Technology and Disability 18 (2006) 127–138
IOS Press

Evaluation of an adaptive row/column scanning system

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Abstract. The *Input Device Agent* (IDA) is being designed to improve computer access interventions for people with disabilities. This paper describes how IDA makes recommendations for scan period in row-column scanning systems and empirically evaluates the appropriateness of those recommendations. Two groups of subjects (8 people who were either able-bodied or had spinal cord injuries and 6 individuals with severe physical disability secondary to cerebral palsy) performed a single switch scanning task in four blocks of trials. In each trial, subjects were asked to select a target letter from a scanning matrix, using a single switch. Results suggest that IDA can recommend an appropriate fixed scan period for single switch scanning. In an absolute sense, participants' speed, accuracy, and subjective ratings in the IDA condition support this conclusion. In relative terms, participants' performance was at least as good for the IDA-selected scan period as for the self-selected scan period.

Keywords: Alternative computer access technology, one-switch row-column scanning, assessment

1. Introduction

1.1. IDA project

Computer technology has much to offer individuals who have disabilities, including enhanced educational and vocational opportunities, independent means of written and/or spoken communication, and a form of recreation and exploration. To fulfill this potential, it is critical that the computer system be closely matched to the user's needs and abilities. An important part of this matching process is configuring the user's computer input devices to appropriately leverage user strengths and accommodate limitations.

The behavior of most computer input devices today, such as keyboards and mice, is adjustable. Because each person's disability is unique, tuning these devices to each user's strengths and limitations is critical for success in many cases. Ideally, configuration is performed in consultation with a clinician who has expertise in computer access for people with disabilities. However, a trained clinician may not always be available, and even when one is, proper tuning of a device to the needs of a particular user can be a difficult and time-consuming task. The challenge is magnified by the fact that many users' needs and abilities change over time, whether in the short term due to factors such as fatigue or in the long term due to factors such as progression of the individual's underlying impairment. For these reasons, input devices are often not appropriately configured to meet users' needs, with consequent negative effects on user productivity and comfort.

The *Input Device Agent* (IDA) [6] is being designed to improve educational, vocational, and clinical interventions related to computer use for people with disabilities. IDA will provide an easy-to-use tool to measure current user performance with an input device and recommend an appropriate configuration for that device. Three main groups of input devices will be sup-

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ISSN 1055-4181/06/$17.00

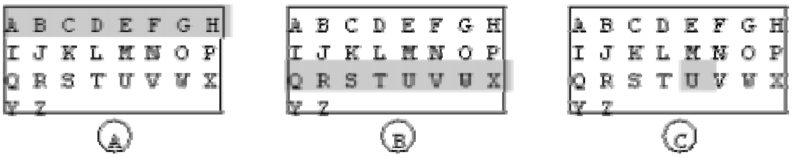

Fig. 1. Single switch row-column scanning. In panel A, the system is row-scanning, following the first switch hit, and the first row is highlighted. In panel B, the target row has been reached; pressing the switch will select this row. In panel C, the system is scanning through each column within the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

ported: keyboards, mice and other pointing devices, and switches. This paper describes how IDA makes recommendations for scan period in row-column scanning systems and empirically evaluates the appropriateness of those recommendations.

1.2. Row-column scanning

Row-column scanning is a technique used by some individuals with physical disabilities for entering text and other data into computers and augmentative communication devices. It is an important method because it can be used with as little as one switch for input. 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 Fig. 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 [1].

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 [2]. If the scan period 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 period is too slow, this unnecessarily slows down performance in an interface method that is already inherently very slow.

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 6 and 8 words/minute using this method [5, 7]. Despite its limitations, however, row-column scanning fills an important niche within access techniques by providing an affordable and reliable option for many individuals with limited movement and limited vocal abilities. 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.

2. Background

2.1. Current approaches to scan period selection

The scan period and other configuration parameters for a single-switch row-column scanning system determine the minimum Character Entry Time (CET), measured in seconds per character, that is possible for a user. Values for these parameters are typically determined in one or more of the following ways. The first, and perhaps most common, is to use the default values for the device. This scenario typically occurs when the individual is using a computer without the benefit of any specific intervention relative to accessibility. Moderately inappropriate values may result in decreased user performance and satisfaction. In a more extreme case, the system may be virtually unusable under the default values.

A second method of parameter selection is when the user does his or her own adjustment. This requires the user to know that these parameters are available for adjustment and what to do to adjust them. This alone is a complex task, and knowing the most appropriate values for all applicable settings may be even more difficult. Users may not understand how the parameter settings relate to the interface problems they are having, or if they do, the best choice of specific values may be unclear. Finally, interface configuration is secondary to the user's primary computer tasks; even if it can be done effectively, it takes time, physical effort, and cognitive focus away from more central tasks.

A third scenario occurs when a clinician or teacher is available to assist with the configuration process, using

Table 1
Typical configuration options for single-switch scanning

Parameter	Description
Scan period	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

clinical observations and knowledge of the possible accommodations as a guide. However, not all clinicians have the skills to do this effectively. Even when they do, configuration in this scenario takes time. Clinician-assisted adjustment may result in more appropriate settings for an individual, but most users with physical disabilities do not have a qualified clinician available to them. For example, Trewin and Pain [12] found that only 35% of 30 computer users with physical disabilities had a "computer teacher."

Under each of these three approaches, it may be difficult to define appropriate settings for a user's initial configuration. It is equally difficult, if not more so, to address changes in the user's abilities over time, which may happen over the course of a day, a month, or a year, depending on the nature of the user's disability. Current methods may lead to appropriate input device configurations in some cases, but it does take special knowledge, additional time, and continued maintenance to do it right [2].

The research described here was conducted to determine whether our software-based agent (IDA) could effectively recommend a specific, fixed scan period for users of single switch scanning input. The goal was to determine the feasibility and adequacy of IDA's scan period recommendation, while also gaining information about how to refine the recommendation algorithm as part of future work. If IDA is able to give appropriate guidance about a user's scan period setting, this could help improve a user's initial and ongoing performance and satisfaction with their scanning system. Showing that it works within the IDA system is also a necessary step towards either integrating IDA into existing commercial systems, or showing that IDA recommendations can generalize to non-IDA scanning systems.

2.2. *Previous work on configuration agents*

To address the challenges of manual configuration of input devices, several groups have been working toward *configuration agents* [10,11,14]. A configuration agent models a user's strengths and limitations and, based on the model, helps configure the user's input devices appropriately. In general, a configuration agent can operate in one of four modes [13], as shown in Table 2. A given implementation of an agent supports one or more of these modes. The choice of the most appropriate mode depends on the technical feasibility of increased agent responsibility as well as the desirability of retaining user control.

Three research groups have worked on methods of automatically adapting the scan period of a single-switch row-column scanning system. Cronk and Schubert [3] developed an expert system for the adaptation of scan period, but it was never integrated into any commercial systems. Lesher et al. [8,9] developed a rule-based method of scan period adjustment based on user errors and the time required for the user to make a selection relative to the available time. Their primary goal was to provide a means of scan period adjustment for empirical studies comparing different scanning displays, and their system performed well enough to meet this goal with able-bodied subjects [9].

Simpson and Koester [10] developed and evaluated a single switch scanning system that used a Bayesian network to adjust the user's scan period in real time. Two studies, involving a total of 16 subjects without disabilities, demonstrated that the system could make reasonable adaptation decisions, with no human intervention, for a system with a single scan delay. Subjects' text entry performance and subjective opinion was no different with the automatic system as compared to a manual adjustment protocol, in which able-bodied subjects could change the scan period at will with a single keypress. A major limitation is that the work was not validated with users with disabilities.

3. Methods

The current study simplifies the agent developed in our previous work [10], and validates its effectiveness with able-bodied and disabled subjects. This study focused on recommending an appropriate scan period to meet the user's current abilities. This focus was chosen because the scan period is the basic timing parameter that controls user performance with single-switch scanning. The goal was to find the ideal midpoint be-

Table 2
Matrix of operating modes for a configuration agent

		Who initiates the change?	
		User	Agent
Who controls the change?	User	The user initiates the configuration process with an explicit action, and the agent suggests a configuration. The user decides what if any changes should be made.	The agent continuously monitors user performance, suggesting configuration changes as needed. The user decides what if any changes should be made.
	Agent	The user initiates the configuration process. The agent determines and automatically implements any configuration changes.	The agent continuously monitors user performance. The agent determines and automatically implements any configuration changes.

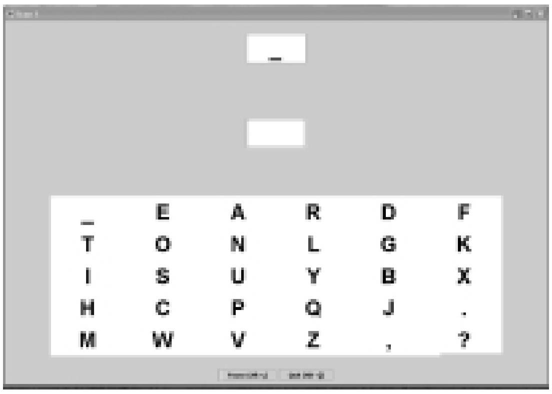

Fig. 2. Screen shot from experimental interface.

tween a scan period that is too fast, which increases user errors, and one that is too slow, which unnecessarily constrains the user's CET. The protocol and recruitment procedures for this study were approved by the University of Pittsburgh Institutional Review Board (Reference #0504137).

3.1. Testing environment

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

3.2. Subjects

Two groups of subjects participated in this experiment: 8 people who were either able-bodied or had physical disabilities that did not interfere with their ability to activate a switch with their hand (the ND group) and 6 individuals with severe physical disability secondary to cerebral palsy (the CP group). All six in the CP group 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 non-switch users were chosen based on trial and error. All 14 subjects were familiar with the letters of the alphabet and the punctuation used in the scanning matrix. All 14 subjects verified that they could see the target and all items in the scanning matrix prior to initiation of the study.

3.3. Protocol

The study was designed to allow for assessment of the scan period recommended by IDA, as well as for a comparison between IDA's recommendation and the user's self-selected scan period. 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 period chosen by IDA
- B1: self-selection phase
- B2: evaluation of performance with the self-selected scan period.

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

Each subject participated in one session, which lasted for approximately one hour. At the beginning of the session, subjects were given an opportunity to practice

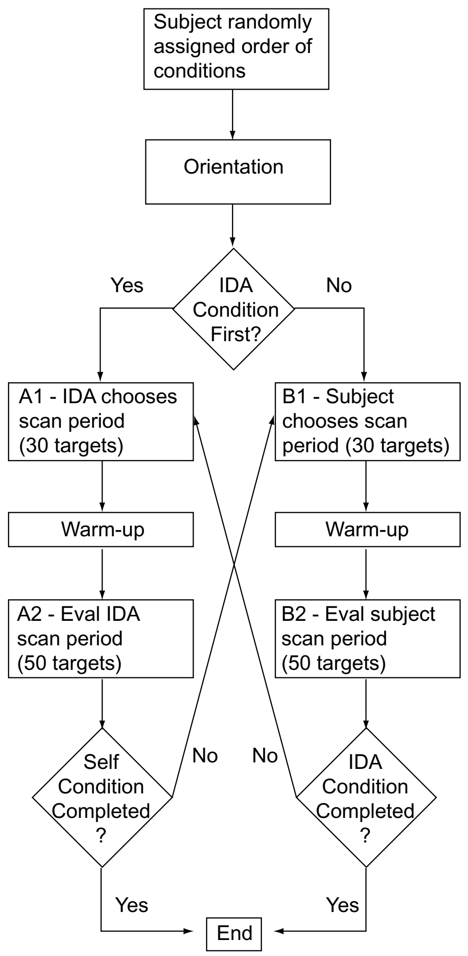

Fig. 3. Order of experimental conditions.

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-letter warm-up using the scan period that was chosen by IDA or themselves.

In each trial, a target character (either a letter, a space, or a punctuation mark) was displayed in 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.

3.3.1. A1: IDA-selected scan period

The initial scan period for this block of 30 trials was set to match the scan period of the subject's communication device (if they regularly used row-column scanning) or was set to one second (if they were not regular row-column scanning users). After each selection, the system "decided" whether to keep the scan period the same, speed it up by 25 msec, or slow it down by 25 msec. An increment size of 25 msec was chosen as a reasonable value based on our previous work [10].

The decision of whether, and in what direction, to adjust the scan period was based on the number of errors made since the last scan period adjustment, as well as the user's switch press time as compared to the scan period. More than one error increased the scan period by 25 msec, while no errors, combined with a press time comfortably within the available scan period, led to a decrease of 25 msec in the scan period. The purpose of these automatic adjustments was to present a scanning situation that matched the user's abilities better than the arbitrary starting scan period.

After completing 30 trials, IDA made a scan period recommendation by dividing the average switch press time by 0.65. This formula is based on the results of two research groups [4,8], who found that the ratio between a user's reaction time and an appropriate scan period for that user is approximately 0.65.

3.3.2. B1: Self-selected scan period

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

3.3.3. 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 5), but the order was randomized within each block. For the second block in the IDA-selected condition (A2), the scan period 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 period was set to the scan period used for the final letter in the first self-selected condition (B1).

Table 3
Study participants in the ND group

Participant	Gender	Age
SA1	M	40 – No physical disability
JA1	F	38 – No physical disability
SA2	F	44 – No physical disability
AA1	F	22 – No physical disability
DA1	F	47 – Fibromyalgia, rheumatoid arthritis
GA1	M	37 – C4-5 Spinal Cord Injury
CA1	F	57 – lower-limb amputation
RA1	F	27 – T1 Spinal Cord Injury

Table 4
Study participants in the CP group

Subject	Gender	Age	Normal Selection Method
JC1	M	36	Direct Select (head-mounted laser pointer)
JC2	F	55	Single Switch (positioned on chest, activated with chin)
MC1	F	29	Direct Select (head-mounted aluminum rod)
DC1	M	47	Single Switch (positioned on inside of right knee, activated by left knee)
DC2	M	41	Single Switch (positioned on left side of headrest, activated with side of head)
RC1	F	50	Single Switch (positioned on stomach, activated with left hand)

Table 5
Distribution of target letters

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		

3.4. Data collection

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

- What matrix item was presented as the target;
- The scan period 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 3rd row, 2nd column. To select ‘S’ on the first opportunity, a user must hit the switch on the first time the 3rd row is scanned, and the first time the 2nd 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. A high percentage of timing errors can indicate that the scan period 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:

- Character Entry Time (CET) – the average time (in seconds) to select a target;
- Selection Accuracy (SA) – the percentage of targets correctly selected from the matrix;
- Timing Errors (TE) – the percentage of targets during which a timing error occurred;
- Start Scan (SS) – the average time (in seconds) to initiate scanning;
- Row Press (RP) – the average time (in seconds) to select a row;
- Col Press (CP) – the average time (in seconds) to select a column.

Following blocks A2 and B2, each participant was asked to provide numerical responses between 1 and 7 to the two statements shown in Fig. 4. After both blocks A2 and B2 were completed, participants were

The scan rate during this test was:

Much too slow			Just right			Much too fast
1	2	3	4	5	6	7

The difficulty of entering letters during this test was:

Extremely easy						Extremely difficult
1	2	3	4	5	6	7

Fig. 4. Questions asked after block A2 and after block B2.

Which condition did you prefer?

Condition One			No Preference			Condition Two
1	2	3	4	5	6	7

How useful would it be if your scanning system helped adjust their scan rate at times to better match their abilities?

Not at all useful						Extremely useful
1	2	3	4	5	6	7

Fig. 5. Questions asked after both A2 and B2.

asked to respond to the two additional statements shown in Fig. 5.

3.5. *Hypotheses and data analysis*

To determine whether IDA can effectively recommend a specific, fixed scan period for users of single switch scanning input, we established some absolute and relative targets for user performance during the IDA evaluation condition. In absolute terms, one measure of effectiveness is how accurately subjects could select targets using the IDA-recommended scan period. For subjects in the ND group, our benchmark for effectiveness was selection accuracy averaging greater than 90% and timing errors averaging lower than 10%. These values were chosen based on our prior research [10] and clinical experience. For subjects in the CP group, we did not establish a fixed absolute target, but did calculate means and confidence intervals across subjects to measure the accuracy.

In relative terms, if subjects could perform as well or better with the IDA-recommended scan period as compared to their self-selected scan period, we took that as evidence in support of IDA's effectiveness. Specifically, we hypothesized that:

1. CET using the IDA-recommended scan period would be at least as fast as CET using the self-selected scan period.
2. Timing errors (TE) using the IDA-recommended scan period would be less than or equal to TE using the self-selected scan period.
3. Selection accuracy (SA) using the IDA-recommended scan period would be greater than or equal to SA using the self-selected scan period.

Each measure (CET, TE, SA) was considered equal (i.e., not significantly different) for the IDA and self-selected conditions if:

1. a repeated measures ANOVA model did not identify a statistically significant difference at $p < 0.05$; and
2. the mean difference across subjects for the measure was less than 15%. The value of 15% was chosen based on prior research experience [10].

Table 6
Results from ND Group. Participants in the first four rows used the IDA condition first; those in the last four rows used the Self-selected condition first

Participant	Scan period (msec)		CET (sec/char)		Sel'n Accuracy (%)		Timing Errors (%)	
	IDA	Self	IDA	Self	IDA	Self	IDA	Self
JA1	489	650	3.33	3.44	98	100	2	0
DA1	540	550	3.54	2.94	98	94	14	8
RA1	509	475	3.16	3.15	96	96	12	12
AA1	529	625	3.33	3.32	100	100	6	2
CA1	522	775	3.99	5.15	84	90	14	20
GA1	577	700	3.51	3.84	100	98	8	4
SA2	602	775	4.58	4.56	94	100	14	8
SA1	420	750	2.82	4.24	98	100	6	12
Average	523	662	3.53	3.83	96	97	9.5	8.2

Table 7
Results from CP Group. Participants in the first three rows used the IDA condition first; those in the last three rows used the Self-selected condition first

Participant	Scan period (msec)		CET (sec/char)		Sel'n Accuracy (%)		Timing Errors (%)	
	IDA	Self	IDA	Self	IDA	Self	IDA	Self
JC1	859	1450	12.19	13.03	76	98	36	18
JC2	1199	1325	6.54	13.45	84	78	6	32
MC1	1263	2250	8.17	8.26	92	84	10	0
DC1	1110	1875	8.56	8.24	98	98	16	6
DC2	891	1200	5.86	7.99	92	100	8	8
RC1	1293	1200	11.06	10.82	100	90	16	20
Average	1102	1550	8.73	10.30	90.3	91.3	15.3	14.0

The repeated measures ANOVA analysis used scan period condition (IDA vs. Self-selected) as the within subjects factor and subject group (ND vs. CP) as the between subjects factor. In addition to statistical analysis, establishing a mean difference criterion helps to reduce the chance of a false conclusion based on limited statistical power or high variation between subjects. We expected that while the two subject groups may differ from each other on some performance measures, each of the relative hypotheses would hold within each group. We did not have a specific expectation for how the scan periods would differ between the IDA and the Self-selected conditions. We did analyze scan period differences, however, in order to assess this difference.

4. Results

Results for the primary speed and accuracy measures for each subject group are presented in Tables 6 and 7. Across both conditions, participants in the ND Group averaged 3.68 sec/char, which is equivalent to 3.26 words/min (assuming 5 characters per word), while those in the CP Group averaged 9.52 sec/char, equivalent to 1.26 words/min. Selection accuracy averaged above 90% for both groups, while timing errors averaged less than 10% and 15% for the ND and CP groups, respectively.

Tables 8 and 9 present the subjective questionnaire responses for each participant group. Subject JC2 was not asked some of the subjective questions, due to experimenter error. The scanning speed was generally rated faster in the IDA condition as compared to the Self-selected, although in both conditions, a strong majority of ratings were within 1 point of the "Just Right" value of 4. Participants generally rated the task to be moderately difficult, or easier, except for one participant (DC2) who felt the IDA condition was "Extremely difficult." Ratings for 6 of 8 participants in the ND Group reflected a definite preference for the self-selected condition, while this was the case for only 1 CP participant. Two participants in the CP group felt that automatic scan period adjustments would be "Extremely useful," and none of the subjects felt that automatic scan period adjustments would be "Not at all useful."

4.1. Performance using IDA-recommended scan period

Subjects in the ND group took an average of 3.53 seconds to select each letter using the IDA-recommended

Table 8
Subjective Responses from ND Group. All responses are on a 1–7 scale. For the scan speed rating, 1 is "Much too slow," 4 is "Just right," and 7 is "Much too fast." For the difficulty rating, higher values indicate higher perceived difficulty. For the preference rating, values greater than 4 indicate preference for the Self-selected condition, and values less than 4 indicate preference for the IDA condition

Subject	IDA		Self		Preference for "self-selected"
	Scan Speed Rating	Difficulty Rating	Speed Rating	Difficulty Rating	
JA1	5	5	4	4	6
DA1	3	3	4	4	7
RA1	4	2	5	3	6
AA1	4	1	4	1	7
CA1	5	3	4	4	2
GA1	5	2	4	2	6
SA2	5	5	4	1	6
SA1	5	3	3	2	2
Avg	4.5	3.0	4.0	2.6	5.3

Table 9
Subjective Responses from CP Group. All responses are on a 1–7 scale. For the scan speed rating, 1 is "Much too slow," 4 is "Just right," and 7 is "Much too fast." For the difficulty rating, higher values indicate higher perceived difficulty. For the preference rating, values greater than 4 indicate preference for the Self-selected condition, and values less than 4 indicate preference for the IDA condition. For the usefulness rating, 1 is "Not at all useful" and 7 is "Extremely useful"

Subject	IDA		Self		Preference for "self-selected"	Usefulness
	Scan Speed Rating	Difficulty Rating	Speed Rating	Difficulty Rating		
JC1	5	5	4	4	7	5
JC2	–	–	–	–	3	3
MC1	7	4	4	4	4	4
DC1	4	1	2	1	4	7
DC2	6	7	4	4	1	7
RC1	3	2	4	1	4	4
Avg	5.0	3.8	3.6	2.8	3.8	5.0

scan period. Their average selection accuracy was 96%, with a 95% confidence interval of [91.6, 100.4], and they committed an average of 9.5% timing errors [5.6, 13.4]. Both accuracy measures meet the a priori criteria and provide evidence that the IDA-recommended scan period was not too fast to be usable by these subjects. The subjective ratings are consistent with these findings, since the average scan speed rating was slightly above "Just Right", and the difficulty rating averaged only 3.0 on a 1–7 scale.

Subjects in the CP group took 8.73 seconds to select each letter [6.13, 11.33] with the IDA-recommended scan period. They averaged 90.3% selection accuracy [80.9, 99.8] and 15.3% timing errors [3.9, 26.8]. While not as high as the ND group, this relatively high accuracy also suggests that the IDA-recommended scan period was usable by subjects in the CP group. The CP Group's subjective ratings for the IDA condition were less consistent than for the ND Group, and ratings for 2 participants indicate that the IDA scan period may have felt a bit too fast for them.

Overall, in absolute terms, the data suggest that IDA recommended a usable scan period for subjects.

4.2. *Performance with IDA- vs. self-selected scan period*

4.2.1. *Scan period*

Across all 14 subjects, there was a significant difference between the scan period chosen by IDA and the self-determined scan period ($p = 0.002$). The IDA-recommended scan period was consistently faster than the self-selected scan period, averaging 21.7% faster across all 14 subjects (19% faster for ND Group; 25.5% faster for CP Group).

4.2.2. Character entry time

Although the scan period for the IDA condition was faster, there was not a significant difference in CET with the IDA scan period as compared to the self-selected rate, ($p = 0.088$). The general trend was toward slightly faster CETs using the IDA-recommended scan period, averaging 9.0% faster across all subjects (5.8% faster for ND Group; 13.3% faster for CP Group).

4.2.3. Selection Accuracy

Selection Accuracy was relatively high whether the IDA or self-selected scan period was used. Selection accuracy averaged 93% for the IDA-selected scan period and 94% for self-selected, which was not significantly different ($p = 0.625$).

4.2.4. Timing Eerrors

The amount of Timing Errors committed was not affected by whether the scan period was recommended by IDA or selected by the subject ($p = 0.663$). Timing Errors with IDA averaged 1.33 percentage points higher than Timing Errors with self-selected scan period (1.25 pp more for ND Group; 1.33 pp more for CP group).

4.3. Group Differences

Overall, Group ND used a significantly faster scan period than Group CP (593 vs. 1326 msec, $p < 0.001$), and had a correspondingly faster CET (3.7 vs. 9.5 sec/char, $p < 0.001$). Members of Group ND tended to be more accurate than Group CP, but the differences were small and not statistically significant. Specifically, selection accuracy for the ND and CP Groups averaged 97% and 91%, respectively ($p = 0.066$), while the timing errors averaged 9% and 15% ($p = 0.127$).

5. Discussion

Our results suggest that IDA can recommend an appropriate fixed scan period for users of single switch scanning input. In an absolute sense, participants' speed, accuracy, and subjective ratings in the IDA condition support this conclusion. In relative terms, participants' performance, as measured by CET, selection accuracy, and timing error, was at least as good for the IDA-selected scan period as for the self-selected scan period.

IDA did tend to recommend scan periods that were significantly faster than subjects' selected periods, about 22% faster on average. However, this increase in scan period did not lead to significantly more errors, as both Selection Accuracy and Timing Errors were almost identical across the two scan period conditions. Somewhat surprisingly, the faster IDA scan period did not yield a significantly faster CET, although CET with IDA did average 9% faster than CET with self-selected scan period.

Why didn't the CETs more strongly reflect the increase in scan period? We explored the relationship between scan period and CET a bit further, to try to gain insight into this result. As Fig. 6 shows, CET did generally improve with faster scan periods, as one would expect. The relationship is similar across both scan period conditions, again as one would expect.

But the figure also shows that CET is not unilaterally determined by the scan period. For example, CETs at a scan period of approximately 1250 msec ranged from 6.5 to 13.5 sec/char. One factor in this range is the time it takes to begin scanning, from when the target letter is presented until the first switch hit is made. This initiation time is included in the measured CET, but is completely independent of the scan period setting. We could determine the exact contribution of this factor by separating time to initiate scanning from the time to scan to each letter, but that is beyond the scope of our current analysis. A second factor clouding the relationship between scan period and CET is the effect of timing errors. For example, waiting to select the target letter until the 2nd or 3rd time its row is scanned adds significant time to the CET. In the extreme case, a user who **always** waits until the 2nd row scan to select a letter would have a CET about 5 times slower than the user who always gets the letter on its 1st row scan (for a 5-row selection matrix).

The findings reported here must be interpreted within the limitations of the study's design. Of the six members of the CP group, only four regularly used single-switch scanning. Subjects only participated in a single session, which limited opportunity for them to improve with practice. Subjects were also tasked with transcribing letters and punctuation marks one-at-a-time from an unfamiliar display, rather than communicating with their own personal device. All of these elements reduce the authenticity of the experimental task.

Two additional differences between the experimental interface and "real" row/column scanning interfaces are also worth noting. First, the experimental interface had a single scan period for rows and columns, and no additional delay was possible for the first row or column. For at least one subject in the CP group (DC1), there appeared to be a real need for an initial delay due

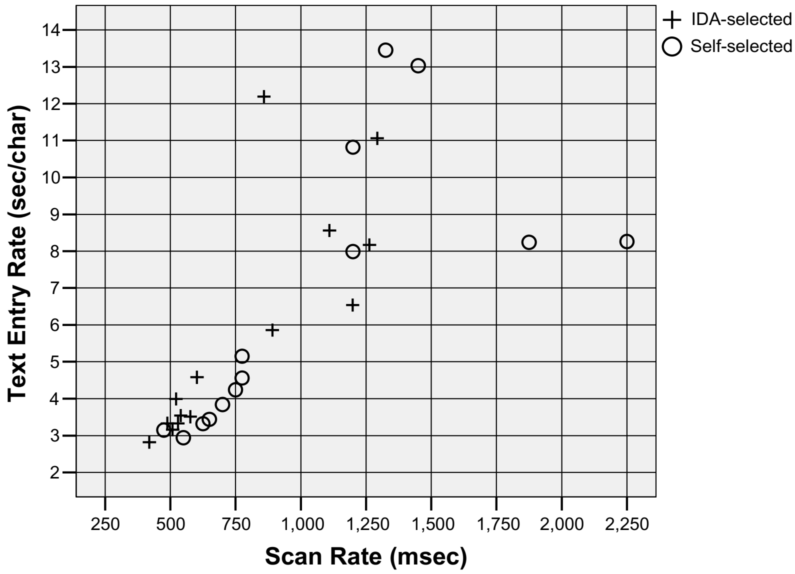

Fig. 6. CET vs. scan period for all participants under both conditions.

to his extended recovery time between switch presses. Second, the self-selected condition is an idealized condition, because most row/column scanning systems do not provide users with such immediate access to the scan period.

A final methodological note involves the use of a group who were unimpaired in their ability to press a single switch (the ND Group). Given our difficulty in recruiting people who use single-switch scanning, the ND Group was a useful complement to the smaller CP Group. In some ways, such as the achieved CETs, the ND Group was not representative of the CP Group's performance, as might be expected given their physical differences. However, in other ways, such as accuracy of performance, and the **relative** performance under the two scan period conditions, the two groups were remarkably similar. This suggests that while there is no substitute for direct involvement by members of the target population, a group of unimpaired participants can be a useful way to augment findings from the target group, if employed carefully.

6. Conclusions

This study demonstrates the validity of a particular approach to determining an appropriate scan period for single-switch row-column scanning. The apparent accuracy of the ".65 rule" for choosing scan period may be a useful result for clinicians. While more work is needed to understand the conditions under which the rule works, it does provide a useful starting point for selecting a scan period. Applying this rule does require measurement of a user's switch hit times during use of their scanning system, and we suggest that manufacturers of such systems provide a means to take these measurements as needed.

Clinicians should also take notice of the complex relationship between scan period and CET. While faster scan periods often translate into faster CETs, the benefit may not always be as large as expected. Other factors, such as accuracy and scan initiation time, can partially, or even completely, counteract the gain from a faster CET. We suggest that clinicians measure a client's performance to determine the extent to which changes in scan period are having the desired effects.

For future development of IDA, the results provide several avenues of future study. For a small number of subjects, an initial scan delay might have been very useful. Learning to identify when someone might benefit from such a delay is an important goal for future versions of IDA.

Future work will also focus on the long-term effects of using IDA. For most subjects, IDA selected a faster scan period than the subjects chose for themselves. Over an extended period of time, this might result in faster CET with the IDA-selected condition. Further study across multiple sessions is needed to determine the extent to which this might be true.

Acknowledgements

This research was supported by funding from the NIH (grant #1 R43 HD045015-01) and the NSF (grant #0133395).

Koester Performance Research (KPR) currently sells a software-package called Compass, and the IDA project makes use of software originally developed for Compass (along with other, original, code). All three co-authors participated in the development of Compass. Dr. Koester is the owner of KPR, and Dr. LoPresti is an employee of KPR. Dr. Simpson has no financial or management relationship with KPR and receives no royalties from the sale of Compass.

References

[1] D.K. Anson, *Alternative Computer Access: A Guide to Selection,* 1 ed., Philadelphia, PA: F.A. Davis Company, 1997.

[2] D. Anson, *Alternative Computer Access: A Guide to Selection,* Philadelphia, PA: F.A. Davis Company, 1997.

[3] S.R. Cronk and R.W. Schubert, *Development of a Real-Time Expert System for Automatic Adaptation of Scanning Rates,* Annual Conference on Rehabilitation Technology (RESNA), San Jose, CA: RESNA Press, 1987.

[4] S. Cronk and W. Wang, *Investigating relationships between user performance and scan delays in aids that scan,* Annual Conference on Rehabilitation Technology (RESNA), Minneapolis, MN: RESNA Press, 2002.

[5] R.I. Damper, Text composition by the physically disabled: A rate prediction model for scanning input, *Applied Ergonomics* **15**(4) (December 1984), 289–296.

[6] H.H. Koester, E.F. LoPresti and R.C. Simpson, *Toward Goldilocks' pointing device: Determining a "just right" gain setting for users with physical impairments,* ACM SIGACCESS Conference on Assistive Technologies (ASSETS), Baltimore, MD: ACM Press, 2005.

[7] H.H. Koester and S.P. Levine, Modeling the speed of text entry with a word prediction interface, *IEEE Transactions on Neural Systems and Rehabilitation Engineering* **2**(3) (September 1994), 177–187.

[8] G.W. Lesher, J. Higginbotham and B.J. Moulton, *Techniques for automatically updating scanning delays,* Annual Conference on Rehabilitation Technology (RESNA), Orlando, FL: RESNA Press, 2000.

[9] G.W. Lesher, B.J. Moulton, J. Higginbotham and B. Alsofrom, *Acquisition of scanning skills: The use of an adaptive scanning delay algorithm across four scanning displays,* Annual Conference on Rehabilitation Technology (RESNA), Minneapolis, MN: RESNA Press, 2002.

[10] R.C. Simpson and H.H. Koester, Adaptive one-switch row-column scanning, *IEEE Transactions on Neural Systems and Rehabilitation Engineering* **7**(4) (December 1999), 464–473.

[11] M. Tracey and J. Winters, *Neuro-fuzzy advisor for mouse setting in Microsoft Windows,* Joint BMES/EMBS Conference. Atlanta, GA: IEEE, 1999.

[12] S. Trewin, A model of keyboard configuration requirements, *Behaviour & Information Technology* **18**(1) (1 January 1999), 27–35.

[13] S. Trewin, *Configuration agents, control and privacy,* ACM Conference on Universal Usability, Arlington, VA: ACM Press, 2000.

[14] S. Trewin and H. Pain, Keyboard and mouse errors due to motor disabilities, *International Journal of Human-Computer Studies* **50**(2) (February 1999), 109–144.