Computers in Human Behavior 24 (2008) 3045–3051

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

The role of spatial abilities and age in performance in an auditory computer navigation task

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ARTICLE INFO

Article history:
Available online 26 June 2008

Keywords:
Interactive voice response systems
Aging
Cognitive abilities
Interface

ABSTRACT

Age-related differences in spatial ability have been suggested as a mediator of age-related differences in computer-based task performance. However, the vast majority of tasks studied have primarily used a visual display (e.g., graphical user interfaces). In the current study, the relationship between spatial ability and performance in a non-visual computer-based navigation task was examined in a sample of 196 participants ranging in age from 18 to 91. Participants called into a simulated interactive voice response system and carried out a variety of transactions. They also completed measures of attention, working memory, and spatial abilities. The results showed that age-related differences in spatial ability predicted a significant amount of variance in performance in the non-visual computer task, even after controlling for other abilities. Understanding the abilities that influence performance with technology may provide insight into the source of age-related performance differences in the successful use of technology.

In light of evidence that cognitive abilities play an important role in the performance of everyday activities (e.g., Diehl, Willis, & Schaie, 1995), researchers have attempted to identify and measure the influence of cognitive abilities on a wide variety of activities (e.g., Czaja et al., 2006; Kelley & Charness, 1995; Sharit, Czaja, Nair, & Lee, 2003). One such ability, spatial ability, has been shown to be predictive of performance on a wide variety of everyday tasks such as way finding, map reading and

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doi:10.1016/j.chb.2008.05.010

computer tasks such as text-editing, spreadsheet usage, map- and computer-based information search tasks, even when other more general ability factors are controlled (for a review, see Pak, Rogers, & Fisk, 2006). Spatial ability is generally defined as the ability to perceive and transform visual patterns (Ekstrom, French, Harman, & Dermen, 1976). In studies examining spatial ability and computer-based information search, measures of spatial ability (e.g., paper folding, cube comparison) show significant relationships with measures such as task completion time and error rates. However, a question that arises is whether the relationship between spatial ability and computer-based task performance is an artifact of the need to actively engage in activities that require spatial visual processing, or is due to a need to manipulate abstract system representations of the computer system (Ehrlich, 1996). If computer-based task performance is related to the visual processing demands, one solution to improving performance would be to reduce or eliminate these demands (e.g., use an auditory interface). However, if performance is related to the need to create and manipulate abstract system representations, a deeper analysis of the task is required before strategies for improving performance can be suggested.

In general, finding information online or in a database requires users to navigate complex, hierarchically organized information structures. In these kinds of tasks, it may be beneficial to have access to a mental model, or system representation of the organization of the information system (Vicente, Hayes, & Williges, 1987). For example, having a mental model of the organization of a menu system can serve as top-down knowledge that may speed access to that menu option, or reduce the need to search all the menus for a specific option. Similarly, such a mental model may allow users to backtrack more easily if the user gets lost within the system. Previous research has clearly demonstrated the benefits to performance of having such models (e.g., Kieras & Bovair, 1984). However, the need to create and use system representations may place demands on spatial ability (Gilbert & Rogers, 1999), which may be problematic for older adults. Cross-sectional (e.g., Salthouse, 1992) and longitudinal studies (e.g., Willis & Schaie, 1986) have shown that older adults tend to have reduced spatial ability compared to their younger counterparts. In these studies, older adults consistently performed about .5–1.5 standard deviations lower on tests of spatial ability than younger adults (Salthouse). Consequently, age-related declines in spatial ability have been suggested as a potentially significant moderator of older adults' computer-based task performance (Kelley & Charness, 1995).

If visual computer-based information search task performance is moderated by the need to create a system representation, or mental model, we should observe spatial ability/performance relationships in non-visual computer-based tasks that could benefit from models of system structure or organization. Furthermore, measures of spatial ability should be able to account for age-related differences in performance in these types of tasks after controlling for other abilities such as attention or working memory.

The goal of the present study was to examine the role of spatial ability in an auditory processing task. This represents an important area of investigation given the increased use and importance of auditory interfaces in computerized interactions such as interactive voice response systems (IVRS) for health or financial information or portable navigation systems for driving directions (e.g., McNulty & Mangan, 2006). Auditory interfaces are also used to aid persons with visual deficits, which is a common problem with older adults.

We chose to examine an interactive voice response system (IVRS) as these systems are increasingly being used for everyday tasks such as banking, appointment scheduling, filling prescriptions, or finding travel or entertainment information. In fact, it is becoming rare to interact with a human when using telephone systems for activities other than social interactions.

The IVRS represents an ideal system in which to test the generality of the spatial ability/performance relationship in auditory task environments as these systems require traversing hierarchically organized menu options that are presented through the auditory channel. Sharit et al. (2003) found age-related differences on the performance of these types of tasks. Their results also suggested that cognitive abilities such as working memory influenced performance. Given normative age declines in spatial ability we predicted that spatial abilities would also play an important role in explaining the age-related performance differences. Ultimately, understanding factors that influence successful interactions with complex auditory systems is important to the development of interventions to enhance user performance. The current analyses used the Sharit et al. data to extend their explanation of the factors that affect performance with IVRSs.

1. Method

1.1. Participants

One hundred and ninety six participants ranging in age from 18 to 91 years completed the study. They were recruited from the community through advertisements in local newspapers. Participants were recruited in three age groups: younger (ages 18–39), middle-aged (40–59) and older (60–91). The mean age was 47.32 (SD = 19.78). Descriptive statistics on the participants and ability measures are in Table 1.

1.2. Task

Participants dialed into a fictional IVRS to complete 24 tasks. The tasks involved obtaining information in a banking or electric utility context (e.g., “Transfer $500 from your savings account to your checking account and obtain your confirmation number”). A scoring system was used to evaluate performance on each of the IVRS tasks that was based on the completeness of the answer (e.g., completing one part of the task but not the other). For example, the problem, “Transfer $500 from your savings account to your checking account and obtain your confirmation number,” involves two sub-tasks (transfer and confirmation). Successful completion of each problem sub-task earned five points. The problems varied in the number of sub-tasks and the maximum score obtainable for correct responses for all tasks was 358. More details on the IVRS task are contained in Sharit et al. (2003).

1.3. Procedure

Participation involved two days. On the first day, participants completed a core battery that assessed perceptual speed, working memory, long term memory, verbal ability, reasoning, and spatial abilities as well as a hearing and vision screening (see Czaja et al., 2006 for details of the protocol). For the present analysis, the ability measures of interest were working memory (alphabet span; Craik, 1986), attention (trail making test; Reitan, 1958), and spatial abilities (paper folding and cube comparison; Ekstrom et al., 1976). While the focus of the current analyses were on spatial abilities and performance on a IVRS task, we wanted to compare the relative contributions of memory and attention to spatial abilities and to determine whether spatial ability predicted performance in the IVRS task above and beyond attention and working memory prior experience with IVRS was also assessed with a questionnaire but did not contribute significant variance in performance and was removed from the models; this removal did not alter the ability-performance patterns.

Table 1
Descriptive statistics for demographic and ability measures

	Young ($N = 74$)			Middle ($N = 64$)			Old ($N = 61$)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Age	26.31	7.34	18–39	48.89	5.54	40–59	71.23	6.90	60–91
Prior IVRS experience	20.73	8.13	7–43	18.98	9.80	0–52	16.31	7.39	0–30
Attention[a]	1.74	0.15	1.45–2.21	1.92	0.18	1.49–2.42	2.00	0.22	1.66–2.74
Working memory[b]	44.86	10.69	20–85	37.95	9.28	20–75	35.74	9.99	20–55
Spatial ability[c]	0.39	0.79	−1.26–2.36	0.07	0.79	−1.69–2.12	−0.54	0.71	−1.82–1.97
Total score[d]	257.16	49.48	130–341	232.80	68.85	42–323	189.46	68.40	61–298

[a] Trailmaking test part B (Reitan, 1958).

[b] Alphabet span (Craik, 1986).

[c] Mean of paper folding and cube comparison tests (Ekstrom et al., 1976).

[d] Computed based on the participants’ responses to each task, taking into account the complexity of the problem (max=358).

2. Results

Hierarchical regression analysis was used to examine the influence of age and cognitive abilities on performance on the IVRS task. As indicated above, the participant's score on each IVRS task depended on whether that task's components were completed successfully. For example, if a question contained three components (e.g., they were asked to provided the date, type, and amount of a banking transaction), participants would receive points depending on the completeness of their answers. These point values were summed to create a total score for each participant. In the present analysis, the predictors of total score were prior IVRS experience (via a questionnaire), and measures of attention, working memory, and spatial ability. For spatial ability a composite measure was computed, which was the mean of each individual's normalized score on the paper-folding test and cube comparison test. The decision to use a composite measure of spatial ability (composed of measures of spatial orientation and visualization) was motivated by the results of a previous study (Pak, 2001), which found that for older adults the individual sub-factors of spatial ability did not differentially contribute to performance in a computer task (the sub-factors differentially predicted performance in young adults). Table 2 presents correlations between age, the ability measures, and the total task performance score. As indicated in the table, the ability variables of interest (attention, working memory, and spatial ability) were all significantly correlated with each other, indicating some level of shared variance.

The goal of the hierarchical regression (Table 3) was to examine unique contributions of individual and age-related differences in spatial ability on TMVS task performance. Attention and working memory were used as control variables to examine the unique effect of spatial ability on performance and to compare the magnitude of the spatial ability relationship. The logic of the regression was to examine the predictability of chronological age before and after age-related differences in abilities were controlled for. If after controlling for ability differences age is no longer a significant predictor of performance, then the implication is that differences in performance can be explained by differences in those abilities that are known to be age-related.

When chronological age alone was entered into the regression (Model 1), it accounted for 17% of the age-related variance in performance scores, $F(1,195) = 40.13$, $p < .001$. Subsequent regressions controlled for attention, working memory, and spatial ability. Models 2-4 show that when controlling for attention, working memory, or spatial ability, the predictability of age was greatly reduced (the percent attenuation column indicates the degree to which the predictability of age was attenuated). This suggests that a large portion of differences in IVRS performance was due to age-related differences in each of these abilities.

The correlation table suggests that the ability variables shared common variance. Nevertheless spatial ability predicted a significant amount of unique variance in task performance *after* attention and working memory were controlled for (Model 5), $F(1,195) = 15.56$, $p < .001$. While spatial ability only added an extra 3% in the prediction of total score, this was *unique* variance. It should be noted that when only attention and working memory were entered into the regression equation (model not shown), age was still a significant predictor of performance, $F(1,195) = 4.64$, $p < .05$, suggesting

Table 2
Age, ability, and performance correlations

		1	2	3	4	5
1	Age	–				
2	Attention[a]	0.51[*]	–			
3	Working memory[b]	−0.36[*]	−0.53[*]	–		
4	Spatial ability[c]	−0.48[*]	−0.48[*]	0.32[*]	–	
5	IVRS performance[d]	−0.41[*]	−0.55[*]	0.55[*]	0.48[*]	–

[a] Trailmaking test part B (Reitan, 1958).

[b] Alphabet span (Craik, 1986).

[c] Mean of paper folding and cube comparison tests (Ekstrom et al., 1976).

[d] Computed score based on the participants' responses to each task, taking into account the complexity of the problem.

[*] $p < .05$.

Table 3
Hierarchical regression analyses of IVRS performance

Model	Variable	Cumulative R^2	Increment in R^2	ΔF	Percent attenuation
1	Age	0.17		40.13*	
2	Attention[a]	0.30		83.24*	
	Age	0.33	0.03	7.17*	82
3	Working memory[b]	0.30		82.24*	
	Age	0.35	0.05	16.05*	70
4	Spatial ability[c]	0.23		56.73*	
	Age	0.27	0.04	11.98*	76
5	Attention[a]	0.30		83.24*	
	Working memory[b]	0.39	0.09	29.18*	
	Spatial ability[c]	0.44	0.05	15.56*	
	Age	0.44	0.00	1.17	100

[a] Trailmaking test part B (Reitan, 1958).

[b] Alphabet span (Craik, 1986).

[c] mean of paper folding and cube comparison tests (Ekstrom et al., 1976).

* $p < .05$. The cumulative R^2 column indicates the total amount of variance in IVRS performance due to the variables in the corresponding model. The increment in R^2 column indicates the variance in performance accounted for by the addition of the variable in the corresponding row. The ΔF indicates the change in F-statistic associated with the inclusion of additional variables and the significance of the increment in R^2 in the corresponding row. The Percent Attenuation column indicates the degree of reduction of the predictability of age after controlling for a variable within a model (compared to the predictability of age alone).

remaining age-related variance yet to be accounted for. However with spatial ability in the model, 100% of the age-related variance was explained.

3. Discussion

Interacting with technological systems is becoming a requirement for many aspects of independent living. However, older adults are often less successful than their younger counterparts in using technology (e.g., Charness, Schumann, & Boritz, 1992; Czaja et al., 2006; Czaja, Sharit, Ownby, Roth, & Nair, 2001; Kelley & Charness, 1995). This may be due, at least in part, to age-related changes in cognitive abilities that are required by current systems for successful task performance.

In this regard, previous studies have identified an important cognitive ability, spatial ability, which is critical to computer-based task performance; however, the results have been limited to visual-computer applications (e.g., desktop computing). The current results show that the relationship between spatial ability and performance on technology-based navigation types of activities extends to tasks that are non-visual in nature (i.e., the IVRS task). The results thus provide support for the hypothesis that the creation and utilization of an intermediate system representation may be in part responsible for the relationship between spatial ability and computer task performance. The current study, however, does not rule out the more general explanation that general fluid ability, of which spatial ability is an example, is related to performance in complex, novel tasks (Ackerman, 1988). However, this seems unlikely because working memory is highly correlated with fluid ability (Kyllonen & Christal, 1990), yet spatial ability accounted for significant variance above and beyond that accounted for by working memory. This pattern suggests some uniqueness to the spatial ability construct as it relates to computer task performance.

The important finding was that spatial ability accounted for performance variability even after controlling for individual differences in attention and working memory. Also, after accounting for spatial ability, chronological age was no longer predictive of performance. This suggests that one component of age-related differences in IVRS performance is age-related differences in spatial ability.

Previous investigations of spatial ability and working memory have suggested a great deal of shared variance between these measures (e.g., Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Despite this shared variance, there was a unique aspect of the IVRS task that relied on aspects of spatial ability in addition to working memory and attention. We suggest that it is the need to create and manipulate a spatial mental model.

The results have implications for the design of technological systems for use by older adults. In addition to reducing demands on attention and memory, future work should examine ways of reducing spatial ability demands. One example may be to provide clear spatial information of the organization of the menu system. For example, Sharit et al. (2003) found that providing a simple help card which gave a high level overview of the navigational structure of the IVRS menu tree seemed to help performance. In addition to potentially alleviating working memory demands, the high level overview may have alleviated spatial ability demands of the IVRS task. However, designers need to exercise caution to ensure that such "navigational aids" are not, in and of themselves, demanding of spatial ability (e.g., Pak et al., 2006). Moreover, one clearly cannot assume that just because a task is not visually-based it will not rely on spatial abilities.

Acknowledgement

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. Portions of this research were presented at the Human Factors and Ergonomics Society 47th Annual Meeting in Denver, CO (October 2003) with proceedings (Pak et al., 2003).

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