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Efficiency of route selection as a function of adult age

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Abstract

Two tasks hypothesized to assess the efficiency of route selection were administered to 328 adults ranging from 18 to 93 years of age. Increased age was associated with slower completion of mazes, even after adjusting for differences in perceptual-motor speed, and with longer and less accurate routes in a task in which participants were asked to visit designated exhibits in a zoo. The route selection measures were correlated with measures hypothesized to represent executive functioning, such as the number of categories in the Wisconsin card sorting test and the number of words generated in a category fluency test. However, most of the age-related influences on the measures from the route selection tasks were shared with age-related effects on established cognitive abilities, which implies that the same mechanisms may account for the relations of age on both sets of variables.

Keywords: Route selection; Aging; Executive functioning

1. Introduction

Selecting routes is an interesting cognitive task because it requires decisions about how to achieve a specific goal (i.e., reach a destination) while satisfying various constraints (such as avoiding barriers, visiting intermediate locations, etc.). Route selection almost certainly involves aspects of planning, but it is likely to involve other cognitive abilities as well. Furthermore, tasks with these requirements have been hypothesized to be particularly sensitive to frontal lobe damage (e.g., Shallice & Burgess, 1991; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). The two major goals of the research described in this report were to examine the influences of different cognitive abilities, including measures often used to assess executive functioning, on route selection measures, and to investigate the effects of aging on measures of route selection efficiency.

A number of studies have investigated age differences in learning or memory of routes, and have found that older adults tend to perform at lower levels than young adults on many measures (e.g., Caplan & Lipman, 1995; Lipman, 1991; Lipman & Caplan, 1992). Age differences favoring young adults have also been reported in learning to navigate through real (e.g., Barrash, 1994; Wilkniss, Jones, Korol, Gold, & Manning, 1997), or virtual (e.g., Moffat & Resnick, 2002; Moffat, Zonderman, & Resnick, 2001), environments. Although the learning and memory of spatial information is interesting, the focus in the current study was on processes concerned with planning or selecting routes rather than learning or remembering them. That is, we were more interested in aspects of planning than in learning or memory.

Two measures were used to assess efficiency of route selection. One was the time to complete perceptual mazes, and the other was the distance of the route selected to visit six exhibits in a zoo. Several studies have compared adults of different ages in maze tasks (e.g., Davies, 1973; Heron & Chown, 1967; Newman & Kaszniak, 2000; Salthouse, 1995), and in most of them time to complete the maze was the primary outcome measure. However, simple solution time likely includes the time for perceptual-motor processes, visual search, etc. in addition to the time to select a route, and therefore it is desirable to attempt to minimize

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these other influences when studying efficiency of route selection.

The Mazes task in the current study consisted of two conditions in which the participants were asked either merely to trace a path through a maze, or to solve and trace the maze by planning and drawing a path through the maze. In both conditions the instructions were to complete the activity as quickly as possible. The additional time to solve, as opposed to trace, the maze can be postulated to reflect the duration of processes associated with route selection. People who are more efficient at selecting routes might therefore be expected to have a smaller difference between their solution time and their tracing time.

The second route selection task included in the study was an adaptation of a zoo trip task described in Wilson et al. (1996) and recently used by Allain et al. (2005). In our version of the task the participants were given a map of a zoo and were allowed as much time as desired to select the most efficient route to visit a specified set of exhibits. Shallice and Burgess (1991) speculated that this type of route selection or planning task is dependent on the frontal lobes, in contrast to the posterior and parietal involvement that has been found to be associated with the learning or remembering of routes (e.g., Meulenbroek, Petersson, Voermans, Weber, & Fernandez, 2004).

In addition to examining how measures of performance on these two route selection tasks were related to one another and to the age of the participant, we were also interested in the relations of performance on these tasks to other types of cognitive functioning. One other type of cognitive functioning is executive functioning, which might be expected to be related to route selection because it likely requires planning, which is often considered to be an aspect of executive functioning. All of the participants in the project also performed three tasks often assumed to assess executive functioning, namely, the Wisconsin card sorting test, and the letter fluency, and category fluency tests.

In addition to examining the relations among the route selection variables and other cognitive abilities, we were also interested in the relations of age on the measures of route selection. However, because adult age differences have been found in a wide variety of cognitive variables (e.g., Craik & Salthouse, 2000; Salthouse, 2004a, 2004b, 2005), it is important to determine the degree to which any age-related influences on the route selection variables are unique, and statistically independent of age-related influences on other variables. That is, no separate explanation of age-related effects on route selection may be needed if all of the age-related effects on the variables of interest are shared with effects on other variables. A reference battery of cognitive tests designed to assess four cognitive abilities was therefore also administered to the participants, and the age-related effects on the route selection variables were examined in the context of age-related effects on these abilities.

Two potentially informative sets of results can be obtained from these types of contextual analyses in which the age relations on the variables of interest are examined in the context of age-related influences on other cognitive variables (cf. Salthouse, 2005; Salthouse, Siedlecki, & Krueger, 2006). One relevant result concerns the unique age relations on the target variable, which indicate age-related influences on the route selection variables that are statistically independent of influences on established cognitive abilities. Only if the unique age-related effect is significantly different from zero would a distinct explanation necessarily be required to account for age-related effects in measures of route selection. The second informative result from the contextual analyses concerns the influences of different cognitive abilities on the target variable, as manifested by relations between an individual's level of a particular cognitive ability and his or her performance on the route selection task. Because the relative magnitudes of these relations indicate which cognitive abilities are important for successful performance in the task, this information is valuable in determining what the variables actually represent (cf. Salthouse, 2005).

2. Method

2.1. Participants

The research participants were 328 individuals between 18 and 93 years of age recruited via flyers, newspaper advertisements, and referrals from other participants. Approximately 78% of the participants were Caucasian, 12% African-American, with the remaining individuals representing a variety, or mixture, of ethnicities. Two participants were excluded because their scores on a dementia screening instrument, the mini-mental status examination (Folstein, Folstein, & McHugh, 1975), were less than 24, which is sometimes considered to be in the range of possible dementia. Characteristics of the remaining sample in terms of the scores on a variety of demographic and reference variables are summarized in Table 1. Scaled scores on the Wechsler Adult Intelligence Scale III (WAIS III; Wechsler, 1997) vocabulary and digit symbol tasks were above the normative sample mean of 10, indicating that the participants were functioning at a high cognitive level. However, because these scaled scores were not significantly correlated with age, the individuals in each age group can be inferred to be functioning at similar high levels relative to the nationally representative normative sample.

2.2. Procedure

The participants reported to the laboratory on three separate occasions for about two hours each. In addition to the route selection tasks of primary interest in this report, they also completed a battery of 16 tests designed to assess the cognitive abilities of fluid ability, episodic memory, processing speed, and vocabulary. Detailed information on the reference cognitive variables, as well as results of confirmatory factor analyses supporting the assignment of variables to abilities, are reported in a manuscript describing results from other tasks performed by the participants (Salthouse et al., 2006). Each of the reference cognitive variables was converted to a *z*-score, and the *z*-scores averaged to form a composite score for each ability. (See the footnote at the bottom of Table 1 for the variables used in each composite score.) Means and standard deviations of these composite scores for three age groups are reported in the bottom of Table 1. As is frequently found, increased age was associated with lower levels of each cognitive ability except vocabulary. These well-established relations can be viewed as the context within which age differences on any new variables should be examined.

The participants also performed a computer-administered version of the Wisconsin card sorting test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993), and fluency tests in which participants were asked to generate as many words as they could in 60 s that began with a certain letter (F, A, or S) or that were members of a specific category (animals, boy's names). The number of categories variable was used as the primary dependent variable in the WCST because it correlated .72 with the number of trials, and .87 with the proportion of correct responses. The number of appropriate items produced in 60 s served as the dependent measure in both of the fluency tasks. Age relations on these and other variables performed by participants in this project, with the exception of the Mazes and Zoo Trip tasks, are reported in Salthouse (2005).

1.3. Mazes

The Mazes task, which was administered in the first session of the project, consisted of two conditions (trace and solve) and three levels of complexity (simple, medium, and complex). Maze complexity was manipulated by increasing the number of embedded lines within the same perimeter (i.e., averages of 48, 96, and 165 lines for the three levels). Examples of the mazes used in each condition of this task are illustrated in Fig. 1. In the trace condition the participants were asked to trace a dotted line, which represented the optimal path from the start to the finish, as quickly as possible. In the solve condition participants had to determine the optimal path through the maze in addition to drawing a line along that path as quickly as possible. The time to trace a path through the maze served as an estimate of perceptual-motor speed in this situation, and the additional time to solve the maze was used as an estimate of route selection time.

The participants worked on two mazes in each of six conditions in the order simple-trace, medium-trace, complex-trace, simple-solve, medium-solve, and complex-solve, followed by new mazes in the same conditions in the reverse sequence. Because there were very few errors, the time to complete the maze was the primary measure of performance in the task.

1.4. Zoo trip

The zoo trip task was administered in the second session of the project and was loosely based on the multiple errands test (e.g., Bisiacchi, Sgaramella, & Farinello, 1998; Garden, Phillips, & MacPherson, 2001) and a test in the behavioural assessment of the Dysexecutive syndrome battery (Wilson et al., 1996). The stimulus materials consisted of maps of two different zoos, each with 13

Table 1
Characteristics of research participants

	Age Group			Age R^2		
	18–39	40–59	60–93	Age	Age^2	Age^3
N	89	132	105			
Age	28.3 (6.0)	49.8 (5.4)	70.9 (7.7)			
Prop. Females	.66	.66	.60	.00	.01	.01
Years of education	15.2 (2.2)	15.8 (2.8)	15.9 (2.7)	.02	.02*	.00
Health	1.9 (0.8)	2.1 (0.9)	2.3 (1.0)	.04*	.00	.00
MMSE	29.2 (1.2)	28.9 (1.3)	28.6 (1.8)	.03*	.00	.03*
Scaled scores						
Vocabulary	12.8 (3.1)	12.2 (3.0)	13.6 (2.9)	.01	.03*	.04*
Digit symbol	11.0 (2.8)	10.7 (2.8)	11.4 (2.7)	.01	.00	.01
Cognitive ability scores						
Fluid ability (gF)	.45 (.81)	.03 (.73)	−.39 (.71)	.22*	.00	.03*
Episodic memory	.36 (.75)	.02 (.74)	−.31 (.85)	.15*	.01	.04*
Perceptual speed	.65 (.71)	.09 (.70)	−.65 (.79)	.37*	.02*	.00
Vocabulary	−.33 (.83)	.02 (.90)	.27 (.83)	.06*	.01	.04*

Note: Values in parentheses are standard deviations. Health was a rating on a scale from 1 for Excellent to 5 for Poor. MMSE was the score on the mini mental status examination (Folstein et al., 1975) often used as a preliminary screening instrument for dementia. The cognitive ability scores were the average *z*-scores of six reasoning and spatial visualization measures (Raven's progressive matrices, Shipley abstraction, letter sets, spatial relations, paper folding, form boards) for fluid ability, three episodic memory measures (logical memory, word recall, paired associates), three perceptual speed measures (digit symbol substitution, letter comparison, pattern comparison), and four vocabulary measures (WAIS III vocabulary, Woodcock–Johnson picture vocabulary, synonym vocabulary, antonym vocabulary). See Salthouse et al., 2006 for further details of the reference cognitive tasks.

* $p < .01$.

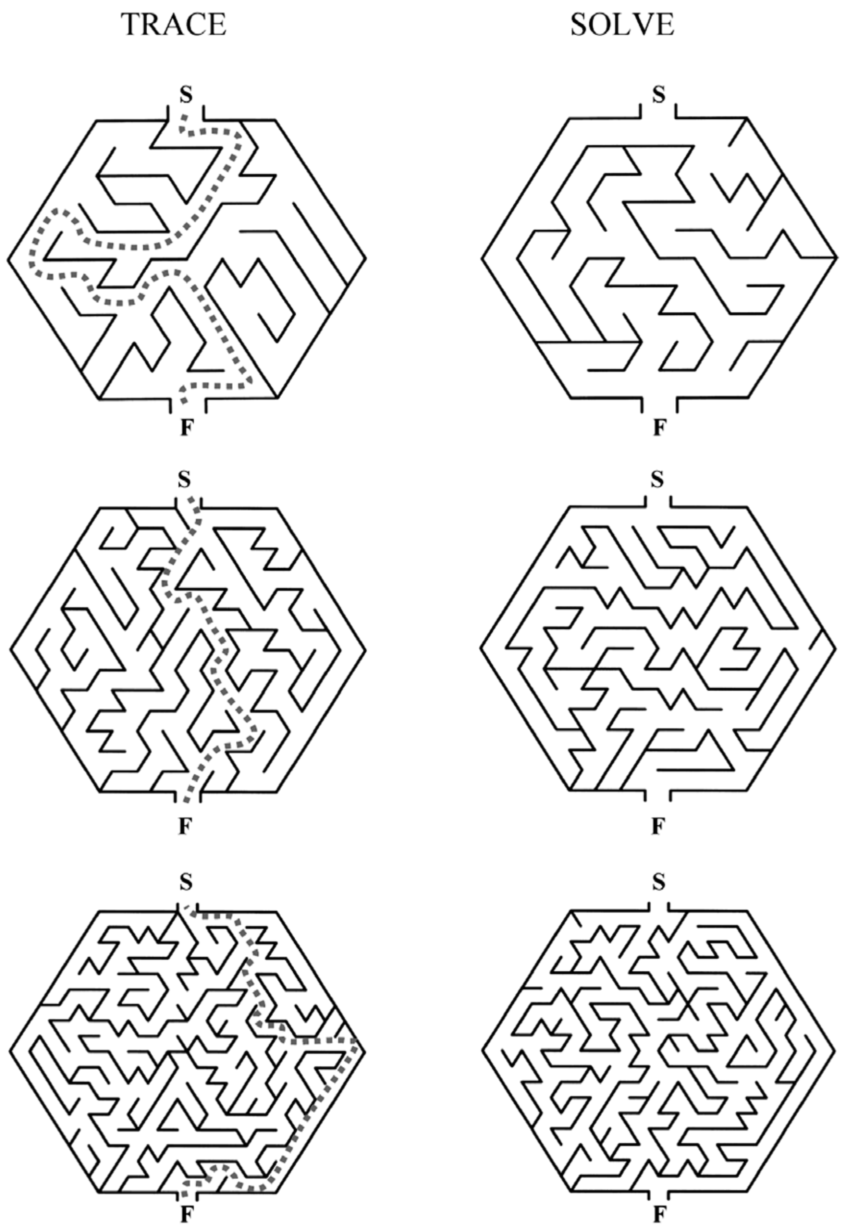

Fig. 1. Illustration of sample mazes in the trace (left) and solution (right) conditions, at each level of complexity (from top to bottom).

different exhibits. (See Fig. 2 for an example.) The task for the participant was to select the most efficient route for visiting six designated exhibits by specifying the order in which the six exhibits would be visited. The same zoo map was used on two successive trials, with a different set of exhibits that were to be visited on each trial, followed by two trials with the other map. There were no time limits for the participants to complete the four separate zoo trips.

Route efficiency was assessed by the straight line distance for the selected sequence of exhibits. Although the presence of obstacles, such as ponds, grass, and bushes, precluded the most direct route in some cases, these "as the bird flies" measurements were considered reasonable approximations to the distances of the optimal routes, and were much easier to measure reliably than routes that followed curved paths. The correlation of the measured distances for two independent raters was greater than .99, and the average distance across the two raters was used as the distance measure. In addition to the distance of the shortest route between the selected sequence of exhibits, the proportion of errors in which the sequence did not include all of the designated exhibits was also used as a dependent variable in the zoo trip task.

1.5. Analytical strategy

There were three stages in our analyses. First, we examined relations of age to all of the performance measures in the two route selection tasks. Next, we investigated the reliability of the primary measures from the Maze and Zoo Trip tasks, and their correlations with one another, and

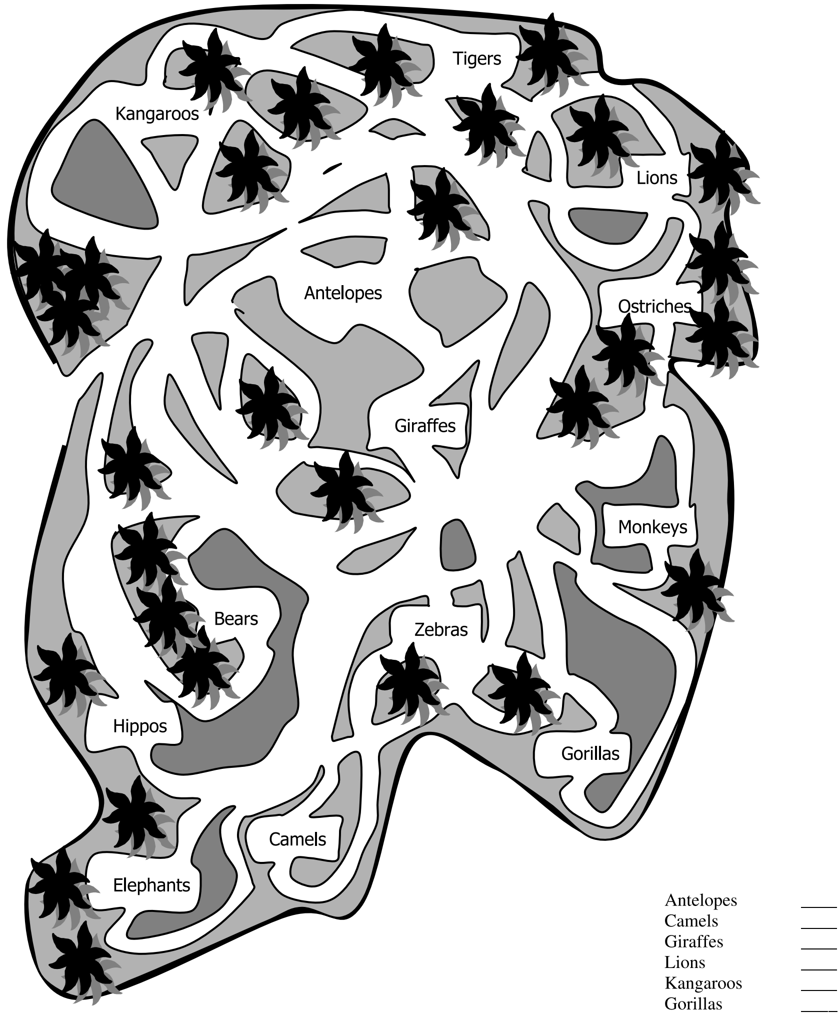

Fig. 2. Illustration of one of the zoo maps used in the Zoo Trip task, with the six exhibits to be visited in the lower right.

Table 2
Summary statistics for the measures from the tasks postulated to involve planning

	Age group			Age R^2		
	18–39	40–59	60–93	Age	Age^2	Age^3
Mazes						
Trace (s)	5.7 (3.4)	5.8 (3.0)	7.8 (4.4)	.08*	.02	.04*
Solve (s)	10.8 (4.5)	14.6 (6.4)	21.9 (12.3)	.27*	.02*	.01
Difference (solve–trace)	5.1 (3.8)	8.9 (6.1)	14.1 (11.6)	.20*	.01	.00
Ratio (solve/trace)	2.2 (0.9)	2.9 (1.4)	3.3 (2.5)	.07*	.00	.00
Zoo trip						
Errors	.03 (.18)	.05 (.22)	.13 (.37)	.04*	.04*	.04*
Inefficiency	54.4 (2.7)	54.9 (3.7)	56.3 (4.4)	.05*	.04*	.03*

Note: Values in parentheses are standard deviations.
* $p < .01$.

with variables frequently assumed to represent executive functioning. Finally, we used structural equation models with cognitive abilities and age as predictors of the route selection measures to determine which abilities contributed to performance on the measures and the extent to which the age-related influences were independent of other cognitive abilities.

2. Results[2]

Summary measures of performance for each task in the three age groups are presented in Table 2. It is apparent

[2] Because of the moderately large sample and the numerous statistical comparisons, a .01 significance level was used in all statistical tests.

that both maze tracing time and maze solution time were greater with increased age. An analysis of variance was conducted on the maze completion times with age (three levels; age 18–39, 40–59, and 60–93) complexity (three levels; simple, medium, and complex) and condition (two levels; trace and solve) as factors. All main effects and interactions in this analysis were significant ($F > 11.4$). The three-way interaction indicated that the largest age differences occurred for solution times on medium and complex mazes, with relatively small age differences in the maze tracing times regardless of maze complexity.

In addition to examining the difference between solution time and tracing time, the ratio of the two times was also investigated. Both the difference and the ratio had significant positive correlations with age, and thus the relation of age with maze solution performance was not merely attributable to proportional slowing.

In order to examine possible non-linearities in the age relations, quadratic (age^2) and cubic (age^3) terms were examined in addition to the linear (age) term. As can be seen in the right-most columns of Table 2, several of the non-linear trends were significant, indicating an accelerated decline with increased age.

Errors in the zoo trip routes occurred either by repeating, or omitting, one of the designated exhibits. Although errors were relatively infrequent, they were significantly more likely with increased age. The distance between the selected exhibits was also longer with increased age, indicating that the routes were less efficient. However, the number of errors in the zoo trip was not significantly correlated with the length of the selected route (i.e., $r = .07$). The age differences were small relative to the total distances of the routes (i.e., the percentage difference in average route length between the oldest and youngest groups was only 3.5%), but they were moderately large when expressed in standard deviation units (i.e., the mean of the older group was .7 young-group standard deviations greater than the mean of the young group).

Reliabilities of the solve-trace difference in the maze task and the inefficiency measure in the zoo trip were estimated with coefficient alpha. Neither of these estimates, which are presented in parentheses along the diagonal in Table 3, were very high. Nevertheless the two route selection measures were significantly correlated with one another and with the WCST and category fluency measures. These latter correlations are consistent with suggestions of executive functioning involvement in this aspect of planning.

Age-related effects on the variables from the route selection tasks were next considered in the context of age-related effects on established cognitive abilities. The analyses were based on a structural equation model in which age was related to four latent constructs corresponding to different cognitive abilities, and with age and each ability related to the target variable. The analytical model and procedures are described in detail in Salthouse (2005) and Salthouse et al. (2006). Standardized coefficients representing the total and unique relations of age on each variable, and the relations of the cognitive abilities to the variable, are presented in Table 4.

Table 3
Correlations before (below diagonal) and after (above diagonal) adjustment for reliability of the variables

	1	2	3	4	5
1. Mazes difference	(.55)	.41*	−.26*	.01	−.34*
2. Zoo trip inefficiency	.25*	(.68)	−.41*	−.14	−.26*
3. WCST # Categories	−.19*	−.34*	(NA)	.23*	.33*
4. Letter fluency	.01	−.10	.21*	(.86)	.59*
5. Category fluency	−.24*	−.18*	.31*	.51*	(.88)

Note: Values in parentheses are estimated reliabilities. Correlations below the diagonal are raw correlations and those above the diagonal are adjusted for reliability with the formula $(rXY' = rXY)/\sqrt{([rXX * rYY])}$. Because no estimate of reliability was available for the WCST variable the adjusted correlations assume that the reliability for that variable is 1.0, and thus they are underestimates of the reliability-adjusted correlations.
* $p < .01$.

Table 4
Standardized coefficients relating age and cognitive abilities to individual variables

Variable	Total age	Unique age	Cognitive ability				R^2
			gF	Mem	Speed	Voc	
Mazes							
Trace	.28*	−.11	−.07	−.24*	−.35*	.07	.21
Solve	.52*	.15	−.25*	−.01	−.31*	.14*	.38
Difference	.45*	.21*	−.24*	.09	−.19*	.12	.28
Ratio	.26*	.25*	−.21*	.17	.08	.13	.14
Zoo trip							
Errors	.20*	.13	−.00	−.17	.01	−.01	.06
Inefficiency	.23*	.02	−.32*	−.11	−.06	−.08	.15

* $p < .01$.

Inspection of the entries in Table 4 indicates that maze tracing performance was faster among individuals with higher perceptual speed abilities, but inexplicably, people with high memory ability were also faster at maze tracing. Because this relation is not easily explained and occurred in the context of a large number of statistical comparisons, it may be spurious and should probably be replicated before it is treated as genuine. Maze solution time was related both to perceptual speed and gF abilities. The influence of speed is understandable because of the timed nature of the task, and the gF influence may be related to the requirement to evaluate options and select an optimal route. It is noteworthy that a higher level of gF ability was associated with a smaller discrepancy between tracing and solving with both the difference and ratio measures. This finding is consistent with the interpretation that the additional time needed to solve, as opposed to merely trace, the mazes reflects aspects of higher-order cognition such as route selection. Participants with higher levels of gF ability selected shorter and more efficient routes in the zoo trip task, but there were no ability relations on the error measure in this task.

The entries in the third column of Table 4 indicate that only the maze difference and ratio measures had significant unique relations with age. These results imply that the age-related influences on the other measures from these tasks, represented by the entries in the second column, were shared with age-related influences on the cognitive abilities. However, an additional explanation is required for the age-related influences on the maze difference and maze ratio measures because some of these effects are independent of effects on the reference cognitive abilities.

The final column in Table 4 indicates the proportion of variance in the target variables that could be accounted for by age and the cognitive ability factors in the model. It is worth noting that none of the values is particularly large, which may be a reflection of low reliability of the target variables and/or omission of relevant predictor variables.

3. Discussion

The results of this study suggest that there is a moderate age-related decline in measures of the efficiency of route selection (i.e., the solve—trace difference in the maze task, and efficiency of routes in the zoo trip task). The results in Table 2 suggest that the decline may accelerate after about age 60, but this trend needs to be interpreted cautiously because it could be at least partially attributable to a ceiling effect in the performance of younger adults.

The measures of performance in the zoo trip task were rather crude because the differences in distance between the optimal and non-optimal routes were very small. Because the zoo trip task appears promising as a measure of route selection, it is worth considering how the task could be redesigned to create larger differences between optimal and non-optimal solutions. For example, the map might be made more complex, the participants could be asked to visit more exhibits, or additional constraints could be included, such as visiting the elephant exhibit during feeding time.

The current findings are consistent with other research that has reported age differences in variants of the zoo trip task. For example, Bisiacchi et al. (1998) have reported age differences in a task that required participants to complete a series of errands in a fictitious town using the most efficient route. Allain et al. (2005) recently administered a zoo trip task to groups of young and older participants, and reported that older adults used less efficient routes, and committed more errors compared to the younger adults. Based on their findings, Allain et al. (2005) suggested that the age-related decline in route selection was due to impairment in the formulation rather than execution of the plan. Our discovery that route selection efficiency was correlated with measures of executive functioning and higher–order cognitive abilities is consistent with their argument.

The route selection measures were significantly related to several variables often assumed to reflect executive functioning, but they were also related to other cognitive abilities. All of these relations therefore need to be considered when evaluating what the route selection variables represent because it may be just as plausible to claim that the route selection measures represent fluid ability as executive functioning.

Because a considerable amount of research has established the existence of adult age differences on many different cognitive abilities, it is important to determine the extent to which the age differences in the variable of interest are statistically independent of age-related differences that have already been established. The particular set of variables or abilities selected to function as the reference or context constructs in these types of analyses depends upon the researcher's theoretical perspective, but only by examining multiple variables simultaneously is it possible to determine the number, and nature, of any unique age-related influences that may be operating on the target variable. In the current study there was considerable overlap of the age-related differences in the variance common to the route selection measures and the age-related differences in the gF variables, suggesting that the same sets of explanatory mechanisms are likely to be involved in the age differences in both sets of measures.

The specific nature of the explanatory mechanisms contributing to age-related cognitive declines is still largely a matter of speculation, and could involve speed, inhibition, working memory, or other factors. However, given the wide range of variables that are affected, it seems likely that multiple mechanisms are involved. In fact, based on the pattern of unique age-related influences observed in a large data set, Salthouse (2004b) hypothesized that aging reduces the effectiveness of frontal lobe functioning, of medial-temporal lobe functioning, and of the efficiency of communicating across different regions of the brain.

The additional time needed to solve as well as trace the mazes was related to age even after considering influences through the cognitive abilities, which included perceptual speed. Because relevant perceptual-motor aspects are presumably controlled by adjusting for performance in the tracing condition, these unique effects are unlikely to reflect simple perceptual or motoric factors. They may represent an aspect of planning that is not incorporated into the gF construct, but additional research is needed to determine if that is the case, and if so, the nature of that aspect. One possible approach might be to include additional measures of selection and planning processes in future studies to determine which of the variables are related to one another, and might be influenced by the same mechanisms.

In conclusion, measures of performance on two tests designed to assess route selection efficiency were found to be moderately correlated with one another, and with measures often assumed to represent executive functioning and with cognitive abilities such as fluid ability and perceptual speed. Although increased age was associated with lower levels of performance on both route selection tasks, large proportions of those age-related influences were shared with established cognitive abilities. No specific explanation may therefore be needed to account for age differences in route selection beyond those that are applicable to age differences in other cognitive abilities.

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References

Allain, P., Nicoleau, S., Pinon, K., Etcharry-Boux, F., Barre, J., Gerrut, G., et al. (2005). Executive functioning in normal aging: a study of action planning using the Zoo Map Test. *Brain and Cognition, 57*, 4–7.

Barrash, J. (1994). Age-related decline in route learning ability. *Developmental Neuropsychology, 10*, 189–201.

Bisiacchi, P. S., Sgaramella, T. M., & Farinello, C. (1998). Planning strategies and control mechanisms: evidence from closed head injury and aging. *Brain and Cognition, 37*, 113–116.

Caplan, L. J., & Lipman, P. D. (1995). Age and gender differences in the effectiveness of map-like learning aids in memory for routes. *Journal of Gerontology: Psychological Sciences, 50B*, P126–P133.

Craik, F.I.M. & Salthouse, T.A. (Eds.). (2000). *Handbook of Aging and Cognition*. (2nd ed.). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Davies, A. D. (1973). Age and temperament effects on maze performance under speed and accuracy stress. *Perceptual and Motor Skills, 37*, 502.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198.

Garden, S. E., Phillips, L. H., & MacPherson, S. E. (2001). Midlife aging, open-ended planning, and laboratory measures of executive function. *Neuropsychology, 15*, 472–482.

Heaton, R.K., Chelune, G.J., Talley, J.L., Kay, G.G. & Curtiss, G. (1993). Wisconsin Card Sorting Test Manual: Revised and Expanded. Odessa, FL: Psychological Assessment Resources.

Heron, A., & Chown, S. M. (1967). *Age and function*. Boston: Little-Brown & Co.

Lipman, P. D. (1991). Age and exposure differences in acquisition of route information. *Psychology and Aging, 6*, 128–133.

Lipman, P. D., & Caplan, L. J. (1992). Adult age differences in memory for routes: effects of instruction and spatial diagram. *Psychology and Aging, 7*, 435–442.

Meulenbroek, O., Petersson, K. M., Voermans, N., Weber, B., & Fernandez, G. (2004). Age differences in neural correlates of route encoding and route recognition. *Neuroimage, 22*, 1503–1514.

Moffat, S. D., & Resnick, S. M. (2002). Effects of age on virtual environment place navigation and allocentric cognitive mapping. *Behavioral Neuroscience, 116*, 851–859.

Moffat, S. D., Zonderman, A. B., & Resnick, S. M. (2001). Age differences in spatial memory in a virtual environment navigation task. *Neurobiology of Aging, 22*, 787–796.

Newman, M. C., & Kaszniak, A. W. (2000). Spatial memory and aging: performance on a human analog of the Morris water maze. *Aging, Neuropsychology, and Cognition, 7*, 86–93.

Salthouse, T. A. (1995). Influence of processing speed on adult age differences in learning. *Swiss Journal of Psychology, 54*, 102–112.

Salthouse, T. A. (2004a). What and when of cognitive aging. *Current Directions in Psychological Science, 13*, 140–144.

Salthouse, T. A. (2004b). Localizing age-related individual differences in a hierarchical structure. *Intelligence, 32*, 541–561.

Salthouse, T. A. (2005). Relations between cognitive abilities and measures of executive functioning. *Neuropsychology, 19*, 532–545.

Salthouse, T. A., Siedlecki, K. L., & Krueger, L. E. (2006). Individual differences in controlling the contents of memory. *Journal of Memory and Language, 55*, 102–125.

Shallice, T., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain, 114*, 727–741.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale–Third Edition*. San Antonio, TX: Psychological Corporation.

Wilkniss, S. M., Jones, M. G., Korol, D. L., Gold, P. E., & Manning, C. A. (1997). Age-related differences in an ecologically based study of route learning. *Psychology and Aging, 12*, 372–375.

Wilson, B. A., Alderman, N., Burgess, P., Emslie, H., & Evans, J. J. (1996). *Behavioural Assessment of the Dysexecutive Syndrome (BADS)*. London: Harcourt Assessment.