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BRIEF REPORT

Using contextual analysis to investigate the nature of spatial memory

Karen L. Siedlecki · Timothy A. Salthouse

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Abstract The present study investigated the properties of episodic spatial memory by conducting contextual analysis on spatial memory tasks in a large sample of individuals ($N = 778$) between the ages of 18 and 92. The results suggest that episodic spatial memory as measured by a dot location task is not uniquely influenced by memory but is strongly influenced by fluid ability (Gf). The spatial memory–Gf relationship is evident and robust even when spatial memory is operationalized with a very simple single-dot location task, suggesting that allocation of attention across space may play a role in the relationship. Results also indicate that the spatial memory–Gf relations are not dependent on complexity of processing, because Gf has a similar magnitude of relations with a more complex version of the dot location task. Collectively, the results suggest that spatial memory likely represents some aspect of fluid intelligence and is not uniquely related to measures of verbal memory.

Keywords Fluid ability · Memory · Spatial memory

Whereas much research has examined distinctions within the memory system (e.g., long-term memory vs. short-term memory, semantic memory vs. procedural memory, working memory vs. short-term memory, etc.), little research has examined the nature of spatial episodic memory, especially when compared with other types of memory. One way to get a better understanding of spatial memory is to examine its relations with other constructs. However, the relations among spatial memory and other cognitive constructs have not been extensively studied. In fact, the comprehensive taxonomy of intellectual functioning, the Cattell–Horn–Carroll model of human cognitive abilities, does not include an assessment of spatial memory in its description of intellectual functioning (e.g., McGrew, 2009). Furthermore, although verbal episodic memory is routinely included in cognitive and neuropsychological batteries, few cognitive batteries include tests of spatial episodic memory. For example, the Wechsler Memory Scale (WMS; Wechsler, 1997), a widely used battery of memory tests, does not contain a measure of spatial memory. The Neuropsychological Assessment Battery (Stern & White, 2003) includes a spatial module, but none of the subtests explicitly measures memory for location (for an exception, see the Rivermead Behavioral Memory Test; Wilson, Cockburn, & Baddeley, 1991).

It should be noted that although spatial memory is often referred to interchangeably with visual memory, spatial memory and visual memory reflect memory for different types of information. Spatial memory refers to "where" information (i.e., location), and visual memory refers to "what" information (typically measured using visually presented stimuli that cannot be verbalized) (Klauer & Zhao, 2004). This is in contrast to verbal memory, which generally refers to memory for information that can be stored phonetically and is tested in the laboratory with visual or auditory stimuli including words, stories, or facts.

The purpose of this study was to further examine the nature of episodic spatial memory by examining its relations with other types of constructs. Evaluating which cognitive constructs contribute to spatial memory performance will provide us with a better understanding of spatial memory. The most informative type of relational analyses are not simple correlations, with single variables representing each construct, but simultaneous analyses of multiple constructs,

K. L. Siedlecki (✉)
Department of Psychology, Fordham University, 113 W. 60th Street, New York, NY 10023, USA
e-mail: klsiedlecki@fordham.edu

T. A. Salthouse
Department of Psychology, University of Virginia, Charlottesville, VA 22904, USA

with each construct represented by multiple variables. This is because no single variable exclusively and exhaustively corresponds to a theoretical construct. Instead, any single variable is likely influenced by many factors and probably represents just a portion of the theoretical construct of interest. Furthermore, when only one variable is used to represent a construct, the contribution of the theoretical construct cannot be separated from the specific way in which it is measured (Salthouse, 2000). Therefore, multiple variables and analyses at the level of latent constructs will frequently be more informative than analyses based on single variables. Also, considering several predictors simultaneously allows for the examination of unique relations; when only one predictor is included, all of the variance it shares with other constructs is attributed to the predictor, even though the variance is not unique. An analytical procedure termed *contextual analysis* allows the meaning of a target variable to be examined in terms of a set of latent reference abilities. The reference abilities are simultaneous predictors of the target variable (similar to a multiple regression, but with latent factors as predictors), and the magnitudes of the standardized coefficients reflect the degree to which the target variable is uniquely related to each of the reference abilities.

Although it was not the focus in the original report, data from a study by Siedlecki (2007) can be reanalyzed with contextual analysis to examine how different types of memory, including spatial memory, relate to a set of latent reference abilities. Siedlecki examined the structure of episodic memory by administering several memory tasks incorporating three types of stimuli (verbal, visual, and spatial) and three types of memory tasks (recall, cued recall, and recognition). Verbal memory was assessed for memory for lists of words, visual memory (also termed figural memory) was assessed for memory for abstract line drawings, and spatial memory was operationalized as memory for the location of dots within a matrix (see Fig. 3 in Siedlecki, 2007, for an illustration of stimuli and testing modalities). To gain a better understanding of the nature of spatial memory, we reanalyzed the Siedlecki (2007) data using contextual analysis. Table 1 summarizes the results in which each target construct represents three different retrieval modes (recognition, cued recall, and recall) for each type of stimulus material (words, figures, and spatial location). The reference constructs include the latent factors of Gf, processing speed, memory, and vocabulary. Age was also included as a predictor. The numbers in the first row for each variable is the standardized coefficient from the latent reference factor to the target construct when the Gf factor comprises measures of visual-spatial ability and reasoning, including matrix reasoning, letter sets, Shipley abstraction, spatial relations, paper folding, and form boards. The numbers in the second row for each variable are the standardized coefficients from the latent reference factors to the target variable when the Gf factor is represented more narrowly, comprising variables whose stimuli consist only of verbal material (i.e., letter sets, Shipley abstraction). Specifically, Shipley abstraction (Zachary, 1986) is a reasoning task that requires participants to determine the words or numbers that provide the best continuation of a sequence. The letter set task requires participants to determine which set of letters is different from among five sets of letters (Ekstrom, French, Harman, & Dermen, 1976).

Table 1 Contextual analysis of the Siedlecki (2007) constructs

		Latent Reference Factors			
Target Construct	Age	Gf	Memory	Speed	Vocab
Words	.19	−.08	.85*	.35*	−.19
	.19	−.31	.93*	.44*	−.10
Figures	.09	.68*	.35*	.14	−.26*
	−.11	.43*	.33*	.18	−.11
Locations	.12	.80*	.03	.21*	−.17
	−.09	.69*	−.05	.20	−.08

Note. The values reflect standardized regression coefficients when the target construct is simultaneously predicted by age and the reference constructs. For each target construct, the first row of numbers reflects the relationship among the constructs and the target construct when the Gf construct consists of spatial and verbal tasks, and the second row of numbers reflects the relationship when the Gf construct consists of only verbal reasoning tasks.

* $p < .01$

The results presented in Table 1 indicate that memory for words (verbal memory) is predicted by the memory and processing speed factors and memory for figures (visual memory) is predicted by fluid ability, memory, and also vocabulary (in one set of contextual analyses). What is striking is that memory for location (spatial memory) is not predicted by the memory factor. Rather, it is predicted by the Gf factor (and the processing speed factor in one contextual analysis). Notably, the relationship between spatial memory and the Gf factor exists even when the tests of Gf that include spatial components are eliminated from the Gf factor. The standardized coefficient from the Gf factor to the spatial memory construct was .80 when the Gf construct was operationalized with both verbal and spatial tasks and was .69 when the Gf construct was operationalized with only verbal tasks. Age did not have any significant unique relations to the target memory constructs, once the influence of the reference constructs was considered.

These results suggest that Gf has a unique (i.e., independent of other cognitive abilities) influence on memory tasks that are spatial in nature and, importantly, this influence exists regardless of whether Gf is operationalized with or without spatial tasks. Thus, an important question is the following: What explains the strong, unique relationship between spatial memory and Gf? One possibility is that Gf is related to the flexible allocation of attention across space.

Because there were no significant unique relations between Gf and verbal memory, it seems unlikely that Gf is related to general aspects of attention allocation. We therefore hypothesized that if an important aspect of the spatial memory–Gf relationship is the distribution of attention across space, substantial Gf involvement might be found even with a very simple spatial memory task. To address this hypothesis, we designed a dot location task in which a dot was displayed on a computer screen and, after a brief mask, the participant used the mouse to reproduce the position of the dot. This version of the task was expected to have minimal processing requirements, because participants merely have to reproduce the position of a single dot. This single-dot task is similar to previous tasks used to measure spatial memory (e.g., Huttenlocher, Hedges, & Duncan, 1991). A three-dot condition was also administered in which three dots were presented and the task was to reproduce the position of one randomly cued dot (see Fig. 1). It was hypothesized that the more complex condition was more demanding in terms of cognitive resources because three positions had to be maintained in memory before reproduction.

Another explanation for the relationship between spatial memory and Gf relates to the nature of spatial information and its differences from verbal information. It is possible that recalling spatial information is more complex or difficult than recalling verbal information and, therefore, fluid intelligence plays a role in spatial memory because of the increased complexity of spatial information. For example, we know that verbal information activates a semantic network that presumably allows familiarity to play a role in remembering (thereby likely enhancing memory performance), whereas no comparable network exists or is activated with the presentation of spatial information. We examined whether complexity played a role in the spatial memory–Gf relationship by examining whether the relationship was stronger in the more demanding three-dot version of the task. If so, that would suggest that the amount of processing is an important component in the spatial memory–Gf relationship. In contrast, if the Gf relations were of similar magnitude across the two task conditions, that would suggest that the spatial memory–Gf relationship is independent of task demand and that complexity of information does not explain the relationship.

In sum, the results presented in Table 1 provide compelling evidence that spatial memory as measured by memory for location is different in some ways from visual and verbal memory, both of which have a significant relationship with the reference memory construct. In contrast, spatial memory had no unique relations with the reference memory construct and, instead, was significantly related to Gf. The present study was designed to expand on the findings presented in Table 1 and further characterize the nature of spatial memory by examining the relationships among a very simple spatial memory task and Gf (and other cognitive constructs), using contextual analysis. We examined two different aspects of the spatial memory–Gf relationship in the present study. First, in order to ascertain whether some aspect of the relationship can be explained by the distribution of attention across space, we examined whether there was a strong relationship between spatial memory and Gf when a very simple (single-dot) location task was administered. Second, we examined whether task complexity played a role in the relationship.

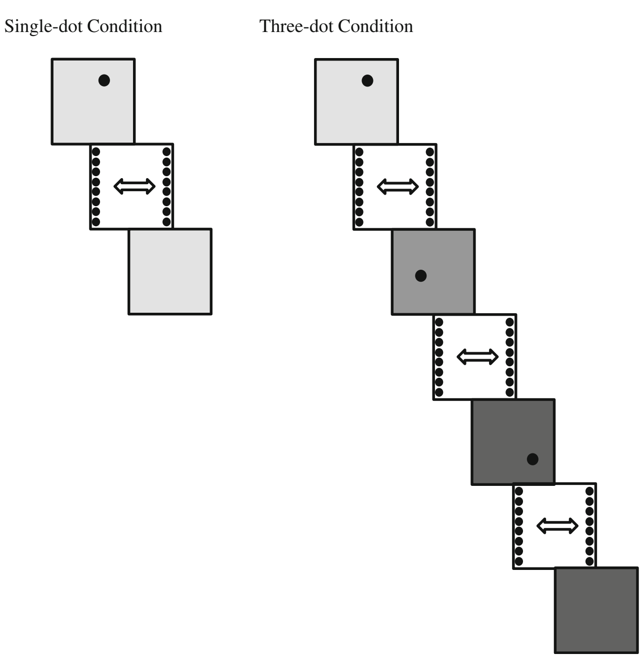

Fig. 1 Illustration of the sequence of displays in the dot location task. In the laboratory task, the dots were presented on colored backgrounds (e.g., blue, yellow, red) rather than on backgrounds in different shades of gray. Duration of each stimulus display and each mask was 1 s

Method

Participants

Participants consisted of 778 adults between the ages of 18 and 92 years (M = 54.7, SD = 14.5), who were recruited through newspaper advertisement, flyers, and referrals from other participants. Only participants with a Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) score greater than 23 were included in the analyses. The resulting sample was 70 % female, was highly educated (mean years of education = 15.1, SD = 9.6), and had a mean MMSE score of 28.5 (SD = 1.6).

Procedure

Participants each completed three 2-h testing sessions in which they were administered a battery of cognitive tests, including the 16 variables that make up the latent cognitive reference constructs, and the dot location task. A list of the tasks can be found in Table 2, and detailed descriptions of each task can be found in Salthouse, Atkinson, and Berish (2003). Of note, the reference memory construct consisted of three verbal memory tasks, including the word list recall and logical memory subtests of the WMS (Wechsler, 1997) and a paired associate task (Salthouse, Fristoe, & Rhee, 1996).

Dot location task

In the single-dot condition, a dot was displayed on colored background for 1 s, followed by 1 s in which two vertical columns of dots moved from the edge to the center and back to mask the initial display and then a colored background. In the three-dot condition, three successive pairs of dot and mask were displayed (with a 1-s stimulus display followed by a 1-s mask), each with a different colored background. Three different background colors were used, and the color was used as a probe for location of a particular dot in the three-dot condition (but was irrelevant in the single-dot condition; see Fig. 1). The dot presented in the first position in the three-dot condition is referred to as three-dot 1, the dot presented in the second position is referred to as three-dot 2, and the dot presented in the third position is referred to as three-dot 3. Participants were instructed to use the computer mouse to reproduce the dot location. Each block of trials consisted of 20 trials, with the first block of each type (single or multiple) preceded by 3 practice trials, which could be repeated if desired. The instructions emphasized accuracy, and there was no time limit for responding. The measure of performance was the distance from the correct location in pixels.

Table 2 Means, standard deviations, and age correlations for the reference ability variables

	Mean	*SD*	Age *r*
Gf			
Form boards	7.61	4.01	−.32
Matrix reasoning	7.77	3.26	−.36
Letter sets	11.19	2.69	−.17
Paper folding	6.03	2.63	−.26
Shipley abstraction	13.57	3.34	−.29
Spatial relations	8.66	4.91	−.14
Memory			
Paired associates	2.99	1.78	−.24
Word recall	35.02	6.21	−.28
Logical memory	44.63	9.87	−.18
Processing speed			
Letter comparison	10.45	2.32	−.40
Pattern comparison	16.26	3.46	−.43
Digit symbol	73.51	16.70	−.45
Vocabulary			
Antonym vocabulary	6.59	2.97	.25
Synonym vocabulary	6.92	2.97	.31
Vocabulary	49.73	12.54	.15
Picture vocabulary	18.31	5.71	.31

Note. All age correlations are significant at the $p < .01$ level.

Modeling procedure

Structural equation modeling was used to conduct the contextual analysis on the dot location task. Each dot location task served as target variable in separate models, and the reference constructs (comprising the latent constructs of Gf, memory, speed, and vocabulary) were simultaneous predictors of the target variable (for additional information on contextual analysis, see the description in the introduction). Each of the latent reference constructs comprised between three and six variables from different tests. These constructs have been used extensively by Salthouse and colleagues (e.g., Krueger & Salthouse, 2011; Salthouse, 2011). Maximum likelihood estimation was used to deal with missing data. A significance level of .01 was used in all analyses.

Results

A confirmatory factor analysis (CFA) was performed on a four-factor model comprising the reference constructs of vocabulary, Gf, memory, and processing speed. CFA refers to a type of factor analysis in which a researcher specifies a model and then examines how well the hypothesized model fits the data. The four-factor model had an acceptable fit to the data, $\chi^2(98) = 639.77$, CFI = .93, RMSEA = .084. A second four-factor model in which the spatial variables were excluded from the Gf construct and only the verbal reasoning variables (Shipley abstraction, letter sets) were included in the Gf construct also had a reasonable fit, $\chi^2(48) = 292.70$, CFI,= .96, RMSEA = .081. In both models, the standardized loadings from the latent construct to the observed variables were greater than .70 (all ps < .01). Means, standard deviations, and age correlations for the reference ability variables are presented in Table 2. Correlations among the variables are presented in Table 3.

Dot location task

The mean magnitude of error in the single-dot condition was 15.1 (*SD* = 7.8). The mean errors for each of the multiple-dot variables were the following: position 1, *M* = 67.67, *SD* = 49.23; position 2, *M* = 56.00, *SD* = 43.86; position 3, *M* = 33.38, *SD* = 22.81. The Cronbach alpha across the eight administrations of the test (i.e., two administrations for each

Table 3 Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Single-dot	1.00																		
2. Three-dot 1	.44	1.00																	
3. Three-dot 2	.43	.60	1.00																
4. Three-dot 3	.57	.38	.49	1.00															
5. Form boards	−.29	−.32	−.31	−.23	1.00														
6. Matrix reasoning	−.31	−.39	−.37	−.27	.59	1.00													
7. Letter sets	−.31	−.46	−.44	−.34	.45	.60	1.00												
8. Paper folding	−.29	−.37	−.34	−.24	.58	.64	.50	1.00											
9. Shipley abstraction	−.37	−.48	−.49	−.41	.53	.66	.65	.57	1.00										
10. Spatial relations	−.29	−.39	−.33	−.23	.61	.65	.57	.69	.59	1.00									
11. Paired associates	−.20	−.30	−.30	−.24	.39	.47	.44	.41	.50	.42	1.00								
12. Word recall	−.24	−.35	−.36	−.34	.34	.45	.44	.38	.49	.35	.62	1.00							
13. Logical memory	−.24	−.32	−.35	−.30	.37	.46	.44	.42	.56	.38	.53	.55	1.00						
14. Letter comparison	−.32	−.35	−.35	−.32	.33	.34	.40	.28	.47	.24	.31	.38	.31	1.00					
15. Pattern comparison	−.31	−.29	−.29	−.28	.42	.40	.37	.32	.44	.31	.33	.37	.30	.68	1.00				
16. Digit symbol	−.30	−.35	−.36	−.31	.41	.50	.47	.40	.54	.35	.45	.52	.43	.65	.62	1.00			
17. Antonym vocabulary	−.15	−.31	−.25	−.15	.25	.32	.39	.29	.40	.35	.39	.27	.39	.14	.08	.14	1.00		
18. Synonym vocabulary	−.13	−.30	−.27	−.17	.22	.34	.38	.32	.41	.39	.37	.26	.42	.12	.08	.12	.82	1.00	
19. Vocabulary	−.19	−.36	−.33	−.26	.30	.43	.47	.36	.51	.41	.39	.35	.48	.22	.18	.25	.68	.71	1.00
20. Picture vocabulary	−.18	−.34	−.28	−.14	.30	.34	.42	.36	.45	.43	.39	.27	.41	.12	.10	.16	.67	.70	.72

Note. All ps < .01

of the four variables) was .79, indicating that the dot location task had adequate reliability.

A repeated measures ANOVA indicated that there was a significant effect of condition on magnitude of errors, $F(3, 2331) = 540, p < .01$. The partial eta-squared was large ($\eta_\rho^2 = .41$). Post hoc comparisons of the four variables indicated that participants had significantly smaller errors in the single-dot condition, as compared with the three-dot conditions. Cohen's d values indicate large effect sizes for the differences among the single-dot variable and the three-dot 1, three-dot 2, and three-dot 3 variables (Cohen's d = 1.49, 1.30, and 1.07, respectively). Furthermore, in the three-dot variable, there was an association between serial position of the dot location pair in the trial and magnitude of error. Specifically, the mean magnitude of error was significantly greater in position 1 than in position 2 (Cohen's $d = 0.25$) and position 3 (Cohen's $d = 0.89$), and the mean magnitude of error was significantly greater in position 2 than in position 3 (Cohen's $d = 0.65$, all ps < .01).

Contextual analysis

Results of the contextual analysis for the dot location variables are presented in Table 4. The values reported in the table are standardized coefficients from the latent reference construct to each respective dot location variable and reflect the unique influence of each latent predictor on the target variable that is independent of the other predictors. Preliminary models indicated that gender had no significant unique relations with

Table 4 Contextual analysis of the dot location task

		Latent Reference Factors			
Target Variable	Age	Gf	Memory	Speed	Vocab
Single-dot	−.12	−.36*	.06	−.27*	.07
	−.09	−.41*	.07	−.22*	.09
Three-dot 1	−.09	−.36*	.01	−.22*	−.11
	−.09	−.53*	.06	−.12	−.03
Three-dot 2	−.09	−.31*	−.10	−.21*	−.03
	−.11	−.56*	−.04	−.09	.09
Three-dot 3	−.07	−.14	−.20	−.21*	.05
	−.11	−.41*	−.14	−.11	.17

Note. The values reflect standardized regression coefficients when the target variable is simultaneously predicted by age and the reference constructs. For each target variable, the first row of numbers reflects the relationship among the constructs and the target variable when the Gf construct consists of spatial and verbal tasks. The second row of numbers reflects those relationships when the Gf construct consists of only verbal tasks.

* p < .01

the target variables and was thus excluded from the final models.

Both the broad conceptualization of the Gf factor (first row of numbers for each target variable) and the narrow verbal-only conceptualization of the Gf factor (second row of numbers for each target variable) had significant and moderate-sized relations (significant standardized coefficients range from −.31 to −.56) with each of the dot location variables, except in one case. Surprisingly, in each case, the dot location task had a somewhat stronger relationship to the verbal-only Gf factor, rather than the Gf factor that was more broadly defined with both spatial ability and verbal tasks. The speed construct also had significant relations to the single-dot variable (in both models) but was significantly related to the three-dot variables only in the broad Gf factor model. Neither the memory nor the vocabulary factors had significant unique relations to any of the dot location variables. There were no significant unique relations among age and the dot location variables after influences of age on the reference abilities were considered.

Results of additional analyses examining the correlations between the latent reference abilities and each of the dot location variables indicate that each of the dot location variables was significantly correlated to the memory construct, rs = −.30, −.43, −.45, and −.39 between memory and single-dot, three-dot 1, three-dot 2, and three-dot 3 variables, respectively. However, as was described above, these relations are no longer significant when the unique relations among the memory construct and the dot location variables are examined.

Discussion

The results of the present study suggest that different spatial memory tasks have strong unique relations with measures of fluid intelligence and, surprisingly, are not significantly uniquely related to memory, despite requiring the recall of information. What is novel about the present analysis is that we are able to examine the unique contribution of the reference constructs on the target variables that is independent of the variance shared with the other cognitive constructs and with age. Even after the shared variance was partialled out using contextual analysis, different measures of spatial memory had substantial relations with the Gf factor. Furthermore, the spatial memory−Gf relationship is robust regardless of whether the Gf factor comprises tests of abstract reasoning and visualization that use figural and spatial stimuli (e.g., matrix reasoning, paper folding) or whether Gf is measured only with tests of verbal logic and analogical reasoning (letter sets and Shipley abstraction).

Results of the reanalysis of the Siedlecki (2007) data presented in Table 1 provide compelling evidence that (1) spatial memory is different from visual and verbal memory and (2) there is something special about the relationship between spatial memory and Gf. This is evidenced by the lack of a unique relationship between memory for locations and the memory factor and the large relations between the Gf factor and memory for locations. In contrast, memory for words was significantly related to the memory factor but had no significant relations to the Gf factor.

In the present study, contextual analysis was used to further examine the relationship between spatial memory and Gf. First, we hypothesized that if the relationship can be linked to the distribution of attention across space, we would find a robust relationship between spatial memory and Gf even when using a very simple dot location task. And, in fact, we found that the unique relationship between spatial memory and Gf was moderate to large in the single-dot condition. Second, we examined whether task complexity plays a role in the relationship. The increased magnitude of error in the three-dot conditions (complex version), as compared with the single-dot condition (simple version), suggests that the three-dot conditions were more demanding. There was also a serial position effect in the three-dot conditions such that information that was presented in position 1 was associated with greater magnitude of error, as compared with positions 2 and 3, and there was greater magnitude of error in position 2, as compared with position 3. However, the magnitude of the relationship between the Gf factor and the dot location task was similar across the very simple single-dot condition and each of the three-dot conditions, independent of serial position. This suggests that task complexity may not be an important component in understanding the spatial memory−Gf relationship.

A limitation of the present study is that we examined the nature of spatial memory using two separate tasks, rather than creating a latent spatial memory construct comprising several different spatial memory tasks. Future research should seek to replicate the present findings when a latent construct comprising several spatial memory tasks is used as a target construct.

Collectively, these results provide important information about the properties of spatial memory as measured by two different dot location tasks. First, the results suggest that despite requiring the recall of information, episodic spatial memory does not have significant unique relations with memory (in this study, the reference memory construct was represented by measures of verbal memory, which is typical in laboratory assessments of memory). Second, spatial memory is strongly influenced by fluid ability, and this relationship is not due to the spatial nature of Gf, since the relationship exists and, in the case of the dot location variables, is even larger when Gf comprises only verbal reasoning tasks. Third, the spatial memory–Gf relationship is evident and robust even when spatial memory is operationalized with a very simple one-dot location task, suggesting that allocation of attention across space may play a role in the relationship. However, the role of spatial attention is speculative, and future research is recommended to further clarify the role of attention in the spatial memory–GF relationship. Fourth, the spatial memory–Gf relations are not dependent on complexity of processing, because Gf has a similar magnitude of relations with the three-dot variables (in which accuracy was substantially lower), as compared with the single-dot condition. In sum, these results suggest that memory for location likely represents some aspect of fluid intelligence and is not uniquely related to measures of verbal memory.

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References

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.

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.

Huttenlocher, J., Hedges, L. V., & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review, 78,* 352–376.

Klauer, K. C., & Zhao, Z. (2004). Double dissociation in visual and spatial short-term memory. *Journal of Experimental Psychology: General, 135,* 355–381.

Krueger, L., & Salthouse, T. A. (2011). Influence of cognitive abilities on word recall performance across trials and list segments. *American Journal of Psychology, 124,* 291–300.

McGrew, K. S. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence, 37,* 1–10.

Salthouse, T. A. (2000). Methodological assumptions in cognitive aging research. In F. I. M. Craik & T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 467–498). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Salthouse, T. A. (2011). What cognitive abilities are involved in trail-making performance? *Intelligence, 39,* 222–232.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology. General, 132,* 566–594.

Salthouse, T. A., Fristoe, N., & Rhee, S. H. (1996). How localized are age-related effects on neuropsychological measures? *Neuropsychology, 10,* 272–285.

Siedlecki, K. L. (2007). Investigating the structure and age invariance of episodic memory across the adult lifespan. *Psychology and Aging, 22,* 251–268.

Stern, R. A., & White, T. (2003). *Neuropsychological Assessment Battery*. Lutz, FL: Psychological Assessment Resources.

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

Wilson, B. A., Cockburn, J., & Baddeley, A. D. (1991). *The Rivermead Behavioral Memory Test* (2nd ed.). Suffolk, UK: Thames Valley Test Company. Manual.

Zachary, R. A. (1986). *Shipley Institute of Living Scale-Revised*. Los Angeles, CA: Western Psychological Services.