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Human vs Filter as Data Extrapolator in a Two-Coordinate, Sampled-Data Tracking System

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ABSTRACT

The performance of human operators was compared with that of a singly augmented filter in the continuous determination of the present position of a constant rate target moving in two coordinates. Target position was indicated intermittently in low, medium, or high noise levels and at low, medium, or high data rates. In addition, the target was subjected to a 10°, 20°, or 60° course change in each trial. The filter evidenced less average tracking error in 23 of the 27 combinations of conditions of data rate, noise level, and course change. In twelve of these instances the filter was significantly superior at $p = .02$ level. Also, the results indicated increased error in human and filter performance as a function of increasing noise levels and decreasing data rates.

Relative to the further enhancement of data extrapolation, several avenues of investigation recommend themselves. An immediate possibility is the employment of filter networks as an aid to the human operator. A second avenue of investigation is the study of more sophisticated filter designs. This experiment employed a filter of fixed time constant and fixed augmentation. An optimum filter would be of an "adaptive" type, automatically adjusting its time constant and augmentation as a function of noise and data rate.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem Y02-01
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HUMAN VS FILTER AS DATA EXTRAPOLATOR
IN A TWO-COORDINATE, SAMPLED-DATA TRACKING SYSTEM

BACKGROUND

A large number of weapon systems receive intermittent and discrete data inputs, which must be translated by a human operator into continuous control data or from which an operator must extrapolate continuous data on a problem status. Systems using sensors, which create a sampled or pulsed input, such as active sonar and scanning radars, can be considered sampled-data systems (1). The general elements of a typical open-cycle, sampled-data system are presented in Fig. 1, together with the equivalent elements found in conventional weapon systems.

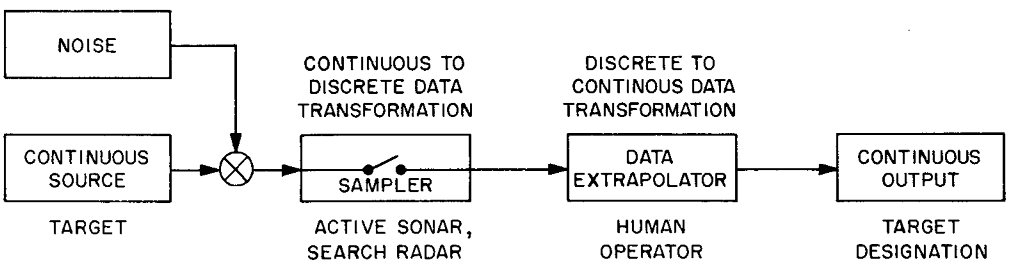


Fig. 1 - Typical open-cycle, sample data system

The inability of the samplers – or sensors – in the presence of noise and performance limits to reflect accurately target position and motion places a substantial dependence on the data extrapolator – or human – to produce an accurate output – or target designation. Under such conditions, enhanced system performance resides in large part with the optimization of the data extrapolator – human or automata. Of particular influence on the performance of the data extrapolator is the data rate, the noise level, and the evasive character of the target or the system forcing function. This experiment attempts (a) to characterize the response of the human operator to variations in these primary variables of the sampled-data system and (b) to compare human performance with that of a singly augmented filter.

METHOD

Subjects

Three college graduates, knowledgeable in conditional probabilities and experienced in tracking, were employed as subjects in this experiment. The use of sophisticated subjects was an intentional sampling bias. Thus, should the experimental results show the filter superior, the conclusion would not be an artifact attributable to a substandard group arising from a small, randomly selected sample.

Apparatus

The experiment was performed with a dual-channel, two-coordinate tracking system which made possible the simultaneous comparison of human and filter performance. This setup is shown in the block diagram of Fig. 2. The equipment provided an open-cycle, sampled-data system for the employment of a human and a filter as parallel, but separate, data extrapolators. For scoring, the continuous x and y outputs of the filter and the human were compared separately with the x and y components of the course. The difference, or error, in the respective x and y coordinates was rectified, summed, and integrated over time ($\int |e| dt$) to produce separate error scores for the human and the filter. The general form of a singly augmented RC filter is shown in Fig. 3 together with a block diagram of this filter system and the analog design of the active network used in this study (2). The double integration of a step input to this second-order system produces an acceleration component in the output. In addition, the augmentation by a single feed-forward loop adds a velocity component to the output. The unity-gain feedback loop allows the filter output to match a step or ramp input, if permitted to reach a steady state condition. Thus, the filter is a low-pass network having a capacity to smooth transient inputs as well as to perform a short-term target course extrapolation. The parameters of the filter were established empirically through a series of preliminary investigations using the independent variables of the present experiment. Identical active filters were used in the x and the y coordinates on the filter side of the experimental system.

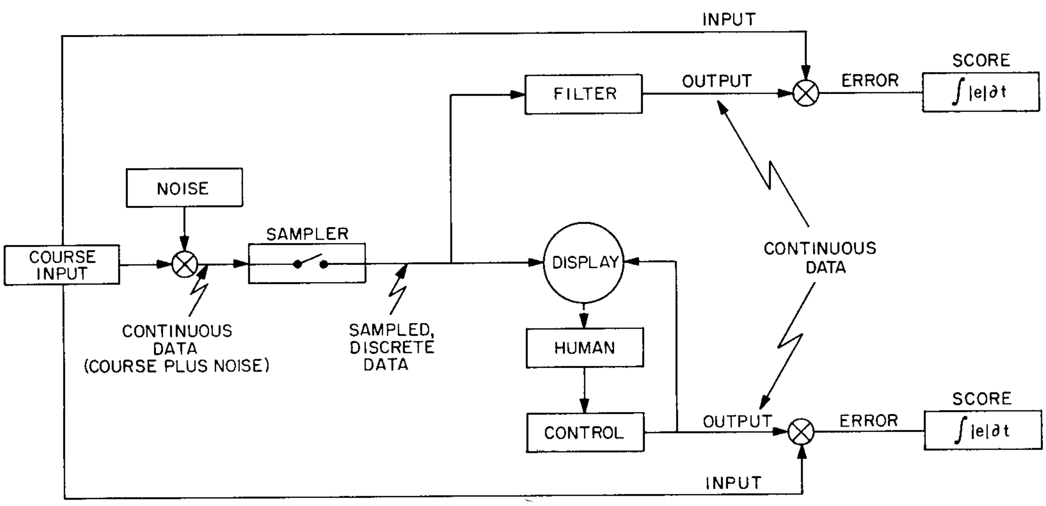


Fig. 2 - Experimental sampled-data system for the comparison of human and filter tracking performance

The same course, noise, and data rate conditions were presented simultaneously to the human and the filter. Subjects observed the problem conditions displayed on a 4-in. Memotron cathode-ray oscilloscope. A spring-centered control lever was used by the subjects in the position control of a continuously displayed "tracking" dot. The single beam of the oscilloscope was time-shared so as to display both the intermittent target data points and the tracking dot. The memory feature of this display retained all history of the target data points as well as the positions of the tracking dot caused by the subject's control manipulation during a given run. Figure 4 is a composite illustration showing a typical underlying target course (not a displayed quantity), the "course-plus-noise" displayed target data points, and the position history of the tracking dot resulting from the subject's control manipulations.

(a) GENERAL FORM OF THE SINGLY AUGMENTED RC FILTER

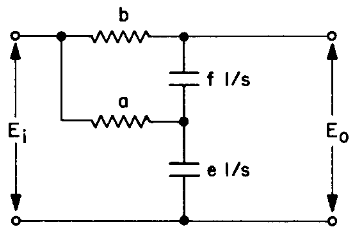
$$\frac{E_o}{E_i} = \frac{As+1}{Bs^2+As+1}$$

WHERE: a, b, e 1/s, f 1/s = IMPEDANCES

s = THE LAPLACIAN DIFFERENTIAL OPERATOR

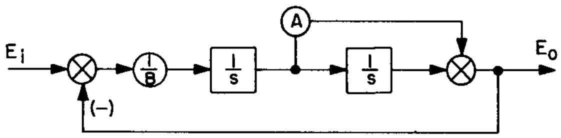
$A = ae + af + bf$

$B = abef$



(b) BLOCK DIAGRAM OF THE SINGLY AUGMENTED FILTER

$$\frac{E_o}{E_i} = \frac{As+1}{Bs^2+As+1}$$



(c) ANALOG SCHEMATIC OF TRACKING FILTER

$$\frac{E_o}{E_i} = \frac{As+1}{Bs^2+As+1}$$

WHERE: $A = R_2 C_2 = 5.2$,

$B = (R_1 C_1)^2 = 27.04$,

$$\frac{E_i}{E_o} = \frac{5.2\,s+1}{(5.2)^2 s^2 + 5.2\,s+1}$$

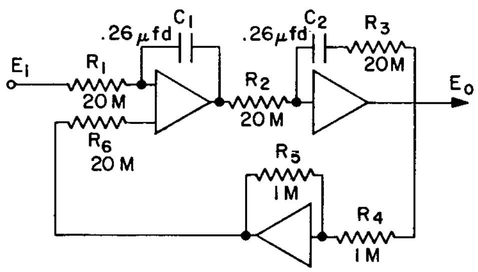


Fig. 3 - General form of the singly augmented filter and design of the second order tracking filter

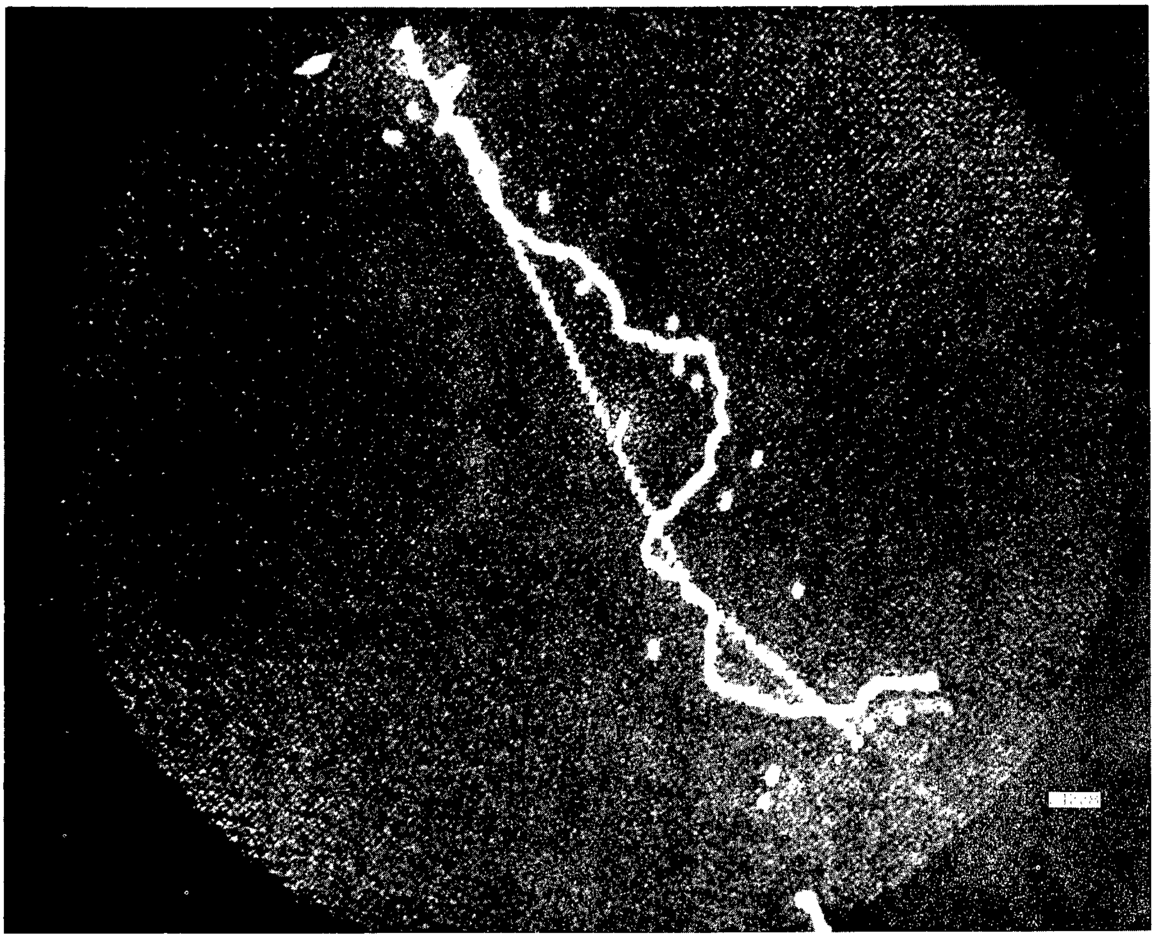


Fig. 4 - Composite picture of: basic target track with 20° course change (dotted line); sampled data points taken from a medium noise, medium data rate condition; and the human estimate of target track (solid line)

The noise generator in each coordinate of the tracking system produced a varying voltage of 2 to 5 cps with amplitude variations approximating a Gaussian distribution. The noise generating equipment consisted of ten neon lamps, each across a given RC network and each discharging at a different frequency. The outputs from the RC networks were summed algebraically and fed through a low-pass filter. This varying or "noise" voltage was added to the course voltage and the resulting course-plus-noise voltage was sampled simultaneously in both coordinates at the selected sampling rate. The resulting data points were presented simultaneously to the human and the filter. All system dynamics and problem programming were accomplished with analog computers.

Procedure

The human subjects and tracking filter were given a pursuit type tracking task, i.e., the pursuit of an intermittently designated, moving target in the presence of various levels of noise. The above equipment developed a pattern of dots distributed about a target trace, moving at a constant-rate of 3 in./min. The distributive nature of this pattern and the pattern density were determined by the selected data rate and the amplitude of the noise.

The independent variables of this experiment were noise amplitude, data rate, and angle of course change. The following amounts of noise, data rate, and course change were employed:

1. Peak noise amplitudes: 2.25 in., 1.5 in., and 0.75 in. as measured at the display.

2. Data rates: 60, 15, and 8 points per minute.

3. Course changes: 10°, 20°, and 60°. A single course change was initiated within 15 seconds in each run. It should be noted that the course originated at the 45°, 135°, 225°, or 315° point on the perimeter of the display (0° understood to be at the 12-o'clock position). The initial course vector was a diagonal toward the display center. Course changes were made either positively or negatively from the initial course direction. Course starting position, direction of course change, and amounts of course change were presented in a randomized order.

The dependent variable of this experiment was the average integrated error ($\int |e| dt$) simultaneously and separately obtained for the human and the filter. Alignment procedures, performed prior to each experimental session insured the maintenance of equivalence in the separate scoring systems. The subjects were instructed to track their estimate of the target's location, based on the moving distribution of target dots. Subjects were informed of their error score after each trial. Each trial was 64 seconds long and was scored for the terminal 60 seconds. The subjects were given preliminary training of twelve trials of differing conditions. The three levels of each of the three independent variables produced twenty-seven combinations of conditions. These conditions were presented in a randomized blocks design and replicated five times for each subject. Thus, each subject received 135 trials.

RESULTS

Comparative performance plots illustrating the influence of the independent variables on the human and the filter are shown in Figs. 5 through 10. The significance of treatment effects was determined by an analysis of variance, performed separately on human and filter data. The significance of differences between the human and the filter was tested by Wilcoxon's method of unpaired replicates (3). Table 1 summarizes the significance of differences between the human and the filter for all individual conditions of data rates, noise amplitudes, and course changes. The filter performance evidenced lower average error scores in 23 of the 27 conditions. Filter performance, in addition, was significantly superior ($p = .02$) in twelve of these conditions. The analysis of variance for the human and filter respectively (Tables 2 and 3) shows that all main effects – noise, data rate, and course change – are significant at $p = 0.25$ level.

It is concluded that:

1. The singly augmented filter is generally superior to the human as a "data extrapolator" under the conditions of this study.

2. Increasing noise and decreasing data rate have a deteriorating effect on the performance of both the human and the filter.

3. Course change up to 60°, although having a statistically significant influence, has a less marked effect on error performance.

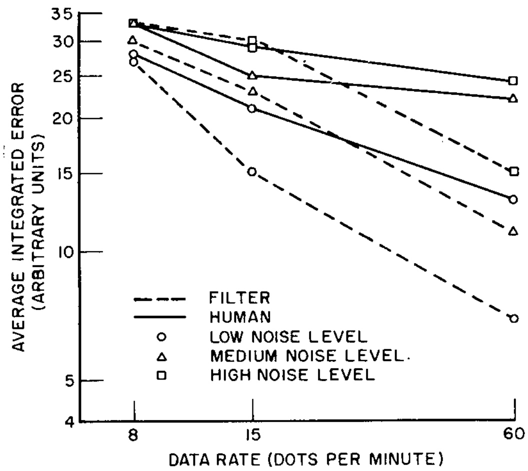


Fig. 5 - Average integrated error as a function of data rate at low, medium, and high noise levels

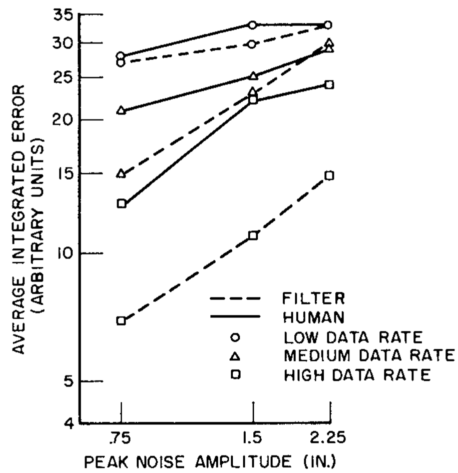


Fig. 6 - Average integrated error as a function of noise level at low, medium, and high data rates

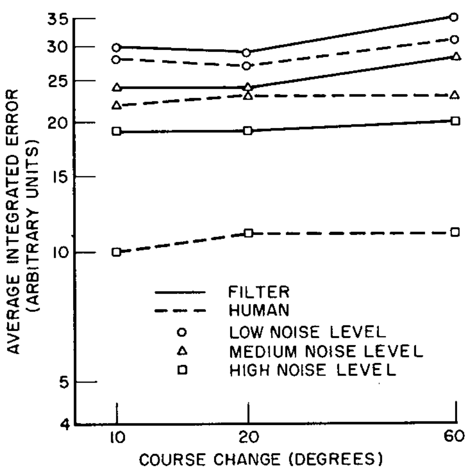


Fig. 7 - Average integrated error as a function of course change at low, medium, and high data rates

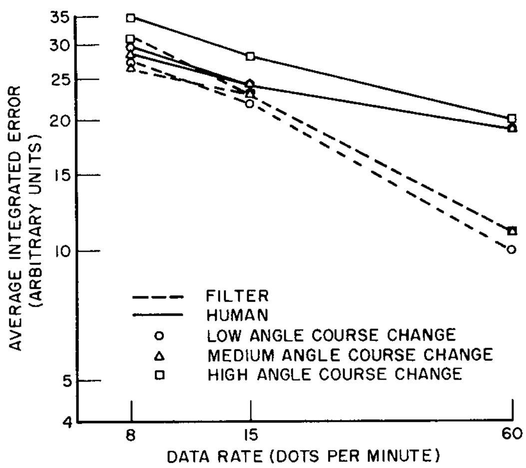


Fig. 8 - Average integrated error as a function of data rate at low, medium, and high angles of course change

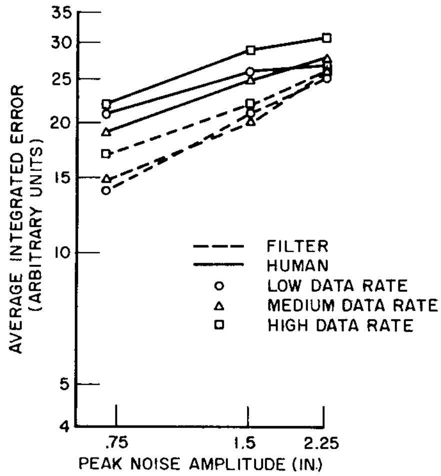


Fig. 9 - Average integrated error as a function of noise level at low, medium, and high angles of course change

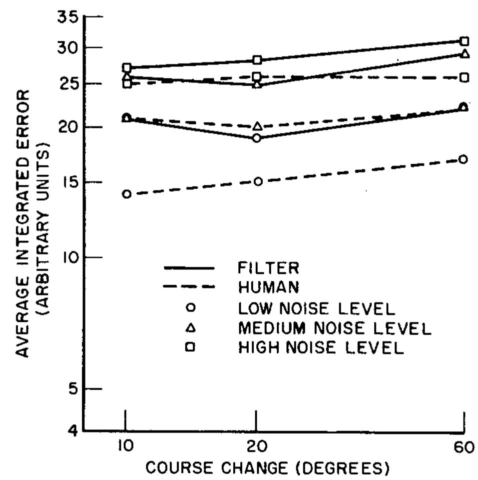


Fig. 10 - Average integrated error as a function of course change at low, medium, and high noise levels

Table 1
The Significance of Differences Between Filter and Human Performance in Each Experimental Condition

Noise		10° Course Change			20° Course Change			60° Course Change		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
Data Rate	Low	f 172.5*	f 226	h 203	f 187	f 201	h 224	f 192	f 175	f 198
	Med.	f 144†	f 205.5	h 178	f 182	f 212.5	h 206	f 141†	f 188	f 195.5
	High	f 124†	f 129†	f 154†	f 136.5†	f 120.5†	f 148†	f 124.5†	f 134†	f 147.5†

h = Human Obtained Smaller Error Statistic
f = Filter Obtained Smaller Error Statistic
* = $p<.02$
† = $p<.01$

Table 2
Analysis of Variance for the Human

Source of Variation	D.F.	Mean Square	F	Sig.
A: Angle Deviation	2	516.1	12.53	$p < .01$
B: Noise	2	2,135.6	51.88	$p < .01$
C: Data Rate	2	4,871.2	118.23	$p < .01$
A × B: Angle Deviation × Noise	4	77.0	1.87	
A × C: Angle Deviation × Data Rate	4	90.8	2.20	
B × C: Noise × Data Rate	4	172.6	4.19	$p < .01$
A × B × C: Angle Deviation × Noise × Data Rate	8	59.4	1.44	
Error Within Treatments	378	41.2		

Table 3
Analysis of Variance for the Filter

Source of Variation	D.F.	Mean Square	F	Sig.
A: Angle Deviation	2	102.4	4.34	$p < .025$
B: Noise	2	3,828.5	162.22	$p < .01$
C: Data Rate	2	11,469.3	485.99	$p < .01$
A × B: Angle Deviation × Noise	4	37.0	1.57	
A × C: Angle Deviation × Data Rate	4	64.6	2.74	
B × C: Noise × Data Rate	4	168.4	7.16	$p < .01$
A × B × C: Angle Deviation × Noise × Data Rate	8	29.4	1.25	
Error Within Treatments	378	23.6		

DISCUSSION

The above results primarily attest to the general superiority of the tracking filter under the conditions of this study. This improvement over human performance is more pronounced (30 to 50 percent less error) at the high data rate, for all levels of noise. Generally speaking, however, increasing noise and decreasing data rates tend to reduce the difference between the filter and the human performance. Apart from the statistical differences, it is interesting to note the similarity in the general character of the human and filter responses to variations in data rates, noise levels, and course changes. The similarity suggests that a transfer function close to that of this second-order filter system could be an approximate model of the human performance in the sampled-data tracking system. Relative to the further enhancement of data extrapolation, several avenues of investigation recommend themselves. An immediate possibility is the employment of filter networks as an aid to the human operator. Thus, an even more accurate description of target position and motion might result from the human extrapolation of target information from filtered data. A second avenue of investigation is the study of more sophisticated filter designs. This experiment employed a filter of fixed time constant and fixed augmentation to "smooth" input data having substantial variations in noise levels (3:1) and data rates (7.5:1). Ideally, the time constant and augmentation of a filter should be specific to each level of noise and data rate. Thus, an optimum filter would be of an "adaptive" type, automatically adjusting its time constant and augmentation as a function of noise and data rate. The investigation of such networks is a significant area of study which could prove beneficial to a large number and variety of weapon systems.

ACKNOWLEDGMENTS

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REFERENCES

1. Ragazzini, J.R., and Franklin, G.F., "Sampled-Data Control Systems," New York: McGraw-Hill, 1958, p. 1

2. White, C.F., "Augmented Networks," NRL Report 4261, Dec. 1953

3. Wilcoxon, F., "Some Rapid Approximate Statistical Procedures," New York:American Cyanamid Co., 1949, p. 4

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13. ABSTRACT

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