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Selecting an Appropriate Scan Rate: The ".65 Rule"

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Investigators have discovered that the ratio between a user's reaction time and an appropriate scan rate for that user is approximately .65, which we refer to as "the .65 rule." As part of a larger effort to develop software that automatically adapts the configuration of switch access software, data were collected comparing subject performance with a scan rate chosen using the .65 rule and a scan rate chosen by the user. Analysis of the data indicates that for many people, the .65 rule produces a scan rate that is approximately the same as the average switch press time plus 2 standard deviations. Further analysis demonstrates a relationship between the coefficient of variation (the standard deviation divided by the mean) and error rate. If accurate information is available about the mean, standard deviation, and distribution of a client's switch press time, a scan rate can be chosen that will yield a specific error level. If a rigorous statistical approach is impractical, the .65 rule will generally yield a usable scan rate based on mean press time alone.

Key Words: Assessment—Row-column scanning—Physical impairment—Assistive technology—Computer access.

One-switch row-column scanning is a technique used by individuals with severe disabilities for entering text and other data into computers, augmentative communication devices, environmental control units, and other assistive technologies. One-switch row-column scanning can be tiring to use and is generally a relatively slow method of communication. An able-bodied individual using an optimally designed matrix of 26 letters and a space can produce between six and eight words per minute using this method (Damper, 1984; Koester & Levine, 1994). Despite its limitations, however, row-column scanning fills an important niche within access techniques by providing an affordable and reliable switch-based option for many individuals with limited movement and vocal abilities who are unwilling or unable to use Morse code. Hence, despite increasing interest in speech recognition, eye tracking, and direct-brain interfaces for accessing assistive technology, there remain valid reasons for seeking to enhance performance using row-column scanning.

A common implementation of row-column scanning with one switch requires three switch hits to make one selection from a two-dimensional matrix of letters, numbers, symbols, words, or phrases, as illustrated in Figure 1. The first switch hit initiates a scan through the rows of the matrix. Each row of the matrix, beginning with the first, is highlighted in turn until the second switch hit is made to select a row. Each column of the row is then highlighted in turn until the target is highlighted, when the third switch hit is made to select the target. Variations on this theme are abundant and include column-row scanning and continuous row scanning, which eliminates the first switch hit needed to initiate row scanning (Anson, 1997).

Depending on the exact scanning system used, there may be three or more adjustable parameters (see Table 1). The consequences of inappropriate parameter settings can be severe (Anson, 1997). If the scan rate in single-switch scanning is too fast, the user will make a lot of errors or may be unable to use the system. If the scan rate is too slow, this unnecessarily slows down performance in an interface method that is already inherently very slow.

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FIG. 1. Single-switch row-column scanning. In panel A, the system is row scanning following the first switch hit, and the first row is highlighted. In panel B, the target row has been reached; pressing the switch will select this row. In panel C, the system is scanning through each column within the target row. The switch is pressed a third time to choose the target letter (U).

TABLE 1. Typical configuration options for single-switch scanning

Parameter	Description
Scan rate	The amount of time an item remains highlighted for the user to make a selection
Initial scan delay	Additional delay applied to the first row or column
Column scans	Maximum number of times the columns within a row are scanned
Layout	Arrangement of targets within the scanning matrix

Working independently, two groups (Cronk & Wang, 2002; Lesher, Higginbotham, & Moulton, 2000) found that the ratio between a user's reaction time and an appropriate scan rate for that user is approximately .65 (which we refer to as "the .65 rule"), although neither group empirically demonstrated that the resulting scan rate was, in fact, literally optimal. As part of a larger effort to develop the Input Device Agent (IDA)—software that automatically adapts the configuration of switch, pointing, and text-entry devices to the needs of a user (Koester, LoPresti, & Simpson, 2005)—data were collected comparing subject performance with a scan rate chosen using the .65 rule and a scan rate chosen by the user. The results suggest that IDA, using the .65 rule, can recommend an appropriate fixed rate for scanning. Subjects' performance, in terms of speed, accuracy, and subjective ratings, was at least as good with the IDA-selected rate as for the self-selected rate (Simpson, Koester, & LoPresti, 2007). This article presents some further analyses on that data to help understand why and under what conditions the .65 rule is an appropriate method for choosing an individual's row-column scanning rate. The methods and basic results are presented here as well to provide a context for the analyses related to the .65 rule.

METHOD

The protocol described below focused on recommending an appropriate scan rate to meet the user's current abilities. This focus was chosen because the scan rate is the basic timing parameter that controls user performance with single-switch scanning. The goal was to find the ideal midpoint between a scan rate that is too fast, which increases user errors, and one that is too slow, which unnecessarily constrains the user's text entry rate. The protocol and recruitment procedures for this study were approved by the University of Pittsburgh Institutional Review Board (Reference 0504137).

Testing Environment

During testing, subjects interacted with the row-column scanning matrix shown in Figure 2. The target character was presented in the top box, with a new target character presented after the user selected a character in the scanning matrix or after 60 s had elapsed (whichever occurred first). The interface was implemented in Java as part of the IDA project. Switch access was implemented through an X-Keys USB Switch Interface (P.I. Engineering, Williamston, MI).

Subjects

Six individuals with significant physical disability secondary to cerebral palsy participated in this study (see Table 2). All six regularly used augmentative communication devices. Four of the six used single-switch scanning to operate their communication device, and the remaining two used direct selection. Switch sites for the nonswitch users

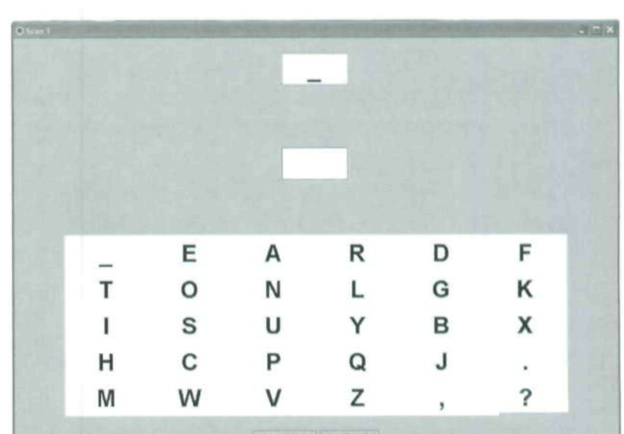

FIG. 2. Screen shot from experimental interface.

TABLE 2. Study participants

Subject	Gender	Age	Normal selection method
45	M	41	Single switch (positioned on left side of headrest, activatd with side of head)
55	M	47	Single switch (positioned on inside of right knee, activated by left knee)
32	F	50	Single switch (positioned on stomach, activated with left hand)
04	F	55	Single switch (positioned on chest, activated with chin)
02	M	36	Direct select (head-mounted laser pointer)
53	F	29	Direct select (head-mounted aluminum rod)

were chosen based on trial and error. All six subjects were familiar with the letters of the alphabet and the punctuation used in the scanning matrix, and all six subjects verified that they could see the target and all items in the scanning matrix prior to initiation of the study.

Protocol

The study was designed to allow for assessment of the scan rate recommended by IDA, as well as for a comparison between IDA's recommendation and the user's self-selected scan rate. Subjects performed a single-switch scanning task in four blocks of trials as follows:

A1: recommendation phase with IDA
A2: evaluation of performance with the scan rate chosen by IDA
B1: self-selection phase
B2: evaluation of performance with the self-selected scan rate

Activities for each block are described below. The order of blocks for half the subjects in each group was A1, A2, B1, and B2, counterbalanced for the other half of the subjects as B1, B2, A1, and A2 (see Fig. 3). This order was chosen because it allowed subjects to immediately work with the scan rate that had just been recommended or selected.

Each subject participated in one session, which lasted for approximately 1 hr. At the beginning of the session, subjects were given an opportunity to practice entering letters to orient themselves to the system. Before the second block of each block pair (i.e., before A2 or B2), subjects completed a three-trial warm-up using the scan rate that was chosen by IDA or themselves.

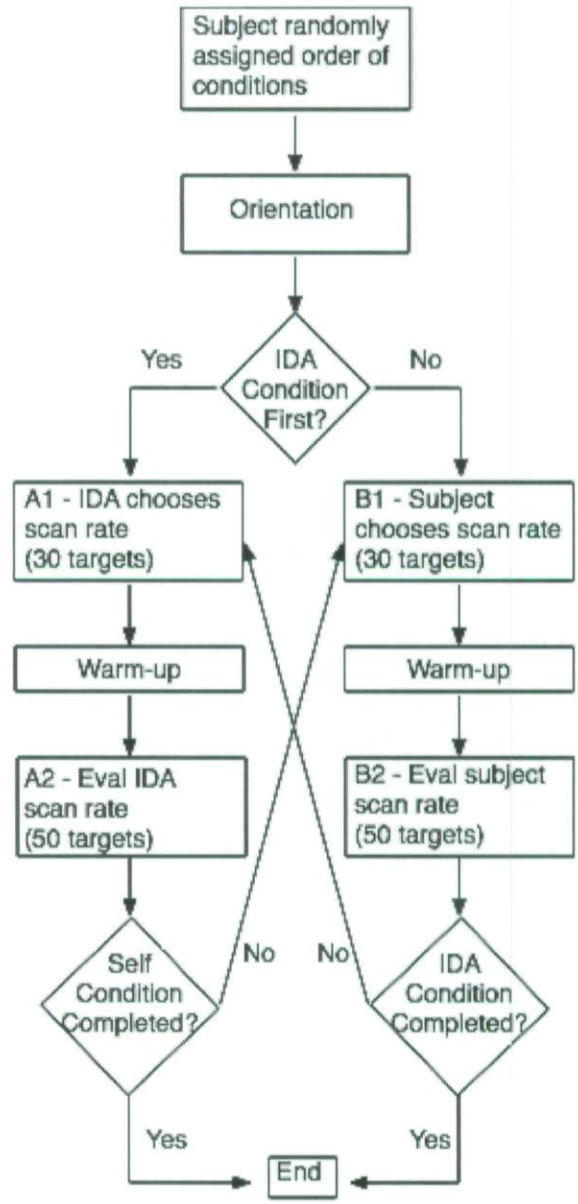

FIG. 3. Order of experimental conditions.

In each trial, a target character (either a letter, a space, or a punctuation mark) was displayed on the upper middle portion of the screen, with a row-column scanning display on the lower portion (see Fig. 2). Subjects were asked to select each target letter from the scanning matrix using a single switch. The first switch hit initiated row scanning, the second switch hit selected the desired row, and the third switch hit selected a particular letter in that row. Target letters were chosen based on frequency of occurrence in the English language.

Subjects were read the following instructions before each block of trials:

> It usually helps to find the letter you're going to select before you hit the switch to start the scanning. Try to enter each letter as quickly and accurately as you can. But if you do make a mistake, don't worry about it. In fact, you can't correct mistakes, so just go on to the next letter and keep going. If for some reason it takes more than 60 seconds for you to choose a letter, it will automatically move on to the next letter.

A1: IDA-Selected Scan Rate

The initial scan rate for this block of 30 trials was set to match the scan rate of the subject's communication device (if they regularly used row-column scanning) or was set to 1 s (if they were not regular row-column scanning users). After each character selection, the system decided whether to keep the scan rate the same, speed it up by 25 ms, or slow it down by 25 ms. This decision was based on the number of errors made since the last rate adjustment, as well as the user's switch press time as compared to the scan rate. The purpose of this was to present a scanning situation that matched the user's abilities better than the arbitrary starting scan rate. Note, however, that the scan rate arrived at by IDA after 30 trials was not used in any subsequent block of trials. Instead, IDA made a scan rate recommendation by dividing the average switch press time (over the last row press and last column press from each trial) by .65.

B1: Self-Selected Scan Rate

As in A1, the initial scan rate for this block of 30 trials was set to match the scan rate of the subject's communication device or to 1 s, based on whether the subject regularly used row-column scanning. Unlike A1, however, the subject was given the responsibility for selecting the scan rate. After each trial, the subject could request the scan rate to be increased or decreased by 25 ms. The scan rate was adjusted by an investigator by pressing the up or down arrow key in response to a request from the subject.

A2 and B2: Evaluation Trials

In blocks A2 and B2, subjects were presented with 50 trials. The same set of 50 targets was used in each condition (see Table 3), but the order was randomized within each block. For the second block in the IDA-selected condition (A2), the scan rate was set to the value recommended by IDA and did not vary during the test. For the second block in the self-selected condition (B2), the scan rate was set to the scan rate used for the final letter in the first self-selected condition (B1).

TABLE 3. Distribution of target characters

Character	*n*	Character	*n*	Character	*n*	Character	*n*	Character	*n*
A	5	G	0	M	1	S	3	Y	1
B	0	H	1	N	1	T	5	Z	0
C	0	I	4	O	2	U	0	.	1
D	2	J	0	P	1	V	1	?	0
E	7	K	1	Q	0	W	1	—	10
F	0	L	2	R	1	X	0		

Note: *n* is the number of times a character was presented in the evaluation trials. The frequencey of presentation is based on frequency of use in English. Note that "—" was used to represent a space (" ").

Data Collection

For each trial, the scanning system recorded the following data:

- What matrix item was presented as the target
- The scan rate used for that target
- What matrix item was actually selected by the user
- The time required to initiate scanning (i.e., the time elapsed between the final switch press of the previous target and the first switch press of the current target)
- The time required to press the switch to select the row (i.e., the time elapsed between when the row was highlighted and when the switch closure was recorded)
- The time required to press the switch to select the column (i.e., the time elapsed between when the column was highlighted and when the switch closure was recorded)
- The total time to select an item

If more than one row selection occurred during a single trial (i.e., if the subject selected the wrong row then selected the correct row), the last row press time was recorded.

In addition to the above data, a timing error was counted for each trial in which the target letter was not selected on the first opportunity. For example, the letter S is located in the third row, second column. To select S on the first opportunity, a user must hit the switch on the first time the third row is scanned and the first time the second column is scanned. Waiting until the scan highlight comes around a second or third time is counted as a timing error, even if the S is eventually selected correctly. Hence, selection accuracy reflected errors of commission (i.e., the wrong row or column had been selected at any point within a trial), whereas timing accuracy reflected errors of omis-

TABLE 4. Experimental results

	Scan rate (ms)		Text entry rate (s/ character)		Selection accuracy (%)		Timing errors (%)	
Subject	IDA	Self	IDA	Self	IDA	Self	IDA	Self
45	891	1,200	5.86	7.99	92	100	8	8
55	1,110	1,875	8.56	8.24	98	98	16	6
32	1,293	1,200	11.06	10.82	100	90	16	20
04	1,199	1,325	6.54	13.45	84	78	6	32
02	859	1,450	12.19	13.03	76	98	36	18
53	1,263	2,250	8.17	8.26	92	84	10	0
Average	1,102	1,550	8.73	10.30	90.3	91.3	15.3	14.0

Note: IDA = Input Device Agent.

sion (i.e., the correct row or column had been highlighted but not selected at any point within a trial). A high percentage of either type of error can indicate that the scan rate is set too fast for efficient selection.

Data for each trial were used to calculate the following summary measures across all 50 trials in blocks A2 and B2:

- Text entry rate: the average time (in seconds) to select a target
- Selection accuracy: the percentage of targets correctly selected from the matrix
- Timing errors: the percentage of targets in which a timing error occurred
- Start scan: the average time (in seconds) to initiate scanning
- Row press: the average time (in seconds) to select a row
- Col press: the average time (in seconds) to select a column

RESULTS

As shown in Table 4, subjects took 8.73 s to select each letter (with a 95% confidence interval of 6.13, 11.33) with the scan rate derived by IDA using the .65 rule. They averaged 90.3% selection accuracy (80.9, 99.8) and 15.3% timing errors (3.9, 26.8). This relatively high accuracy suggests that the IDA-recommended scan rate was usable by subjects.

The .65 rule tended to recommend scan rates that were significantly faster than subjects' selected rates, about 25% faster on average (p = .043). However, this increase in scan rate did not lead to significantly more errors, as both selection accuracy and timing errors were almost identical across the two scan rate conditions. Somewhat surprisingly, the faster scan rate resulting from the .65 rule did not yield a significantly faster text entry rate, although text entry rate with IDA did average 13.3% faster than text entry rate with the self-selected rate (p = .224).

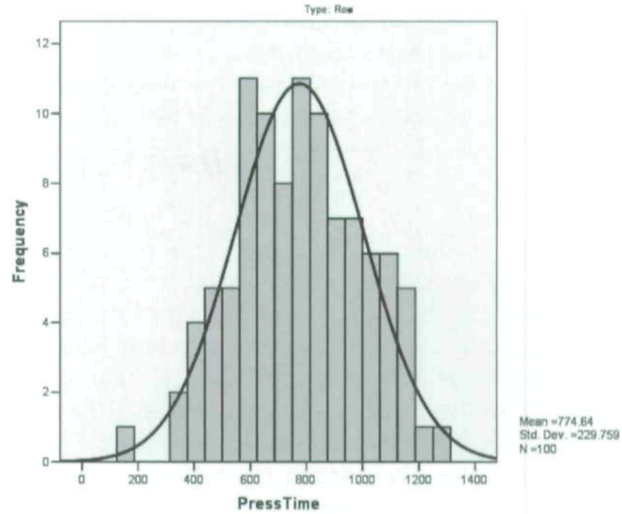

FIG. 4. Distribution of row press times for subject 04. The curve peaks at the mean press time of 775 ms. Press times range from about 180 ms to 1300 ms.

DISCUSSION

Why the .65 Rule Works

Further exploration of the data provides insight into why and under what conditions the .65 rule works. From a practical standpoint, the .65 rule makes sense. Given a person's average switch press time, the .65 rule provides a cushion that ensures that almost all presses occur within the desired scan period. The last 35% of the scan period serves as extra time to accommodate presses that are slower than average. That seems like a reasonable cushion, but given that the text entry rate is limited by scan rate, a smaller cushion would obviously be desirable.

The reason there needs to be any time cushion at all is that the scan rate is invariant whereas the press times are not. Part of this is due to natural variation inherent in human performance, and part of it is due to the fact that the scanning task may be somewhat different depending on the target (e.g., a first column target may be chosen with a double click or a target not spotted until the last milliseconds). Switch press time generally follows a bell-shaped curve, with the highest frequency press times occurring around the mean time and a symmetrical decrease in frequency along both sides of the mean. For example, Figure 4 shows the row press times for subject 04 across blocks A2 and B2.

To accommodate the vast majority of switch presses with a fixed scan rate, a scan rate should be chosen that guarantees a high probability that any given press time for a user will be faster than the fixed scan rate. Any press times that are slower than the scan rate will result in an error, which is costly. If press times are assumed to follow a normal distribution, then the solution is fairly straightforward. For any normally distributed population, with mean M and standard deviation SD, there is a 95% chance that a randomly chosen member of the population is within 2 SDs of the mean, and there is a 97.5% chance that the value of a randomly chosen member is less than ($M + 2SD$). Therefore, to ensure that at least 97.5% of press times are faster than the fixed scan rate, the scan rate (sr) should be set to ($M + 2SD$), using the mean and standard deviation of the user's press times:

$$sr = (M + 2SD). \tag{1}$$

Furthermore, it is also known that it generally works well to use the .65 rule to set the scan rate as

$$sr = M/.65. \qquad 2)$$

If Equations 1 and 2 are combined, then one can gain insight into why the .65 rule is effective for most people (or, at least, most people with approximately normally distributed switch press times). So,

$$M/.65 = (M + 2SD), \tag{3}$$

which leads to

$$0.35M = (2)(.65)SD \tag{4}$$

and

$$SD/M = 0.35/1.3 = 0.27. \tag{5}$$

Another name for (SD/M) is the coefficient of variation, or CV. Based on the above analyses, whenever the CV of press times is at or below 27%, the .65 rule will establish a scan rate that is longer than 97.5% of the row press times. For these six participants, the average CV was 0.298 (or 29.8%), suggesting that a target CV of approximately 27% is a reasonable expectation. For individuals with higher variation in their switch press times, a scan rate set using the .65 rule would be expected to result in more than 2.5% errors because it would be a faster scan rate than the ($M + 2SD$) method.

Figure 5 shows the relationship between CV and selection accuracy that was observed during this study for the IDA condition. As expected, higher CVs led to reduced accuracy. The four subjects with CVs less than 30% enjoyed a selection accuracy greater than 90%. This is consistent with expectations based on the .65 rule. (Note that the total number of selection errors, as reported in Figure 5, will generally exceed the number of errors due to press time variation. A lengthy press time is just one of several ways in which a selection error can occur.)

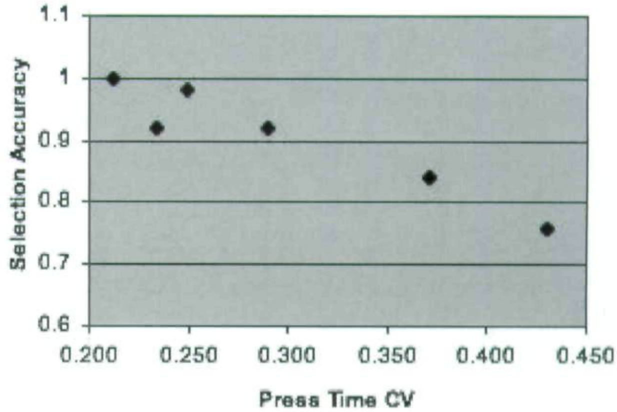

FIG. 5. Relationship between the coefficient of variation (CV) and selection accuracy.

A More General Form of the Model

The statistical model described above assumed a scan rate ratio ($r = M/sr$) of .65 and an error rate of 97.5%. Recall that the error rate of 97.5% comes from a scan rate set at the mean press time plus 2 SDs. The number of standard deviations from the mean is called a z score. So an error rate of 97.5% corresponds to a z score of 2. If z is allowed to vary (as opposed to being fixed at 2), then the equation for r becomes

$$r = \frac{M}{sr} = \frac{M}{M + z(SD)} \tag{6}$$

Solving this equation for SD then yields

$$r = \frac{M}{M + z(SD)} \qquad rM + rz(SD) = M$$

$$SD = \frac{M(1 - r)}{rz} \tag{7}$$

Substituting this formulation of SD into the definition of CV, one can then derive the following relationship:

$$CV = \frac{SD}{M} = \frac{M(1 - r)}{rz} \cdot \frac{1}{M} = \frac{1 - r}{rz} \tag{8}$$

This more general relationship provides a model of how expected errors (due to press time variation)

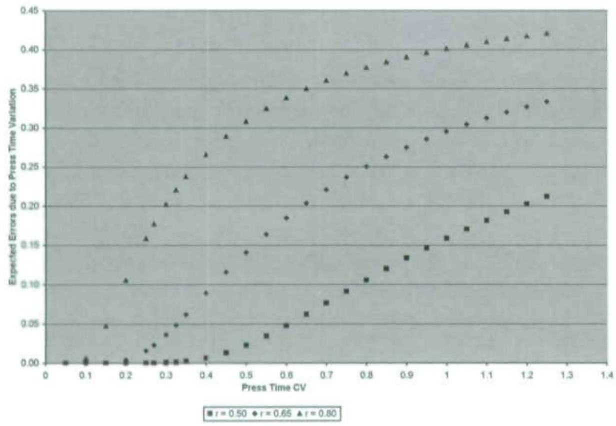

FIG. 6. Predicted relationship between the coefficient of variation (*CV*) and errors.

will increase with higher *CV* under different scan rate ratios. If Equation 8 is solved for *z,* then

$$z = \frac{1 - r}{r(CV)} \tag{9}$$

Equation 9 can then be used to predict error rates as *r* and *CV* vary. Figure 6 illustrates this for three different scan rate ratios: .50, .65, and .80. The figure provides some insight into why a ratio of .50 is a bit too conservative and .80 is probably too aggressive. For example, at a ratio of .5, the press time *CV* must exceed .6 before errors due to press time variation exceed a modest 5%. Because actual user *CV*s are generally lower than that, the .50 ratio is unnecessarily conservative for most users. Conversely, boosting the ratio up to .80 in an attempt to increase productivity may backfire. In that case, variation-related errors will exceed 5% for *CV*s greater than .15. Given the range of *CV*s observed in this study (from .21 to .43), users would experience frequent errors with a scan rate based on the .80 rule.

Caveats About Normal Distribution

Figure 6 is a useful but idealized picture. The underlying calculations assume that press times follow a normal distribution, which was not always true of the actual data recorded from subjects. In analyzing the press time distributions from these individuals, there was some observed nonnormality. However, this was generally due to high kurtosis (a steeper than normal peak in the distribution). The conclusions from the above model still hold in this case because a steeper peak actually yields lower expected error rates than the normal distribution.

However, there may be instances in which the nonnormality does affect the model or in which the distribution is unknown and it is undesirable to assume a normal distribution. One approach in that case is to use Chebyshev's inequality to help determine the probability limits. The probability that any single press time is within *z* standard deviations of the mean press time is at least $(1 - 1/z^2)$. This is true for any distribution. So the probability that a single press time will be within 2 *SD*s of the mean is at least $(1 - ¼) = 75\%$. (The true probability may well be higher, but this gives a minimum probability that we can count on.) This suggests that setting the scan rate at $(M + 2SD)$ will yield an error level no greater than 25%. Similarly, a scan rate of $(M + 3SD)$ should yield errors no greater than 11%.

CONCLUSION

There are three general factors that govern the appropriate setting of the scan rate.

- The acceptable level of selection errors. As scan rate approaches the mean press time, more of these errors will occur.
- Estimates of the mean and standard deviation for switch press times. Certainly, a higher average press time indicates a longer scan period. But understanding the variation within the individual is equally important. For a given mean press time and scan rate, individuals with higher press time variation will commit more errors, and a higher scan rate will be needed to keep the error rate from increasing.
- Assumptions or knowledge about the shape of the press time distribution. If the press times are roughly normally distributed, statistical theory can provide accurate estimates of the expected error level for a given scan rate/press time combination. If nothing is known about the distribution, Chebyshev's inequality can be used to derive very conservative estimates of the error level, but this will generally tend to overestimate expected errors.

If statistically precise information is available about the mean, standard deviation, and distribution of a client's switch press time, a scan rate can be chosen that will yield a specific error level. If a rigorous statistical approach is impractical, the .65 rule will generally yield a usable scan rate based on mean press time alone.

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Asst Technol 2007;19:60

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Quiz 19.2—Selecting An Appropriate Scan Rate: The ".65 Rule"

1. (True or False) According to the article, row-column scanning fills an important niche within access techniques because it provides an affordable and reliable switch-based option for many individuals with limited movement and vocal abilities who are unwilling or unable to use Morse code.
2. The ________ is the basic timing parameter that controls user performance with single-switch scanning.
   A. press time B. scan rate c. scanning matrix
3. (True or False) The goal of the study was to find the ideal midpoint between a scan rate that is too fast, which increases user errors, and one that is too slow, which unnecessarily constrains the user's text entry rate.
4. Subjects were told that if for some reason it takes more than ________ seconds for him/her to choose a letter, it will automatically move on to the next letter.
   A. 60 B. 90 C. 120
5. (True or False) If the subject makes a mistake, he/she can correct it easily and then move on to the next letter.
6. (True or False) IDA made a scan rate recommendation by multiplying the average switch press time by .65.
7. After each trial, the subject could request the scan rate to be increased or decreased by ________ milliseconds.
   A. 15 B. 20 C. 25
8. A ________ error was counted for each trial in which the target letter was not selected on the first opportunity.
   A. timing B. scanning C. selection
9. (True or False) Selection accuracy reflected errors of omission, while timing accuracy reflected errors of commission.
10. A ________ percentage of either type of error can indicate that the scan rate is set too ________ for efficient selection.
    A. low . . . fast B. low . . . slow C. high . . . slow D. high . . . fast
11. The number of standard deviations from the mean is called a ________.
    A. *SD* score B. *y* score C. *z* score
12. (True or False) Expected errors (due to press time variation) will decrease with higher *CV* under different scan rate ratios.