PROCESSING SPEED AND VISUO-SPATIAL EXECUTIVE FUNCTION PREDICT VISUAL WORKING MEMORY ABILITY IN OLDER ADULTS.

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Abstract

Background/Study Context: Visual working memory (VWM) has been shown to be particularly age-sensitive. Determining which measures share variance with this cognitive ability in older adults may help to elucidate the key factors underlying the effects of aging.

Methods: Predictors of VWM (measured by a modified Visual Patterns Test) were investigated in a sub-sample ($N = 44$, mean age = 73) of older adults from the Lothian Birth Cohort 1936 (LBC1936; Deary et al., 2007). Childhood intelligence (Moray House Test) and contemporaneous measures of processing speed (four-choice reaction time), executive function (verbal fluency; block design), and spatial working memory (backward spatial span), were assessed as potential predictors.

Results: All contemporaneous measures except verbal fluency were significantly associated with VWM, and processing speed had the largest effect size ($r = -.53$, $p < .001$). In linear regression analysis, even after adjusting for childhood intelligence, processing speed and the executive measure associated with visuo-spatial organization accounted for 35% of the variance in VWM.

Conclusion: Processing speed may affect VWM performance in older adults via speed of encoding and/or rate of rehearsal, while executive resources specifically associated with visuo-spatial material are also important.

Keywords: cognitive aging; working memory; speed of processing; central executive function; childhood intelligence

Working memory is the limited-capacity cognitive system that allows for the simultaneous retention and manipulation of information. As individuals age, however, working memory performance declines (Bopp & Verhaeghen, 2005; Park, Lautenschlager, Hedden, Davidson, Smith, et al., 2002), which can lead to difficulty performing a multitude of everyday activities. As such, working memory tasks have become an important component of cognitive batteries designed to investigate and characterize age-related changes in mental ability. Unfortunately, the majority of this work has focused on either the verbal or domain-general components of working memory, while much less research has specifically focused on the visuo-spatial component that supports memory for objects, faces, and scenes. The evidence that does exist in this area suggests that visuo-spatial working memory may in fact be more age-sensitive than verbal working memory (Jenkins, Myerson, Joerding, & Hale, 2000; Johnson, Logie, & Brockmole, 2010; Leonards, Ibanez, & Giannakopoulos, 2002; Myerson, Hale, Rhee, & Jenkins, 1999; but see Kemps & Newson, 2006; Park et al., 2002). In particular, working memory for abstract visual information (Smith, Park, Cherry, & Berkovsky, 1990), such as black and white matrix (chequered) patterns (Beigneux, Plaie, & Isingrini, 2007; Brown, McConnell, & Forbes, 2011; Bruyer & Scailquin, 1999; Logie & Maylor, 2009), is especially age-sensitive. The purpose of the present study was to determine the degree to which a variety of cognitive measures share variance with visual working memory in an effort to elucidate, within the working memory architecture, the factors that contribute to these marked age-related changes in visual working memory ability.

A standardized measure of visual working memory is the Visual Patterns Test (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997) during which participants are shown black and white chequered patterns of increasing complexity and are asked to recall each pattern in turn, either immediately or following a delay period (typically 10 s; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999, see Figure 1). Using a modified version of this task

which more tightly restricts verbal encoding (Brown, Forbes, & McConnell, 2006), Brown and colleagues (2011) demonstrated marked decrements (ηp^2 = .29 - .35, independent of years of education) in the performance of older adults relative to young adults. With the aim of determining what accounts for this decrement, we examined the degree to which three important cognitive abilities may be related to visual working memory decline: processing speed (as measured by four-choice reaction time), executive function (as measured by verbal fluency and block design), and spatial working memory (as measured by backward spatial span). In addition, an important correlate of adult cognitive functioning, childhood intelligence, was included in our assessment, because this variable is an indicator of the pre-existing individual differences in general cognitive ability. Visual Working memory was measured by the modified VPT, in a sample of older adults (aged 73) from the Lothian Birth Cohort 1936 (LBC1936; see Deary, Gow, Taylor, Corley, Brett, et al., 2007), who are well-characterized in terms of current cognitive function as well as childhood intelligence. The rationale for selecting the domains under investigation is described below.

Childhood Intelligence

Intelligence has been shown to remain relatively stable between childhood and older adulthood, and to be associated with achievement and health outcomes throughout the lifespan (see Deary, Whalley, & Starr, 2009, and Deary, Penke, & Johnson, 2010, for reviews). This suggests that pre-existing differences in cognitive ability can account for some of the variance in ability measured later in the lifespan, thus limiting the extent of the variance which is due to cognitive aging *per se.* One of the strengths of LBC1936, therefore, is the availability of a valid measure of intelligence in childhood which allows the variance in initial cognitive ability (measured early in the lifespan) to be partialled from variance in contemporaneous cognitive measures (i.e., those taken within older adulthood).

At age 11, as part of the Scottish Mental Survey 1947 (SMS1947), each member of LBC1936 was administered a version of the Moray House Test No. 12 (MHT), a valid measure of intelligence. Subsequently, at around age 70, members were administered the MHT again, along with a large battery of other cognitive tests designed to tap a variety of specific functions (see Deary et al., 2007). The correlation between the two administrations of the same test, almost 60 years apart, was 0.692 (Deary, Johnson, & Starr, 2010). This means that the data relating to numerous cognitive measures were available for use in the present study, including intelligence in childhood and in older adulthood. In a study investigating the stability of psychometric intelligence across the lifespan in a cohort resulting from the Scottish Mental Survey 1932 (the Aberdeen Birth Cohort 1921; ABC1921) Deary, Whalley, Lemmon, Crawford, and Starr (2000) showed that the greatest predictor of MHT performance in a sample of older adults aged 79 was childhood performance, accounting for about half of the variance. Deary, Whiteman, Starr, Whalley, and Fox (2004) later confirmed this level of shared variance within the Lothian Birth Cohort 1921 (LBC1921), a much larger cohort than ABC1921. Furthermore, because individual differences tend to be stable across cognitive domains (Deary, Penke, et al., 2010) it is important to control for childhood intelligence when assessing the influence of other variables, such as nutritional status (Deary et al., 2004) or processing speed (Deary, Johnson, et al.), on cognitive ability in older adulthood. In addition to childhood intelligence, a contemporaneous measure of intelligence, also derived using the MHT, was also available for each participant, and this allowed for the investigation of the stability of intelligence across the lifespan (see Deary, Johnson, et al.; Gow, Johnson, Pattie, Brett, Roberts, et al., 2011).

Processing Speed

Salthouse (1991) proposed that age-related changes in 'fluid' cognition, such as memory, reasoning, and spatial abilities, are due to a decrease in the speed with which cognitive operations may be carried out (see Salthouse, 1996, for a review). Two mechanisms may be responsible for this relationship. The limited time mechanism, in which slowed operations (e.g., associations, elaborations, and rehearsals) cannot be completed successfully in the available time, may exert a greater effect in more complex tasks which are dependent upon the outcome of a number of simpler operations. The simultaneity mechanism, in which slower processing results in a reduction in the simultaneously available information required by dynamic systems including working memory, affects the performance of higher-order functions such as abstraction, elaboration, and integration. Supporting evidence includes moderate to high proportions of shared variance between measures of processing speed and a range of cognitive tasks, including memory, and the attenuation of the effects of age when processing speed is controlled (e.g., Finkel, Reynolds, McArdle, & Pedersen, 2007; Salthouse, 1992, 1994b; Vaughan & Hartman, 2010; Verhaeghen and Salthouse, 1997).

Importantly, Deary, Johnson, and colleague (2010) found that, whereas processing speed was contemporaneously associated with general cognitive ability in older adulthood, these relationships were attenuated when childhood mental ability was taken into account. The authors did show, however, that simpler measures, including four-choice reaction time, exhibit a smaller relationship with childhood ability than more complex measures, such as the Digit Symbol task from the Wechsler battery, and could therefore serve as biomarkers of cognitive aging. Four-choice reaction time was therefore included as the measure of processing speed in the current study.

Central Executive Function

While theoretical perspectives on the structure, components, and independence of working memory vary (e.g., see Baddeley, 2000; Baddeley & Hitch, 1974; Cowan, 2001; Kane & Engle, 2002; Logie, 1995, 2003; Lovett, Reder, & Lebiere, 1999), there is general agreement that the system depends crucially upon the operation of capacity-limited attentional processes (the *central executive*; Baddeley, 2000). A number of authors have critically implicated reduced frontal lobe/attentional resources (to which we will refer as central executive function) in the effects of cognitive aging (e.g., Craik & Byrd, 1982; Dempster, 1992; West, 1996; see Braver & West, 2008, for a recent review). This account of cognitive aging is supported by neuroimaging evidence such as demonstrations of greater age-related decline in white matter integrity in anterior brain regions (Brickman, Zimmerman, Paul, Grieve, Tate, et al., 2006; Buckner, 2004; Head, Buckner, Shimony, Williams, Akbudak, et al., 2004), under-recruitment of frontal brain regions in older adults during tasks involving intentional memory encoding (Logan, Sanders, Snyder, Morris, & Buckner, 2002), and reduced attention-related frontal activity accompanied by increased distractor-related activity in older adults (Chao & Knight, 1997). At the behavioral level, MacPherson, Phillips, and Della Sala (2002) provided evidence that specifically the dorsolateral prefrontal cortex, the area believed to be responsible for executive function, undergoes age-related decline.

Verbal fluency has been associated with central executive functioning (Lezak, Howieson, & Loring, 2004; Stuss, Alexander, Hamer, Palumbo, Dempster, et al., 1998) and is a frequently used measure of this ability in healthy and patient populations (Baddeley, Emslie, Kolodny, & Duncan, 1998; Fisk & Sharp, 2004; Salthouse, Atkinson, & Berish, 2003). We used this measure to tap general central executive function. However, block design is also frequently associated with central executive/frontal lobe function (Lezak et al.,

2004; Wallesch, Curio, Galazky, Jost, & Synowitz, 2001) and assesses strategy and planning skills in the specific context of a visuo-spatial construction task. We therefore employed this as a second measure of central executive function. It was possible for this to share more variance with visual working memory performance than the verbal fluency measure, due to block design's relation to specifically visuo-spatial planning/organization.

Spatial Working Memory

From the multi-component perspective on working memory, modality-specific subsystems are believed to control visuo-spatial and verbal storage and processing. Following the further specification of the verbal subsystem (phonological loop) as comprising separable storage and rehearsal processes (see Baddeley, 2000), Logie (1995, 2003) suggested that the visuo-spatial subsystem is also comprised of separable components. A visual storage component and a more dynamic spatial rehearsal component were both proposed to exist. While the visual component is sensitive to decay and interference, the spatial rehearsal mechanism actively refreshes the contents of the store and helps to retain spatio-sequential information. Supporting evidence includes dissociations in the dual-task interference effects during visual and spatial working memory tasks (e.g., Della Sala et al., 1999; Klauer & Zhao, 2004; Quinn & McConnell, 1996). For example, Della Sala and colleagues, used the VPT to show that visual interference disrupts visual working memory to a greater extent than spatial working memory, while the opposite was true for a spatial interference task.

Including a measure of spatial working memory in the current study (the corsi-type backward spatial span task from the Weschler Memory Scale-III UK; WMS-III UK, Weschler, 1998b) allowed for the investigation of the extent to which these two processes shared variance. Based upon the above evidence, however, although the two tasks have the short-term retention of visuo-spatial information in common, it was expected that the

separability of the two processes would limit the predictive power of spatial working memory.

Methods

Participants

Members of LBC1936 were administered the MHT at age 11. Subsequently, at approximately age 70, the cohort members were administered a battery of tests that has been described in detail previously (Deary et al., 2007). Around three years later, a sample of the cohort's earliest recruited members was recruited for this study ($N = 44$; note that age-11 IQ was unavailable for one participant). The mean age of this sample was 10.93 years ($SD = 0.27$) when completing the MHT in childhood, and 68.34 ($SD = 0.35$) when followed up in older adulthood for LBC1936. The mean age when carrying out the VPT was 72.76 ($SD = 0.32$). There were 19 males and 25 females, and the mean number of years of education was 13.60 ($SD = 3.32$). All participants were cognitively healthy, as determined by the Mini-Mental State Examination (MMSE) which screened for dementia (Folstein, Folstein, & McHugh, 1975). The mean MMSE score was 29.52 ($SD = 0.82$, range = 27-30). All participants reported normal or corrected-to-normal visual acuity which was confirmed by near-perfect performance on practice trials.

Measures

Visual working memory.   Participants were administered a modified version of the VPT (see Brown et al., 2006; Della Sala et al., 1997). This task involves presenting participants with a series of black and white chequered patterns which increase in size and therefore complexity (see Figure 1). Participants were required to recall each pattern in turn by placing an 'X' in the cells of blank paper templates that they remembered to be black.

Each trial consisted of a fixation cross (2 s), the presentation of the pattern (3 s), a delay (maintenance) period (10 s), and finally the word *recall* displayed on the computer screen, which prompted participants to respond. There were three practice trials followed by three trials at each of the levels of complexity 4 through 9 (with level of complexity referring to the number of black cells to be recalled). All participants were administered the same number of trials (18). The outcome measure used was the total number of correct patterns recalled[1].

Intelligence.   The Moray House Test No. 12 (MHT) was administered as part of the Scottish Mental Survey 1947 and provides the measure of intelligence in childhood (age 11) and in older adulthood (age 68). In both childhood and older adulthood the raw MHT scores were corrected for age in days at the time of testing and converted into intelligence quotient-type (IQ) scores with *mean* = 100, *SD* = 15.

Processing Speed.   Four-choice reaction time measured information processing speed using a response box (see Deary, Der, & Ford, 2001, for details). Briefly, the box features five keys arranged in an arc and labelled 1, 2, 0, 3, 4, and the participants rest the second and third fingers of the left and right hand on the '1', '2', '3', and '4' keys, respectively. The task is to press the correct button as quickly as possible in response to one of these four digits appearing on a liquid crystal display (LCD) at the top of the box. There were 8 practice trials and 40 test trials. Each number appeared 10 times in a randomized order. There was an interval of between 1 and 3 s between the participant's response and the onset of the next stimulus. Resulting reaction time scores were taken only from the correct trials.

Central executive function.   Verbal fluency provided one measure of central executive function (Lezak et al., 2004) and required participants to name as many words as possible beginning with the letters C, F, and L, with one minute provided for each letter. Proper names

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[1] The mean percentage of cells correctly recalled was highly correlated with the mean number of patterns correctly recalled ($r = .91$), and both measures yield the same results.

were not allowed and no additional score was given for repeated words. The resulting measure was the total number of correct words. The Block Design subtest of the Wechsler Adult Intelligence Scale-III UK (WAIS-III UK; Wechsler, 1998a) was included as a second measure of executive function involving visuo-spatial organization, and required participants to plan and develop strategies for constructing designs from their constituent parts (individual blocks).

Spatial working memory.   The Backward Spatial Span subtest of the WMS-III UK (Wechsler, 1998b) provided a measure of spatial working memory performance. In this task the experimenter tapped out a sequence upon a selection of 10 cubes irregularly spaced across a rectangular board and participants were required to tap out the sequence in the opposite order. Sequences increased from 2 to 9 blocks in length, with two sequences at each level, and the test terminated when the participant failed to recall correctly both sequences from a given level.

Results

Descriptive statistics and Pearson correlations between all variables are provided in Table 1[2]. Age-11 and age-68 MHT IQ scores correlated highly ($r = .73$, $p < .001$). In our modest sample, age-11 IQ did not correlate significantly with visual working memory ($r = .26$, p = .09), but contemporaneous (age-68) IQ did so ($r = .43$, $p < .01$). Interestingly, age-11 IQ correlated significantly with all variables except visual working memory and spatial working memory ($r = .16$, $p = ns$).

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[2] Our results suggest a strong positive manifold among the scores derived from the administered tests; indeed, this has been found in every cognitive dataset since Spearman first described it in 1904 (see Carroll, 1993). That said, we used tasks to represent key theoretical processes in cognitive aging and asked if these can account for performance on the visual working memory task. We therefore accepted, a priori, the role of processing speed and executive function as possible drivers of the cognitive aging process, which legitimized their being used as the predictor variables. Thus, despite the positive manifold, not all of the positively correlated variables has equal explanatory status.

With the exception of verbal fluency and age-11 IQ, all measures correlated significantly with visual working memory, in the direction that better scores were related to better visual working memory performance. The largest correlation was with processing speed ($r = -.53$, $p < .001$), closely followed by block design ($r = .50$, $p < .01$) and spatial working memory ($r = .48$, $p < .01$). With verbal fluency failing to correlate significantly with visual working memory, it is notable that this variable did not correlate significantly with processing speed, the variable with which visual working memory was most highly correlated. In fact, the highest correlation coefficients involving verbal fluency were with the IQ measures, taken both at age 11 ($r = .44$, $p < .01$) and at age 68 ($r = .47$, $p < .01$). On the other hand, block design correlated with all variables, but the strongest relations were with age-68 IQ ($r = .58$, $p < .001$) and visual working memory ($r = .50$, $p < .01$). Finally, spatial working memory correlated with processing speed ($r = -.42$, $p < .01$), verbal fluency ($r = .42$, $p < .01$), and block design ($r = .40$, $p < .01$) at similar levels, but not with the two IQ measures.

Linear Regression Modelling

Stepwise linear regression analyses were carried out to discover the amount of shared variance existing between visual working memory and the potential predictors. In the first of two models, all variables including age-68 IQ and sex were included. The second model was hierarchical, with age-11 IQ entered in the first block, in order to determine whether or not childhood ability attenuates the variance in visual working memory predicted by the significant predictors from model 1, which were entered in the second block using the stepwise method. The models are displayed in Table 2.

Model 1 was significant, $F(2,43) = 12.83$, $p < .001$, and predicted 36% of the variance in visual working memory performance ($R = .62$, adjusted $R^2 = .36$, $SE = 2.65$). Processing

speed (β = -.40, p < .01) and block design (β = .35, p = .01) served as significant predictors in the model, with processing speed predicting 16%, and block design predicting 12%, of the variance. Within this sample and combination of predictors, all other variables were non-significant and so were excluded from the second model. Including age-11 IQ in the second model did not alter the pattern of results, $F(3,42)$ = 8.46, p < .001. This model predicted 35% of the variance (R = .63, adjusted R^2 = .35, SE = 2.67), with processing speed (β = -.44, p < .01) predicting 20%, and block design (β = .37, p = .01) predicting 14%, of the variance in visual working memory performance. Therefore, childhood ability did not serve as a significant predictor (β = -.10, p = ns).

Discussion

This study was aimed at determining predictors of visual working memory performance, as measured by a visual matrix task (modified VPT; Brown et al, 2006; Della Sala et al., 1997, 1999), in a sample of healthy older adults recruited from the Lothian Birth Cohort 1936 (LBC1936; Deary et al., 2007). Visual working memory was related to processing speed, block design, spatial working memory, and older age IQ, but neither to verbal fluency nor childhood IQ (measured at age 11). As the only variables retained in a regression analysis, processing speed and block design (the visuo-spatial executive measure) were the significant predictors of visual working memory performance. An important aim of the present study, however, was to establish whether any predictive value would remain after previous mental ability (age-11 IQ) was adjusted for (Deary et al., 2000, 2004; Deary, Johnson, et al., 2010; Deary, et al., 2009). After age-11 IQ was included, the pattern of results remained the same, with processing speed predicting 20%, and block design predicting 14%, of the variance, suggesting that, with this sample and sample size, visual working memory performance in older adulthood is not related to initial general cognitive ability. Rather, visual working

memory ability appears to be related to changes that have occurred with the aging process, and most likely reflects the fluid nature of the task. It may have been possible for the measure of childhood intelligence to be unreliable; however, there is strong stability in intelligence across the lifespan in LBC1936, and this was one of the advantages of drawing upon this sample (Deary, Johnson, et al., 2010; Gow et al., 2011). Furthermore, a strong positive correlation is also evident in this subsample.

Consideration of the remaining key variables of processing speed and central executive function offers insight regarding the processes affecting visual working memory performance in older age, and age-related cognitive decline more generally. The finding that the verbal fluency central executive measure was neither correlated with, nor predictive of, visual working memory performance, suggests that decline in visual working memory is not simply due to general central executive dysfunction, but may be due to more widespread deterioration (Band, Ridderinkhof, & Segalowitz, 2002; Greenwood, 2000; Tisserand & Jolles, 2003). On the other hand, central executive resources specifically related to the organization of visuo-spatial material were shown to be important. As indicated by the shared variance with block design, the deployment of central executive resources within the context of a visuo-spatial task appears to be particularly important.

The finding that processing speed exhibited the greatest correlation with visual working memory performance, as well as the greatest predictive value, suggests that speed of encoding (the ability to create a stable representation; Salthouse, 1994a), and/or rate of rehearsal are possible candidates for the source of the marked age-related deficit in visual working memory performance. Indeed, elaborations and rehearsals are two possible operations referred to by Salthouse (1996) that could be affected by speed of processing. Within the visual working memory task, it is clear that slower elaboration during pattern encoding time, as well as slower rehearsal speed during the delay period, could each

contribute to poorer recall. Similarly, the simultaneity mechanism offers a conceivable explanation regarding the role of processing speed. Poorer recall could be observed when the result of previous operations is no longer available by the time subsequent operations are completed (i.e., rehearsing individual component parts of the stimuli in turn). Participants with slower processing speed may therefore find themselves able to recall only part of a pattern, or none of the pattern at all.

Inspecting the pattern of correlations with the spatial working memory measure may offer further insight, as this task was related to processing speed and both central executive measures. It is possible that, unlike the visual working memory task, spatial working memory was more related to central executive function due to the requirement of participants to manipulate the information (i.e., reverse sequence order) before providing the response. However, visuo-spatial encoding, representation, maintenance, and elaboration are likely to be represented by processing speed and visuo-spatial organization (block design), the two variables that were also related to, and predictive of, visual working memory. Although visual and spatial working memory were moderately correlated, and each appear to have processing speed and visuo-spatial organization in common, spatial working memory did not predict visual working memory performance. This finding supports the theory that visual and spatial working memory are related but separable processes (Della Sala et al., 1999; Logie 1995, 2003).

At the biological level, the processing speed deficit could be related to a reduction in white matter integrity. Deary, Bastin, Pattie, Clayden, Whalley, et al. (2006; see also Bucur, Madden, Spaniol, Provenzale, Cabeza, et al., 2008; Kennedy & Raz, 2009; Madden, Spaniol, Costello, Bucur, White, et al., 2008) showed that white matter integrity, believed to be crucial for connectivity between the distributed cortical regions which underlie cognition, is related to efficiency of information processing and cognitive ability in older age. Specifically, white

matter integrity was related to reaction time measures of information processing as used in the current study. Furthermore, Waiter, Fox, Murray, Starr, Staff, et al. (2008) provided functional magnetic resonance imaging (fMRI) evidence that successful cognitive aging may be related to the preservation of neural networks subserving such simple information processing.

It is important to highlight the potential limitations of the current study. First, the sample size is relatively small, and it is therefore possible that lack of power did not allow for the detection of small effects, particularly with respect to the correlation between childhood IQ and visual working memory, which exhibited a trend toward significance. Despite this limitation, however, clear results have been found relating to the predictive value of the variables under investigation. A further limitation relates to the lack of correlation with, and predictive power of, verbal fluency. While this has been widely used and accepted as a measure of central executive function (e.g., see Lezak et al., 2004; Stuss et al., 1998), Tisserand and Jolles (2003) highlighted that prefrontal decline may have to be considered as separable. That is, verbal fluency may not tap the most age-sensitive function(s) carried out by prefrontal cortex. Furthermore, Phillips (1999) stated that verbal fluency performance must be interpreted with caution, as poorer performance may reflect a number of factors such as general intelligence (see also Salthouse et al., 2003). Nevertheless, central executive function was found to relate to spatial working memory, which involved manipulation of stimuli prior to response. As highlighted above, performance of the visual working memory task may simply not draw upon central executive function to a large enough extent for the shared variance to go beyond central executive processing specifically involved with visuo-spatial material. Finally, there remains a large proportion of variance in visual working memory performance that is unexplained in the current study. At the heart of visual working memory performance is short-term maintenance of specifically visual information (i.e., a

static visual image). It is likely that this process would have accounted for a significant proportion of the variance, yet no other measures were available to us which would have captured this process.

In summary, neither childhood ability nor verbal fluency predicted visual working memory in the present study, but processing speed was able to predict 20% of the variance, while visuo-spatial organization (block design) predicted 14%. It is suggested that processing speed affects task performance via speed of encoding and/or rate of rehearsal, and that central executive resources specifically related to the use of visuo-spatial material are important for visual working memory performance in older adults. As suggested by recent research, processing speed may indeed be a biomarker of cognitive aging (Deary, Johnson, et al., 2010).

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Figure 1

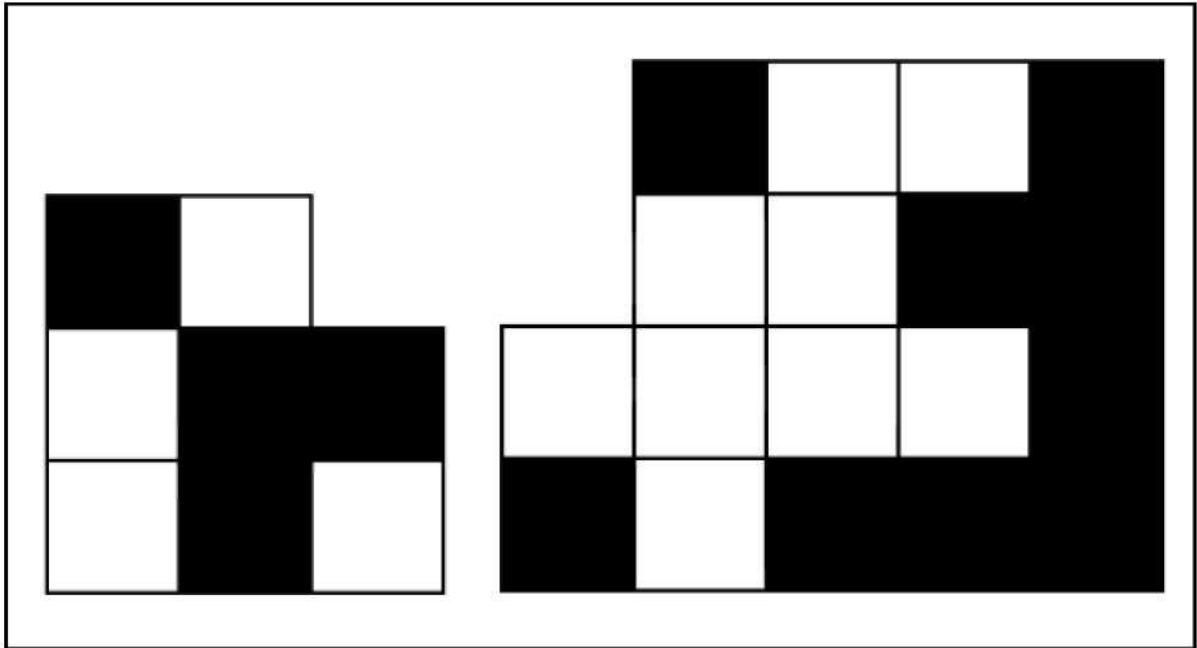*Sample stimuli from the modified Visual Patterns Test (levels 4 and 9).*

Table 1

Means (with standard deviations) and Pearson correlations between each variable.

	1	2	3	4	5	6	7	M (SD)
1. Age-11 IQ	-							105.21 (14.77)
2. Age-68 IQ	.71***	-						102.08 (12.42)
3. Processing speed (four-choice reaction time)	-.45**	-.51***	-					0.623 (0.081)
4. Central executive function (verbal fluency)	44**	.47**	-.28	-				44.84 (13.16)
5. Visuo-spatial organization (block design)	44**	.58***	-.37*	.30*	-			38.73 (10.77)
6. Spatial working memory (backward spatial span)	.14	.23	.42**	.42**	.40**	-		7.95 (1.52)
7. Visual working memory (modified Visual Patterns Test)	.26	.43**	-.53***	.09	.50**	.48**	-	8.77 (3.30)

NB: All correlations based upon $N = 44$, except those involving age-11 IQ for which $N = 43$.
 $p < .05$, ** $p < .01$, *** $p < .001$

Table 2

Linear regression models predicting visual working memory performance in older adulthood.

	B	Standard Error B	P	t (p)
Model 1				
Processing speed	-16.13	5.38	-.40	-3.00 (.005)
Visuo-spatial organization	.11	.04	.35	2.66 (.011)
Model 2a				
Age-11 IQ	.06	.03	.26	1.72 (.092)
Model 2b				
Age-11 IQ	-.02	.03	-.10	-.71 (.484)
Processing speed	-17.90	5.80	-.44	-3.09 (.004)
Visuo-spatial organization	.11	.04	.37	2.61 (.013)

NB: In model 2, age-11 IQ was entered in block 1, while processing speed and visuo-spatial organization were entered stepwise in block 2. Model 2b is the final model.