Spatial Ability Subfactors and Their Influences on a Computer-Based Information Search Task

Richard Pak, Wendy A. Rogers, and **Arthur D. Fisk,** Georgia Institute of Technology, Atlanta, Georgia

Objective: The present study examined the relationship between two distinct subfactors of spatial ability and performance in an information search task modeled on browsing the Web. **Background:** Previous studies have found relationships between various measures of spatial ability and performance in a wide variety of computer-based tasks. **Method:** In the search task 101 participants (18–29 years of age) searched for the answer to a question by navigating the system. They completed the experimental task as well as a battery of cognitive ability measures that included two different measures of spatial ability. **Results:** The results indicate that spatial orientation ability was related to performance with tasks that were high in their navigational requirement (engendered by the use of a novel aid), whereas spatial visualization was unrelated to performance in any task condition. **Conclusion:** A closer inspection of the cognitive requirements of a task may reveal what interventions could be most useful when designing computer systems or developing training programs. **Application:** Given the unique differences between the different spatial abilities, the current results suggest the design of navigational aids that place less demand on spatial orientation ability.

INTRODUCTION

Are there basic cognitive abilities that can predict a person's ability to perform computer tasks in general? It should not be surprising that numerous abilities predict such a broadly defined task as "using a computer." However, there is a consistent finding that spatial abilities in particular are related to various measures of performance on computer-based tasks. A substantial amount of research has demonstrated that measures of spatial ability and performance in computer-based tasks often correlate with one another (see Table 1). However, to create usable systems for everyone, or to develop training programs for existing systems, it is necessary to understand how spatial ability contributes to computer-based task performance and whether different types of spatial abilities are predictive of computer-based tasks.

The studies listed in Table 1 show the variety of spatial ability measures that have been examined in the context of computer interaction. Research has shown that general spatial ability can be thought of as being composed of two primary subfactors: *spatial visualization* and *spatial orientation.* Spatial visualization can be defined as the "ability to manipulate or transform the image of spatial patterns into other arrangements" (Ekstrom, French, Harman, & Dermen, 1976, p. 173), whereas spatial orientation (also called *spatial relations*) is the "ability to perceive spatial patterns or to maintain orientation with respect to objects in space" (Ekstrom et al., 1976, p. 149). These two subfactors have been shown to be psychometrically distinct, yet most studies of ability-computer performance relationships have examined only one or the other.

Table 1 also illustrates the variety of tasks in which spatial abilities relate to performance. A characteristic of the tasks is that they varied on many dimensions, making it difficult to be precise about the aspect of the task that was influenced by spatial abilities.

Why is spatial ability related to performance on such a variety of computer-based tasks? Many computer-based tasks require the user to "navigate"

Address correspondence to Richard Pak, Department of Psychology, Clemson University, Clemson, SC 29634; richpak@clemson.edu. ***HUMAN FACTORS,*** Vol. 48, No. 1, Spring 2006, pp. 154–165.

TABLE 1: Published Studies Examining Spatial Ability and Computer-Based Task Performance

Study	*N*	Age Range	Computer Task	Performance Measure	Spatial Ability Measure	Correlation With Performance/Relationship
Campagnoni & Ehrlich (1989)	12	18–26	Information search	Solution time[1]	Spatial visualization[a]	–.75
Dyck & Smither (1994)	28	58–83	Word processing	Number of commands found[2]	Spatial scanning[b]	.53
Garfein, Schaie, & Willis (1988)	56	55–65	Spreadsheet usage	General ledger proficiency[3]	Spatial orientation[c]	.40
				Check register proficiency[4]	Spatial orientation[c]	.39
Gomez, Egan, & Bowers (1986)	33	28–62	Word processing	Execution time[5]	Spatial memory[d]	–.58
				First try errors[6]	Spatial memory[d]	–.49
Gomez, Egan, Wheeler, Sharma, & Gruchacz (1983)	40	28–62	Word processing	Execution time[5]	Spatial visualization[e]	–.57
				Execution time[5]	Spatial memory[d]	–.43
				First try errors[6]	Spatial visualization[e]	–.32
				First try errors[6]	Spatial memory[d]	–.34
				Number of cursor moves[7]	Spatial visualization[e]	–.43
				Number of cursor moves[7]	Spatial memory[d]	–.31
Jennings, Benyon, & Murray (1991)	24	25–40	Information search	Button interface RT[1]	Spatial visualization[a]	–.37
				Command line interface RT[1]	Spatial visualization[a]	–.58
				Question interface RT[1]	Spatial visualization[a]	–.48
Seagull & Walker (1992)	44	Under-graduate	Information search	Task completion time (flat hierarchy)[1]	Spatial visualization[a]	–.26
				Task completion time (2-level hierarchy)[1]	Spatial visualization[a]	–.37
				Task completion time (mixed-level hierarchy)[1]	Spatial visualization[a]	–.33
Sebrechts, Deck, Wagner, & Black (1984)	24	n.a.	Word processing	Word processing performance	Spatial memory[d]	.40
Vicente, Hayes, & Williges (1987)	30	18–31	Information search	Time to complete menu task[1]	Spatial scanning[f]	–.38
				Time to complete menu task[1]	Spatial visualization[g]	–.47
				Time to complete menu task[1]	Spatial visualization[a]	–.57
Vicente & Williges (1988)	40	18–31	Information search/ verbal	Time to complete menu task[1]	Spatial visualization[a]	hi spatial > low spatial
			Information search/ graphical visualization	Time to complete menu task[1]	Spatial visualization[a]	hi spatial > low spatial
Westerman (1997)	64	18–30	Command line generation	Command generation speed[8]	Spatial memory[d]	hi spatial > low spatial
				Command generation speed[8]	Spatial visualization[a]	hi spatial > low spatial

Note. Only significant correlations ($p > .05$) are presented. When available, performance measures presented are task completion time measures, a composite performance measure, or an error measure.

[1]Total time required to complete a task; lower is better. [2]Number of commands found in a command look-up task; higher is better. [3]Task was to replicate a general ledger; a composite score of five subtasks; higher is better. [4]Task was to replicate a check register; a composite score of five subtasks; higher is better. [5]Total time required to execute changes divided by number of steps required; lower score is better. [6]Number of times participant made error in first attempt to start task; lower is better. [7]Total number of cursor moves made divided by the number of corrections; lower is better.

[a]ETS Paper Folding Test. [b]ETS Maze Tracing Speed. [c]SRA Primary Mental Abilities Space Test. [d]ETS Building Memory Test. [e]Two-Dimensional Space Test. [f]ETS Card Rotations Test. [g]ETS Form Board Test.

the system. For example, to change the page orientation in a word processor, one would have to navigate through different screens of information, successively drilling deeper into a hierarchically organized system. Similar to navigating in natural space (e.g., a new city), successful navigation in computer space requires keeping track of where one has been and one's current position in relation to the start and the goal. The success of such navigation may be reliant on spatial abilities.

Overview of the Experiment

To investigate the specific influence of spatial abilities on computer tasks, we manipulated the extent to which the task required spatial abilities. Assuming that the spatial demands are imposed by the requirement to navigate through different layers of the system, we manipulated the navigational demand of the task by varying the navigational aid (a map or step-by-step directions). The map navigational aid was designed to be relatively high in navigational demand, similar to using a traditional paper map to navigate an unfamiliar city. Users were required to examine the graphically presented map to determine where they were and where the target was located. Using the map, they located the path between the starting location and the destination. Participants needed to be aware of their current position and its relationship to both the goal and to the origin. Use of this aid was expected to be more successful and efficient for people with higher spatial abilities (Wochinger & Boehm-Davis, 1995).

The alternative to the graphical map was the step-by-step navigational aid. This aid was designed to be lower in its navigational demand because the user only had to follow written directions indicating which label to click on the screen. The step-by-step aid was similar to written driving directions. The user was simply required to examine the text label indicating the starting point and to follow the directions indicating the next step toward the goal. Use of this aid was expected to be less related to level of spatial ability. The two conditions were selected to be relatively high (the map condition) and relatively low (the step-by-step condition) in their demands for spatial ability.

In the current study, task difficulty was manipulated by increasing the number of steps. Previous studies had not manipulated this important task characteristic. It may be that spatial abilities are more predictive when task difficulty is high but less so when task difficulty is low.

This study examined the extent to which individual differences in the two subfactors of spatial abilities (i.e., spatial visualization and spatial orientation) contributed to individual differences in performance on a computerized information search task. Previous psychometric research has indicated that the two subfactors of general spatial ability are distinct on multiple dimensions (Kozhevnikov & Hegarty, 2001; Pellegrino, Alderton, & Shute, 1984). However, their differential predictions of computer-based task performance have not been directly examined. In addition, we included other measures of cognitive abilities and speed to separate their effects from the effects of spatial visualization and spatial orientation on task performance.

METHOD

Participants

One hundred one undergraduate students, 48 women and 53 men ranging in age from 18 to 29 years, completed the study; mean age was 19.9 years (SD = 1.58). All participants were intermediate computer users, defined as having used computers for more than 3 years and more frequently than "every month" but less frequently than "several days per week." To ensure that participants of various levels of spatial visualization ability were equally distributed, participants were assigned to the map or the step-by-step navigational aid conditions based on their scores on the spatial visualization test. This resulted in 48 participants assigned to the map condition (24 men, 24 women) and 53 participants assigned to the step-by-step condition (29 men, 24 women).

All participants were screened for both near and far visual acuity of at least 20/40 vision (corrected or uncorrected). The participants chose to receive either course credit or $10/hr.

Apparatus

Ability measures. The following abilities were assessed: psychomotor speed, perceptual speed, attention, memory, verbal ability, spatial abilities, and reasoning. (Participants completed the CREATE battery of tests; Czaja et al., in press; Czaja, Charness, Fisk, Rogers, & Sharit, 2001).

Spatial visualization ability was measured using the Educational Testing Service (ETS) Paper Folding test, whereas spatial orientation was measured using the ETS Cube Comparison test (Ekstrom et al., 1976).

Equipment. Pentium II computers running at 333 MHz with 128 MB of RAM were used with a 19-inch (48.3-cm) monitor. Participants were seated approximately 18 inches (45.7 cm) from the monitor. The mouse was placed on the left or right side according to the participant's self-reported dominant hand.

Information search task. The task used a specially modified Web browser (Figure 1), which displayed task instructions and the primary task and collected user responses. In the left pane, instructions for the task were provided along with the navigational aid. In the right pane, a standard Web browser allowed navigation through the hypertext system. Participants could click on active links within the hypertext system, and there were two navigation tools displayed in the upper left corner (Figures 1 and 2). Clicking the back button moved the right pane back one page, consistent with common Web browsers (e.g., Internet Explorer, Netscape). The "start over" button moved the right pane back to the start page for that task. After the participant completed one task, the right and left pane changed to reflect the new task.

Navigation aids. The two navigational aids were designed to contain approximately the same information, but each was arranged differently to convey less or more spatial information. Both aids were static images and did not change to indicate the current step or position within the task. In the step-by-step condition, navigational information was arranged in an outline format in which each major heading of the outline indicated a "step." Subheadings represented a subset of potential options within a particular step. The correct action was indicated by underlining one of the options. The position of the underlined, correct response on the aid was randomized in each step. The goal of this aid was to present information necessary to complete the task, without conveying additional spatial information concerning the organization of the hierarchically organized task space.

In the map condition, the task information was organized to indicate relative positioning in the task space. Each step represented a node in the map. The correct next step was indicated by radiating lines leading to more options. Nodes without more options were the incorrect responses. This type of aid conveyed spatial location information that could be helpful if the participant was lost and needed to backtrack.

Tasks. There were 2 practice tasks and 32 experimental tasks. The experimental tasks consisted of searching for information on eight topical domains (e.g., cooking, shopping) on Web pages that had been modified (e.g., regulating font size and colors, removing graphics). Tasks were designed at two levels of difficulty (easy tasks required three to four steps, whereas difficult tasks

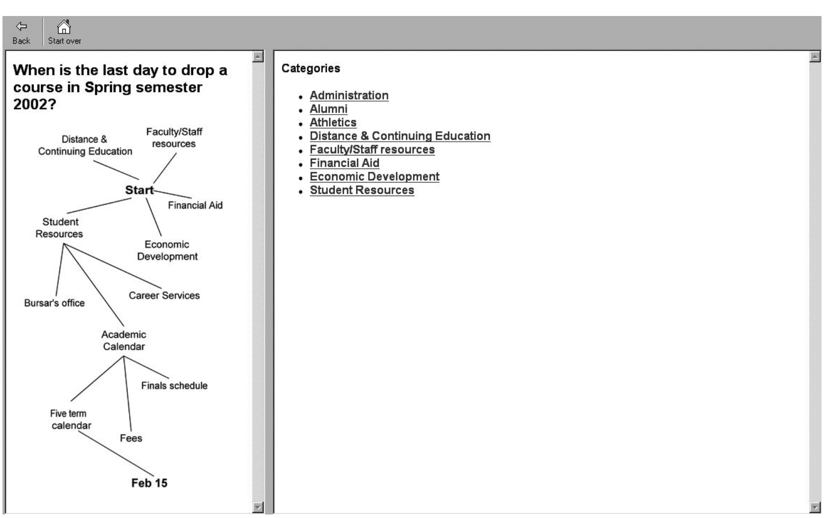

Figure 1. Screen capture of the map condition.

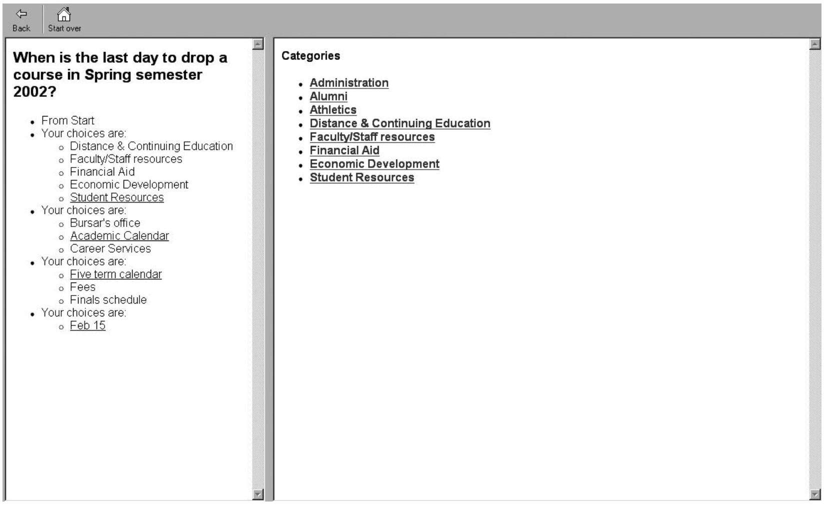

Figure 2. Screen capture of the step-by-step condition.

required six to seven steps). There were 4 tasks in each domain, with 2 at each level of difficulty.

The task was phrased in the form of a statement to find a particular page that contained a specific piece of information: for example, "When is the last day to drop a course in the Spring semester 2002?" Below this task statement, the participant saw, depending on condition, a graphical tree-like representation of the path needed to get to that particular link (map condition; Figure 1) or a bulleted, step-by-step list to get to the link (Figure 2).

The program captured the name of the visited pages, the amount of time spent on each page (in milliseconds), and the number of times as well as when the "back" and "start over" buttons were clicked during the task. Clicking on any one of these buttons constituted an error because it indicated that the participant arrived at a page in error (back button) or got lost and needed to start over (start over button).

Design and Procedure

The study design was a 2 (navigational aid: map, step-by-step) × 2 (task difficulty: easy, difficult) mixed factorial with navigational aid a between-participants variable and task difficulty a within-participants variable. The dependent variables were task completion time (in seconds) and the number of errors (cumulative times the back or start over buttons were pushed).

Participants were prescreened over the telephone. The prescreening consisted of the Short Portable Mental Status Questionnaire (SPMSQ; Pfeiffer, 1975) and the Wechsler Memory Scale III (Wechsler, 1997). The SPMSQ is a test of general cognitive status. The test involves answering questions such as "What is the date today?" and "Who is the current president of the United States?" Participants who missed no more than two of these questions were selected to participate. The Wechsler Memory Scale involved repeating a short story that was read aloud. If the participants were able to recall the main themes of the story, they were selected to participate in the study. Once scheduled, the participant was mailed a packet of questionnaires assessing general health, technology usage, and demographic information.

On the first day of testing participants completed a cognitive ability battery of standard tests. The ability testing session required approximately 4.5 hr. The ability tests in the first session were administered in a group of 5 to 10 people. Participants returned to complete a second day of testing where additional ability tests (measures of attention and psychomotor speed) were administered on an individual basis. Hearing and vision were also tested. All participants were required to have corrected or uncorrected vision of 20/40 or better and normal hearing as screened using an Earscan audiometer, with 40-dB hearing loss as a failure criterion. Participants also completed the experimental task during the second day, 1.5-hr session. This protocol of administering the ability battery was also followed at two other sites for other, unrelated projects, Florida State University and the University of Miami, as part of the Center for Research and Education on Aging and Technology Enhancement (CREATE), a multisite center investigating issues in aging and interaction with technology (Czaja et al., 2001; Czaja et al., in press). More detailed methodological and design details can be found in Pak (2001a).

Participants completed mouse training that allowed them to practice common mouse activities (e.g., clicking, using a scroll bar) and were required to achieve better than 95% accuracy before starting the information search portion of the study. After practice, participants were given a tour of the interface, which included descriptions of the three main sections (navigational aid, navigation buttons, browsing window). The researcher then guided the participant through two practice tasks demonstrating the navigation buttons and answered any experiment-related questions. Participants were told they were being timed and that it was important to complete the task as quickly and accurately as possible. Participant completed 32 experimental search tasks.

RESULTS

The means and standard deviations of task completion time presented as a function of navigational aid and task difficulty are shown in Table 2. There were no indications that speed-accuracy trade-off problems interfered with interpretation of the completion time data. Indeed, error rate did not contribute to understanding performance differences because it was extremely low (on average, less than one error per task; see Table 2) and the correlation between completion time and error rate was positive ($r = .30, p < .05$), indicating that interpretations of error data would be similar to the interpretations of task completion time.

A Navigational Aid (map, step-by-step) × Difficulty (easy, difficult) analysis of variance was conducted on the task completion time data. The participants using the step-by-step navigational aid completed the information search tasks more quickly than those who had the map aid, $F(1, 99) = 15.6, p < .05$. Performance was faster for the easy relative to difficult tasks, $F(1, 99) = 511.0$, $p < .05$, and difficulty interacted with aid: The difference between easy and difficult tasks was larger in the map condition than in the step-by-step condition, $F(1, 99) = 13.7, p < .05$. To analyze the relationship between measures of abilities such as spatial ability and performance in the computer-based task, we conducted correlation and hierarchical regression analyses.

Predictors of Task Performance

Correlations. Correlations between the ability variable composites and performance are presented in Tables 3 and 4. In the map-based navigational aid condition, task completion times were significantly related to psychomotor speed, verbal ability, crystallized intelligence, attention, and spatial orientation ability. In the step-by-step condition, task completion times were significantly related to perceptual speed and verbal ability. The pattern of ability/performance correlations in the two navigational aid conditions reflects the differential task demands from the different aids. Spatial orientation was the only spatial subfactor that was significantly related to performance, and this was so only in the navigation-intensive map condition. However, it could be the case that spatial orientation simply shared variance with other

TABLE 2: Mean Task Completion Time and Mean Number of Errors by Navigational Aid and Task Difficulty

	Task Completion Time (s)		Errors perTask	
	M	*SD*	*M*	*SD*
Map				
Easy tasks	20.75	5.35	0.09	0.08
Difficult tasks	33.05	9.08	0.14	0.20
Step by step				
Easy tasks	17.77	4.11	0.06	0.05
Difficult tasks	26.61	6.35	0.07	0.01

TABLE 3: Correlations Between Abilities and Task Completion Time in the Map Condition

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Psychomotor speed[a]	—													
2	Perceptual speed[b]	–.13	—												
3	Long term memory[b]	–.30*	.10	—											
4	Memory span[b]	–.08	–.02	.02	—										
5	Verbal ability[b]	–.38*	–.11	.42*	.15	—									
6	Working memory[b]	–.04	.06	.26	.72*	.21	—								
7	Crystallized intelligence[b]	–.14	–.12	.17	.10	.66	.10	—							
8	Attention[a]	.79*	–.07	–.38*	.04	–.38*	.03	–.27	—						
9	Reasoning[b]	–.25	.08	.27	.36*	.38*	.44*	.30*	–.21	—					
10	Spatial visualization[b]	–.17	.30*	.27	.32*	.12	.41*	.22	–.17	.55*	—				
11	Spatial orientation[b]	–.04	.08	.10	.42*	.00	.41*	.18	–.06	.36*	.66*	—			
12	Task completion time (easy)[a]	.42*	–.07	–.25	.00	–.36*	–.07	–.26	.55*	–.21	–.16	–.33*	—		
13	Task completion time (difficult)[a]	.30*	.19	–.23	.03	–.48*	–.12	–.42*	.37*	–.24	–.15	–.29*	.79*	—	
14	Task completion time (all tasks)[a]	.36*	.10	–.25	.02	–.46*	–.11	–.38*	.46*	–.24	–.16	–.32*	.91*	.97*	—

[a]Lower is better. [b]Higher is better.

*Correlations significant at .05 level (two-tailed).

TABLE 4: Correlations Between Abilities and Task Completion Time in the Step-by-Step Condition

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Psychomotor speed[a]	—													
2	Perceptual speed[b]	.19	—												
3	Long term memory[b]	.20	.23	—											
4	Memory span[b]	.10	.10	.29	—										
5	Verbal ability[b]	–.09	.11	.30*	.27*	—									
6	Working memory[b]	.23	.17	.40*	.55*	.21	—								
7	Crystallized intelligence[b]	.13	–.01	.59*	.22	.50*	.28*	—							
8	Attention[a]	.93*	.11	.14	.16	–.06	.20	.11	—						
9	Reasoning[b]	.10	.25	.45*	.43*	.57*	.47*	.46*	.16	—					
10	Spatial visualization[b]	–.08	–.06	.36*	.31*	.11	.20	.38*	–.02	.29*	—				
11	Spatial orientation[b]	.05	.09	.29*	–.13	.21	.10	.42*	.03	.29*	.22	—			
12	Task completion time (easy)[a]	.15	–.28*	–.03	–.09	–.28*	–.19	–.13	.14	–.18	.02	–.13	—		
13	Task completion time (difficult)[a]	.09	–.32*	–.05	–.07	–.41*	–.18	–.26	.09	–.24	.07	–.15	.89*	—	
14	Task completion time (all tasks)[a]	.12	–.31*	–.04	–.08	–.37*	–.18	–.22	.11	–.22	.05	–.15	.96*	.98*	—

[a]Lower is better. [b]Higher is better.

*Correlations significant at .05 level (two-tailed).

measures (e.g., working memory) that contributed to performance in the current task. To examine the unique contributions of perceptual speed, psychomotor speed, working memory, and spatial abilities on task performance, we conducted hierarchical regressions predicting task performance.

Regression analysis. Regression analyses were conducted to determine the predictors of task completion time for each navigational aid. Separate analyses were not conducted for easy and difficult task completion times because they showed similar patterns in the correlation analysis and were significantly correlated with each other; instead, a general task completion time was computed by taking the mean of the easy and difficult task completion times. Based on the pattern of correlations, previous research (e.g., Ackerman, 1988; also see Table 1), and our cognitive task decomposition analysis, the ability variables moderating the demands of using a computer and mouse to navigate a hierarchically organized information system were theorized to be psychomotor speed, perceptual speed, working memory, crystallized intelligence, attention, and the two measures of spatial ability: paper folding score (a measure of spatial visualization) and cube comparison score (a measure of spatial orientation). Note that verbal ability was excluded because it is a specific indicator of crystallized intelligence.

The order of entry into the regression equation was determined by the presumed causal priority of the chosen abilities on the current task (Cohen & Cohen, 1983). An underlying assumption is that the structure of human abilities is organized such that abilities dominated by speed of response (psychomotor speed and perceptual speed) are at one end of a continuum, whereas abilities dominated by level of responding (spatial ability and working memory) are at the other (modified radex; Ackerman, 1988). The goal of the regressions was to determine how much additional unique variance would be accounted for by the measures of spatial ability in task completion time after the influence of other abilities were removed (Step 4). Table 5 provides the results of the hierarchical regression analyses.

In the map condition, psychomotor and perceptual speed were significant predictors of performance. Working memory did not account for additional variance. However, spatial orientation ability did account for additional variance after the influences of speed and working memory were removed. On the contrary, spatial visualization did not account for additional variance. In the step-by-step condition, only measures of speed were predictive of performance. Working memory, spatial orientation, and spatial visualization did not account for additional variance in task performance.

These analyses show that in the more navigationally demanding condition (map-based condition) the most predictive abilities were speed, memory, and spatial orientation. In the less navigationally demanding step-by-step condition, only measures of speed were predictive of performance.

In the hierarchical regression, spatial orientation was arbitrarily entered before spatial visualization. Because spatial orientation and visualization both represent the higher order factor of spatial ability and were moderately correlated with each other ($r = .44$, $p < .05$), removing the influence of spatial orientation could have also removed a substantial portion of the variance associated with spatial visualization in task performance. To test this possibility, we conducted regression analyses entering spatial visualization before spatial orientation (see Table 6). The pattern was unchanged in that measures of speed and spatial orientation were still significant predictors of performance in the map condition whereas measures of working memory and spatial visualization were not. In the step-by-step condition, only speed was a significant predictor of performance.

CONCLUSION

The results of the regression analyses show that even after controlling for individual differences in psychomotor speed, perceptual speed, working memory, crystallized intelligence, and attention, spatial orientation was significantly predictive of performance in a hypertext-based information search task. However, spatial orientation was predictive of performance only when navigational demands were high (i.e., in the map condition). Spatial visualization was not found to be significantly related to performance under any task condition.

The divergent pattern for different measures of spatial ability, as well as the role of navigational demand in the current study, may explain the

TABLE 5: Summary of Hierarchical Regression Analysis with Spatial Orientation Entered First

Variable	R^2	ΔR^2	β	ΔF	*p*
Map condition					
Step 1	.142	.142		3.64	.035
Psychomotor speed			.375		
Perceptual speed			.118		
Step 2	.306	.164		3.24	.032
Psychomotor speed			.040		
Perceptual speed			.061		
Working memory			–.090		
Crystallized intelligence			–.282		
Attention			.358		
Step 3	.383	.077		4.97	.031
Psychomotor speed			.061		
Perceptual speed			.072		
Working memory			.035		
Crystallized intelligence			–.248		
Attention			.326		
Spatial orientation			–.308		
Step 4	.405	.023		1.48	.231
Psychomotor speed			.071		
Perceptual speed			.015		
Working memory			.003		
Crystallized intelligence			–.274		
Attention			.338		
Spatial orientation			–.430		
Spatial visualization			.221		
Step-by-step condition					
Step 1	.135	.135		3.76	.031
Psychomotor speed			.222		
Perceptual speed			–.345		
Step 2	.217	.082		1.57	.210
Psychomotor speed			.501		
Perceptual speed			–.330		
Working memory			–.172		
Crystallized intelligence			–.180		
Attention			–.241		
Step 3	.218	.000		.026	.874
Psychomotor speed			.500		
Perceptual speed			–.332		
Working memory			–.172		
Crystallized intelligence			–.189		
Attention			–.239		
Spatial orientation			.023		
Step 4	.233	.016		.876	.354
Psychomotor speed			.573		
Perceptual speed			–.326		
Working memory			–.190		
Crystallized intelligence			–.236		
Attention			–.297		
Spatial orientation			.007		
Spatial visualization			.141		

Note. The increment in R^2 (ΔR^2) is associated with the inclusion of additional variables in the corresponding step. The ΔF statistic indicates the change in F associated with the inclusion of additional variables. The *p* statistic indicates the significance of each additional block of variables in accounting for variance in performance.

TABLE 6: Summary of Hierarchical Regression Analysis for Spatial Visualization Entered First

Variable	R^2	ΔR^2	β	ΔF	*p*
Map condition					
Step 1	.142	.142		3.64	.035
Psychomotor speed			.375		
Perceptual speed			.118		
Step 2	.306	.164		3.24	.032
Psychomotor speed			.040		
Perceptual speed			.061		
Working memory			–.090		
Crystallized intelligence			–.282		
Attention			.358		
Step 3	.308	.002		.106	.747
Psychomotor speed			.040		
Perceptual speed			.075		
Working memory			–.071		
Crystallized intelligence			–.272		
Attention			.352		
Spatial visualization			–.051		
Step 4	.405	.097		6.39	.016
Psychomotor speed			.071		
Perceptual speed			.015		
Working memory			.003		
Crystallized intelligence			–.274		
Attention			.338		
Spatial visualization			.221		
Spatial orientation			–.430		
Step-by-step condition					
Step 1	.135	.135		3.76	.031
Psychomotor speed			.222		
Perceptual speed			–.345		
Step 2	.217	.082		1.57	.210
Psychomotor speed			.501		
Perceptual speed			–.330		
Working memory			–.172		
Crystallized intelligence			–.180		
Attention			–.241		
Step 3	.233	.016		.920	.343
Psychomotor speed			.574		
Perceptual speed			–.326		
Working memory			–.190		
Crystallized intelligence			–.233		
Attention			–.298		
Spatial visualization			.142		
Step 4	.233	.000		.002	.963
Psychomotor speed			.573		
Perceptual speed			–.326		
Working memory			–.190		
Crystallized intelligence			–.236		
Attention			–.297		
Spatial visualization			.141		
Spatial orientation			.007		

Note. The increment in R^2 (ΔR^2) is associated with the inclusion of additional variables in the corresponding step. The ΔF statistic indicates the change in F associated with the inclusion of additional variables. The p statistic indicates the significance of each additional block of variables in accounting for variance in performance.

mixed pattern of results listed in Table 1. A predominant number of those studies did not use multiple measures of spatial ability and did not control for specific and possibly important task characteristics. The present study demonstrated that the ability-performance relationship between spatial abilities and computer-based task performance depends on which spatial ability measure is being used and the characteristics of the task under study.

The current data also showed that even after controlling for psychomotor and perceptual speed and other cognitive variables such as working memory, crystallized intelligence, and attention, spatial orientation contributed significant variance to predicting performance. Thus, the specific ability of spatial orientation added a significant amount of unique variance when the task had a high navigational requirement (i.e., the map condition).

What are the implications of these findings for the design of computer systems? In addition to relieving the working memory demands of a computer task (e.g., via environmental support), research should determine ways in which the spatial orientation demand of a computer task could be reduced. One strategy to lessen spatial orientation demand might be to reduce the navigational requirements (e.g., through a simpler navigational aid). However, future research should also measure the relationship of spatial orientation demand after extended practice with a particular system. It is conceivable that the more spatially demanding map aid slows performance initially but leads to better development of a mental model or system representation (e.g., Kieras & Bovair, 1984).

There is a complex relationship among abilities, performance, design features, and learning. However, it is clear that for unfamiliar search tasks (a) navigational aids that minimize spatial demands lead to more efficient searches and (b) if the navigational aid is demanding of spatial ability, individuals with higher spatial orientation ability will do better than individuals with lower spatial orientation ability.

ACKNOWLEDGMENTS

This research was supported in part by a grant from the National Institutes of Health (National Institute on Aging), Grant P01 AG17211, under the auspices of the Center for Research and Education on Aging and Technology Enhancement (CREATE).

The article is based on a thesis submitted by the first author as partial fulfillment of the master of science degree. Portions of this research were presented at the Human Factors and Ergonomics Society 46th Annual Meeting in Minneapolis, Minnesota (October 2001), with proceedings (Pak, 2001b), the Ninth Cognitive Aging Conference in Atlanta, Georgia (April 2002), and the Fourth International Conference on Gerontechnology in Miami, Florida (November 2002).

REFERENCES

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117,* 288–318.

Campagnoni, F. R., & Ehrlich, K. (1989). Information retrieval using a hypertext-based help system. *ACM Transactions on Information Systems, 7,* 271–291.

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences* (2nd ed.). Mahwah, NJ: Erlbaum.

Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., Rogers, W. A., & Sharit, J. (in press). Factors predicting the use of technology: Findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). *Psychology and Aging.*

Czaja, S. J., Charness, N., Fisk, A. D., Rogers, W., & Sharit, J. (2001). The center for research and education on aging and technology enhancement: A program for enhancing technology for older adults. *Gerontology, 1,* 50–59.

Dyck, J. L., & Smither, J. A. (1994). Age differences in computer anxiety: The role of computer experience, gender and education. *Journal of Educational Computing Research, 10,* 239–248.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests.* Princeton, NJ: Educational Testing Service.

Garfein, A. J., Schaie, K. W., & Willis, S. L. (1988). Microcomputer proficiency in later-middle-aged and older adults: Teaching old dogs new tricks. *Social Behavior, 3*(2), 131–148.

Gomez, L. M., Egan, D. E., & Bowers, C. (1986). Learning to use a text editor: Some learner characteristics that predict success. *Human-Computer Interaction, 2,* 1–23.

Gomez, L. M., Egan, D. E., Wheeler, E. A., Sharma, D. K., & Gruchacz, A. M. (1983). How interface design determines who has difficulty learning to use a text editor. In *Proceedings of ACM CHI'83 Conference on Human Factors in Computing Systems* (pp. 176–181). New York: Association for Computing Machinery.

Jennings, F., Benyon, D., & Murray, D. (1991). Adapting systems to differences between individuals. *Acta Psychologica, 78,* 243–256.

Kieras, D. E, & Bovair, S. (1984). The role of a mental model in learning to operate a device. *Cognitive Science, 8,* 255–273.

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory and Cognition, 29,* 745–756.

Pak, R. (2001a). *A further examination of the influence of spatial abilities on computer task performance in younger and older adults.* Unpublished master's thesis, Georgia Institute of Technology, Atlanta, GA.

Pak, R. (2001b). A further investigation of spatial abilities and computer-based task performance in younger and older adults. In *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting* (pp. 1551–1555). Santa Monica, CA: Human Factors and Ergonomics Society.

Pellegrino, J. W., Alderton, D. L., & Shute, V. J. (1984). Understanding spatial ability. *Educational Psychologist, 19*, 239–253.

Pfeiffer, R. I. (1975). A short portable mental status questionnaire for the assessment of organic brain deficit in elderly patients. *Journal of the American Geriatrics Society, 23,* 433-441.

Seagull, F. J., & Walker, N. (1992). The effects of hierarchical structure and visualization ability on computerized information retrieval. *International Journal of Human-Computer Interaction, 4,* 369–385.

Sebrechts, M. M., Deck, J. G., Wagner, R. K., & Black, J. B. (1984). How human abilities affect component skills in word processing. *Behavior Research Methods, Instruments & Computers, 16*, 234–237.

Vicente, K. J., Hayes, B. C., & Williges, R. C. (1987). Assaying and isolating individual differences in searching a hierarchical files system. *Human Factors, 29,* 349–359.

Vicente, K. J., & Williges, R. C. (1988). Accommodating individual differences in searching a hierarchical file system. *International Journal of Man-Machine Studies, 29,* 647–668.

Wechsler, D. (1997). *Wechsler Memory Scale III* (3rd ed.). San Antonio, TX: The Psychological Corporation.

Westerman, S. J. (1997). Individual differences in the use of command line and menu computer interfaces. *International Journal of Human-Computer Interaction, 9,* 183–198.

Wochinger, K., & Boehm-Davis, D. (1995). *The effects of age, spatial ability, and navigational information on navigational performance* (FHA Publication No. FHWA-RD-95166). McLean, VA: U.S. Department of Transportation.

Richard Pak is now an assistant professor in the Department of Psychology at Clemson University. He received his Ph.D. in psychology in 2005 from the Georgia Institute of Technology.

Wendy A. Rogers is a professor of psychology at the Georgia Institute of Technology, where she received her Ph.D. in psychology in 1991.

Arthur D. Fisk is a professor of psychology at the Georgia Institute of Technology. He received his Ph.D. in psychology in 1982 at the University of Illinois.

Date received: March 4, 2004
Date accepted: December 27, 2004