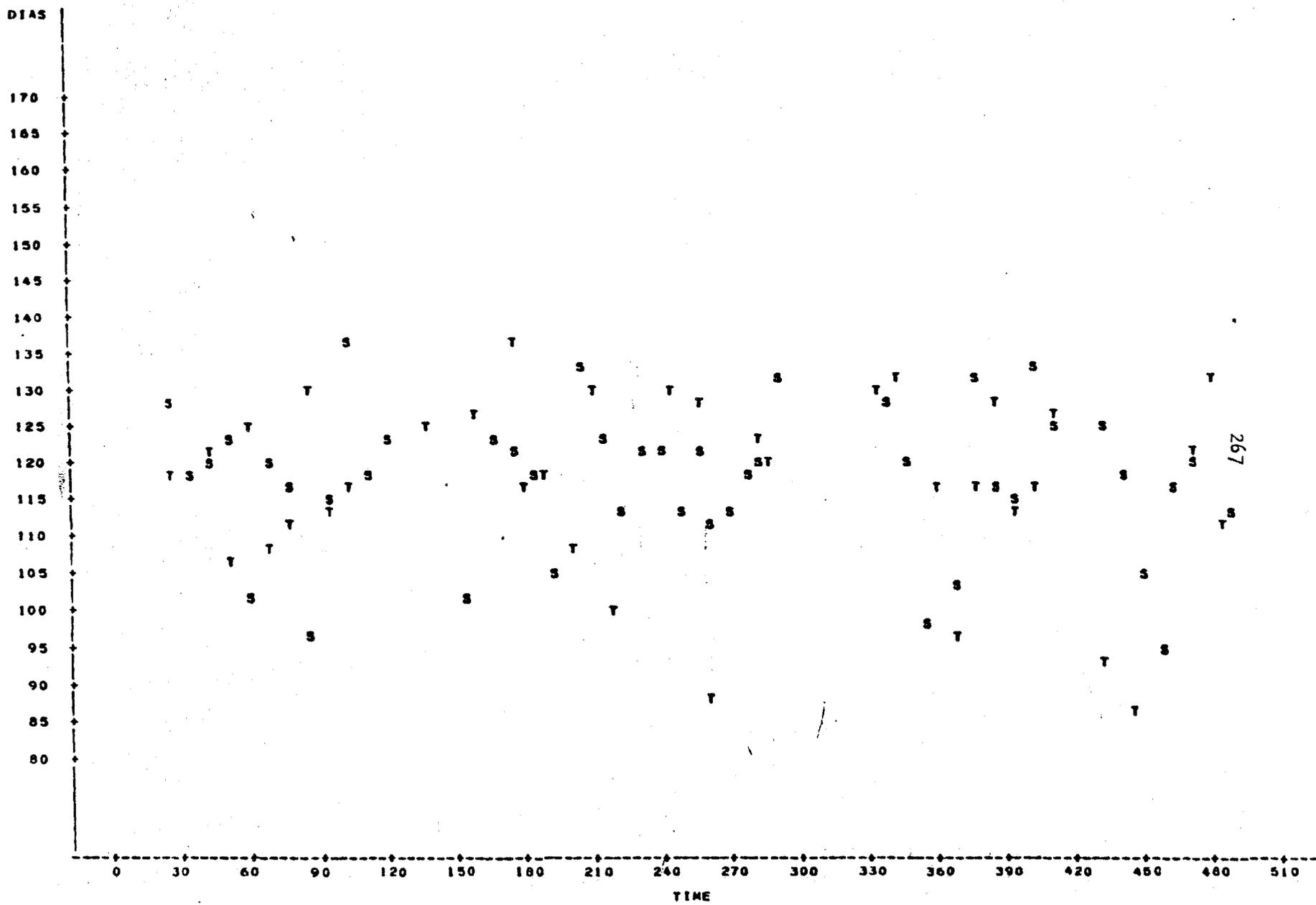
SYSTOLIC VS TIME
SUBJECT 6, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 5 OBS HAD MISSING VALUES

Figure 1.37.

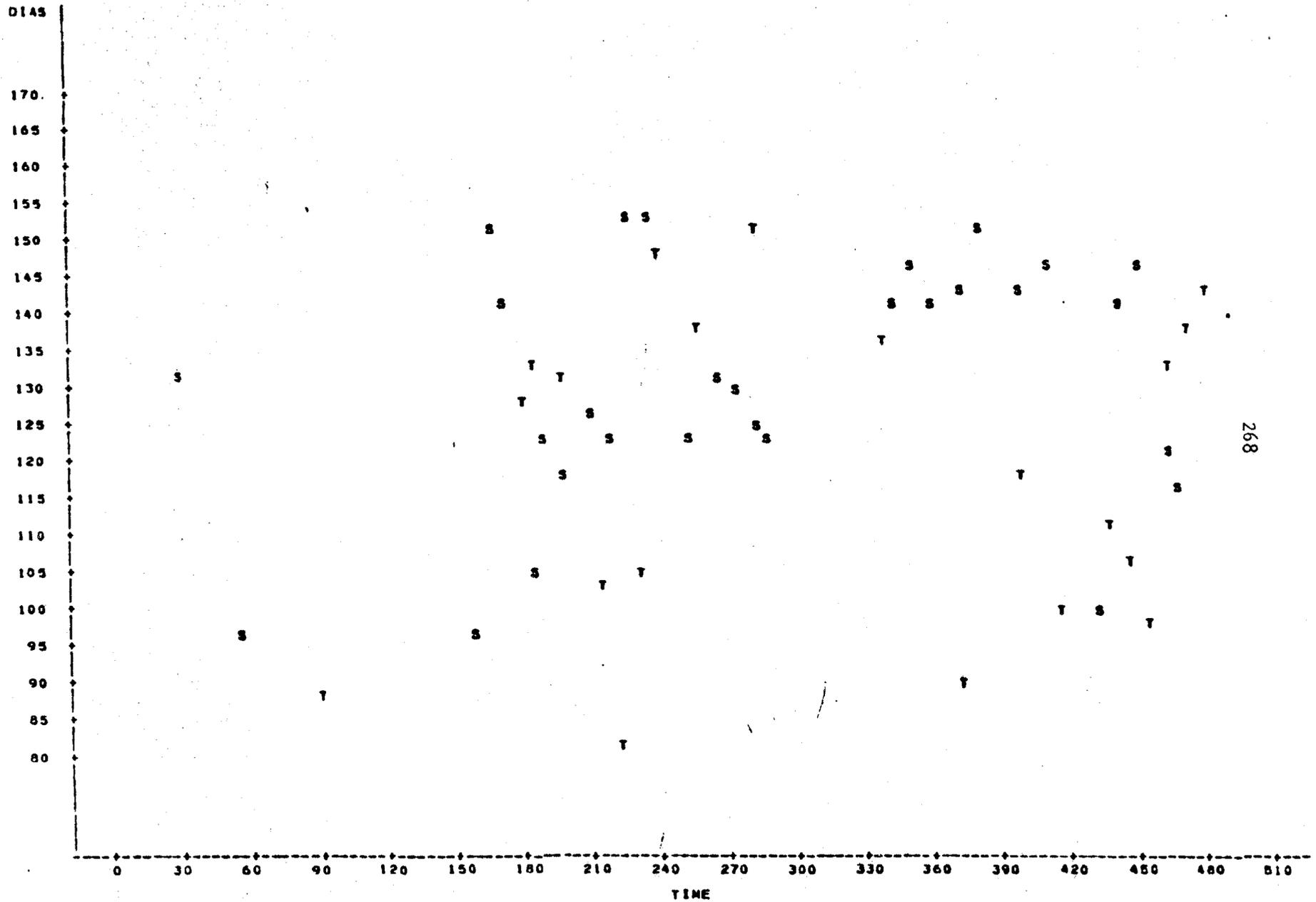
DIASTOLIC VS TIME
SUBJECT 1, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 11 OBS HAD MISSING VALUES

Figure 1.38.

DIASTOLIC VS TIME
SUBJECT 2, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

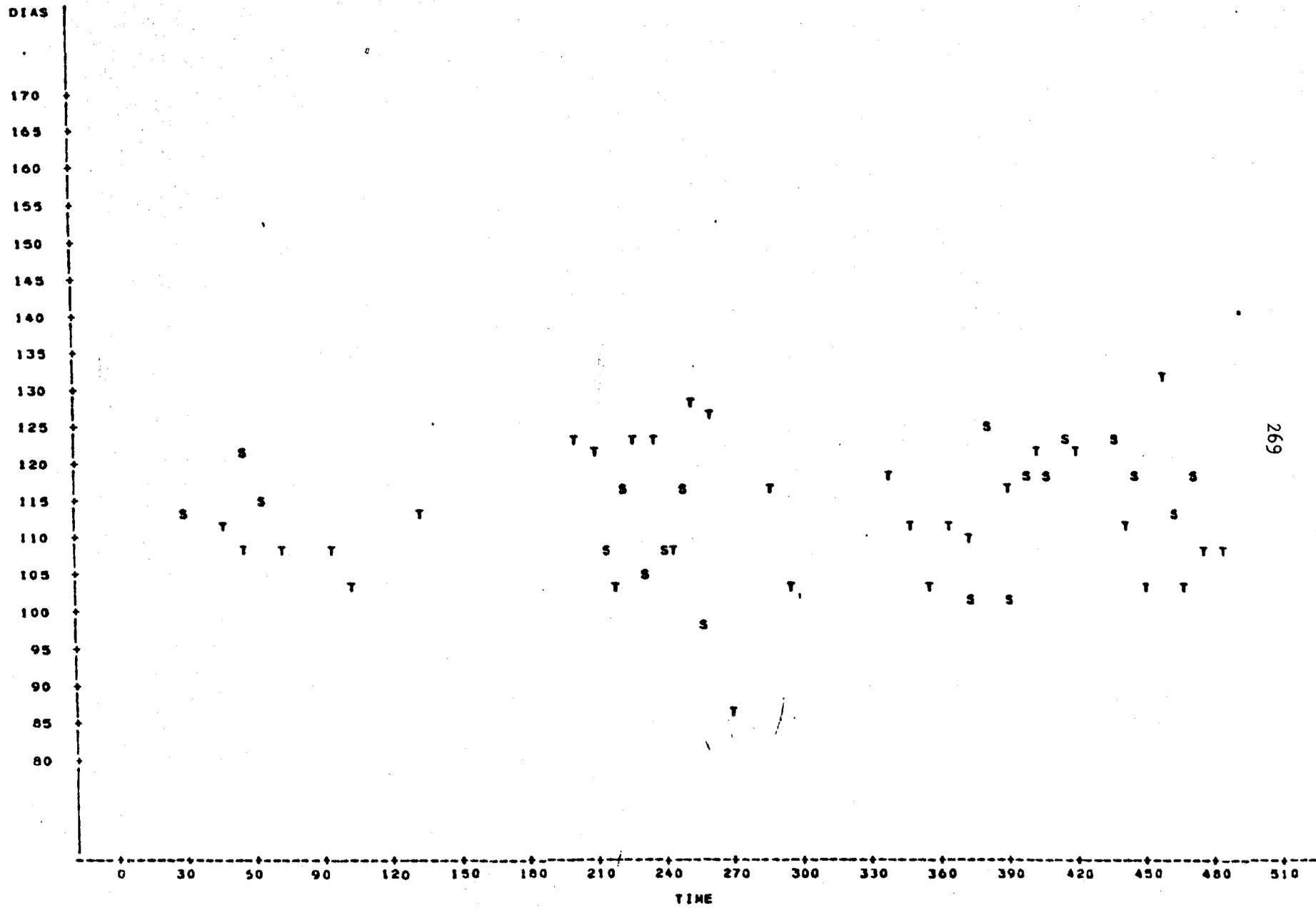


268

NOTE: 34 OBS HAD MISSING VALUES

Figure 1.39.

DIASTOLIC VS TIME
SUBJECT 3, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



NOTE: 6 OBS HAD MISSING VALUES

Figure 1.40.

DIASTOLIC VS TIME
SUBJECT 4, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

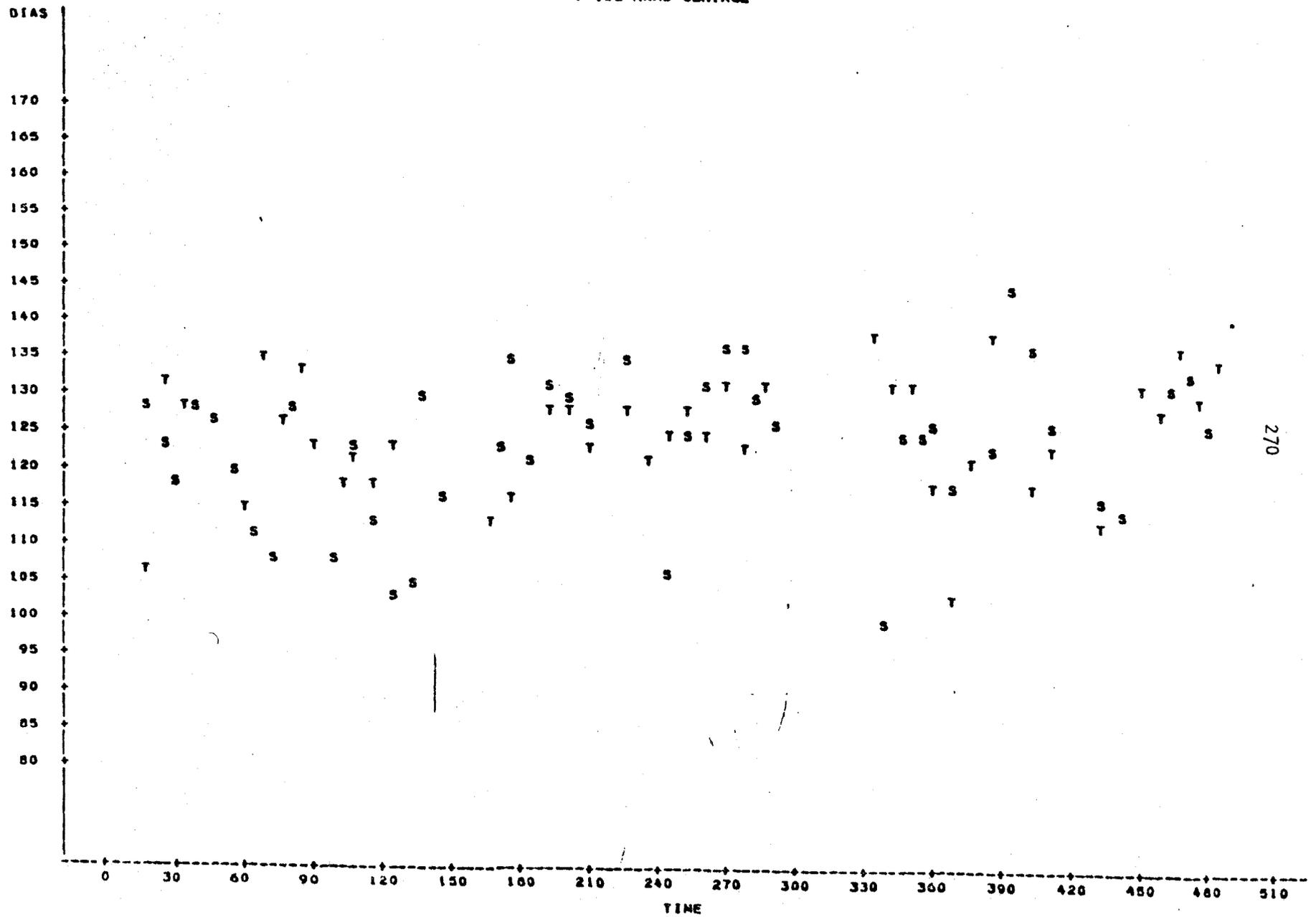


Figure 1.41.

DIASTOLIC VS TIME
SUBJECT S, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

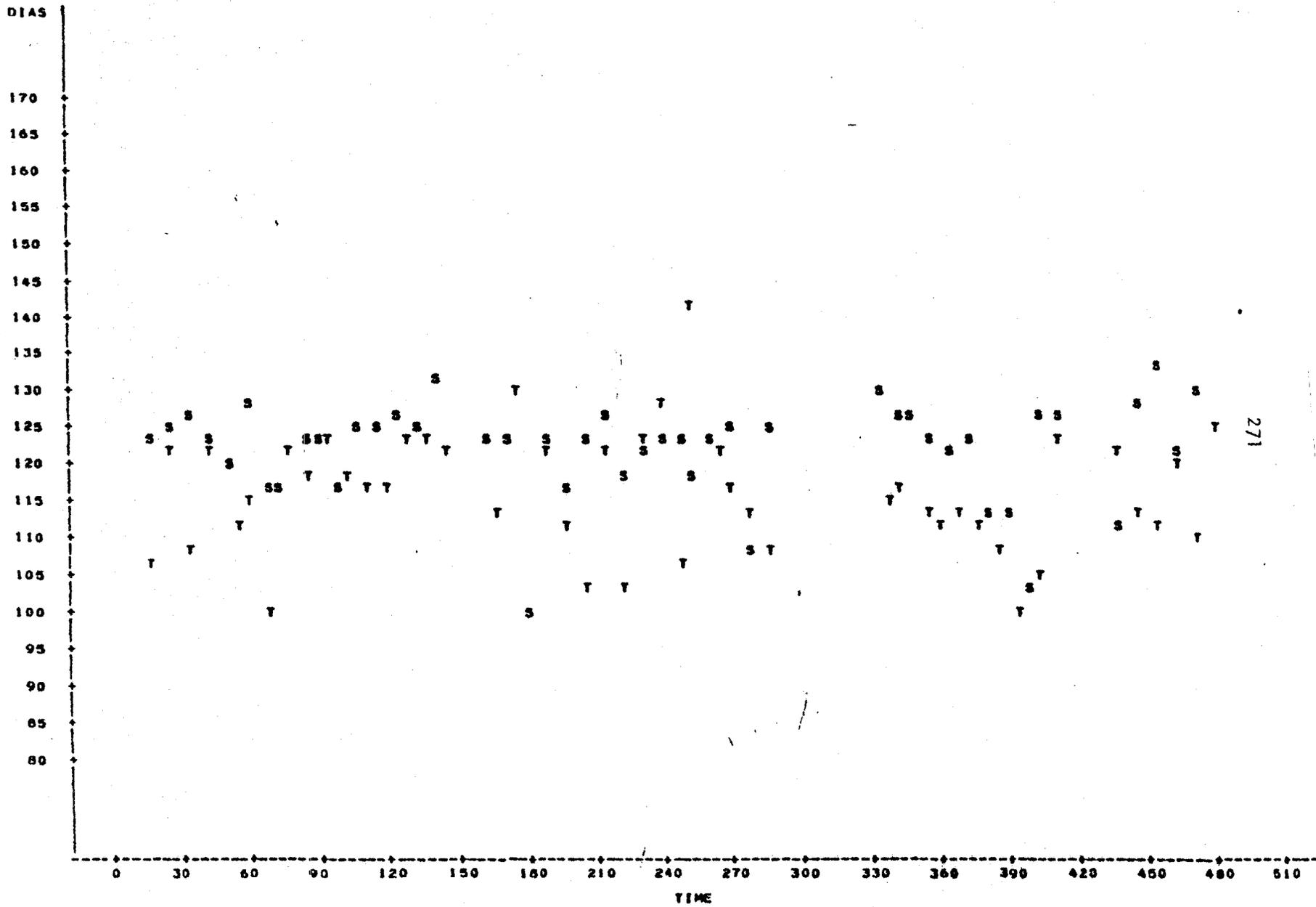
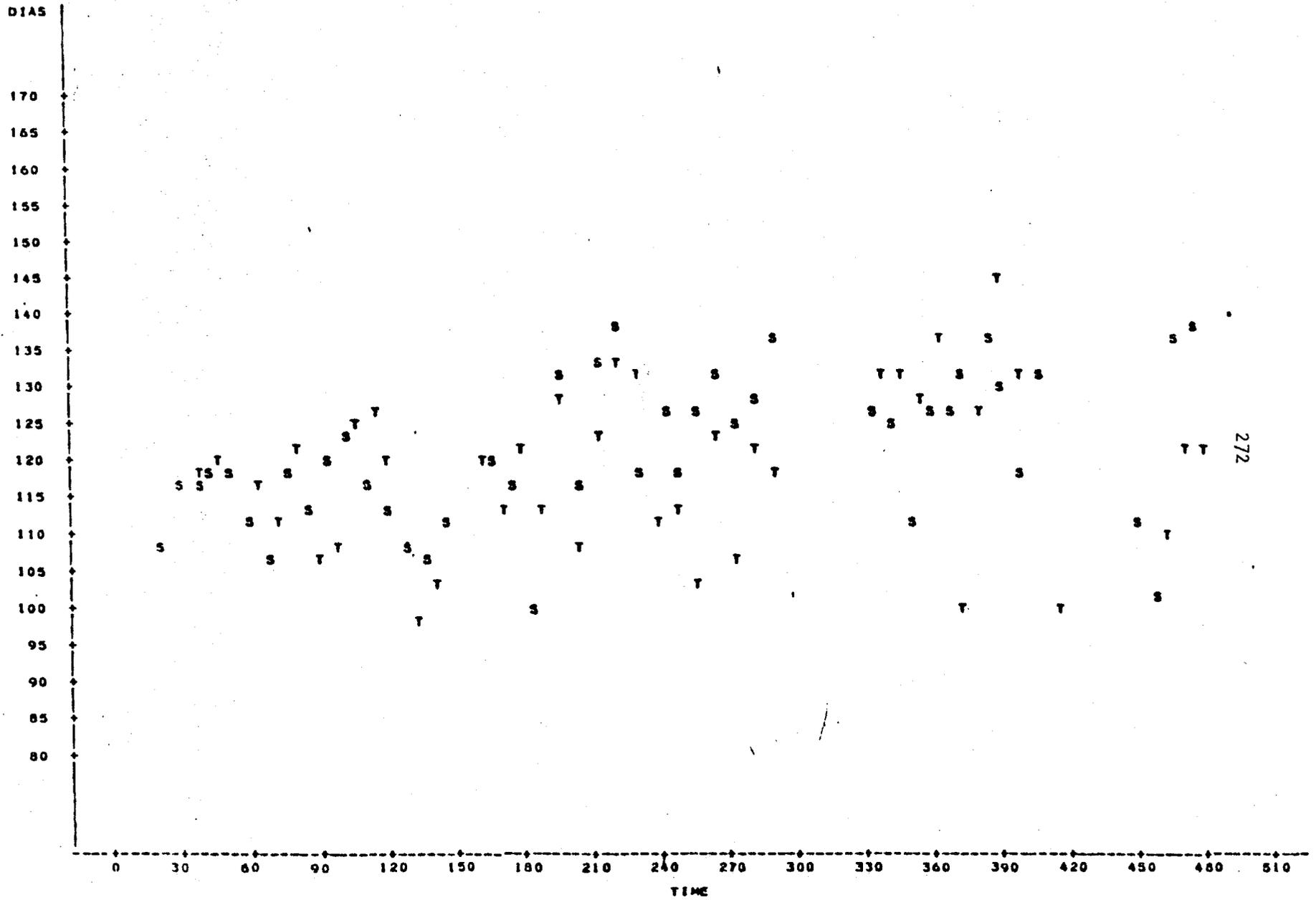


Figure 1.42.

DIASTOLIC VS TIME
SUBJECT 6, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

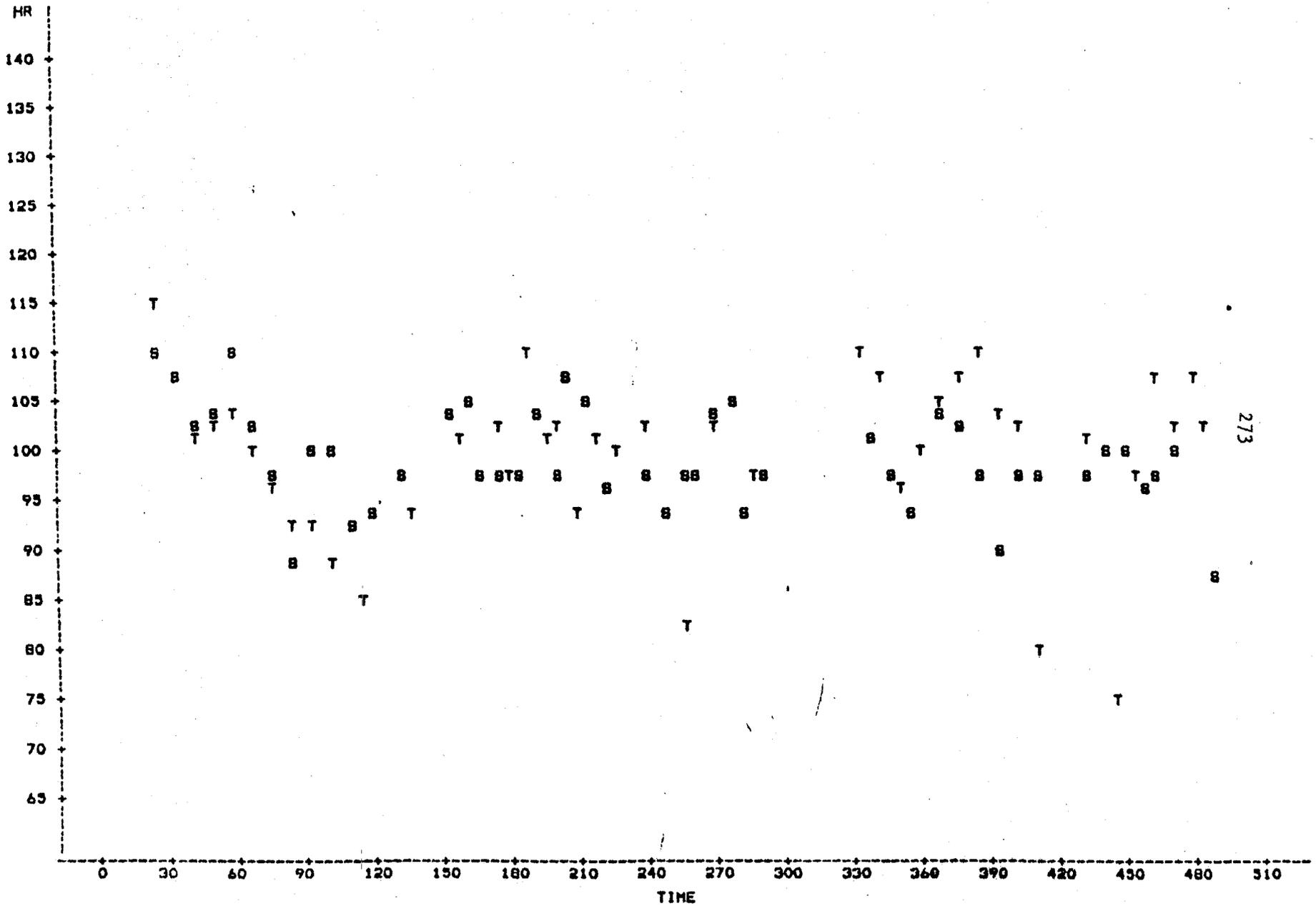


272

NOTE: S OBS HAD MISSING VALUES

Figure 1.43.

HR VS TIME
SUBJECT 1, DAYS 3 AND 4
B-BELT TRIPPING
T-TWO HAND CONTROL

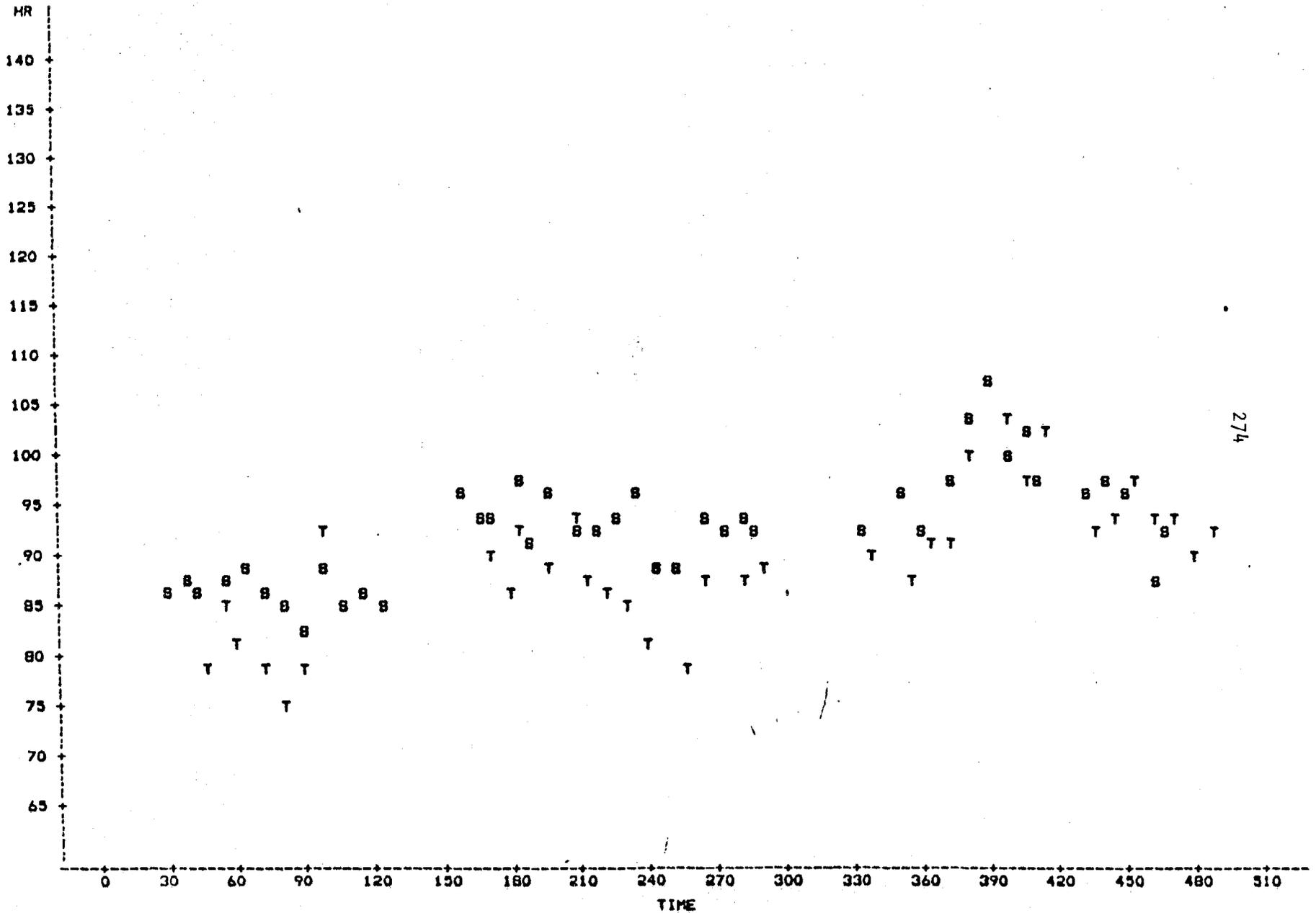


273

NOTE. 2 OBS HAD MISSING VALUES

Figure 1.44.

HR VS TIME
SUBJECT 2, DAYS 3 AND 4
B=SELF TRIPPING
T=TWO HAND CONTROL

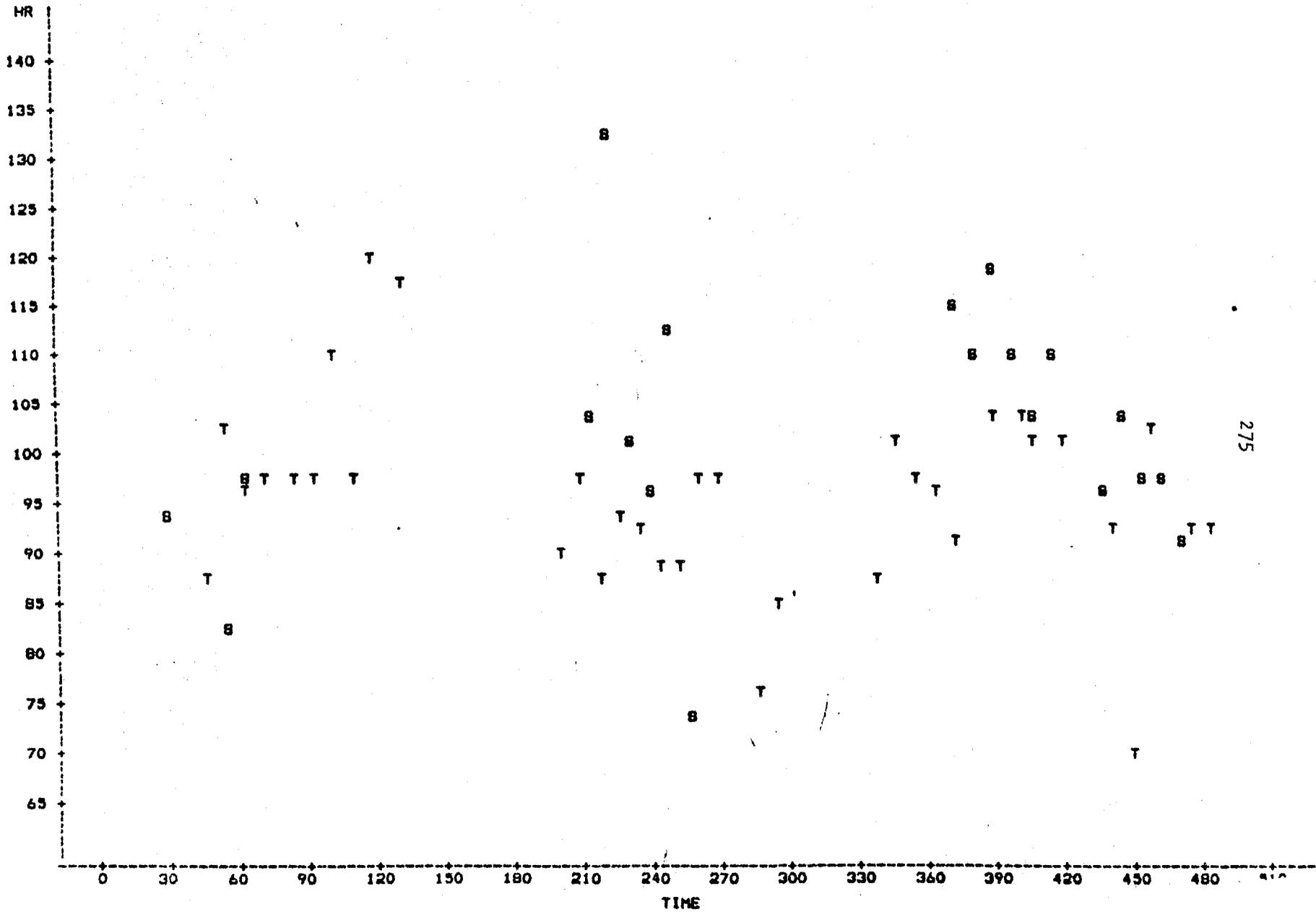


NOTE: 1 OBS HAD MISSING VALUES

274

Figure 1.45.

HR VS TIME
 SUBJECT 3, DAYS 3 AND 4
 B-BELT TRIPPING
 T-TWO HAND CONTROL

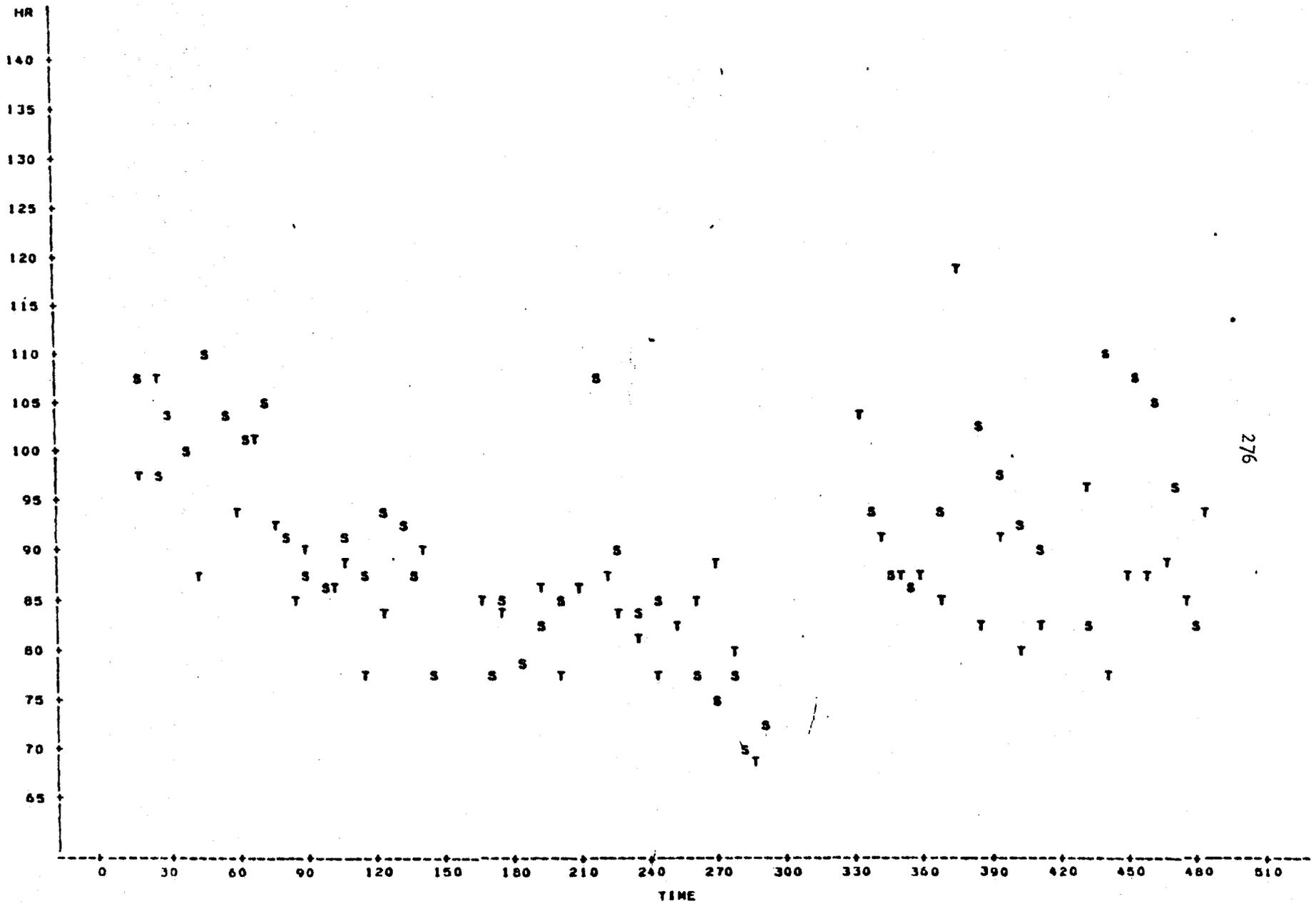


NOTE: 2 OBS HAD MISSING VALUES

275

Figure 1.46.

HR VS TIME
SUBJECT 4, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL

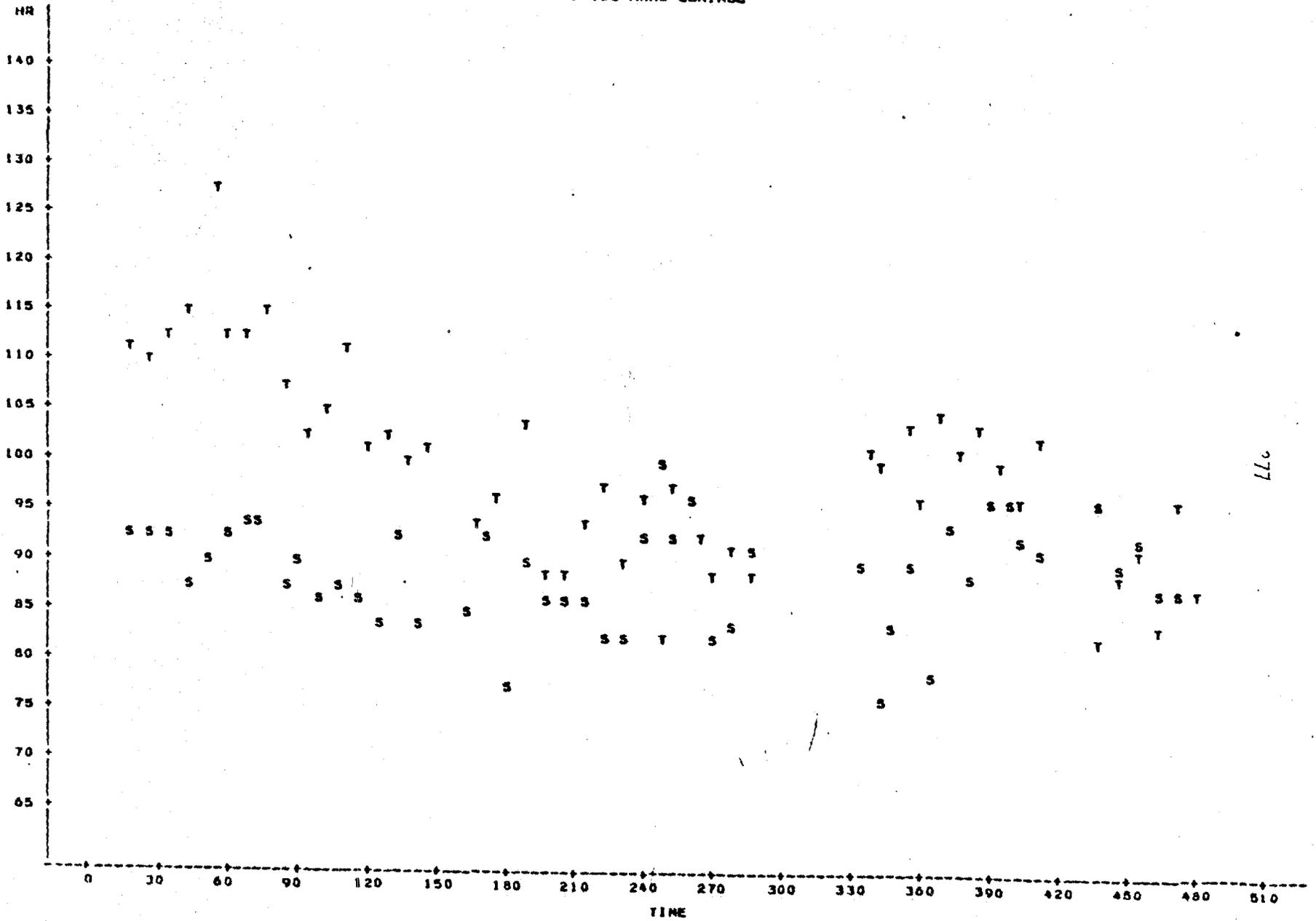


NOTE: 1 OBS HAD MISSING VALUES

276

Figure 1.47.

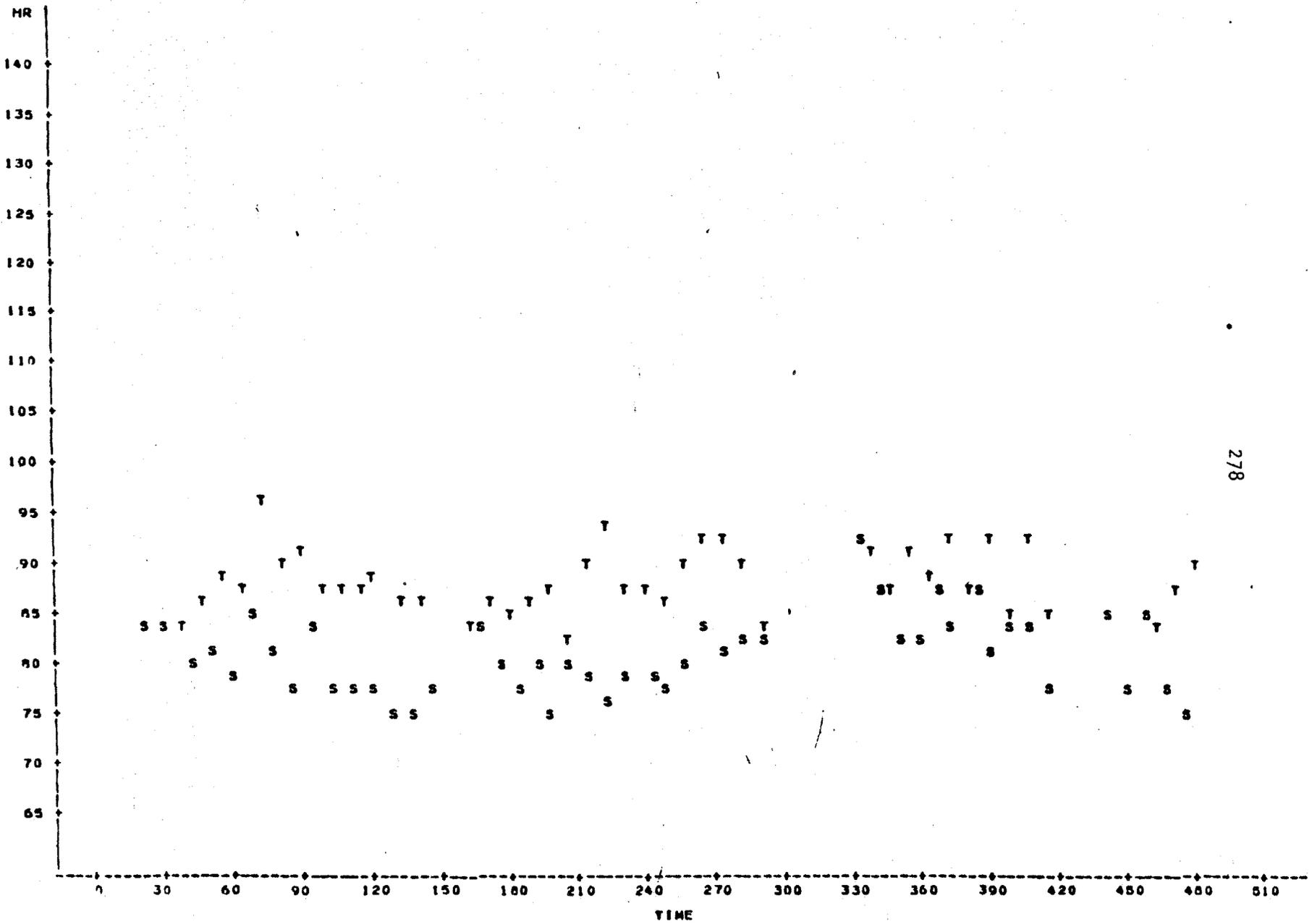
HR VS TIME
SUBJECT S, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



LLc

Figure 1.48.

HR VS TIME
SUBJECT S, DAYS 3 AND 4
S=SELF TRIPPING
T=TWO HAND CONTROL



Appendix J. Baseline and Recovery Data

Table J.1. BASELINE AND RECOVERY MEASURES

MBP (mm Hg)

Subject		Day 1	Day 2	Day 3	Day 4
1	Baseline	129	134	124	110
	Recovery	145	136	130	134
2	Baseline	146	125	146	Missing
	Recovery	129	146	137	149
3	Baseline	137	129	128	117
	Recovery	139	139	129	129
4	Baseline	128	125	121	136
	Recovery	Missing	Missing	138	136
5	Baseline	137	127	128	136
	Recovery	129	120	123	133
6	Baseline	125	126	147	131
	Recovery	141	147	148	137

Table J.2. BASELINE AND RECOVERY MEASURES

SYSTOLIC Bp (mm Hg)

Subject		Day 1	Day 2	Day 3	Day 4
1	Baseline	153	155	144	147
	Recovery	169	158	148	156
2	Baseline	168	156	171	Missing
	Recovery	156	172	156	172
3	Baseline	155	148	146	135
	Recovery	158	158	147	148
4	Baseline	146	142	147	168
	Recovery	Missing	119	158	157
5	Baseline	157	146	147	168
	Recovery	147	147	149	150
6	Baseline	140	150	167	158
	Recovery	158	167	171	156

Table J.3. BASELINE AND RECOVERY MEASURES

DIASTOLIC Bp (mm Hg)

Subject		Day 1	Day 2	Day 3	Day 4
1	Baseline	114	119	110	101
	Recovery	121	121	116	129
2	Baseline	130	107	121	Missing
	Recovery	116	119	119	126
3	Baseline	120	120	114	112
	Recovery	130	130	124	124
4	Baseline	120	116	109	114
	Recovery	Missing	Missing	128	126
5	Baseline	123	109	120	110
	Recovery	120	112	111	126
6	Baseline	110	105	129	107
	Recovery	128	138	122	120

Table J.4. BASELINE AND RECOVERY MEASURES

HEART RATE (Beats/minutes)

Subject		Day 1	Day 2	Day 3	Day 4
1	Baseline	97	97	111	94
	Recovery	89	81	88	96
2	Baseline	75	85	74	75
	Recovery	94	96	89	80
3	Baseline	88	100	89	87
	Recovery	90	82	85	86
4	Baseline	87	120	91	100
	Recovery	Missing	89	70	68
5	Baseline	87	101	98	88
	Recovery	82	71	72	82
6	Baseline	87	92	86	82
	Recovery	93	81	79	69