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Performance Benefits of Simultaneous Over Sequential Menus as Task Complexity Increases

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To date, experimental comparisons of menu layouts have concentrated on variants of hierarchical structures of sequentially presented menus. Simultaneous menus—layouts that present multiple active menus on a screen at the same time—are an alternative arrangement that may be useful in many Web design situations. This article describes an experiment involving a between-subject comparison of simultaneous menus and their traditional sequential counterparts. A total of 20 experienced Web users used either simultaneous or sequential menus in a standard Web browser to answer questions based on U.S. Census data. Our results suggest that appropriate use of simultaneous menus can lead to improved task performance speeds without harming subjective satisfaction measures. For novice users performing simple tasks, the simplicity of sequential menus appears to be helpful, but experienced users performing complex tasks may benefit from simultaneous menus. Design improvements can amplify the benefits of simultaneous menu layouts.

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1. INTRODUCTION

Despite the proliferation of drop-down menus and other enhancements, most modern Web sites use one of two strategies to support navigation and location of desired information resources. *Hierarchical* or *sequential* menus present choices that must be made in some predetermined order, with the impact of a given choice constrained by the sum total of all previous choices. *Query-based,* form-fill-in interfaces use input widgets to support searches based on a specified set of attributes. This article discusses a third possibility—*simultaneous menus*—that may be appropriate for design situations that are not well suited for sequential or query-based menu systems.

Sequential menus (Figure 1) are most appropriate for situations requiring context-dependent menu choices, such as choosing a continent, then a country, then a city, to get a list of tourist attractions. However, the rigidity of hierarchical menus causes difficulties for some tasks, particularly when explorations and comparisons among the results of multiple selections are required. To complete such tasks with a hierarchical menu layout, users must make repeated choices involving repeated backtracking through the hierarchy. Sequential menus may also lead to disorientation: Without appropriate contextual information, users may find themselves lost in the menu structure.

Query-based, form-fill-in interfaces are frequently provided for searches of nonhierarchical, multiattribute data sets. Familiar examples include airline reservation sites, “power searches” on search engines, and online automobile sales.

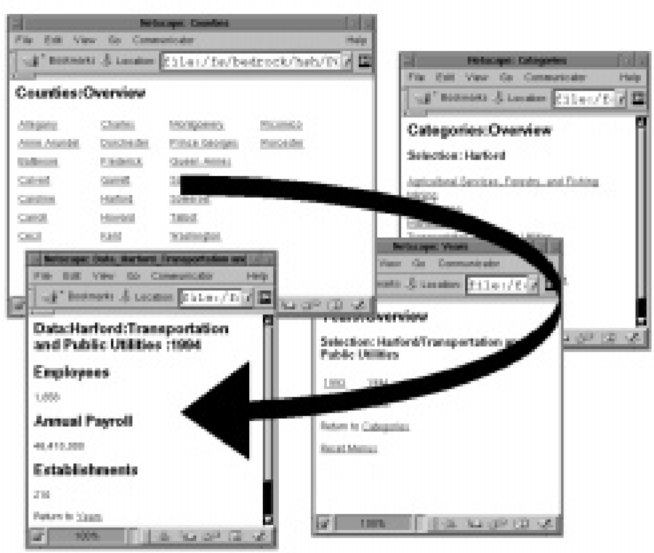

FIGURE 1 Sequential menus. Users must make one choice from each menu in succession. Users can select the “Return to …” links to revisit the previously displayed menu or the “Reset Menus” link to return to the first menu selection.

These forms are particularly useful when users must select options from a large range of alternatives presented as drop-down menus, and list boxes can be used to support query specification in a compact space. For searches based on user-provided text, form-based interfaces can use text input boxes for query terms, providing additional power with the risk of increased user errors.

Despite these advantages, query-based interfaces often suffer from some of the serialization problems associated with sequential menus. Searching is often provided in a "batch" mode—a search is submitted, results are displayed, and the user must return to the search screen to make another search. As a result, comparison between results of searches may be cumbersome. Forms must also provide appropriate contextual cues: Form output displays that fail to indicate the values of the search parameters may disorient users.

Simultaneous menu presentation (Figure 2) is an alternative design possibility appropriate for tasks that do not involve context-dependent modification of menu contents or unconstrained text input. These menus, which simultaneously display choices from multiple levels in the hierarchy, provide users with the ability to make choices from the menu in any order, for example, choosing continents, primary language, and types of tourist attractions to get a list of cities with their attractions.

Simultaneous menus are similar to query-based interfaces, in that both offer a variety of choices that can be made independently. However, simultaneous menus have the advantage of supporting simple and straightforward comparison between options, as a single selection in any of the menus is sufficient to move from one data point to the next. This flexibility may lead to improved performance or user satisfaction for some tasks.

Simultaneous menus have some drawbacks. Effective use of this strategy depends on the availability of screen real estate necessary for display of the appropriate menu choices, so simultaneous menus may not be appropriate for very broad (or very deep) menu structures. Furthermore, for simultaneous menu structures that display large amounts of information, the available screen space may require additional mouse movement or cognitive processing that could offset improvements in performance.

Although systems such as the National Digital Library collection browser (Plaisant, Marchionini, Bruns, Komlodi, & Campbell, 1997) and Spotfire (Spotfire, 1999) used simultaneous menus, evaluation has been limited. One study found that tasks involving simultaneous menus took less time and had fewer errors than tasks involving hierarchical menus (Seppälä & Salvendy, 1985). The authors of this study hypothesized that the use of a stable spatial presentation of the menus would eliminate the need for repeated visual scanning, thus reducing the cognitive load of a larger display.

This article presents an experiment that compares user task performance times for sequential versus simultaneous menus. Our hypotheses were that simultaneous menus would have faster performance times and greater user satisfaction than sequential menus would. Furthermore, the performance advantage of simultaneous menus should increase with the number of menu choices required to complete a task.

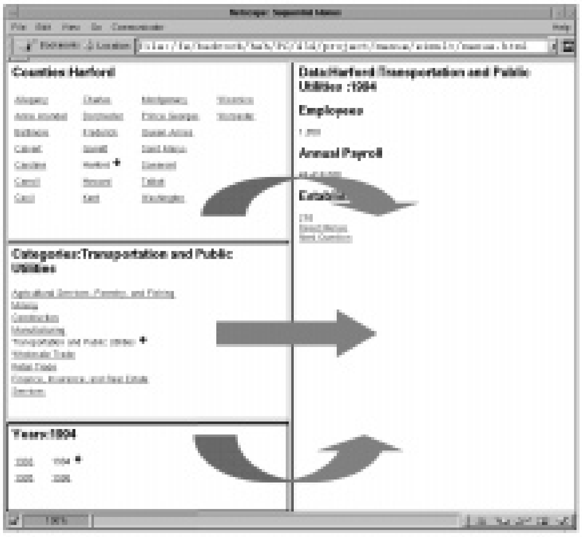

FIGURE 2 Simultaneous menus. Users can choose from any one of the three menus on the left at any point in time.

2. RELATED RESEARCH

Numerous experimental studies have been conducted to clarify trade-offs affecting performance in menu usage. Much of this work has focused on the breadth versus depth trade-off in design of sequential menus systems for navigating through hierarchies. Empirical studies conducted by Miller (1981); Snowberry, Parksinson, and Sisson (1983); Kiger (1984); and others (Jacko & Salvendy, 1996; Landauer & Nachbar, 1985; Wallace, Anderson, & Shneiderman, 1987) compared user performance with menu structures of various depths and breadths. These studies have consistently found that increases in menu depth lead to increased task completion times and error rates. Jacko and Salvendy (1996) examined the relation between task complexity and performance for menus of various breadths and depths. Building on Campbell's (1988) model of task complexity, they found that response time and number of errors increased as menu depth increased. Furthermore, users found deeper menus to be more complex.

The consistent performance advantages for broad, shallow menus indicate that designers should favor control structures with fewer steps. Deep, narrow menu structures distribute selections over a greater number of menus, resulting in increased task performance times, perceived complexity (Jacko & Salvendy, 1996), risk of disorientation, and cost of error recovery. Broad, shallow menus avoid these difficulties by reducing the number of steps necessary even though there are more choices at each step. One possible implication of the superior performance of broader menus is that additional performance gains may be realized by presenting all choices at once. This is the motivation behind simultaneous menus.

Recent studies focusing on Web-based systems have confirmed the benefits of broader, shallower menu structures. Zaphiris and Mtei (1997) examined user performance in a system based on World Wide Web (WWW) hyperlinks. Using hierarchies similar to those used by Kiger (1984), they found that two-level structures were faster than three- or four-level structures.

Larson and Czerwinski (1998) raised several concerns regarding earlier work and its applicability to Web-based systems. Specifically, many existing Web sites have link fan-out significantly greater than the ranges used in earlier breadth versus depth studies. Furthermore, earlier studies often used the same categories across all structures, leading to potentially unnatural menu categories. These concerns were addressed by a study using broader structures and menu contents that were designed to be natural. This study involved the comparison between layouts consisting of eight choices at each of three levels (8^3), with 16 choices followed by 32 (16×32) and 32 choices followed by 16 (32×16), and with menu structures based on an editor's design of category contents that both fit the desired structure and appeared natural. They found that the two-level hierarchies performed better than the three-level (8^3) version, with no significant differences in user preference between the three layouts.

Larson and Czerwinski (1998) also questioned the effect of training on menu performance and applicability to Web sites. After observing that earlier studies provided users with the ability to study hierarchies and learn from mistakes, Larson and Czerwinski noted that the continual evolution of Web sites may deny users the opportunity to realize performance gains that may be associated with training. Although their study does not address this issue directly, they raise an important issue: Transferability of earlier studies on menu designs to Web sites is likely to be dependent on a clear understanding of the similarities and differences between the environments involved.

Several investigators have moved beyond questions of breadth versus depth to investigate the impact of other features of menu structure design and layout. Parkinson, Sisson, and Snowberry (1985) examined the impact of layout decisions, such as spacing or no spacing between category groups, alphabetical versus categorical ordering of options within category groups, and arrangement by column or row. They found that spacing between categories and columnar organization independently and significantly improved performance. Alphabetical versus categorical ordering within categorized groups did not affect performance.

Norman and Chin (1988) examined the effect of menu structure shape. Using a 256-item menu structure and a constant depth of four, they compared structures with a range of items at each level, including constant ($4 \times 4 \times 4 \times 4$), decreasing ($8 \times 8 \times 2 \times 2$), increasing ($2 \times 2 \times 8 \times 8$), concave ($8 \times 2 \times 2 \times 8$), and convex ($2 \times 8 \times 8 \times 2$). For "scenario targets" involving a search for items that met a set of specified criteria, concave menus were shown to have the best performance.

Another perspective on the impact of menu structure and presentation can be found in Zaphiris, Shneiderman, and Norman's (1999) study of the use of expandable menus in Web environments. Expandable menus—layouts that use in-place expansion to present hierarchical choices in context—were expected to improve user performance and reduce backtracking. However, for hierarchies of depths of two, three, and four, sequential menus had faster response times. Expandable menus did not reduce backtracking. In fact, trials with expandable menus and hierarchy depth of four had more backtracking than sequential menus did, although this result was not significant.

Empirical research has provided evidence supporting the use of simultaneous menus. In a study involving monitoring of functional variables of simulated machines, Seppälä and Salvendy (1985) compared "parallel" presentation of menus to three different hierarchical presentations. Tasks were categorized in four distances, which varied the number of changes that users would need to make to move between targets. In all cases, the parallel menus had faster task performance and lower rates.

Simultaneous menus are closely related to query preview interfaces (Doan, Plaisant, Shneiderman, & Bruns, 1999). These environments combine widgets for specifying query constraints with feedback describing the size of the result set meeting those constraints. Simultaneous menus may be seen as a special case of query previews, in which all data are immediately available without execution of a database query.

Further insight into menu structure and design issues can be found in analytic models and simulations of performance with various layouts. Lee and MacGregor (1985) combined analytical models based on the number of alternatives per page, key press times, assumed reading rates, and computer response times with simulations. They concluded that the optimal number of alternatives per menu page is usually less than 10 and may be as low as 4 to 8. It is not clear how these models may be reconciled with the empirical results indicating improved performance with greater menu breadth.

In other work, Hornof and Kieras (1997) used simulation models to predict performance for both ordered and unordered pull-down menus. For unordered menus, they found that models involving parallel processing of multiple menu items using both random and systematic strategies provided the most accurate predictions. For ordered menus, models accounting for use of motor preparation based on approximate known location information best account for observed data (Hornof & Kieras, 1999). Although these studies are based on the use of pull-down menus and therefore may not be directly applicable to Web environments, they provide an illustration of the complex interaction of multiple cognitive and motor issues that may be involved in menu operation.

3. TASK-BASED PREDICTIVE MODEL

Intuitively, the simultaneous menu layout would appear to have the advantage of freeing users from making selections in a predetermined order. For simple tasks involving a single selection from each menu, this may lead to a performance improvement. However, the real benefits of simultaneous menus are likely to be seen in tasks that require revisitation of menus to compare results of different choices.

To see why this is so, we imagine a set of three menus and three types of questions, involving varying levels of difficulty. Type 1 tasks require one selection from each of the three menus. Type 2 tasks require comparison between two selections, which differ only in the choice made from the third menu. To complete this task, the user must traverse the menu tree once, note the appropriate result, and make a second selection from the last menu to select the appropriate comparison data. Finally, Type 3 tasks are similar to Type 2 tasks, but the selections differ only in the choice made from the second menu.

For simultaneous menus, these more complicated tasks involve minimal additional overhead: Because all menus are constantly available, the user can simply move to the appropriate menu and make the desired choice. However, these tasks place sequential menus at a significant disadvantage because users must explicitly "backtrack" to return to a previously displayed menu and make a new choice. Thus, our expectation was that simultaneous menus would lead to faster task performance than sequential menus and that performance advantages of simultaneous menus would be greater for tasks involving more backtracking through the menu structure.

A simple "clicks model" (Chimera & Shneiderman, 1994), based on the number of clicks required for the task types described earlier, will provide a more specific understanding of the predicted performance differences:

- Type 1: For both menu layouts, users must make one selection in each of the three menus, for a total of three clicks.
- Type 2: Users must make one selection at each of the three levels, plus appropriate clicks to get the second data point. For simultaneous menus, this involves one additional click on the third menu, for a total of four clicks. For sequential menus, one click of the "Back" button is required, along with one additional click on the third menu, for a total of five clicks.
- Type 3: For simultaneous menus, four selections are necessary, because these questions alter only one of the three menu choices. However, sequential menus require seven clicks: The five required for Type 2, plus one Back click and a new menu selection at the second level.

These results are summarized in Table 1. The items varied for any given task is the total number of menu choices that change. For Type 3, two backtracking steps

Table 1: Summary of the Three Task Types

Task	*No. Items Varied*	*No. Backtrack Steps*	*Simultaneous Clicks*	*Sequential Clicks*
Type 1	0	0	3	3
Type 2	1	1	4	5 (= 3 + 1 + 1)
Type 3	1	2	4	7 (= 3 + 2 + 2)

Note. Type 1 included no backtracking, so three clicks were needed for both sequential and simultaneous menus. Type 2 questions involved two choices from the third menu, thus requiring two additional clicks for sequential menu users (one to return to the previous menu and one to make a second choice) and one additional click for simultaneous menus. Finally, Type 3 questions varied the second category. For simultaneous menus, this added only the one click required to make the additional choice, so these questions were no harder than those in Type 2. However, sequential users had to make four additional clicks: two to return to the second menu, one to make a new choice from that menu, and one to repeat the selection made from the third menu.

are required in the sequential case even though only one item is varied: These questions require a different choice on the second menu while requiring the same choice for both visits to the third menu. Thus, these questions are somewhat easier for simultaneous menu users, who need make only one additional selection from the second menu to complete the task.

Further analysis can generalize the contents of Table 1 into a predictive model based on the number of clicks required to complete each task. For simultaneous menus, users must make one selection at each of the initial menus, followed by an additional click for each comparison that must be made. If we refer to the result of one complete traversal of the menu sequence as a single data point, the total number of comparisons that must be made is one less than the number of data points that must be accessed: To make one comparison, I must access two data points, and so on. Thus, tasks involving the use of d simultaneous menus to compare data from s data points will require a total of $d + s - 1$ clicks.

For sequential menus, the number of backtracking steps is the crucial factor in determining the number of clicks required to complete a task. To see why this is so, we first note that one choice from each menu will be necessary to view the first data screen. After those choices are made, each backtracking step involves two additional clicks: one to return to the previous menu and a second click to make a selection from the menu to which the user was backtracking. Thus, b backtracking steps require $2b$ additional clicks, for a total of $d + 2b$ clicks (d is the number of menus, as mentioned).

For both menu types, we assume that each menu selection action takes a given time, t_{sim} for simultaneous menus or t_{seq} for sequential menus. Each task involves a constant (possibly zero) initiation time, k_{sim} or k_{seq}. Combining these observations, we derive the following equations:

$$\text{Simultaneous: } T_{sim} = (d + s - 1)t_{sim}\, c_{sim} + k_{sim} \quad (1)$$

$$\text{Sequential: } T_{seq} = (d + 2b)t_{seq}\, c_{seq} + k_{seq} \quad (2)$$

As introduced, d is the number of menus (three in our examples), s is the number of screens that must be compared in the simultaneous case, b is the number of backtracking steps required in the sequential case, and c_{sim} and c_{seq} are constants determined by the type of menu layout being used (sequential or simultaneous). Expanding terms, these equations become:

$$\text{Simultaneous: } T_{sim} = st_{sim}\, c_{sim} + (d - 1)t_{sim}\, c_{sim} + k_{sim} \quad (3)$$

$$\text{Sequential: } T_{seq} = 2bt_{seq}\, c_{seq} + dt_{seq}\, c_{seq} + k_{seq} \quad (4)$$

For any given set of menus, the second and third terms of these equations will be constants.

This experiment uses the number of backtracking steps in the sequential case as a measure of complexity. This measure implies that Type 3 questions are more complex than Type 2 questions, even though they require the same number of clicks for users of simultaneous menus. This measure accounts for one of the primary advantages of simultaneous menus: Because all menus are displayed concurrently, a single change in any menu is not dependent on the ordering of the menus. This is in stark contrast with the different costs of changing menu selections in the sequential model, as we see in question Types 2 and 3. In those cases, a single change in the second menu (Type 3) is more expensive than a change in Type 2. However, in the simultaneous case, we do not expect Type 3 to be significantly more expensive than Type 2 questions.

These models assume that all clicks take approximately equal amounts of time. A more complete model would include predictors for times required to make choices from each of the *d* menus. Such a model would build on research showing that menu selection times can be roughly logarithmic or linear (Landauer & Nachbar, 1985; Norman, 1991; Sears & Shneiderman, 1994). Although we expect that selection times for individual menus used in this experiment will conform to these earlier findings, item selection times for individual menus may differ when used in different layouts. Specifically, the increased amount of information on the simultaneous menu screen may lead to greater cognitive load, causing item selection times to be greater than for sequential menus. However, the increased number of reorientations required may slow users of sequential menus.

4. EXPERIMENT

Informal investigation and the aforementioned predictive model led us to hypothesize that users of simultaneous menus would be able to complete tasks in less time than users of comparable sequential menu layouts. Furthermore, simultaneous menus should show increasing performance advantages as task complexity increases. Although other dependent factors—specifically learning time and accuracy—may be measured, they were not addressed in this experiment.

Our experiment used the three question types described earlier to provide three separate types of tasks. Each participant answered questions using one of the two menu layouts. The experimental task consisted of 15 questions, divided evenly among the three types described earlier. Task completion times were aggregated by menu type and task type, and mean times for the three types were compared by menu layout.

Experimental tasks were based on data taken from the U.S. Census Bureau's MapStats Web page (http://www.census.gov/datamap/www/index.html). County business patterns profile data for 1993 to 1996 provided a data set covering 23 counties, 9 industries, and 4 years. These attributes formed the basis for a three-menu layout, with the sequential menu layout displaying counties first, industries second, and years third.

Each combination of county, industry, and year had three corresponding facts: annual payroll, number of employees, and number of establishments. This formed the basis for the questions, which required retrieving individual facts (How many people were employed in Kent County in service businesses during

1993?) or comparing between two different data points (Which business category employed the larger number of people in Howard County in 1995: manufacturing or wholesale trade?).The experiment involved a total of 21 questions, split evenly among the three question types described in Section 3. Thus, one third of the questions required one selection from each of the three menus, one third required an additional selection from the third (year) menu, and the remainder required an additional selection from the second (industries) menu. The differences between these tasks are comparable to the four distances used previously in an evaluation of simultaneous menus by Seppälä and Salvendy (1985). Of the 21 questions, 6 were practice questions, and experimental data were taken from the 15 remaining questions. Practice and experimental questions were presented in a balanced order consisting of sets of three questions, with each set containing one question of each type.

The menus were presented to users as HTML hyperlinks displayed in a Netscape browser. In the simultaneous menu case (Figure 2), menus were displayed in three frames on the left-hand side of the browser window, and a frame on the right-hand side contained either the results or text asking the user to make a choice from any menus that had not yet been selected. After selections were made, the relevant menu windows would refresh to highlight the selected item. At any time, the user had the option of selecting the "Return to Start" link, which would reset the menus to their original configuration.

Sequential menus (Figure 1) were presented in a series of three screens, each containing one of the three menu items. Users moved forward in the menu sequence by simply selecting a single item from a menu. Two types of links supported returning to previously viewed menus in the sequence: a "Return to Start" link cleared the selection state of the system and returned to the initial menu screen, and a "Return to …" link on the second and third menu screens was available for moving back to the previously displayed menu. All menu screens (with the exception of the first menu) contained feedback mechanisms summarizing the choices that had been made on previous menus.

To eliminate variation due to network delays, files were served from a Web server running locally on the machines used for testing. Browser cache functionality was disabled to guarantee that each menu request generated a page request to the server. Because this configuration guarantees an entry in the server log file for each menu selection, request timestamps in the server logs were used to extract task performance times.

Twenty-two volunteers participated in the experiment. Data collected for 2 of the users of sequential menus were not used in the analysis, because task completion times for these users were several times greater than for other users. These participants were both older than the other participants and less experienced with Web browsers. These differences in background presented the possibility of other factors that may have influenced task performance. Furthermore, inclusion of these data may have artificially skewed the statistical analysis toward favoring simultaneous menus. To avoid these artifacts, we eliminated these data from the analysis.

Of the remaining 20 participants, 15 were men, 5 were women, and all were under 45 years of age. All participants were graduate students, undergraduate students, or technical staff, and all had previous Web-browsing experience. Participants were randomly assigned to use either sequential or simultaneous menus: Of the 20 data sets used in the analysis, 11 involved simultaneous menus, and the other 9 used sequential menus.

Participants began their experimental sessions by signing the consent form, completing the background questionnaire, and reading a one-page instruction document appropriate for the menu layout being used. After indicating their understanding of the instructions, users completed the practice tasks, took a short break if needed, and continued on to the experimental tasks. Finally, users completed a short postexperimental questionnaire aimed at understanding their subjective reactions. This questionnaire consisted of eight questions asking users to rate the screen layout, system navigation, information arrangement, amount of information displayed, and initial instructions on a scale of 1 to 9.

Task presentation and completion were handled identically for both menu layouts and phases of the experimental session (practice and experimental questions). All questions were presented to users on a sheet of paper, which was also used to record the answers. Each task began with the browser screen on a page containing a single link labeled "Next Question." Users were instructed to read the question first and to select the link only after they had completely read the question. Selection of this link led to display of the appropriate menu screen, allowing the users to navigate the menus to find the appropriate data. Users were instructed to continue until they found the information needed to answer the question, at which point they were to write the answer on the sheet. After writing the answer, users chose the link marked "Next Question," which returned the browser to the initial start page, ready for the next question. The elapsed time between the selections of the "Next Question" links was recorded as the time required to complete the task. The instructions, task presentation, and menu layout were all revised to account for feedback from a pilot test with 4 participants.

This experiment measures task performance times for users who are unfamiliar with simultaneous menus. To understand the potential performance as users become more comfortable with simultaneous menus, three individuals familiar with the study completed the experimental tasks three times for each menu layout. The best time for each question was extracted from the resulting data set, and the results were averaged across question type, creating an estimated performance profile for proficient users. Although less formal and thorough than an experimental evaluation of learning effects, this analysis provides some insights into the possible benefits of simultaneous menus for experienced users.

5. RESULTS

Table 2 and Figures 3 and 4 summarize the results.

Average task times for each task type and user combination were used for statistical analysis. As expected, task type had a significant impact on performance, $F(2, 36) = 67.17$, $p < .001$. The menu presentation style was not a significant factor,

Table 2: Summary of Task Completion Times

Task	*Menu Layout*	*Minimum*	*Maximum*	*Average*[a]	*SD*	*Proficient User Estimates*[b]
Type 1	Sequential	5	36	14.6	5.9	8.4
	Simultaneous	12	43	21.3	6.1	7.8
Type 2	Sequential	9	41	25.1	8.1	15.0
	Simultaneous	12	72	29.3	8.7	10.2
Type 3	Sequential	12	69	39.4	12.7	22.2
	Simultaneous	15	62	33.5	9.6	13.2

Note. Task completion times are expressed in seconds. For the experimental results, sequential menus were faster for Type 1 and Type 2, and simultaneous menus were faster for Type 3. In the estimated proficient user profile, simultaneous menus were always faster. In all cases, task completion times increased as complexity increased (*complexity* is defined as the number of backtracking steps for the simultaneous case).
[a]$n = 20$. [b]$n = 3$.

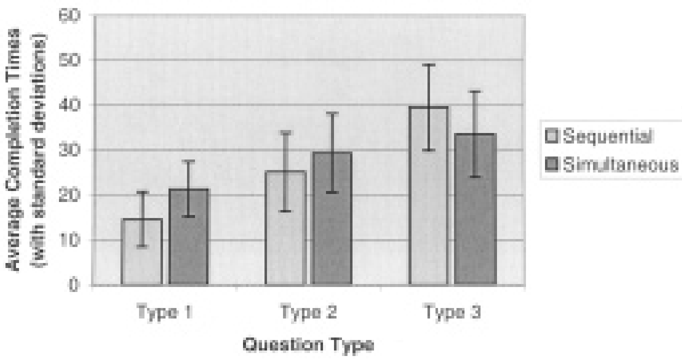

FIGURE 3 Experimental results: Sequential menus produced better performance for Types 1 and 2, but simultaneous menus were faster for Type 3 ($N = 20$). Error bars indicate a range of 1 *SD* from the mean.

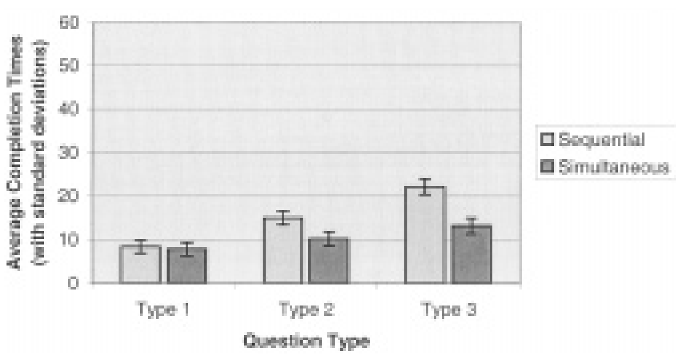

FIGURE 4 Estimated performance results for proficient users, based on composite results from three experienced users: Simultaneous menus were faster for all three types of questions, indicating a possible learning effect that may favor simultaneous menus.

$F(1, 18) = 0.68$, $p > .05$, but the interaction between menu style and task type was significant, $F(2, 36) = 8.65$, $p = .01$. Thus, although sequential menus appear to have benefits for simple tasks, simultaneous menus are preferable for complex tasks, and the advantages of simultaneous menus increase with task complexity. This result supports the use of simultaneous menus for tasks involving comparisons between the results of multiple menu selections.

These data include times for incorrect responses: We assume that the participants took their time and did the appropriate page navigation even if the final answer was incorrect.

Results from the estimated performance profile based on the experienced users are given in Figure 4. Simultaneous menus outperformed sequential menus for all three task types, and performance differences increased with task complexity. Although the informal nature of these data clearly limits the conclusions that can be drawn, these results provide preliminary evidence for increased advantages of simultaneous menus for more experienced users.

Subjective responses to the two menu types were similar (see Figure 5). Individual *t* tests for each of the eight questions showed no significant differences (at the .05 level) between the responses for the two different menu types. Users found both simultaneous and sequential menu layouts to be somewhat satisfying, easy to use, and easy to navigate. Additional evaluation—particularly involving individuals with less computer experience—may clarify user preferences, but the lack of a clear trend of confusion or disorientation among users of the simultaneous menu layout is encouraging. A within-subjects design might be more likely to show preference differences.

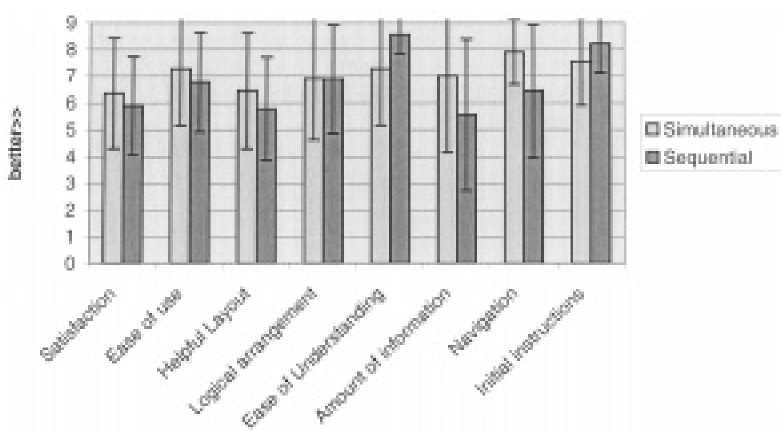

FIGURE 5 Subjective questionnaire results: Average values are shown for 20 participants, with error bars indicating differences of 1 *SD*. Higher numbers are better results. Roughly comparable subjective responses to the two menu types provide some indication that users are not necessarily confused or disoriented by simultaneous menus.

6. PREDICTIVE MODEL REVISITED

Our models assume a single item selection time for all menus used in a given layout: For any single layout (simultaneous or sequential), selection times for the three menus (counties, industries, and years) should be comparable. For both sequential and simultaneous windows, analysis of data for the individual menus showed similar item selection times. In both cases, selection times for the county and year menus were significantly shorter than times for the industry menus, and no significant differences between the county and year menus were observed. This result is somewhat surprising, because the industry menu had fewer items (9) than the county menu did (23).

Two possible factors may explain this performance difference. The ordering of the choices within each menu may have been a factor. Whereas county names were presented in alphabetical order, industry names were presented in the essentially random order used on the census Web site. A more likely explanation may be that the cognitive load involved in processing the menu choices may have been a factor: Whereas county names are short (one or two words) and possibly familiar, industry names involve greater amounts of text, with which participants were less likely to be familiar, such as "Agricultural Services, Forestry, and Fishing" or "Transportation and Public Utilities."

The performance selection times for the second and third menus may explain the surprising differences between performance times for Type 2 and Type 3 for simultaneous menus. Because tasks of both of these types involved only one additional selection in either the second (Type 3) or third (Type 2) menu, we expected the task performance times to be comparable. The observed slower performance on Type 3 tasks is consistent with the observation that menu choices from the second menu took significantly longer than choices from the third menu.

In any case, the absence of any evidence of a relation between menu lengths and item selection times provides initial justification for the assumption of a single item selection time for each layout.

To examine the fit between our data and the predictive models given earlier, we conducted a regression of the task completion times against the number of data points compared (for simultaneous menus) or against the number of backtracking steps required (for sequential menus).

For the simultaneous menus, the linear regression equation was

$$T_{sim} = 11.4 + 10.0s,\ r^2 = .24 \tag{5}$$

For sequential menus, the linear equation was

$$T_{seq} = 14.0 + 12.4b,\ r^2 = .54 \tag{6}$$

A quadratic regression fits the data equally well:

$$T_{seq} = 14.6 + 8.6b + 1.9b^2,\ r^2 = .54 \tag{7}$$

This suggests the possibility of a nonlinear effect for sequential menus. A more thorough characterization of this effect would require more data, but it seems possible that the time required for a given backtracking step may be influenced by the number of preceding backtracking steps, thus leading to a nonlinear effect.

On average, the choice time required for a menu in a simultaneous layout is greater than the time required for the same menu in a sequential layout. We can use the average menu selection times for each of the menu layouts to relate the linear equations back to the predictive models presented earlier. For simultaneous menus, the average selection time was 4.9 sec (t_{sim} = 4.9), and the average for sequential menus was 3.0 sec (t_{seq} = 3.0).

Using these values and the depth of the menu structure used (d = 3), we can identify the constants that match the calculated regressions. Specifically, for the simultaneous menus, we find $c_{sim} = 2.0$ and $k_{sim} = -8.2$, so $T_{sim} = 2.0t_{sim}s + (2 \times 2.0)t_{sim} - 8.2$. Using the average value $t_{sim} = 4.9$, this becomes $T_{sim} = 2.0t_{sim}s + 11.4$, where s is the number of data points visited. Similarly, for sequential menus, we find that $c_{seq} = 2.1$ and $k_{seq} = -4.6$, so $T_{seq} = (2 \times 2.1)bt_{seq} + (3 \times 2.1)t_{seq} - 4.6$, or $T_{seq} = 4.1t_{seq}b + 14.0$, where b is the number of backtracking steps required to complete a task.

Although these results support the use of a clicks-only predictive model, further work will be needed to validate these models. Specifically, the interaction between menu type and task type observed in the statistical analysis suggests that the advantage for simultaneous menus may grow as tasks become more difficult. We believe that this is the result of the increased cognitive load of repeated backtracking while comparing multiple data points, which is likely to be difficult for sequential menu users.

Additional experiments involving a wider range of backtracking steps and required mouse clicks may clarify the time functions for both menu types. More accurate accounting for the time to read menus and make choices could lead to a deeper understanding of the components of task completion times. Inclusion of appropriate models of mouse motion and distance (perhaps based on Fitts's Law) could account for the effects of screen layout. Finally, investigations of learning rates could lead to models that predict improvements in task performance.

7. DISCUSSION

These results suggest that task complexity—as measured by the amount of backtracking required for sequential menus—is likely to be the largest factor in performance differences between simultaneous menus and sequential menus. For simple tasks that do not require comparisons between multiple result sets, sequential menus are faster. However, the advantage shifts for tasks requiring more than one backtracking step (for the sequential menus), and the observed interaction between task type and menu type suggests that the advantages of simultaneous menus may become even greater for tasks involving more comparisons.

The change in the relative advantages of these menu types may be explained by the relation between cognitive load and task type. For simple tasks, sequential menus provide simpler screen layouts that avoid the clutter and possible confusion of simultaneous menus. However, simultaneous layouts may reduce time and effort spent reading menus. Because the simultaneous menus are constantly displayed on the screen, users may learn the menu contents faster and thus reduce the cost of rescanning menus to make additional selections. For sequential menu layouts, a menu is removed from the screen after a choice is made and remains inaccessible until the user returns from that menu. Users may need to reread menu contents with each visitation, thus slowing learning and decreasing performance.

In terms of Campbell's (1988) task complexity framework, the multiple paths that may be used to reach the goal may cause the simultaneous menus to be more complex, and therefore slower, for simpler (Type 1) tasks. For Types 2 and 3, the increased complexity associated with multiple outcomes is greater and may overshadow the complexity due to multiple paths. Furthermore, Jacko and Salvendy's (1996) results linking greater depth with increased complexity provide reason to believe that the complexity cost of additional outcomes is likely to be greater for sequential menus, thus leading to the performance advantage for simultaneous menus seen for Type 3 tasks. Of course, additional investigation and analysis would be needed to validate these models.

Simultaneous menus are generally unfamiliar, even to experienced users. Our experienced user performance profile suggests the possibility of an advantage for simultaneous menus across all task types. Although further experimentation will be needed to understand learning effects, training and practice may help users take advantage of simultaneous menus for both simple and complex tasks.

Minor design decisions can have significant impacts on performance with menu layouts (Jacko & Salvendy, 1996; Parkinson, Sisson, & Snowberry, 1985). Artifacts of our experimental design may have influenced our results, and these suggest interesting modifications for further study.

7.1. Screen Layout

For the sequential menus, each menu appeared in the screen in the space occupied by the previous menu. This layout minimized the mouse movement required: All tasks could be completed in the upper-left quadrant of the screen. On the other hand, the simultaneous menus were displayed in a vertical column of three frames, occupying the entire left half of the screen. The extra movement required may have degraded performance. Compact menu arrangements could reduce the extra mouse movement required for navigation of simultaneous menus.

7.2. Familiarity of Menu Presentation Style

Because most of the participants were undergraduate and graduate students with substantial experience using Web browsers, it seems reasonable to conclude that the sequential menu format was well understood. Because simultaneous menus are unfamiliar, there may be a learning effect involved in the results.

7.3. Task Choice

All three task types in this experiment involved closed-end questions with known answers. However, the performance advantage of simultaneous menus relative to sequential menus increased with the amount of backtracking required. Repetition of this experiment with tasks that involve more backtracking may lead to results that are still more favorable for simultaneous menus.

7.4. Menu Item Ordering

The second menu (containing industry names) contained items that were significantly longer than the items in the other two menus. Furthermore, the items in this menu were presented in an arbitrary (nonalphabetized) order. These disparities may have contributed to the performance differences between task Types 2 and 3. In particular, these artifacts may be responsible for the unexpected differences between Types 2 and 3 for users of simultaneous menus.

Simultaneous menus fared well on the subjective questionnaire. Ratings for the two menu arrangements were roughly comparable on all of the subjective questions. This provides preliminary support for the conclusion that simultaneous menus do not appear to confuse or disorient users. Because each participant used only one of the two menu presentation styles, a true preference comparison between the two styles is not possible. Further study involving within-subjects comparison of the two menu styles may clarify issues related to user preference while providing additional data for performance comparisons. Ideally, any further work along these lines would involve tasks that are well motivated and more realistic than the tasks used for this study. The resulting data would provide a more robust picture of the impact of simultaneous menus on task performance time and user satisfaction.

This comparison between simultaneous and sequential menus is necessarily limited: As the most familiar, “traditional” style of menu item presentation, sequential menus provided a baseline for evaluation of simultaneous menus. Additional experimentation aimed at comparing simultaneous menus with query-based forms and other menu presentation styles may provide a clearer model of the tasks that may benefit from the use of simultaneous menus.

8. DESIGN IMPLICATIONS

When sequential menu hierarchies can be converted to simultaneous menu presentation, this strategy should be considered if complex or exploratory tasks are anticipated. Simultaneous menus show users all alternatives at all levels at once, thereby aiding comprehension of all possibilities, although the increased perceptual and cognitive load may slow novice users in simple tasks.

Simultaneous menus usually require more display space, which may render them inappropriate for certain display environments and menu structures. This increased screen content may lead to further increases in perceptual load, which could have additional negative effects. Furthermore, simultaneous menus present a trade-off between menu space and data space. Menu configurations that cannot be displayed simultaneously in a manner that leaves sufficient screen space for results may be more appropriate for sequential presentation. Compact presentation formats may be used to present simultaneous menus in a manner that minimizes these detrimental effects. Interface widgets such as sliders or checkboxes may provide more effective and compact representations of menu choices.

For tasks requiring comparisons among multiple data points, simultaneous menus may be most helpful when used in conjunction with other techniques for supporting navigation. For example, dynamic content generation may be used to display multiple results in an appropriate display. The combination of simultaneous display of multiple results sets with simultaneous menus may be used to provide easy access to multiple data points with mechanisms that support comparisons between these results.

The user population may influence the choice between simultaneous and sequential menus. Our experimental data, which were collected from participants unfamiliar with simultaneous menus, showed an advantage for sequential menus on simpler tasks. However, this advantage disappeared in our estimated profile based on more experienced users, suggesting that the benefits of simultaneous menus are likely to increase with user experience.

9. CONCLUSION

We have shown that simultaneous menus can lead to improvements in user performance over comparable sequential layouts. The choice between simultaneous and sequential menu layouts should be made on the basis of the expected task: If users are expected to make multiple selections from two or more menus, simultaneous menus provide better performance. Simultaneous menus appear to be well suited for exploratory tasks, because they also provide a continuous overview of menus at all levels.

Much of the menu design literature has focused on analysis of the breadth versus depth question in hierarchical menu structures. Although clearly important, these investigations present an overly simplistic view of the problem of menu structure design. Our study presents one alternative to strictly hierarchical menus, along with evidence that simultaneous menus can lead to improved performance. Comparisons that limit the parameters of menu designs to depth and breadth may not account for some factors that affect performance. Studies of menu structures with different shapes (Norman & Chin, 1988) and with differing amounts of contextual information (Chimera & Shneiderman, 1994; Zaphiris, Shneiderman, & Norman, 1999) have shown that performance can be influenced by the type of task, the amount of context given, and the shape of the menu. Examination of these issues as they apply to simultaneous menus is a promising direction for future work.

This article does not address the relative performance of form-fill-in menus. Additional experimentation comparing simultaneous menus to form-fill-in menus may clarify the utility of the various approaches. Hybrid layouts—perhaps combining simultaneous menus with form-fill-in or query preview (Doan et al., 1999) functionality—present intriguing possibilities and additional areas for future exploration.

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