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Reaction time measurement errors resulting from the use of CRT displays

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Three sources of potential error in reaction time measurement may occur when raster scan CRT displays are used to present stimuli: phosphor persistence, sweep delay, or transmission delay. For most applications, only the third source of error is likely to be significant.

As a result of the recent proliferation of low-cost microprocessor-based laboratory computer systems, many researchers in the areas of perception and cognition are replacing the traditional tachistiscope with the more versatile computer-controlled cathode-ray tube (CRT) display as a medium for stimulus presentation. Because these devices are frequently used for critical reaction time measurements, a task they were not designed for, several hardware-dependent features need to be considered to determine their potential influence on such measurements.

Most of these CRT devices employ a noninterlaced raster scan technique whereby the image is created by a variable-intensity electron beam that sweeps across successive horizontal lines mapped on the surface of the display. Each line is broken up into a series of dots that form the elements of the image. These dots are made up of a phosphorescent compound that glows when hit by the intensified electron beam. For all practical purposes, the dots may be considered to "switch on" instantaneously. However, since they are designed to continue glowing while the electron beam sweeps the rest of the screen (in order to present a flicker-free image), the decay time may be fairly long (10-50 msec). This is not generally a problem in reaction time experiments because the stimulus is frequently displayed until the subject makes a response, after which it no longer matters if the image persists. Even when the stimulus duration is a critical variable, this phosphor persistence time will be constant so that it may simply be added to the total presentation time.

A potentially more serious problem involves a random error introduced by the raster scan process. Most of these devices are synchronized to the 60-Hz ac line frequency, which means they require 1/60 sec (16.67 msec) to form one full-screen image. On the other hand, the computer circuits used to generate and store the image information often operate at a much higher speed. The result of this mismatch in speed is that a computer may generate the stimulus image, store it in display memory, and start a reaction time clock as much as 16.67 msec before the stimulus is actually displayed on the screen.

Since this error is distributed uniformly from 0 to 16.67 msec, an unbiased estimate of reaction time can be computed by subtracting 8.33 msec from the obtained times. Therefore, the only detrimental effect of this source of measurement error is a decrease in statistical power. The magnitude of this effect is considered below.

The error resulting from the CRT delay is uncorrelated with other sources of error variance, and therefore, the consequent increase in error variance is simply the variance of the CRT-delay error. The variance of a uniform distribution extending from Point a to Point b is $(b - a)^2/12$, as shown by Winkler (1972). Therefore, the variance of the CRT-delay error is $[8.33 - (-8.33)]^2/12 = 23.15$.

It should be noted that 23.15 msec is the increase in error variance that would result if only one reaction time were obtained from each subject. It is common to obtain several reaction times from each subject in each condition and use the within-condition mean for each subject as the dependent variable. In that case, the increase in error variance is 23.15/k, where k is the number of reaction times averaged to obtain each score.

The importance of the CRT-delay error depends upon the magnitude of its variance relative to other sources of error variance. As there is typically very large between-subjects variation in reaction time, an increase of 23.15 msec in the error variance is negligible. However, when an independent variable is manipulated within subjects, much greater precision is obtained and a variance of 23.15 msec may significantly affect the power.

To determine the effect on power, it is necessary to know, on the average, how variable subjects are when

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Table 1
Simple Reaction Times (in Milliseconds) of Four Adult Males

Subject	Mean	Variance
1	211	2842
2	204	2164
3	240	798
4	200	10068
Group Mean	214	3968

they perform multiple trials in the same condition. Of course, this depends on the task: The more complex the task, the more variable reaction is likely to be. Therefore, the CRT-delay error is likely to be most serious in the case of simple reaction time experiments. A brief experiment was conducted on such a task in order to obtain a measure of error variance.

Four adult male subjects performed 10 20-trial blocks each on a simple reaction time task. They were asked to respond as quickly as possible by pressing a key as soon as they saw a string of xs in the center of the CRT. The interstimulus interval was varied randomly and uniformly from 1 to 2 sec. A TRS-80 microcomputer system was used to control presentation and to measure reaction time. The reaction time measurements were made using an assembly language software clock with a resolution of approximately .43 msec and an expected error variance of approximately .015 msec. This routine was incorporated into a BASIC program (Appendix 1) that was used to control the experiment. At the end of each block of trials, the computer displayed the mean and variance of the reaction times for that trial block and then waited for the subject to initiate the next block. The means and variances for each of the four subjects are shown in Table 1.

It is clear that the subjects' variances differed greatly. The extraordinarily high variance of Subject 4 was due to his attempts to anticipate the stimulus. To examine the most serious effect of CRT delay, we considered the loss of power that would result in a one-way within-subjects design with two treatment levels, an error variance (measurement error) of 800 msec, no Subject by Treatment interaction (of true treatment scores), and only one reaction time for each subject within each condition.

Each of nine subjects was assumed to have a true score of 200 msec under Treatment 1 and 234 msec under Treatment 2. Without the CRT-delay error, the power to reject the null hypothesis at the .05 level would be .62. With the CRT error increasing the variance to 823.15 msec, the power would be reduced to .60. Even under these extremely unfavorable conditions, the loss of power due to the CRT-delay error is very small. In practice, the error variance due to measurement error could be expected to be greater than 800 msec, more than one reaction time per condition would be obtained, and the Subject by Treatment (true score) interaction would be likely to be substantial.

In the preceding discussion, we assumed that the computer system has the capability to instantaneously store the stimulus information in display memory. For many integrated microprocessor systems, this is a reasonable assumption because the display shares a portion of memory with the CPU, and transfers into the display section of memory can occur at extremely high speeds. Many systems, however, use a separate CRT display with its own memory. Transfers from the CPU to display memory in such systems typically are made via a serial interface that operates at a much slower rate than the interval memory transfers found in an integrated display.

A typical remote terminal operating at 1,200 baud (bits per second) requires 8.33 msec to transmit one character from the CPU to display memory. In these systems, a six-letter stimulus word does not appear on the screen all at once, but rather, it appears two letters at a time, since only two letters can be transmitted during each raster scan sweep. If a reaction time clock is started immediately after the last character is sent, the first character will have been on the screen for 33.33 ± 8.33 msec; the final characters may not yet have appeared. This problem becomes less serious at higher transmission speeds, but even at 9,600 baud (the highest speed widely available), an eight-letter stimulus item has a .5 probability of being split over two successive sweeps. The implications of this noncontinuous presentation are task specific and, therefore, beyond the scope of this paper. However, since this is potentially the most serious of the three time-related problems discussed, it is important for the experimenter to be aware that the problem exists and to evaluate the potential impact on his or her research, as well as the impact on research reported in the literature.

REFERENCE

Winkler, R. L. *Introduction to Bayesian inference and decision.* New York: Holt, Rinehart, & Winston, 1972.

Appendix

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 5  REM SIMPLE REACTION TIME EXPERIMENT – 16K LEVEL-II BASIC
10  DEFDBL S: DIM M(20),V(20),SS(20)
15  REM THIS PUTS ASSEMBLY LANGUAGE TIMER ROUTINE IN HIGH MEMORY
20  POKE 16526,232: REM LOW ORDER STARTING ADDR.
25  POKE 16527,127: REM HIGH ORDER STARTING ADDR.
30  FOR I = 32744 TO 32766: READ X: POKE I,X: NEXT I
35  CLS: INPUT "# BLKS.";NB: INPUT "TR/BLK";N
40  FOR K = 1 TO NB: S=0: INPUT "PRESS ENTER TO BEGIN";X
45  FOR J = 1 TO N: CLS
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50   Y = RND(700)+300: FOR I = 1 TO Y: NEXT I
55   PRINT @540,"XXXXX"
60   REM FUNCTION USR(1) RETURNS NO. OF TIMES THROUGH COUNTING LOOP
65   REM MULT. USR(1)*.443 (APPROX) TO CONVERT TO MILLISECONDS
70   REM CHARACTER STRUCK IS STORED IN LAST CORE LOCATION - PEEK(32767)
75   X = INT(USR(1)*.443): CLS
80   S = S+X: SS(K) = SS(K)+X*X
85   NEXT J
90   S2 = S2+SS(K): ST = ST+S
95   V(K) = (SS(K)-S*S/N)/(N-1): M(K) = S/N
100  PRINT "BLOCK";K,"N=";N,"MEAN=";M(K),"VAR.=";V(K)
105  NEXT K
110  CLS: PRINT "BLOCK","MEAN","VAR.","SUM-SQS."
115  FOR I = 1 TO NB: PRINT I,M(I),V(I),SS(I): NEXT I
120  NT = N*NB: MT = ST/NT: VT = (S2-ST*ST/NT)/(NT-1)
125  PRINT "TOTAL:",MT,VT,S2
999  DATA 213,253,229,46,0,38,0,205,43,0,35,183,40,249,50,255,127,253,225
1000 DATA 209,195,154,10
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