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The Effect of Input Device on User Performance With a Menu-Based Natural Language Interface

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Menu-Based Natural Language (MBNL) provides a form of constrained natural language dialogue for human-computer interaction where natural language words and phrases are displayed on the screen as menu items.

Previous research on cursor devices has provided mixed results concerning the "best" cursor device and no firm recommendations were available for use with MBNL interfaces.

This study was developed to determine the best input device for MBNL interfaces to Naval command and control databases.

Results showed that search keys were slower than cursor keys and trackball. No-scrolling was faster than scrolling. Trackball was preferred, and was more quickly learned than cursor keys.

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PREFACE

This is the final report for Contract number N66001-87-C-0187 entitled "Software and Input Device for Menu-Based Natural Language Studies." The experiment described herein was designed and prototyped, and the final report was prepared by the User Systems Engineering Organization at Texas Instruments in Dallas, Texas. The experiment was conducted and the data were analyzed by Virginia Polytechnic Institute and State University human factors engineering personnel under Contract number N66001-85-C-0254.

Special thanks goes to Dr. Glenn A. Osga, the technical contract monitor, for his support and consultation throughout this project. Thanks also to Drs. Gerald Birdwell, Harry Snyder, William Muto, Brian Epps, Ann Hammer and Daniel Donohoo for their review and comments. Thanks to Dr. William Fisher for his help in the parsing of the grammar used in the MBNL interface prototype, and to Mr. Ken Stevenson for his support of the input device gain control software. Finally, thanks goes to Mr. Bill Hensley for designing and constructing the custom keypad for the trackball used in the study.

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EXECUTIVE SUMMARY

The use of natural language human-computer dialogue has been a subject of much discussion in recent years. Menu-based natural language (MBNL) provides a form of constrained natural language dialogue for human-computer interaction where natural language words and phrases are displayed on the screen as menu items.

Previous research on cursor devices has provided mixed results concerning the "best" cursor device and no firm recommendations were available for use with menu-based natural language interfaces.

This study was developed to determine the best input device for MBNL interfaces to Naval command and control databases. Three different cursor control and input devices (trackball, keyboard cursor keys, and search keys) were evaluated for use in MBNL interfaces. Another goal of the study was to investigate the effects of scrolling and query length on user performance.

Eighteen Operation Specialists from the Naval Ocean Systems Center performed typical database query tasks using MBNL. A within-subjects design was used to evaluate their performances and preferences while using each of three input devices, for three menu lengths, with scrolling and

no scrolling, over six trial periods.

The dependent measures included total task time, error frequency, ratings of the input devices, and rankings of the input devices. The subjects were given the exact queries they were to enter since query formulation time was not a goal of this study.

All main effects were found to be statistically significant. The performance times for the three input devices showed the search keys to be slower than the cursor keys and the trackball. The performance time for the no-scrolling condition was significantly faster than for the scrolling condition. There was also a significant difference in performance time due to query length.

The trackball was the most preferred device, while the cursor keys were least preferred. Overall, query construction times were faster with the cursor keys and the trackball than with the search keys. Performance with the trackball was apparently asymptotic by the end of the first trial block, and consequently the trackball had an early advantage over the cursor keys.

The results suggest that users perform equally well with the trackball and the cursor keys and that a beginning, intermittent, or infrequent

system user could more quickly "get up to speed" with the trackball than he could with the cursor keys.

INTRODUCTION

Natural language human-computer dialogue has been a subject of much discussion in recent years. Proponents of natural language human-computer dialogue claim that it has several advantages over formal command language dialogue in that natural language dialogue is versatile, is easy to use, does not require much up front training, and permits the possible use of speech recognizers for input. Furthermore, users do not have to learn a command syntax or new syntactical rules, thereby accommodating the inexperienced user. Shneiderman (1987) argues that natural language human-computer dialogue "...can be effective for the user who is knowledgeable about some task domain and computer concepts but who is an intermittent user who cannot retain the syntactic details" (p. 166).

Several applications of restricted scope, such as LUNAR, SOPHIE, ELIZA, CHECKBOOK, BASEBALL, MARGIE, and INTELLECT, have demonstrated that it is possible to design computer programs that will accept natural language instructions to accomplish particular tasks (Bobrow & Collins, 1975; Brown, Burton, & Bell, 1975; Ford, 1981; Green, Wolf, Chomsky, & Laughery, 1963; Petrick, 1976; Schank, 1975; Schank & Colby, 1973; Suding, 1983;

Weizenbaum, 1966; Woods, 1970). Experimental studies of natural language dialogue have included comparisons between natural languages and query languages, laboratory studies of prototype natural query languages, and field studies of prototype systems (see Damerau, 1981; Egly & Wescourt, 1981; Hershman, Kelly, & Miller, 1979; Kaplan, 1982; Krause, 1979; Miller, Hershman, & Kelly, 1978; Shneiderman, 1978; Small & Weldon, 1983; Tennant, 1980; Waltz, 1977). Encouraging results have been reported, but most of the studies also indicate usability problems.

A number of disadvantages and shortcomings of natural language dialogue have been described (see Biermann, Ballard, & Sigmon, 1983; Hauptmann & Green, 1983; Lowden & DeRoeck, 1985; Ogden & Brooks, 1983; Shneiderman, 1980, 1987; Tennant, Ross, & Thompson, 1983; Weizenbaum, 1966, 1976; Winograd, 1972). Relatively high failure rates, high error rates, ease of use problems, and user frustration have been noted. Some have argued that natural language dialogue leads to ambiguity in the formulation of queries and requests and that natural languages are not only ambiguous but overly verbose. Natural language systems are noted to be mysterious about their coverage and capabilities,

and natural language dialogue, it has been argued, leads to an overestimation of computer capabilities and intimidation of the user. Features of natural language systems are thus often not used because users are unaware of them or do not trust them.

The desirability of natural language systems for use across the user spectrum and user-system task variety has been questioned. Despite the user interface problems, natural language dialogue is generally considered preferable for inexperienced users. For knowledgeable and frequent users who are thoroughly aware of available functionality, however, a concise command language seems preferable. Experts, it has has been noted, generally prefer terse, formal command languages.

From the software development perspective, there are also reservations about natural language systems. The programs must handle relatively large grammars and lexicons, and the code required to parse and translate the natural language input can be extensive and complex. The programs typically require "best guess" algorithms to handle spelling, syntactic, and semantic variations. System resources must consequently be allocated for recognizing the variant syntactical structures and synonymous terms. Additionally, resources must be

allocated for error checking and clarification procedures. Conventional natural language systems are thus expensive to build and maintain, and they require large amounts of computer memory.

Menu-Based Natural Language

As an alternate form of human-computer interaction, menu-based natural language (MBNL) stands at the middle ground between the restrictive formal command languages and unconstrained free-form natural language. MBNL provides a form of constrained natural language dialogue for human-computer interaction. With a MBNL interface, natural language words and phrases are displayed on a screen as menu items. The user constructs a natural language sentence by selecting the menu items with a pointing device. As the menu items are selected, the natural language sentence is formed in a window, and when the command sentence is complete, the sentence is sent to the underlying application program for execution.

Work in the area of MBNL dialogue has shown promising results (Osga, 1984; Tennant, Ross, Saenz, Thompson, & Miller, 1983; Tennant, Ross, & Thompson, 1983; Thompson et al., 1983). MBNL interfaces can be developed relatively quickly and require fewer memory resources than a conventional

natural language system. The coverage and limitations of an MBNL system are made more apparent to the user due to the use of a restricted natural language. The user can thus avoid the frustration of over extending beyond the limits of system functionality. Since MBNL interfaces are closed and manageable, they also allegedly encourage exploration and use of the full range of system resources. Furthermore, MBNL interaction requires only the use of a pointing device, such as a mouse, trackball, or lightpen. If a keyboard is used for input, only the cursor keys and enter key are required. Typing is thus eliminated and the user is guaranteed a semantically and syntactically correct query or command input.

Cursor Control and Input Devices

Cursor devices may be indirect, such as the cursor key, joystick, trackball, or touchpad, or direct, such as the lightpen or touch screen (Ohlson, 1978). The few studies that report experimental comparisons of two or more cursor devices generally indicate that the direct devices, such as the lightpen and touch screen, perform the best of all devices in terms of task completion time. The trackball, however, appears to be the best device in terms of accuracy. Overall, it

appears that the mouse and the trackball are the best devices across a variety of tasks (Epps, 1986).

English, Engelbart, and Berman (1967) performed the first notable study aimed at the comparison of cursor devices. The devices included a mechanical mouse, a displacement joystick (absolute and rate modes), a lightpen, a graphacon, and a knee-control device. For experienced subjects, the mouse had the fastest time to target and lowest error rate for both character and word targets. For inexperienced subjects, the knee-control was the best device for time to target, while the mouse had the lowest error rate.

Mehr and Mehr (1972) compared several joystick and trackball configurations for a simple target acquisition task. The joystick was studied under four configurations, including force (rate mode), force (rate mode with thumb operation), displacement (rate mode), and displacement (absolute mode). The trackball was also studied under four conditions with pulses per trackball revolution/grams of drag force ratios of 209/50, 209/35, 409/57, and 409/35. The results showed that the 409/35 trackball configuration and the force (rate mode) joystick were the best devices on

time to position, error, and learning curves.

Goodwin (1975) compared a lightpen and a lightgun to keyboard text keys for three simulated word processing tasks, including arbitrary cursor positioning, sequential cursor positioning, and check reading. The results showed that the two lightpen devices were significantly faster than keyboard text keys for trial completion time.

Card, English, and Burr (1978) performed an experimental comparison of a mechanical mouse, a force joystick (rate mode), cursor keys, and text keys for a simulated word processing task. Target size and target distance were also manipulated. There were four target sizes of 1, 2, 4, and 10 characters, and five target distances of 1, 2, 4, 8, and 16 cm. The results showed that the time to target was significantly faster for the mouse and joystick than for the step keys and text keys across all target sizes and distances. Across target size, the mouse had the lowest error rate of the four devices.

Gomez, Wolfe, Davenport, and Colder (1982) compared a trackball and touchpad (absolute mode) in a study performed at the Naval Ocean Systems Center (NOSC). Half the subjects were trained on the system with a trackball and half had no

experience on either device. No difference was found between the touchpad and trackball for time to target. The error (distance from target center) was significantly lower for the trackball across both groups. Additionally, the trained subjects had a significantly lower error rate across both devices.

Albert (1982) performed a comprehensive comparison of devices on a simple target acquisition task. The devices included a touch screen, a lightpen, a touchpad (with "puck"), a trackball, a displacement joystick (rate mode), a force joystick (rate mode), and cursor keys. Although there were significant differences among the devices, no post-hoc test results were reported. Based on means for positioning speed, the order from best to worst cursor device was touchscreen, lightpen, touchpad, trackball, force joystick, displacement joystick, and cursor keys. For positioning accuracy, the order was trackball, touchpad, force joystick, displacement joystick, and cursor keys. Subjective ratings were also collected, but no statistical analyses were performed on the data. However, an inspection of the mean ratings indicates that the touchscreen, lightpen, and touchpad were considered the most

comfortable, easiest to learn, and least tiring to use.

Following the development of a touchpad for use in the Royal Signals and Radar Establishment (RSRE) for air traffic control tasks, Whitfield, Ball, and Bird (1983) compared the RSRE touchpad with a trackball and a touchscreen. Only the findings from one of three reported experiments are described here. The factors of interest were device type and target size. Target size was varied from 1.5 to 12 cm in 1.5-cm increments. Statistical test results for time to target indicated significant differences among devices. Although no post-hoc test results were given, the authors reported that the touchscreen was ranked the fastest and the trackball the slowest. Again, though no post-hoc test results were reported, the trackball had the lowest percentage of errors and the touchscreen had the highest.

Struckman-Johnson, Swierenga, and Shieh (1984) compared a displacement joystick (absolute mode), a trackball, a lightpen, and non-repeating keyboard keys on a simulated text editing task. Gender was also included as a factor in the study. For males, the lightpen and trackball yielded faster trial completion times than either the joystick or

keyboard keys. For females, the lightpen yielded faster trial completion times than all other devices. Males performed better than females when using the cursor keys, joystick, and trackball, but not the lightpen. The keyboard keys and trackball resulted in lower error rates than the joystick across all subjects. Furthermore, the lightpen and trackball were preferred over the joystick and cursor keys.

Haller, Mutschler, and Voss (1984) compared a lightpen, touchpad (absolute), mouse, trackball, repeating cursor keys, and a speech recognition device on a simulated word processing task. Subjects were allowed to choose their own preferred control/display gain for the touchpad, trackball, and mouse. The lightpen was found to be superior to all other devices and voice input was found to be inferior to all other devices on time to target. In addition, the lightpen and cursor keys showed the smallest error rate. Of all devices in the study, the lightpen was the most preferred.

Karat, McDonald, and Anderson (1984) compared a touchscreen, an optical mouse, and keyboard keys. Subjects performed a menu-type target acquisition task embedded within two applications, including a computer-based telephone aid and an appointment

aid. For target acquisition, the touchscreen was superior for speed and the keyboard was superior for accuracy. For the applications tasks, the touchscreen was superior to the mouse and the keyboard for menu selection. Subjects preferred the touchscreen and keyboard over the mouse for performance of the applications menu selection tasks.

Epps (1986) compared the performances of an absolute touch pad, a relative touchpad, a mouse, a trackball, a force joystick, and a displacement joystick. Prior to comparison, the devices were optimized for display/control dynamics in independent experiments. The devices were then tested on three types of tasks: target acquisition, text editing, and graphics. Epps found a wide variation in the cursor positioning performance of the devices on the three types of tasks. In general, the two joysticks performed worse on the target acquisition and graphics tasks than the two touchpads. On the text editing task, however, the rate-controlled joysticks performed better than the touchpads. The mouse and the trackball performed the best, without exception, across all tasks Additionally, these devices were the most preferred.

Present Study

Research on cursor devices has provided mixed results concerning the "best" cursor device. There is general agreement that touch entry devices (e.g., touch screens, lightpens) are best when fast acquisition of relatively large targets is required. In other words, touch entry devices are typically fast but inaccurate. There is a lack of agreement on the most accurate device, but the mouse or trackball appears to be the recommended device. The research of Epps (1986) indicates that the mouse and trackball are the overall "best" devices for a variety of task environments.

Nevertheless, no firm conclusions can be drawn that would warrant generalizations to menu-based natural language (MBNL) interfaces, particularly MBNL interfaces to Naval command control databases. Furthermore, the shipboard environment adds its own unique set of requirements. For example, a physically stable cursor device is required. Thus, a mouse can be ruled out as an alternative since it will tend to slide around under unstable conditions. Consequently, there was a need to determine the appropriate cursor device to meet the unique requirements of the NOSC MBNL interface.

This study was conducted to compare three

different cursor control and input devices, namely, a trackball, keyboard cursor keys, and search keys. Search keys move the cursor to the first menu item that begins with the keyed letter. For example, if a menu contains the items "Count", "Display" and "List", and the user types an "L", the cursor will jump to the menu item "List".

Additionally, the effects of scrolling and query length were investigated. The effect of scrolling was investigated with a scrolling versus no-scrolling manipulation. The effect of query length was evaluated by requiring subjects to select two, three, or four menu items to construct queries.

METHOD

Subjects

There were 18 Operation Specialists from the Naval Ocean Systems Center who participated in the experiment. The subjects were male and ranged in age from 24 to 43. All subjects had experience on a microcomputer and 15 to 18 months of tactical console experience.

Materials

Query instructions. There were six sets of query instructions developed for the experiment, with 36 query instructions within each set. Each instruction set was produced by a factorial combination of three query lengths (1, 2, or 3 menu items) and two menu lengths (scrolling/no-scrolling). The query instructions were worded without syntactic or semantic variation from the actual menu items (Table 1, Figures 1 and 2). Full listings of the queries and menu items are available in Appendices A and B.

Subjective evaluations. Subjects rated the input devices on five bipolar scales. The scale anchor points included accurate-inaccurate, fast-slow, consistent-inconsistent, comfortable-uncomfortable, and acceptable-unacceptable (see Appendix C).

Subjects rank-ordered the input devices on four dimensions. The ranking dimensions included most preferred-least preferred, fastest selection speed-slowest selection speed, highest accuracy-lowest accuracy, and most comfortable-least comfortable (see Appendix D).

TABLE 1

Example Queries for Each Combination of Query Length and Scrolling

Query Length 2
No-scrolling:
Count Soviet air
Scrolling:
List downed aircraft
Query Length 3
No-scrolling:
List EA2B reported by U.S. Ticonderoga
Scrolling:
Count downed aircraft within 50 nautical miles
Query Length 4
No-scrolling:
Display dot blinking U.K. air controlling jammer mission whose location is hook location
Scrolling:
Display symbol normal special point with remote data source

Software. The menu-based natural language interface was developed using NaturalLink™ (Texas Instruments, 1985a, 1985b). NaturalLink™ combines an interactive menu-based system with a semantic grammar analysis approach to natural language processing (where sentences are parsed according to semantic rather than syntactic categories).

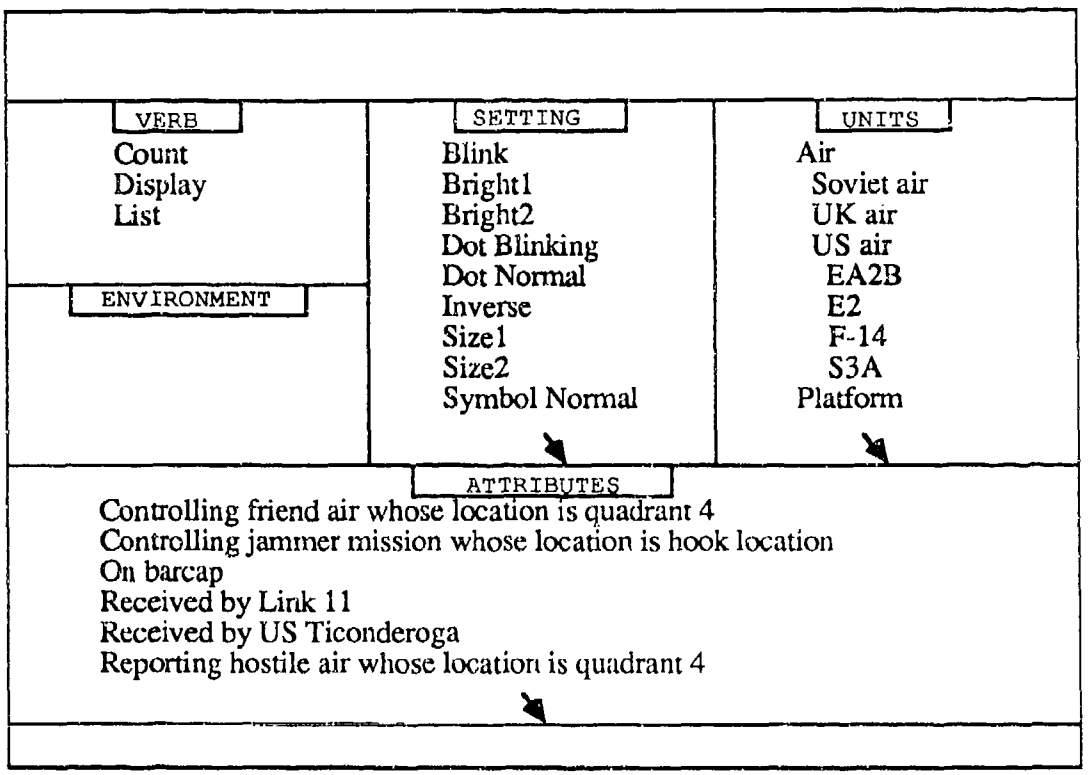

Figure 1. Menu Items Visible on the Work Screen Without Scrolling.

The interaction between the user and application software is handled by a window manager, a parser, a translator, and a sessioner (driver). The window manager runtime controls the screen displays and

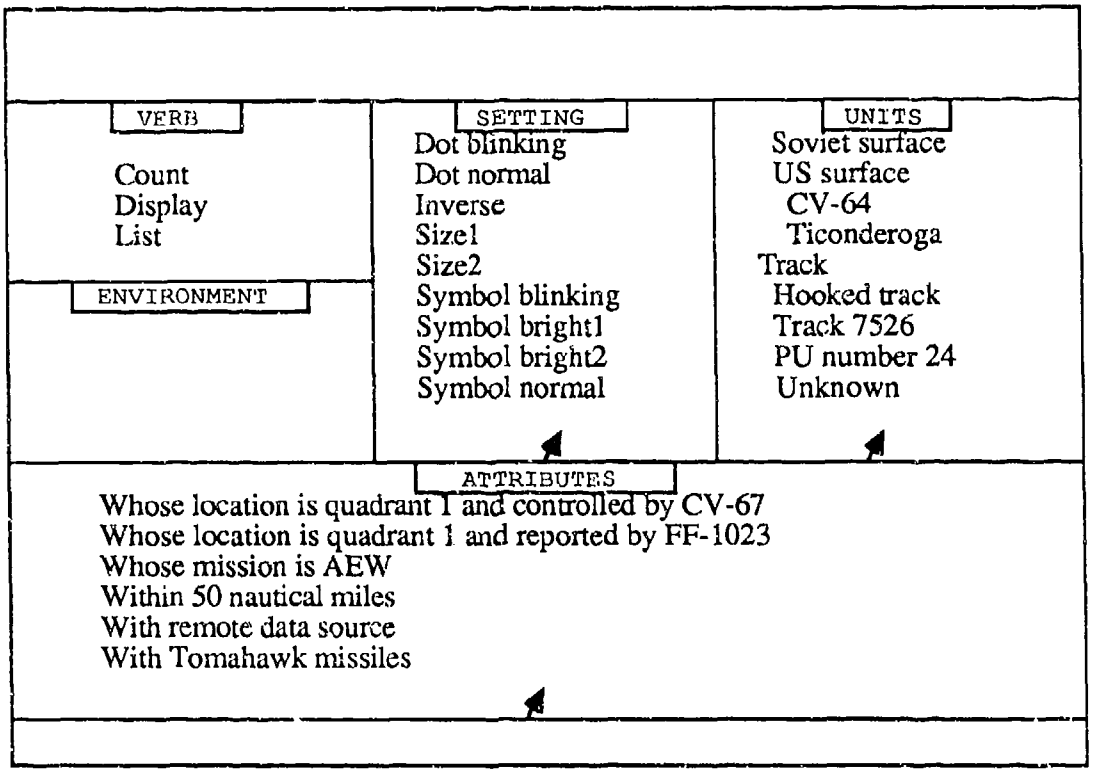

Figure 2. Menu Items Visible on the Work Screen by Scrolling to the Bottom of the Windows.

returns inputs from the windows when menu items are selected. The parser receives the inputs from menu selections, consults grammar and lexicon files, and builds a parse tree. The parse tree is then passed to the translator when the user completes and

anters the query. The translator receives the parse tree, maps it to the elements of the underlying application program, and passes it to the sessioner. As the user builds and executes the queries, the sessioner coordinates the interaction among the parser, translator, and window manager, passing control among these software components and the application. The application finally calls the window manager to display the results of the query.

Calls to the NaturalLink™ runtime software were made by a program written in Microsoft FORTRAN version 4.0. Additionally, the FORTRAN routine received key codes returned from the window manager and performed DOS time calls on each return. The time-stamped key codes were written to a buffer and were subsequently written to disk whenever the user executed a query.

Equipment

Computer system. The MBNL software and keystroke capturing software were run on an NCR PC8 computer with 8 MHz clock speed, 640K memory, a 20MB hard disk, an EGA graphics board, and a monochrome NEC Multisync monitor. The "return" key was used to "select" the particular menu item highlighted by the cursor. The F8 key was designated as the "back

up" key, used to back up, erase a previously selected menu item from the query, and return the cursor to the menu from which the item had been selected. The F10 key was used to "execute" the completed queries.

Trackball. A Measurement Systems Model 621 trackball (4-cm diameter) was used in the present study. The trackball was set to operate at a 0.8 display/control gain (10 cm of cursor movement per 360 deg of trackball revolution (trackball circumference of 12.5 cm)). The gain selected for the trackball had been found by Epps (1986) to be best for text editing tasks. Also, in the pilot testing phase of the present experiment, four subjects were asked to use the trackball with the gain varied over a wide range. The median preferred gain among the four pilot subjects was 0.8, corroborating the desirability of the selected trackball gain.

A three-button custom keypad was used with the trackball. The left button was designated as the "return" key, the middle button was designated as the "execute" key, and the right button was designated as the "back up" key.

Experimental Design

The experiment was conducted as a 3 X 2 X 3 X 6 within-subjects design. The first factor was input device type with three levels representing the three devices, namely, the trackball, the keyboard cursor keys, and the search keys along with the cursor keys. The second factor was menu length with

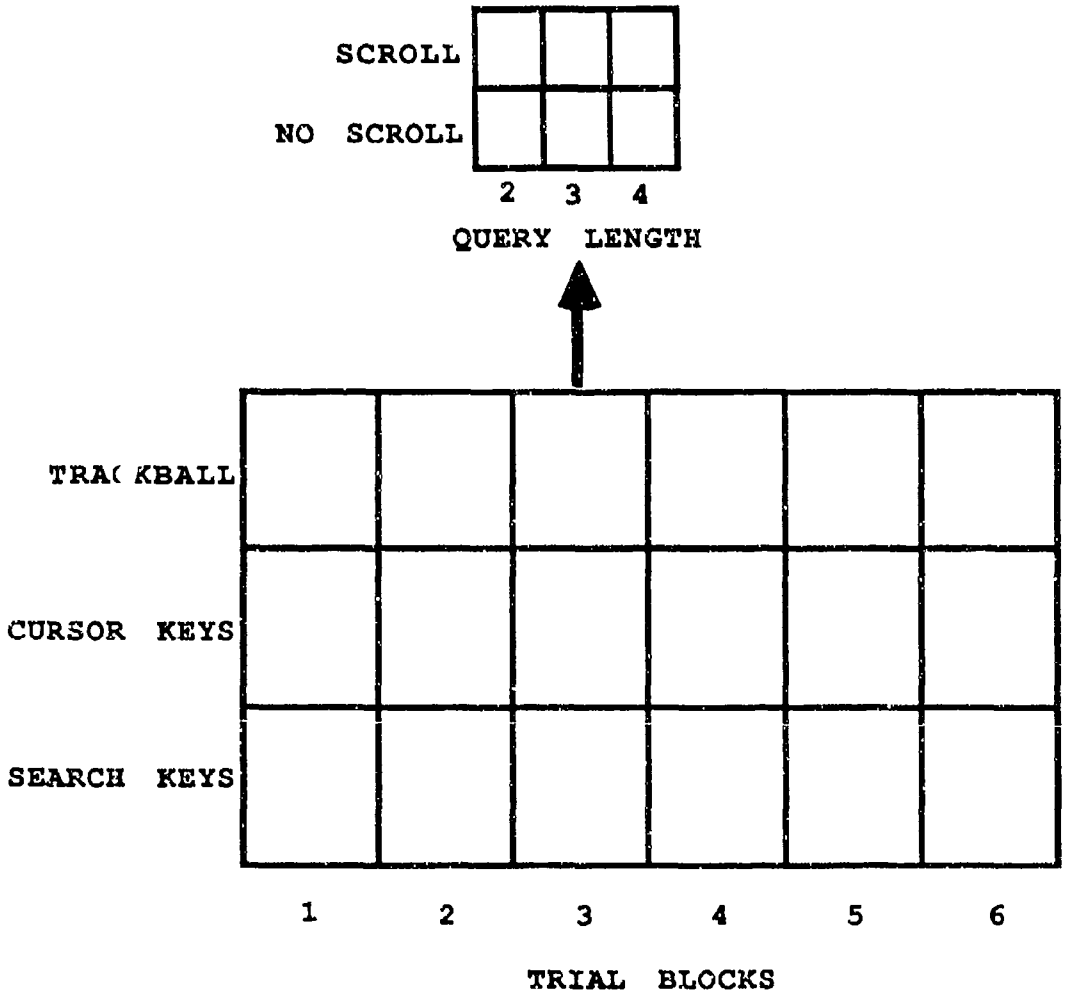

Figure 3. Experimental Design.

two levels representing scrolling and no-scrolling. The third factor was query length with three levels representing queries constructed from two, three, and four menu items. Finally, the fourth factor was replication, with six levels representing the six replications or trial blocks. The six conditions produced by the query length and scrolling/no-scrolling factors were balanced across input device and the six replications of each condition were randomly assigned in six different sequences. These six sequences comprised the six sets of query instructions which were assigned at random for three series of six subjects each. The experimental design is depicted in Figure 3.

The dependent measures included total task time, error frequency, ratings of the input devices, and rankings of the input devices. Total task time was defined in terms of query construction time as the time from when a query was initiated to when a query was executed.

Procedure

Subjects were first given general instructions to read. These instructions included all of the pertinent information about the experiment, with the exception of information pertaining to the input devices. Following the general instructions,

subjects were given the instructions for the first input device, followed by four practice trials for that device. Subjects were then given the instructions for the second input device, and were allowed four practice trials with that device, and likewise with the third input device, for a total of 12 practice trials.

The notebook containing the practice queries and the queries for the experimental trials was positioned on the left side of the subjects' workstation. Subjects were instructed to turn the page in the query instruction notebook and become familiar with the query before initiating query construction. The purpose of this instruction was to exclude the time to prepare for query construction from actual query construction time.

The first screen presented to subjects was an initiation screen, which prompted the subject to "Press Enter to Continue." Pressing "enter" started the timer embedded in the calling program and brought up the work screen with the cursor positioned on the first menu item in the VERB window (Figures 1 and 2). Construction of the query required the selection of appropriate menu items, which was accomplished by moving the cursor with the input device to highlight the desired item and

then pressing "return." When a menu item was selected, it was added to the query in the results window at the top of the screen; then depending on the grammar rules in effect, the cursor automatically moved to the first menu item in the next appropriate window where the subject could continue constructing the query. Once a query was constructed, the subject could then execute the query by pressing the "execute" key. Execution of the query signaled the end of the trial, stopped the timer in the calling program, and brought up the initiation screen again.

During query construction, subjects could back up to previous selections by pressing the "back up" key which, as described earlier, would erase a previously selected menu item from the query and return the cursor to the menu from which the item had been selected. This option allowed subjects to correct any errors they may have noticed during query construction. Once a query was executed, the subjects could not back up. Error correction time was included in the total query construction time.

After the 36th trial with a particular device, the subjects were instructed to stop, at which time they completed the rating scale for that device. Upon completing the rating scale, a 10 to 15 minute

rest break was allowed. After all 108 trials were completed, the devices were rank-ordered.

RESULTS

Total Task Time

A four-way analysis of variance (ANOVA) was conducted on total task time (Device by Menu Length by Query Length by Replication). All main effects were found to be significant (Table 2). Most importantly, there was a significant difference among the performance times of the three input devices ($p = 0.0073$) (Figure 4). A Newman-Keuls test showed that the search keys were slower (13.73 s) than the cursor keys (12.14 s, $p < 0.01$) and the trackball (12.17 s, $p < 0.01$). However, there was no reliable difference between the cursor keys and the trackball.

The performance time for the no-scrolling condition was significantly faster (9.81 s) than for the scrolling condition (15.55 s, $p < 0.0001$) (Figure 5). There was also a significant difference in performance time due to query length ($p < 0.0001$) (Figure 6). A Newman-Keuls test showed that two item queries (6.43 s) were performed more quickly than three-item (12.61 s, $p < 0.01$) and four-item (19.00 s, $p < 0.01$) queries, and three-item queries were performed more quickly than four-item queries ($p < 0.01$).

TABLE 2

ANOVA Summary Table for Total Task Time

SOURCE	MS	df	F	p
BETWEEN				
SUBJECTS	2703.23	17	----	------
WITHIN				
DEVICE	555.07	2	5.70	0.0073
DEV x SUB	93.49	34		
SCROLLING	16049.98	1	76.37	0.0001
SC x SUB	210.16	17		
QUERY LENGTH	25610.71	2	51.23	0.0001
QL x SUB	499.87	34		
TRIAL BLOCK	369.10	5	8.84	0.0001
TB x SUB	41.74	85		
DEV x SC	33.82	2	0.62	0.5414
DEV x SC x SUB	54.12	34		
DEV x QL	68.29	4	1.97	0.1089
DEV x QL x SUB	34.67	68		
DEV x TB	36.43	10	0.91	0.5226
DEV x TB x SUB	39.90	170		
SC x QL	818.94	2	15.14	0.0001
SC x QL x SUB	54.10	34		
SC x TB	47.74	5	1.71	0.1409
SC x TB x SUB	27.91	85		
QL x TB	77.30	10	2.95	0.0019
QL x TB x SUB	26.22	170		
DEV x SC x QL	43.84	4	0.99	0.4181
DEV x SC x QL x SUB	44.20	68		
DEV x SC x TB	45.89	10	1.02	0.4269
DEV x SC x TB x SUB	44.90	170		
DEV x QL x TB	53.15	20	1.68	0.0355
DEV x QL x TB x SUB	31.72	340		
SC x QL x TB	27.66	10	0.85	0.5825
SC x QL x TB x SUB	32.59	170		
DEV x SC x QL x TB	43.45	20	1.12	0.3252
DEV x SC x QL x TB x SUB	38.75	340		
TOTAL		1943		

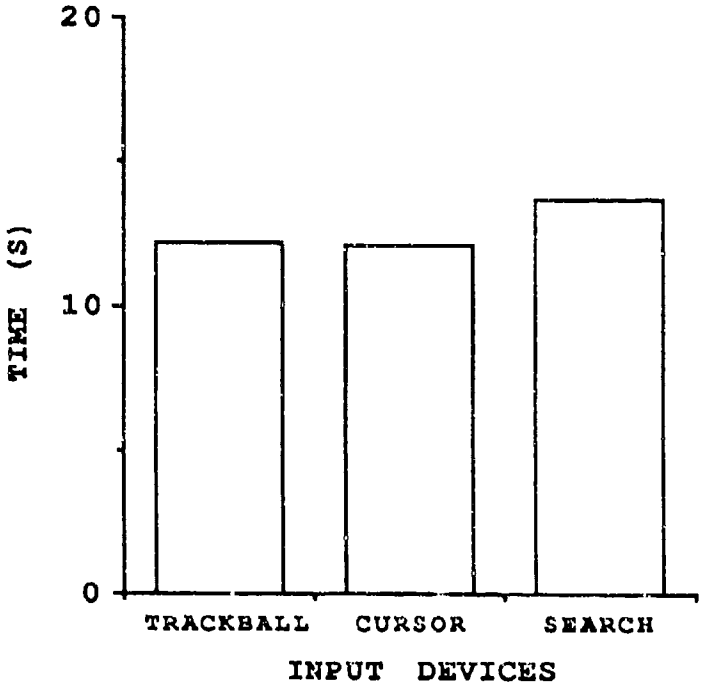

Figure 4. Main Effect of Input Device.

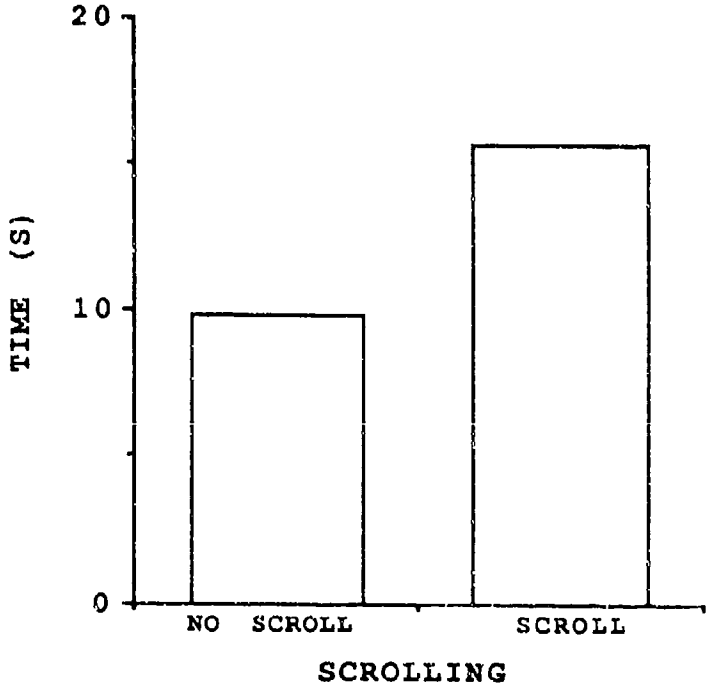

Figure 5. Main Effect of Scrolling.

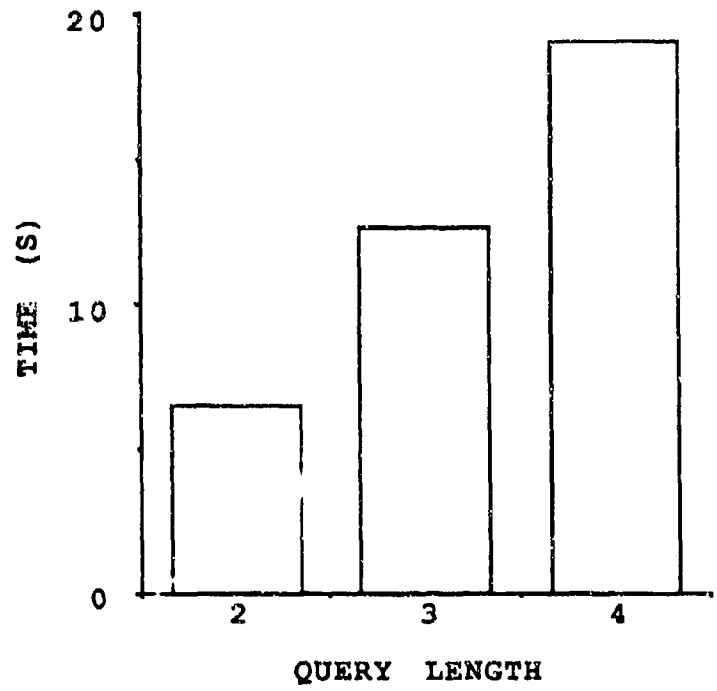

Figure 6. Main Effect of Query Length.

Performance time was further observed to differ across trial blocks ($p < 0.0001$) (Figure 7). A Newman-Keuls test showed that performance times on trial blocks three (12.13 s), four (12.28 s), five (11.77 s), and six (11.89 s) were significantly faster than performance times on trial blocks one (14.37 s, $p < 0.01$) and two (13.64 s, $p < 0.01$). Subjects had apparently reached asymptotic performance by the third trial block.

There was a significant interaction between trial block and query length ($p = 0.0019$) (Figure 8). For three- and four-item queries, performance times

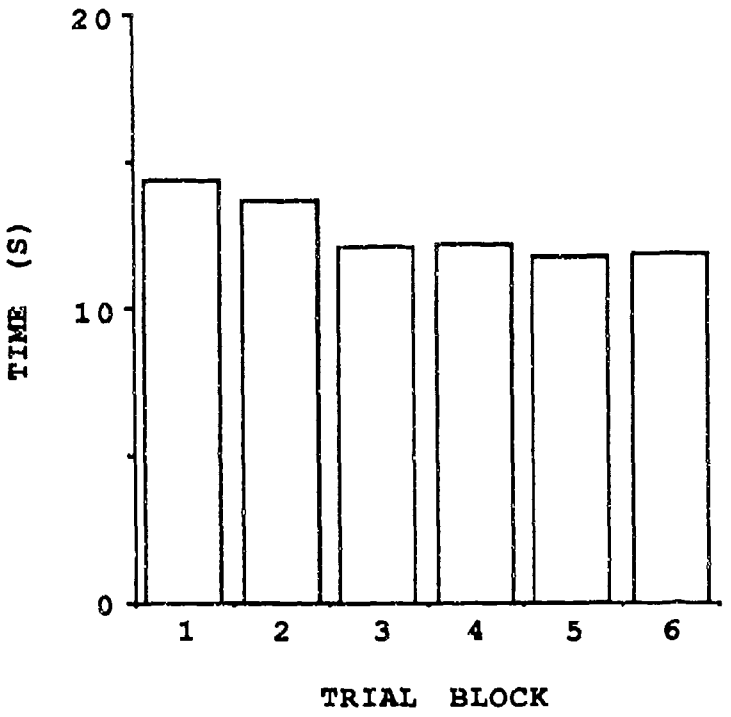

Figure 7. Main Effect of Trial Block.

differed across trial blocks (Table 3). A Newman-Keuls test showed that three-item queries were significantly faster on trial blocks five and six than they were on trial blocks one through four. Further, four-item queries were observed to be significantly faster on trial blocks three through six than they were on trial blocks one and two (Table 4). In general, then, for three- and four-item queries, there was a measurable decrease in task performance time with practice while no improvement was observed for queries requiring only two menu selections.

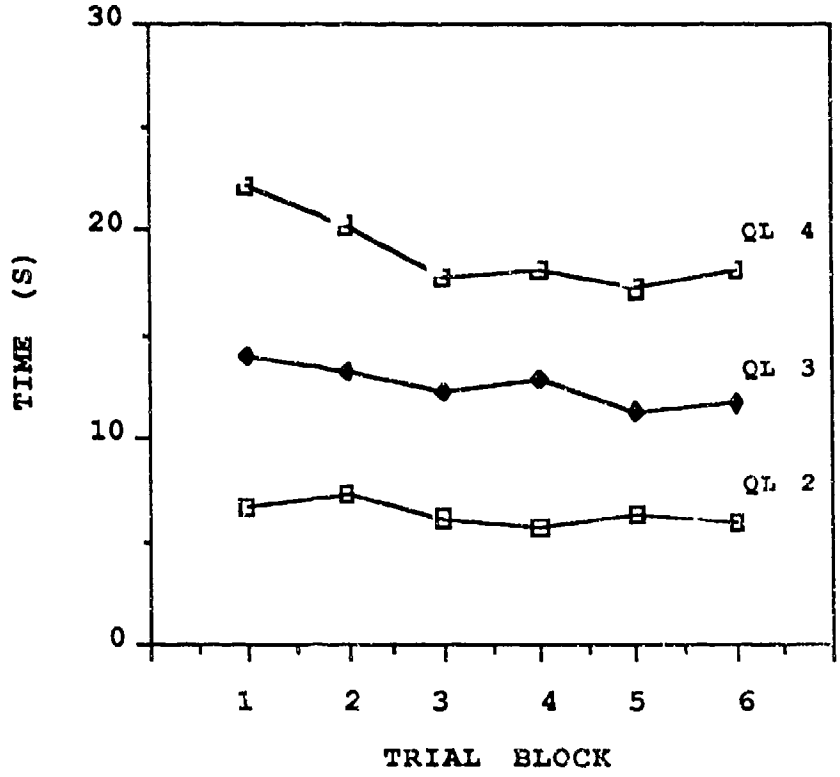

Figure 8. Trial Block by Query Length Interaction.

TABLE 3

Simple-Effect F-Tests on Trial Blocks for Each Query Length

Query Length	MSQL	F	p
Two	33.87	1.29	> 0.05
Three	114.90	4.38	< 0.01
Four	374.92	14.30	< 0.01

TABLE 4

Newman-Keuls Tests on Trial Blocks for Query Lengths Three and Four

Query Length 3		Query Length 4	
Trial Block	Mean	Trial Block	Mean
1	14.03 (A)	1	22.27 (A)
2	13.44 (AB)	2	20.18 (AB)
4	12.89 (AB)	4	18.16 (BC)
3	12.27 (AB)	6	18.14 (B)
6	11.58 (B)	5	17.41 (C)
5	11.44 (B)	3	17.85 (C)

NOTE: Means for the same query length sharing a common letter in parentheses are not significantly different ($p > 0.01$).

There was also a significant interaction between scrolling and query length ($p < 0.0001$). The fastest performance times were observed on two-item queries that did not require scrolling while the slowest performance times were observed on four-item queries requiring scrolling. As can be seen in Figure 9, queries without scrolling were consistently faster than queries with scrolling, and performance times increased with increasing query length. The effect of scrolling was significant for all query lengths (Table 5), while the effect of query length was significant for both

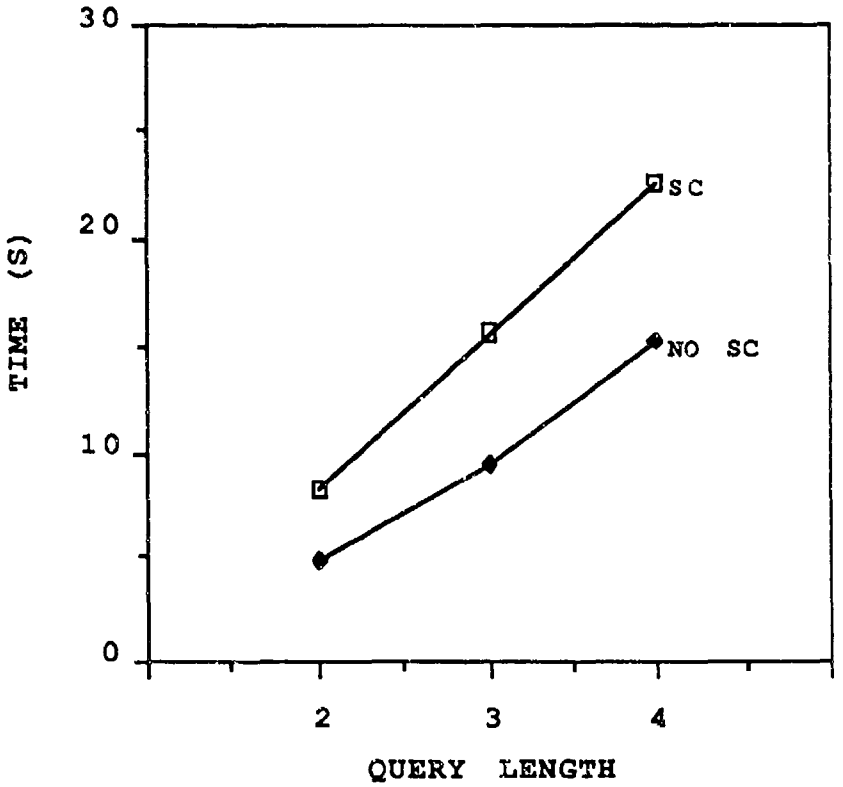

Figure 9. Scrolling by Query Length Interaction.

TABLE 5

Simple-Effect F-Tests on Scrolling for Each Query Length

Query Length	MSsc	F	p
Two	1749.36	32.33	< 0.01
Three	6348.14	117.33	< 0.01
Four	9590.36	177.26	< 0.01

TABLE 6

Simple-Effect F-Tests on Query Length for Each Scroll Level

Scroll	MSQL	F	p
Yes	17695.30	327.06	< 0.01
No	8734.35	161.44	< 0.01

TABLE 7

Newman-Keuls Tests on Query Length for Scroll Level

Scrolling		No-scrolling	
Query Length	Mean	Query Length	Mean
4	22.85 (A)	4	15.15 (A)
3	15.74 (B)	3	9.48 (B)
2	8.07 (C)	2	4.78 (C)

NOTE: Means for either scrolling level sharing a common letter in parentheses are not significantly different ($p > 0.01$).

scroll conditions (Table 6). A Newman-Keuls test showed that within each scrolling condition, performance times increased with increasing query length ($p < 0.01$) (Table 7).

Finally, there was a significant three-way interaction between input device, query length, and trial block ($p = 0.0355$). For each device, a two-

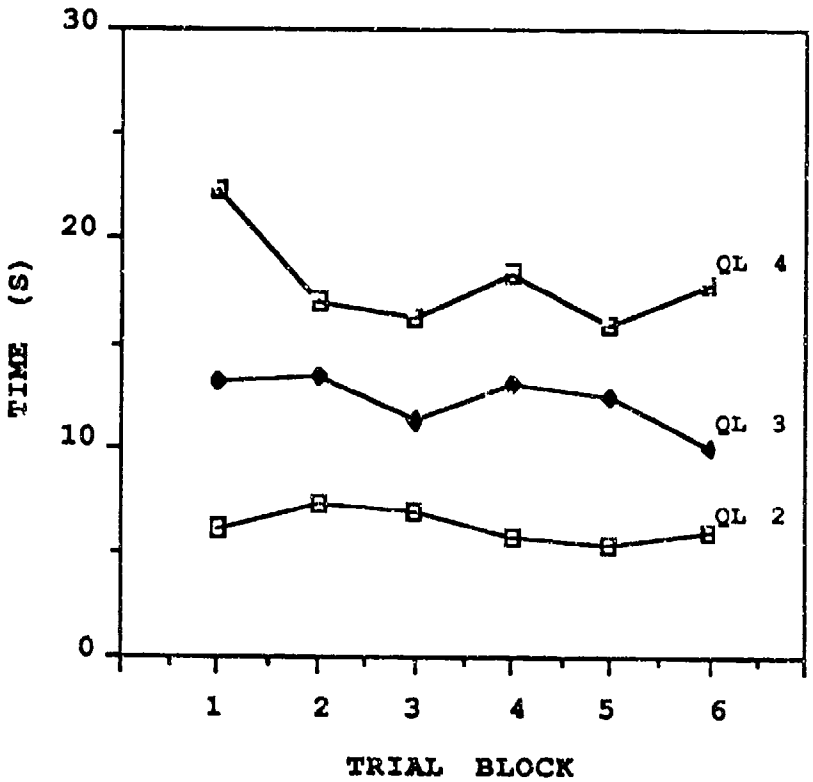

Figure 10. Trial Block by Query Length Interaction, Cursor Keys

item query was faster than a three-item query, which, in turn, was faster than a four-item query (Figures 10-12). There were significant differences in task performance times across trial blocks for three combinations of query length and input device (Table 8). For four-item queries with the cursor keys, there was a general decrease in task performance time over the trial blocks (Figure 10). There were no significant changes in performance time over the trial blocks for any

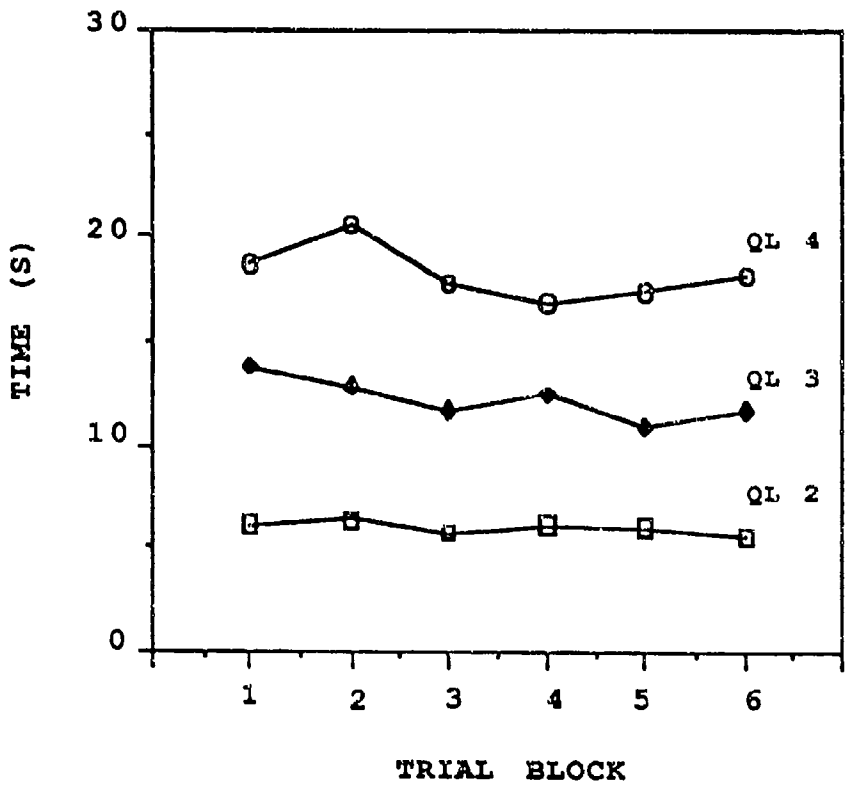

Figure 11. Trial Block by Query Length Interaction, Trackball.

query length with the trackball (Figure 11). For the search keys, there was an improvement in task performance time over trial blocks for four-item queries (Table 8, Figure 12). A Newman-Keuls test showed that for four-item queries with the search keys, performance time was significantly slower in the first trial block than in any other trial block (Table 9). There was no significant change in performance time across trial blocks for three-item queries with the search keys.

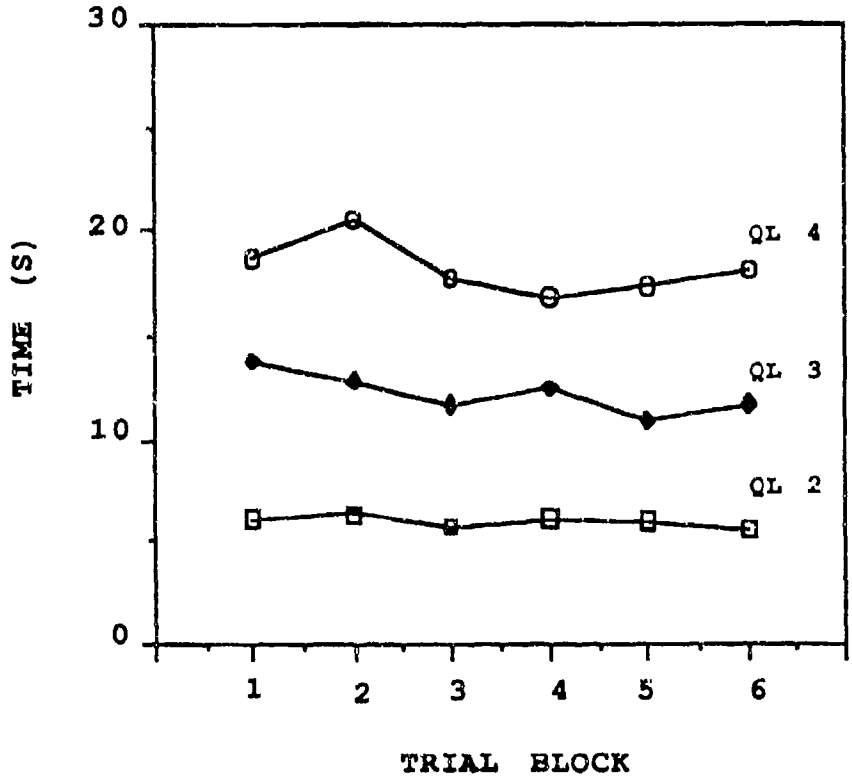

Figure 12. Trial Block by Query Length Interaction, Search Keys.

Error Frequencies

Errors were arranged by frequency of occurrence for each of the 18 cells. The data met the requirements for a Chi-Square test; however, the total Chi-Square was not significant (Chi-Square = 17.86, df = 17, $p > 0.05$). Thus, there were no differences in error frequency attributable to any of the experimental factors of interest.

Rating Scales

For the input device rating scales, a one-way ANOVA was performed on each of the scale dimensions. There were no reliable differences found.

A Friedman One-Way Analysis of Variance by Ranks was performed on each dimension of the device rank-order measure. There was a significant difference in device preference ($p < 0.02$). The trackball was the most preferred device, while the cursor keys were least preferred. Finally, a rank order difference was found for the speed dimension, with the trackball ranked as the fastest device and the cursor keys as the slowest ($p < 0.001$) (Table 10).

TABLE 8

Simple-Effect F-Tests on Trial Blocks for All Combinations of Device and Query Length

Device	Query Length	MS_{TB}	F	p
Cursor Keys	2	17.37	0.55	> 0.05
Cursor Keys	3	63.53	2.00	> 0.05
Cursor Keys	4	204.50	6.45	< 0.01
Trackball	2	3.80	0.12	> 0.05
Trackball	3	38.62	1.22	> 0.05
Trackball	4	65.70	2.07	> 0.05
Search Keys	2	57.18	1.80	> 0.05
Search Keys	3	78.12	2.46	< 0.05
Search Keys	4	280.31	8.84	< 0.01

TABLE 9

Newman-Keuls Tests on Trial Blocks for Query Lengths Three and Four, Search Keys

Query Length 3		Query Length 4	
Trial Block	Mean	Trial Block	Mean
1	14.97 (A)	1	25.49 (A)
2	14.41 (A)	2	22.81 (AB)
3	14.15 (A)	3	19.43 (BC)
4	13.12 (A)	4	19.40 (BC)
5	13.11 (A)	5	19.01 (BC)
6	10.82 (A)	6	18.38 (BC)

NOTE: Means for the same query length sharing a common letter in parentheses are not significantly different ($p > 0.01$).

TABLE 10

Friedman Analysis of Variance for Rank-Order Dimensions

	Rank Sums				
Dimension	Cursor	Trackball	Search	Chi-Square	p
Preference	45	27	36	9.00	< 0.020
Speed	49	28	31	14.30	< 0.001
Accuracy	35	38	35	0.33	> 0.800
Comfort	41	30	37	3.44	> 0.050

DISCUSSION

Overall, query construction times were faster with the cursor keys and the trackball than with the search keys. An initial improvement in the performance of longer queries with the search keys was observed (from trial block 1 to trial block 2), but query construction time showed no further improvement with practice and never reached the levels obtained with the other devices. Although errors did not occur any more frequently with the search keys than with the cursor keys or trackball, the reliably slower query construction time with the search keys would appear to rule them out as a primary means of cursor control. If search keys are permitted as an option, their use should perhaps be limited to circumstances where there are no time-dependent performance requirements. Under more time-critical conditions, the use of search keys are predicted to result in some performance decrement.

In terms of overall performance times and error frequencies, neither the cursor keys nor the trackball displayed any relative disadvantage. Initially, though, query construction was slower using the cursor keys to build longer queries. Performance with the cursor keys on the longer

queries did, however, quickly improve (from the first to the second trial block). Interestingly, there was no significant change in performance time across trial blocks for the trackball with any query length. It would thus appear that performance with the trackball was asymptotic by the first trial block, and, consequently, the trackball had an early advantage over the cursor keys. This might be relevant for any beginning, intermittent, or infrequent system user, insofar as he could more quickly "get up to speed" with the trackball than he could with the cursor keys. Significantly, even though the trackball was not objectively faster than the cursor keys overall, the subjects perceived the trackball to be a faster device. Also, since the subjects preferred the trackball over the cursor keys, use of the trackball may facilitate user acceptance of the system.

The finding that queries requiring scrolling took longer than queries without scrolling is consistent with findings from studies on menu breadth/depth tradeoffs. These studies have shown, in general, that menu selection time increases with greater search depth. In effect, scrolling for menu items is an instance of searching at a deeper level in a

menu than is the case when searching for a menu item that does not require scrolling. As query length increases and the search for menu items requires even more scrolling, the total search "depth" increases and, as a consequence, query construction time increases. Generally, then, the menus should be limited in length, to the extent possible given the size of the vocabulary required by the domain.

The finding that longer queries take longer to construct is, of course, predictable. However, as noted, this effect will be exaggerated as the task of locating the target items requires scrolling. Consequently, there is a tradeoff between query length and menu length.

To decrease query lengths, semantically related items from different menus might be merged together where possible, yielding fewer menu items required for building some queries. The drawback will be that the length of at least one menu must increase, and, consequently, more scrolling will be required to build queries with that menu. On the other hand, to decrease the length of a menu, those menu items that can be separated into different categories could be placed into separate menus. Alternatively, one might consider the frequency

with which menu items can be included as a part of longer queries. Menu items frequently included in longer queries might then be placed within separate shorter menus, and less scrolling would consequently be required for building longer queries. Thus, a tradeoff between query length and menu length would be achieved, with a reduction in the length of some queries, a reduction in the length of some menus, and an overall decrease in the amount of scrolling required to build longer queries.

SUMMARY AND CONCLUSIONS

The significance of this study is in the human factors recommendations for the design of workstations for Navy Operations Specialists who will use menu-based natural language interfaces. For these workstations, the input device tradeoffs should consider the relative performance of the cursor keys and the trackball to be the same. However, the users' preference for the trackball and the early performance benefits in learning the menu-based natural language task gives the trackball an advantage.

The screen design of the MBNL is a difficult task at best. While design issues of menu size and query length were not the prime focus of this research, their interaction with input device performance was evaluated. The trackball demonstrated an initial advantage on the longer queries. The search key performance improved over time reaching asymptote at the third session. Research to provide guidelines for quantitative tradeoffs between menu length and query length is recommended.

If a workstation design allows use on only one of these input device, the clear choice is the trackball. If the task requires keyboard entry,

the combined input options of trackball and cursor keys should be provided. Optionally, providing search keys may be useful to certain experienced individuals performing highly learned tasks.

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Appendix A: Menu Items

VERB Window
Count
Display
List

SETTING Window

blink
bright1
bright2
dot blinking
dot normal
inverse
size1
size2
symbol blinking
symbol bright1
symbol bright2
symbol normal

UNIT Window
air
  Soviet air
  UK air
  US air
    EA2B
    E2
    F-14
    S3A
platform
special point
  ASW search center
  downed aircraft
subsurface
surface
  UK surface
  neutral surface
  Soviet surface
  US surface
    CV-64
    Ticonderoga
track
  hooked track
  track 7526
  PU number 24
  unknown suspect

ATTRIBUTE Window
controlling friend air whose location is quadrant 4
controlling jammer mission whose location is hook
location
on barcap

received by link 11
reported by US Ticonderoga
reporting hostile air whose location is quadrant 3
whose designation is force FAAWC
whose designation is force ID
whose location is quadrant 1
whose location is quadrant 1 and controlled by CV-67
whose location is quadrant 1 and reported by FF-1023
whose mission is AEW
within 50 nautical miles
with remote data source
with Tomahawk missiles

Appendix B: Queries

QL=2 SC=NO

Count air
Count Soviet air
Count UK air
Count US air
Count E2
Count EA2B
Count F-14
Count S3A
Count platform
List air
List Soviet air
List UK air
List US Air
List E2
List EA2B
List F-14
List S3A
List platform

QL=2 SC=YES

Count ASW search center
Count downed aircraft
Count subsurface
Count surface
Count British surface
Count neutral surface
Count Soviet surface
Count US surface
Count track
List ASW search center
List downed aircraft
List subsurface
List surface
List British surface
List neutral surface
List Soviet surface
List US surface
List track

QL=3 SC=NO

List air controlling friend air whose location is quadrant 4
List air controlling jammer mission whose location is hook location
List US air reporting hostile air whose location is quadrant 3
List EA2B reported by US Ticonderoga
List platform controlling friend air whose location is quadrant 4

Appendix B continued

List platform on barcap
Count air on barcap
Count air reported by US Ticonderoga
Count US air controlling friend air whose location is quadrant 4
Count US air reported by US Ticonderoga
Count platform controlling jammer mission whose location is hook location
Count platform reporting hostile air whose location is quadrant 3
Display bright1 air
Display size2 UK air
Display dot blinking US air
Display inverse E2
Display dot normal F-14
Display blink platform

OL=3 SC=YES
Display symbol bright1 ASW search center
Display symbol bright2 subsurface
Display symbol normal neutral surface
Display bright1 US surface
Display symbol bright2 hooked track
Display symbol normal PU number 24
List special point whose location is quadrant 1 and reported by FF-1023
List ASW search center within 50 nautical miles
List subsurface with remote data source
List surface with Tomahawk Missiles
List US surface whose designation is force ID
List neutral surface whose location is quadrant 1
Count special point whose location is quadrant 1
Count downed aircraft within 50 nautical miles
Count UK surface whose designation is force ID
Count neutral surface whose designation is force FAAWC
Count Soviet surface whose location is quadrant 1 and reported by FF-1023
Count track whose mission is AEW

OL=4 SC=NO
Display bright1 air controlling friend air whose location is quadrant 4
Display size1 air on barcap
Display dot blinking air reported by US Ticonderoga
Display dot normal UK air controlling friend air whose location is quadrant 4
Display dot blinking air controlling jammer mission whose location is hook location

Display size2 US air controlling jammer mission whose location is hook location
Display blink US air on barcap
Display bright2 US air reporting hostile air whose location is quadrant 3
Display bright1 E2 reported by US Ticonderoga
Display symbol blinking EA2B reported by US Ticonderoga
Display inverse EA2B reporting hostile air whose location is quadrant 3
Display size1 F-14 on barcap
Display dot normal F-14 reporting hostile air whose location is quadrant 3
Display bright2 S3A reporting hostile air whose location is quadrant 3
Display size2 platform controlling friend air whose location is quadrant 4
Display inverse platform controlling jammer mission whose location is hook location
Display blink platform on barcap

CL=4 SC=YES
Display symbol bright2 special point whose location is quadrant 1 and controlled by CV-67
Display symbol normal special point with remote data source
Display symbol bright1 ASW search center within 50 nautical miles
Display symbol bright2 downed aircraft whose mission is AEW
Display symbol normal subsurface whose designation is force ID
Display bright1 subsurface with remote data source
Display symbol normal surface whose location is quadrant 1
Display symbol bright2 surface within 50 nautical miles
Display symbol bright1 UK surface whose designation is force ID
Display symbol normal UK surface whose designation is force FAAWC
Display symbol bright1 US surface whose location is quadrant 1
Display symbol bright2 US surface with Tomahawk missiles
Display bright2 neutral surface whose designation is force ID
Display symbol normal neutral surface with Tomahawk missiles

Display symbol bright2 Soviet surface whose location is quadrant 1 and reported by FF-1023
Display symbol bright1 track whose location is quadrant 1 and controlled by CV-67
Display symbol bright1 track whose mission is AEW
Display symbol normal track within 50 nautical miles

Appendix C: Rating Form for Devices

SCALES FOR DEVICE

Please rate the device you have just used on the following descriptive scales:

ACCURATE :___:___:___:___:___:___:___: INACCURATE

FAST :___:___:___:___:___:___:___: SLOW

INCONSISTENT :___:___:___:___:___:___:___: CONSISTENT

COMFORTABLE :___:___:___:___:___:___:___: UNCOMFORTABLE

UNACCEPTABLE :___:___:___:___:___:___:___: ACCEPTABLE

Appendix D: Ranking Form for Devices

RANKINGS OF INPUT DEVICES

Please rank the input devices you have used based on the following criteria. Simply place the appropriate letter in the desired space.

C = cursor keys

T = trackball

Z = zoom/cursor key combination

Most Preferred _____

Least Preferred _____

Fastest Selection Speed _____

Slowest Selection Speed _____

Highest Accuracy _____

Lowest Accuracy _____

Most Comfortable _____

Least Comfortable _____