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Active Controllers and The Time Duration To Learn a Task

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Abstract

An active controller was used to help train naive subjects involved in a compensatory tracking task. The controller is called active in this context because it moves the subject's hand in a direction to improve tracking. It is of interest here to question whether the active controller helps the subject to learn a task more rapidly than the passive controller.

At The Air Force Aerospace Medical Research Laboratory six subjects, inexperienced to compensatory tracking, were run to asymptote root mean square error tracking levels with an active controller or a passive controller. The time required to learn the task was defined several different ways. The results of the different measures of learning were examined across pools of subjects and across controllers using statistical tests. The comparison between the active controller and the passive controller as to their ability to accelerate the learning process as well as reduce levels of asymptotic tracking error is reported here.

Introduction

With the advent of microprocessor computer technology, one would like to use this new technology to help improve the interaction of humans with machines. One method to achieve this result is to use controllers or displays which exhibit the ability to adapt or change with time. An example of this type of application occurs with quickened displays where visual information is used to improve the man-machine interaction. In this case the display is "quickened" if it provides the operator with immediate knowledge of the effects of his own responses. Thus the human operator is able to more efficiently process information with this type of display.

Another way to use computers to improve man-machine interaction occurs if the hand controller the human interacts with is computer controlled to move the human arm and assist in the tracking. Intuitively this makes sense because it is known that golf or tennis teachers [1] physically force the limbs of a student through the appropriate movements for a specific stimulus. This appears to give rise to the quickest initial learning, however, the retention of this learning may be poor.

In this paper we consider a side stick controller which moves in one dimension laterally. The stick controller actually puts a force on the human subject's arm as a function of a smart stick algorithm and physically moves the subject's hand. The subject can override this force depending on the commands he wishes to make.

The idea of using adaptive controllers has been considered previously in the manual control area. For example, in 1968, Herzog [2] investigated a manipulator that had mechanical characteristics matching the plant's characteristics in such a way that the control task of the operator is reduced to the problem of positioning the control stick. This was shown [2] to significantly improve tracking performance.

One must, however, separate the effects of practice from the effect of the subject interacting with the smart stick. In reaction time experiments one school of thought [5] views performance changing at all levels of practice. In fact in reference [5] the authors refer to a study in which performance of a simple manual operation involving a decision by operators in an industrial plant was found to be still improving after a million repetitions. Clearly, such investigations are beyond all pragmatic efforts within a laboratory.

The objective in this paper is to use the active (force producing) controller to observe the effect of this controller to help train subjects rapidly. It is desired to see if the use of an active controller may either reduce the time required to learn a task or possibly to help learning in some other manner.

The Experimental Apparatus

Figure (1) illustrates a block diagram description [3] of how the "smart stick" or active controller is presumed to work. The human body is modelled as a mass-spring-dashpot system. Within the dotted box is the "smart stick" controller which, for this paper, consists of a variable mass, spring, and dashpot, or possibly a programmed biomechanical force. The computer algorithm may possibly produce a programmed biomechanical force which will move the stick in a lateral direction to interact with the hand movements of the subject.

Figure (2) illustrates the mechanical components of this stick. A rack and pinion assembly is coupled to a gear and transmits force to the stick. A piston of area A within an airtight cylinder is moved to the right and left as a function of the pressure on each side of the piston. The pressures P_1 and P_2 are controlled by the two current-pressure transducers which regulate P_1 and P_2 via electrical currents I_1 and I_2. The algorithm from the computer determines the currents I_1 and I_2 which produces the desired force on the stick. Figure (3) illustrates the actual device.

Experimental Design

It is desired in this study to examine how this device may help or hinder the ability to learn a tracking task. Six young, healthy, male active duty Air Force personnel participated in this experiment. They were required to be "naive" trackers which, in this experiment, meant they had not previously participated in a tracking experiment at our laboratory involving compensatory tracking. All runs were conducted in a static (1Gz) environment on four days of a normal work week. Three of the subjects were the control group. The other three subjects were the experimental group. Each day a subject tracked nine trials of 85 seconds duration each with a 120 second rest between each trial. This required approximately 31 minutes daily of the subject's time. At the end of each trial the subject was given a display of his score on the screen of the CRT. The score number displayed was proportional to the root mean square tracking error level during the run. This score was illustrated to provide feedback to the subject on his performance level.

The three subjects in the control group tracked the nine trials each day for 4 days using a passive stick. The passive stick is defined as a simple displacement stick [4] with a relatively low spring constant. The remaining three subjects in the experimental group had the first two days of tracking with the passive stick, similar to the control group. On the third day, however, the experimental group tracked with the smart stick. On the fourth day the experimental group tracked again with the passive stick. It was initially hoped that a comparison of performance on the last day between the two groups may easily demonstrate the difference between the two training schemes. If, like the example from golf or tennis, the smart stick can demonstrate to the subject an improved method of tracking, then on the fourth day the subjects in the experimental group will presumeably track better with the passive stick.

Results

Figure (4) illustrates data from subject 3-PA (the third subject in the experimental group who tracked with both the passive and active stick). It is observed from this plot that the RMS error scores were lower on the third day (the active stick day) as compared to the previous two days involving the passive stick. On day 4, the subject now seems to perform slightly better with the passive stick as compared to days 1 and 2. It is necessary, however, to take out the effect of learning that would normally occur in the absence of an exposure to the smart stick.

Figure (5) illustrates the data from subject 1P (the first subject in the control group). The scores seem to asymptote on the second day with little change thereafter. These results were particular to these individuals but across subjects there existed other types of variation. Figure (6) illustrates data from a pilot (flight instructor). His reaction to the smart stick was of great interest because he was an experienced pilot as well as a flight instructor. On his first exposure to the smart stick he tried different strategies and by the eight trial he had settled down to his best performance level. On the fourth day he did show a small improvement in his error scores. It is necessary, however, to average these effects across subjects to see what can be said in a statistical sense.

Table I illustrates the RMS scores for each day and subject. The entries in the table are the minimum e_{RMS} score each day, the mean and standard deviation e_{RMS} score each day, and the coefficient of variation (ratio of s.d./mean). It is important to consider that learning data are exponential in nature [6] and the mean and standard deviation across all the trials that particular day does not have a great deal of meaning. It provides, at best, a crude estimate of performance that particular day.

Table I- min e_{RMS}, mean, s.d., and C.V.(Coefficient of Variation)

Subject	Day	Minimum	Mean	Standard Deviation	Coefficient of Variation
1-P	1	11.4	17.1	10.3	.60
	2	9.3	10.2	1.6	.16
	3	9.0	9.9	0.8	.08
	4	9.1	9.9	0.6	.06
2-P	1	13.9	19.9	9.9	.50
	2	11.0	13.1	1.8	.13
	3	10.5	16.7	15.3	.92
	4	10.8	11.7	0.6	.05
3-P	1	9.0	11.7	5.9	.50
	2	8.6	9.3	0.6	.06
	3	9.3	11.7	5.1	.43
	4	9.8	10.7	0.5	.04
1-PA	1	7.4	10.2	5.8	.57
	2	7.7	8.6	0.9	.10
	3	4.9	10.0	4.8	.48
	4	6.9	7.7	0.5	.07
2-PA	1	10.7	19.4	14.4	.74
	2	11.2	13.2	2.0	.15
	3	5.6	6.9	0.8	.12
	4	11.6	12.3	0.4	.03
3-PA	1	10.1	12.8	4.2	.33
	2	8.8	11.7	3.4	.29
	3	6.6	11.1	9.6	.87
	4	8.1	9.0	1.2	.13

The coefficient of variation appears to be related to learning because one would expect (as a definition of learning) little variation from trial to trial (small values of s.d./mean). In a laboratory setting, we normally accept data as being consistent if the CV is .2 or less. This appears to occur on the second day for both the passive and active stick **data**.

To analyze these data, the minimum error RMS was determined for each subject on day 2 and day 4, and the percent change from day 2 to day 4 was calculated. These percent changes were used in a 2-sample T-test which found no significant difference between the PA group (mean=-5.0, s.d.=7.5) and the P group (mean=3.5, s.d.=9.4), $T(4)=-1.2$, $p=.2876$. Thus, using the active stick on day 3 did not result in significantly lowering the minimum error RMS scores for day 4 as compared with the P group. The following table contains the minimum error RMS scores used in the analysis:

Table II

Subject	E_{RMS} Min Day 2	E_{RMS} Min Day 4	% Change Day 2 to Day 4
1-P	9.3	9.1	-2.4
2-P	11.0	10.8	-1.5
3-P	8.6	9.8	14.3
1-PA	7.7	6.9	-10.2
2-PA	11.2	11.6	3.6
3-PA	8.8	8.1	-8.3

The coefficient of variation for error RMS was determined for each subject on day 2 and day 4, and the percent change from day 2 to day 4 was calculated. These percent changes were used in a 2-sample T-test which found no significant difference between the PA group (mean=-56, s.d.=21) and the P group (mean=-51,s.d.=19), T(4)=-0.3, p=.75238. Thus using the active stick on day 3 did not result in significantly lowering the variability of the error RMS scores for day 4 as compared with the P group. Table III contains the coefficients of variation obtained from these data.

Table III - Coefficient of Variation * 100

Subject	CV Min Day 2	CV Min Day 4	% Change Day 2 to Day 4
1-P	15.6	5.7	-63.5
2-P	13.4	5.4	-59.7
3-P	6.2	4.4	-29.0
1-PA	10.4	6.7	-35.2
2-PA	15.0	3.3	-78.1
3-PA	29.4	13.0	-55.7

The minimum error RMS was determined for each subject on day 2 and day 3, and the percent change from day 2 to day 3 then calculated. These percent changes were used in a 2 sample T-test which found a significant difference between the PA group (mean=-37.1, s.d.=12.5) and the P group (mean=0.3, s.d=7.2), T(4)=-4.5, p=.0109. Thus, there was a greater decrease in the minimum error RMS from day 2 to day 3 for the PA group than for the P group. The following table contains the minimum error RMS scores used in the analysis:

Table IV - Minimum Error Scores (RMS Values)

Sub.	Error RMS Min Day 2	Error RMS Min Day 3	% Change Day 2 to Day 3
1-P	9.3	9.0	-3.0
2-P	11.0	10.5	-4.7
3-P	8.6	9.3	8.5
1-PA	7.7	4.9	-36.0
2-PA	11.2	5.6	-50.2
3-PA	8.8	6.6	-25.2

Discussion

It was initially hoped that a comparison of performance results on the fourth day between the control group and the experimental group would demonstrate the advantage of the use of the smart stick to reduce the time to learn a task. Three questions were answered from this study. First, the question of whether the experimental group performed better on the fourth day as compared to the control group? It was demonstrated that the exposure to the smart stick did not produce any additional improvement in the passive stick scores from day 2 to day 4.

The second question of whether overall variability decreased was answered by studing the coefficient of variation. One could use as a definition of learning a measure of consistent and repeatable score levels. Perhaps the exposure to the smart stick would make the scores on day 4 more consistent which could be detected by a smaller value of the coefficient of variation. The results of the analysis of Table III indicated that subjects were no more consistent on day 4 following the smart stick as the control group had following the passive stick on day 3.

The third question as to whether the smart stick actually improved tracking performance was obtained from analysis of Table IV. A significant difference was found across subjects and controllers in comparing Day 2 to Day 3 between the control group and the experimental group. The percent change reduction in e_{RMS} due to the smart stick exceeded 50% of the passive stick value for one subject.

Conclusions

An active controller was used to train naive subjects in a compensatory tracking task. The subjects apparently did not improve their passive stick scores after being exposed to the active stick anymore than a subject that had just tracked with the passive stick. The amount of variability across replications did not decrease after exposure to the smart stick. Finally, it was demonstrated that tracking with the active controller will significantly reduce error scores to levels sometimes 50% below the asymptotic levels for a passive stick.

References

[1] Sheridan, T. B., and Ferrell, W. R., "Man-Machine Systems", The MIT Press, 1981.

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[4] Levison, W. H., "Effects of Control Stick Parameters on Human Controller Response", Report No. 5510, Bolt, Beranek, and Newman, Inc., January, 1984.

[5] Mowbray, G. H. and Rhoades, M. V., 1959, "On The Reduction of Choice Reaction Times With Practice", Quarterly Journal of Experimental Psychology, 11: pp. 16-23.

[6] Gershoni, H., "An Investigation of Behavior Changes of Subjects Learning Manual Tasks", Ergonomics, 1979, vol. 22, No. 1, pp. 1195-1206.

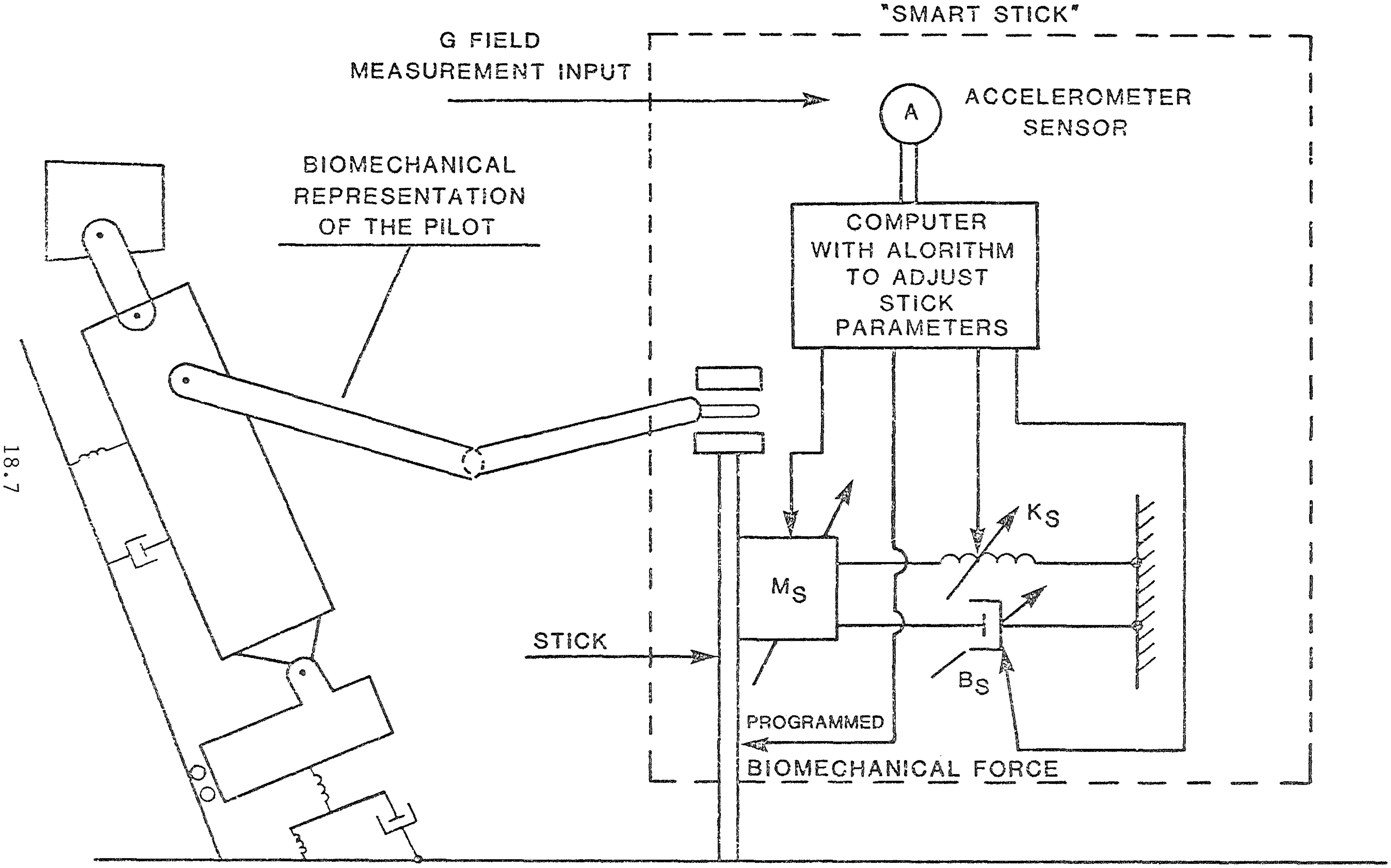


Figure (1) - THE "SMART STICK"

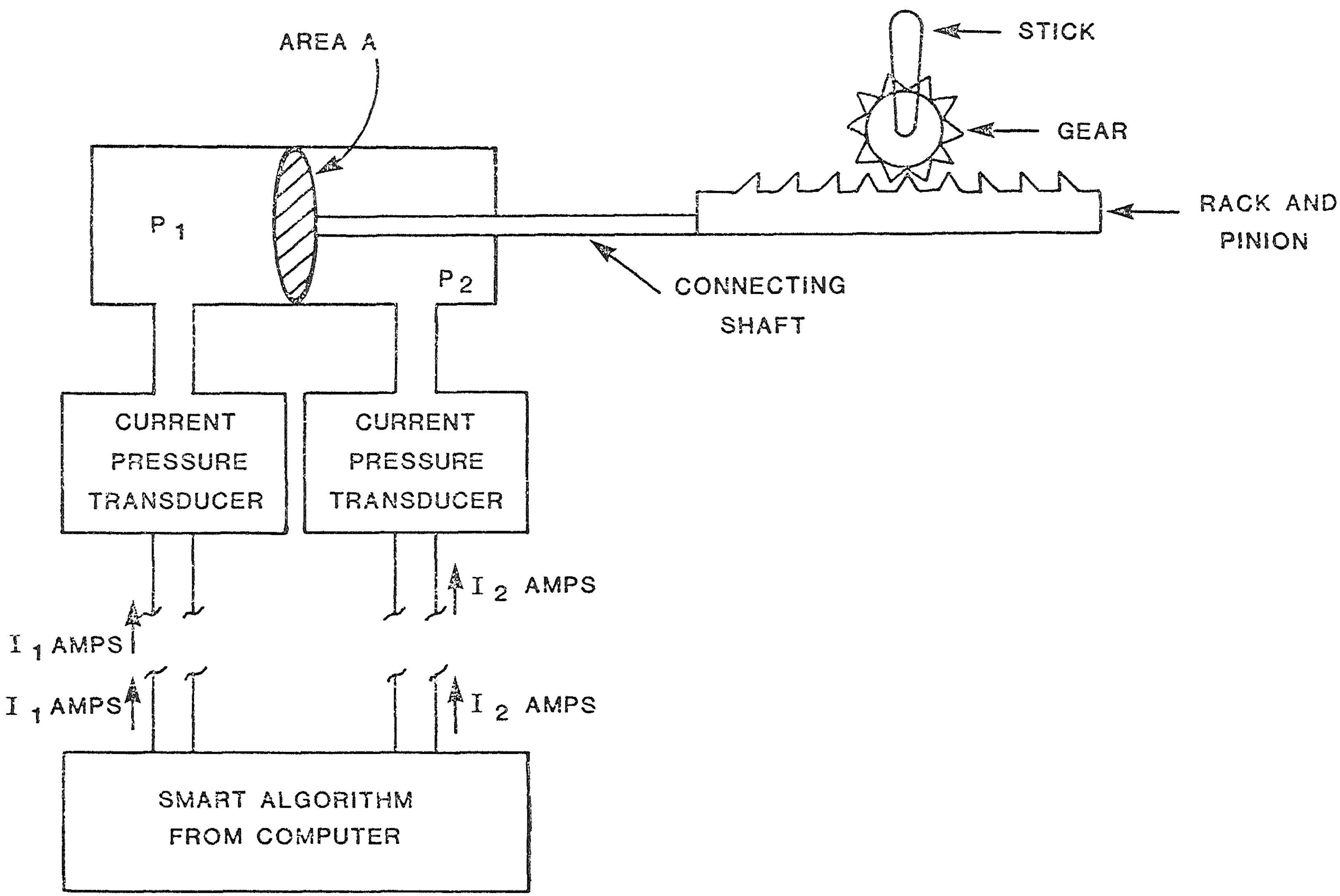


Figure (2) - THE ELECTROMECHANICAL DEVICE

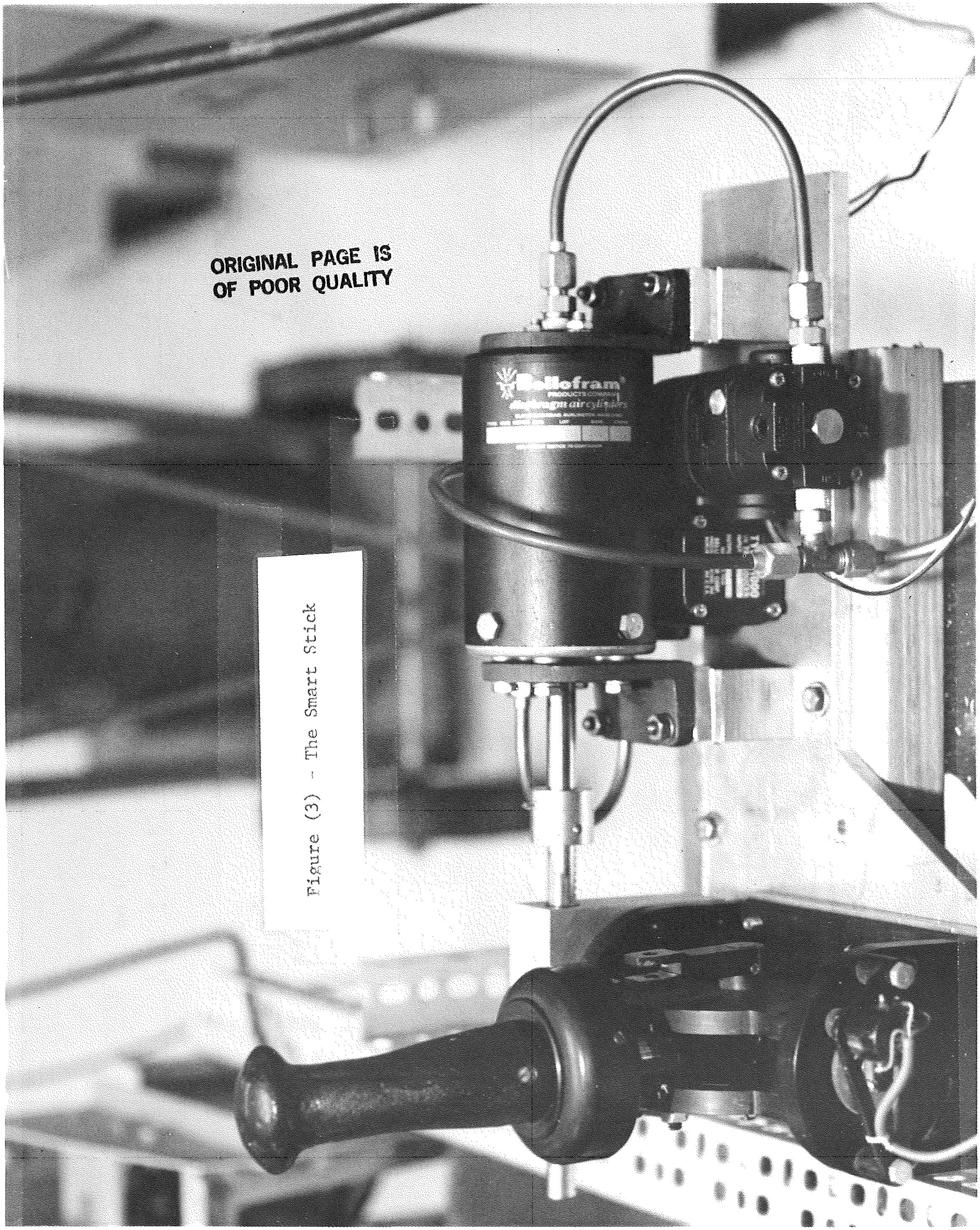
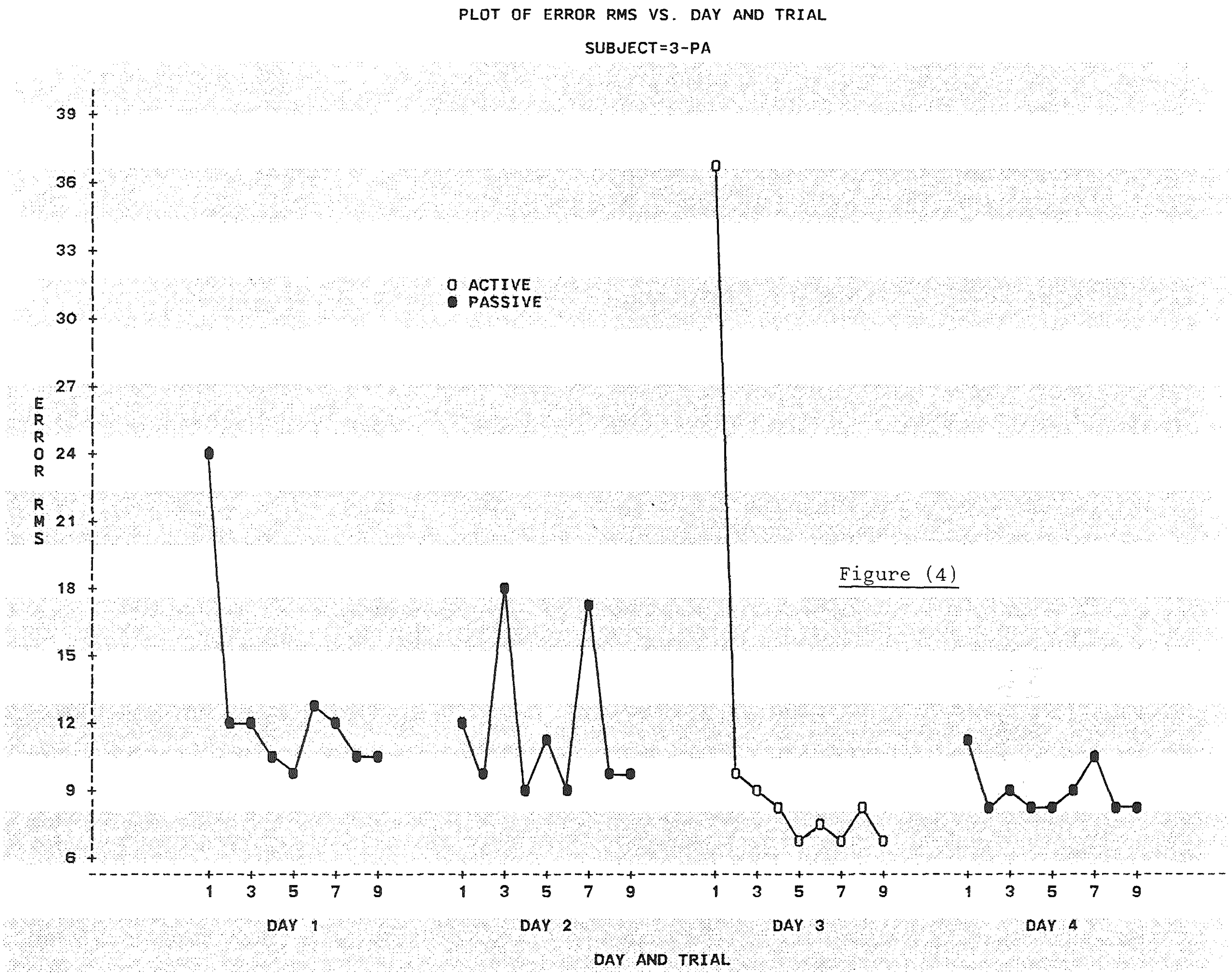


Figure (3) - The Smart Stick



PLOT OF ERROR RMS VS. DAY AND TRIAL
SUBJECT=3-PA
ERROR RMS
39
36
33
30
27
24
21
18
15
12
9
6
O ACTIVE
● PASSIVE
1 3 5 7 9
DAY 1
DAY 2
DAY 3
DAY 4
DAY AND TRIAL

Figure (4)

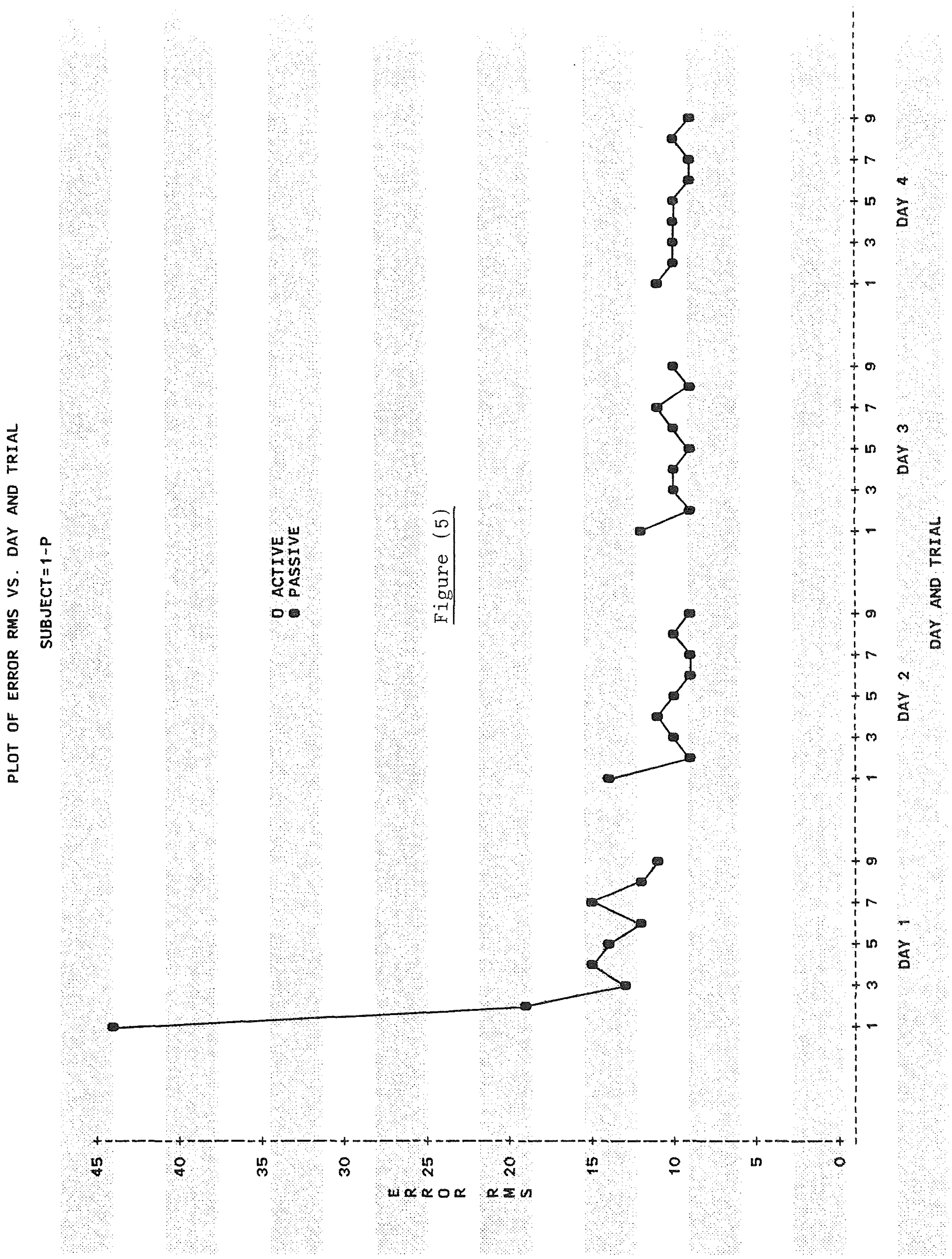

PLOT OF ERROR RMS VS. DAY AND TRIAL
SUBJECT=1-P
O ACTIVE
● PASSIVE
ERROR RMS
45
40
35
30
25
20
15
10
5
0
1 3 5 7 9
DAY 1
DAY 2
DAY 3
DAY 4
DAY AND TRIAL

Figure (5)

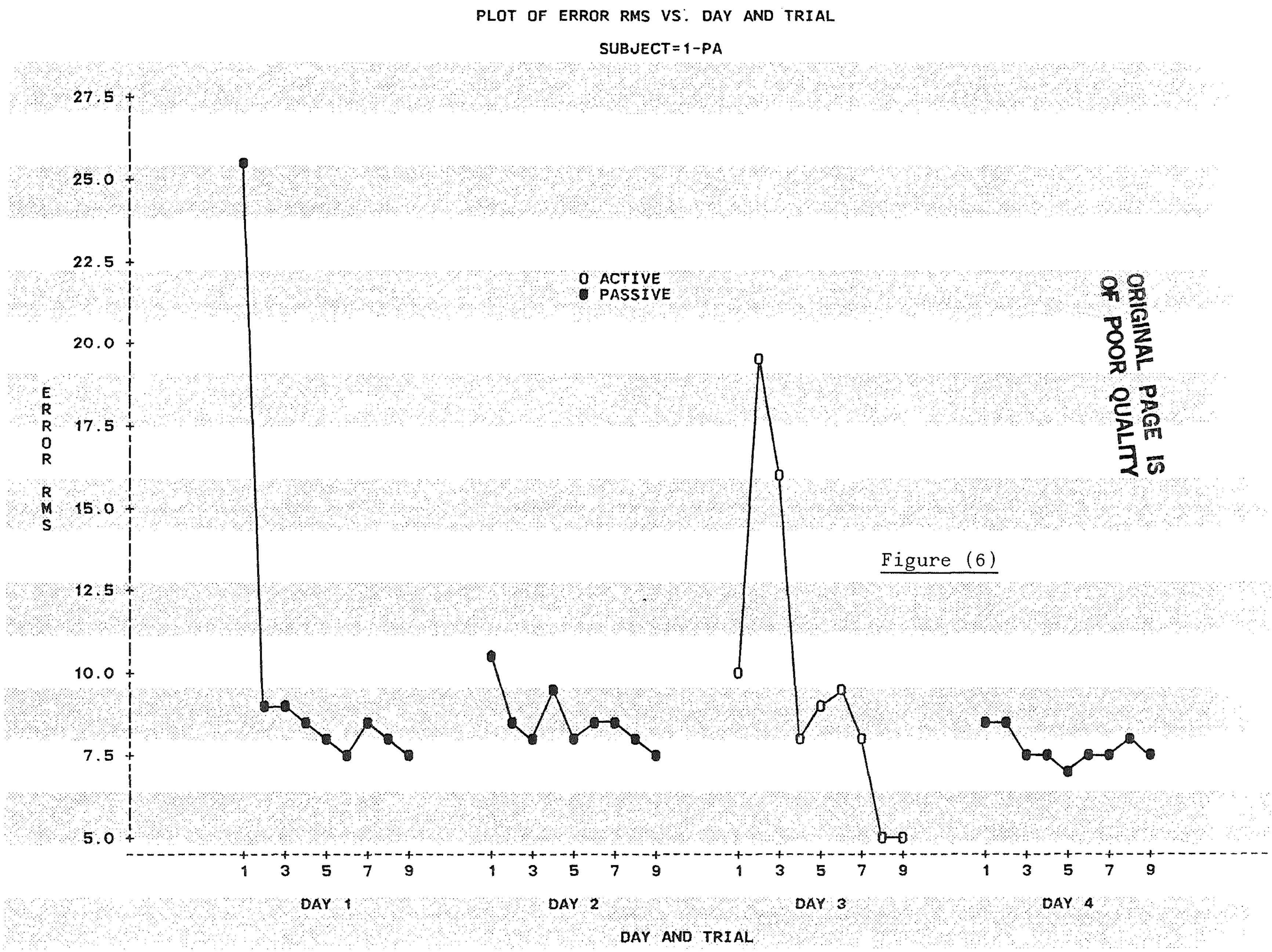

PLOT OF ERROR RMS VS. DAY AND TRIAL
SUBJECT=1-PA
O ACTIVE
PASSIVE
ERROR RMS
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
1 3 5 7 9
DAY 1
DAY 2
DAY 3
DAY 4
DAY AND TRIAL

Figure (6)