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Strategy use fully mediates the relationship between working memory capacity and  
performance on Raven's matrices

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### **Abstract**

Working memory capacity consistently correlates with fluid intelligence. It has been suggested that this relationship is partly attributable to strategy use: participants with high working memory capacity would use more effective strategies, in turn leading to higher performance on fluid intelligence tasks. However, this idea has never been directly investigated. In a series of two experiments, we tested this hypothesis by directly manipulating strategy use in a combined experimental-correlational approach (Experiment 1;  $N = 250$ ) and by measuring strategy use with a self-report questionnaire (Experiment 2;  $N = 93$ ). Inducing all participants to use an effective strategy in Raven's matrices decreased the correlation between working memory capacity and performance; the strategy use measure fully mediated the relationship between working memory capacity and performance on the matrices task. These findings indicate that individual differences in strategic behavior drive the predictive utility of working memory. The results are interpreted within a theoretical framework integrating the multiple mediators of the relationship between working memory capacity and high-level cognition.

### **Keywords**

Working memory capacity; Fluid intelligence; Raven's Advanced Progressive Matrices;  
Strategy use; Individual differences

Working memory capacity (WMC) is the construct that correlates best with fluid intelligence (Oberauer, 2005): participants who are able to maintain a large number of items in working memory consistently perform better in fluid intelligence tasks. This relationship has been observed in a very large number of studies. In a classic meta-analysis, Ackerman and colleagues reviewed 86 different samples relating WMC to fluid intelligence, and observed an average correlation of  $r = .364$  between the two constructs (or  $r = .479$  when correcting for attenuation; Ackerman, Beier, & Boyle, 2005). However, uncertainty remains as to what drives this relationship. A number of hypotheses have been proposed over the years (see Engle & Kane, 2004). In particular, many authors have argued that the relationship between WMC and fluid intelligence is caused by a common dependence on controlled attention (Engle & Kane, 2004), primary memory (e.g. Colom, Flores-Mendoza, Quiroga, & Privado, 2005), and/or secondary memory (e.g. Mogle, Lovett, Stawski, & Sliwinski, 2008). Although it seems likely that all three constructs do play a role (Unsworth, Fukuda, Awh, & Vogel, 2014), another possibility has been little studied: the predictive utility of WMC may be partly driven by strategy use (Thomassin, Gonthier, Guerraz, & Roulin, 2014).

A strategy can be defined as « a procedure or a set of procedures for achieving a higher level goal or task » (Lemaire & Reder, 1999, p. 365); such a procedure may or may not require conscious awareness. Many tasks allow for a range of different strategies, some of which are more effective than others. It could be the case that participants with high WMC tend to implement more effective strategies in complex tasks such as fluid intelligence tests, leading to a higher performance (Thomassin et al., 2014). In support of this idea, a large number of studies have provided evidence that participants with high WMC tend to use more effective strategies in various contexts: the list includes not only short-term and working memory tasks (Bailey, Dunlosky, & Kane, 2011; Kaakinen & Hyönä, 2007; McNamara & Scott, 2001), but also high-level cognitive tasks such as mathematical or reasoning tasks (Beilock & DeCaro,

2007), syllogism tasks (Copeland & Radvansky, 2004; Verschueren, Schaeken, & d'Ydewalle, 2005), verbal fluency tasks (Schelble, Theriault, & Miller, 2012; Unsworth, Brewer, & Spillers, 2013), as well as complex long-term memory tasks involving encoding strategies (Cokely, Kelley, & Gilchrist, 2006; Unsworth & Spillers, 2010) and retrieval strategies (Spillers & Unsworth, 2011; Unsworth, Spillers, & Brewer, 2012a, 2012b).

Importantly, two pieces of evidence also suggest that strategy use is a primary driver of the predictive utility of WMC in these tasks. First, several authors have observed that the use of effective strategies in complex tasks mediates the relationship between WMC and performance, either in part (Unsworth & Spillers, 2010) or in full (Schelble et al., 2012; Unsworth et al., 2013). Second, disrupting the use of effective strategies in a task – either by imposing a secondary task to participants, or by shortening presentation times – eliminates the correlation between WMC and performance (Ang & Lee, 2010; Beilock & Carr, 2005; Beilock & DeCaro, 2007; Gimmig, Huguet, Caverni, & Cury, 2006; Rosen & Engle, 1997; Schelble et al., 2012; Thomassin et al., 2014).

In sum, a number of studies have highlighted a role of strategy use in the relationship between WMC and performance on various high-level cognitive tasks. For this reason, it seems plausible that strategy use contributes more specifically to the relationship between WMC and fluid intelligence. However, this idea has never been investigated. The objective of the present study was to provide evidence for this hypothesis. To this end, we elected to study strategic behavior in the context of a classic fluid intelligence task, Raven's Advanced Progressive Matrices (APM; Raven, Raven, & Court, 1998). The APM are composed of a series of logical problems in the form of incomplete matrices that follow logical rules; participants are required to find the correct piece to complete a matrix among eight possible answers. This task had two advantages for our purposes: its relationship with WMC has been demonstrated on multiple occasions (see Ackerman et al., 2005), and the nature of strategic behavior in the APM is well-

known. Two different strategies are typically observed in inductive reasoning tasks, including the APM (Bethell-Fox, Lohman, & Snow, 1987; Snow, 1980; Vigneau, Caissie, & Bors, 2006). With the first strategy, constructive matching, participants construct a mental representation of the answer and then look for a match among the response alternatives; this strategy is the most effective. By contrast, the least effective strategy, response elimination, consists in comparing the features of the problem and the response alternatives and then eliminating implausible alternatives until only one possible answer remains (Bethell-Fox et al., 1984; Vigneau et al., 2006).

If the correlation between WMC and performance on the APM is actually driven by strategy use, individual differences in WMC should be related to strategic behavior in the task (Wiley & Jarosz, 2012). One study has provided some support for this hypothesis (Jarosz & Wiley, 2012). Using eye-tracking, the authors showed that participants with low WMC spend more time looking at the response alternatives and toggle more frequently between the matrix and the response alternatives; low WMC individuals are also more sensitive to the presence of highly salient distracters. Taken together, these results suggest that participants with low WMC are more likely to use the ineffective response elimination strategy. However, the use of eye-tracking does not allow to unambiguously examine individual differences in strategy use. For example, these results could primarily reflect a greater sensitivity of low WMC participants to distraction, due to their lower attentional abilities (Jarosz & Wiley, 2012). Moreover, this design does not allow to test whether strategy use actually explains the correlation between WMC and performance on the APM.

The present research aimed to provide more direct evidence that strategy use drives the predictive utility of working memory in fluid intelligence tasks. This hypothesis was tested in two steps. In a first experiment, we experimentally controlled the role of strategy use by inducing all participants to use the same strategy in the APM task. This manipulation was

expected to decrease the correlation between WMC and performance on the task. A second experiment directly measured spontaneous strategic behavior to test the hypothesis that strategy use statistically mediates the relationship between WMC and performance on the APM.

### **Experiment 1**

One of the most powerful tools to investigate the role of a construct in the relationship between two other variables is the combined experimental-correlational approach, advocated by Cronbach (1957). The rationale of this approach is to experimentally manipulate the construct of interest, and to assess the effect of this manipulation on the interrelations between other abilities. In this experiment, we elected to take advantage of this design to examine the role of strategy use by directly manipulating strategic behavior in participants. This was achieved by inducing all participants to use the same strategy in the APM task. There were two possible outcomes to this manipulation.

On one hand, if strategic behavior plays a critical role in the relationship between WMC and fluid intelligence, as per our hypothesis, then inducing all participants to use the same strategy in the APM should decrease the correlation between WMC and performance. In other words, if participants with high WMC tend to perform higher in fluid intelligence tasks because they use more efficient strategies, then inducing all participants to use the same strategy should eliminate the advantage of high WMC participants. This result has been observed in prior studies (for a review, see Thomassin et al., 2014), although none of them has directly examined strategic behavior in a fluid intelligence task.

On the other hand, some authors have argued that individual differences in strategy use merely introduce noise in the relationship between WMC and other constructs (Friedman & Miyake, 2004; Lépine et al., 2005; St-Clair Thompson, 2007; Turley-Ames & Whitfield, 2003). If this is the case, then controlling for strategy use should remove this unwanted variance and

actually *increase* the correlation between WMC and performance. Several authors have obtained this result, by statistically controlling for strategy use (Friedman & Miyake, 2004), by constraining strategic behavior through time limitations (Lépine, Barrouillet, & Camos, 2005; St Clair-Thompson, 2007), or by asking all participants to use one strategy (Turley-Ames & Whitfield, 2003), although again no study has examined strategic behavior in high-level cognitive tasks. If strategy use does not play a role in the relationship between WMC and performance on fluid intelligence tasks, similar results should be obtained in the present experiment: the correlation between WMC and performance on the APM should actually increase when inducing all participants to use the same strategy.

Since two main strategies exist in the APM task, participants could be induced to use either the constructive matching strategy, or the response elimination strategy. Although the same predictions apply in both cases, we were concerned that inducing participants to use the inefficient response elimination strategy would artificially lower the correlation between WMC and performance by creating a floor effect. In order to provide a more powerful test of our hypothesis, we elected to induce participants to use constructive matching. The correlation between WMC and performance on the APM was expected to decrease in this situation when compared to a control condition, confirming the role of strategy use and ruling out the strategy-as-noise hypothesis.

## Method

### Participants.

Two hundred and fifty undergraduates<sup>1</sup> at the University of Grenoble participated for course credit (37 males and 213 females; mean age = 21.30 years,  $SD = 2.17$ ). All participants were native French speakers, and none of them had completed Raven's APM before.

### Materials.

#### *Working memory capacity measure.*

WMC was assessed with the Composite Complex Span (CCS; Gonthier, Thomassin, & Roulin, 2015). The CCS is based on short versions of three classic complex span tasks: the reading span, the symmetry span and the operation span (see Redick et al., 2012). In each complex span task, participants are required to memorize simple stimuli (e.g. consonants) while solving judgment tasks (e.g., deciding whether mathematical operations are correct). A working memory score is calculated for each task by tallying the proportion of correctly recalled stimuli in each trial. A composite WMC score is then computed as the average of the working memory scores on each task after standardization. The CCS has demonstrated excellent reliability (with Cronbach's  $\alpha = .86$ ) and validity in a large sample of French participants (Gonthier et al., 2015).

#### *Raven's Advanced Progressive Matrices.*

As described previously, the APM task is composed of a series of incomplete matrices. Each matrix comprises nine black-and-white figures arranged in a 3x3 rectangular display. The succession of figures within a matrix is governed by one to five logical rules. On each matrix,

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<sup>1</sup> The required sample size was estimated with a power analysis using *G\*Power 3.1* (Faul, Erdfelder, Buchner, & Lang, 2009). The raw correlation between WMC and performance on the APM is generally observed to be around .36 (Ackerman et al., 2005). In order to achieve a desirable .80 power, the necessary sample size to detect a decrease of the correlation from  $r = .36$  to  $r = .00$  was estimated to be  $N = 218$ .

the bottom right figure is missing; the participant's task is to select, among eight possible alternatives, the figure that correctly completes the matrix. Participants had 30 minutes to perform set II of Raven's APM (Raven et al., 1998). In order to shorten the completion time, only the 18 odd-numbered items were used (for a similar procedure, see Unsworth, Redick, Lakey, & Young, 2010). Accuracy and response time were registered for each item.

Participants completed the APM task either in a control condition, with no instructions about strategy use, or in a constructive matching condition. At the beginning of the task, participants in the constructive matching condition were explicitly instructed to use the constructive matching strategy<sup>2</sup>. More specifically, they were instructed to thoroughly examine the incomplete matrix; to try to understand the underlying rules; to imagine what the missing piece should look like; and to search for a match among the eight possible answers. In order to encourage participants to use the constructive matching strategy, each item in the APM was presented in two steps (for a similar procedure, see Mitchum & Kelley, 2010). In the first step, only the incomplete matrix was displayed on the screen; participants were to try to understand the underlying rules and to imagine the missing piece before proceeding. This step lasted for a minimum of 15000ms, with participants deciding when to proceed to the second step. In the second step, the eight possible answers appeared along with the incomplete matrix, corresponding to the standard presentation of an item; participants had to choose one of the answers, as in the control condition.

### **Procedure.**

All participants provided written informed consent prior to the experiment. They performed the experiment in groups of two to eight individuals in a university computer room.

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<sup>2</sup> This experimental manipulation was used in an independent study (see Supplemental materials), and demonstrated an effect on both strategic behavior and performance.

Each participant was randomly assigned to either experimental condition at the beginning of the experiment. The first task of the experimental session was the CCS. After a short break, participants completed two training items from set I of the APM. They then completed the rest of the APM task, either in the control condition or in the constructive matching condition. The whole experimental session lasted approximately 60 minutes.

## Results and discussion

The data were screened for outliers using Cook's distance. No participant was excluded from the sample, yielding a final sample size of 250 participants ( $n = 134$  for the control condition and  $n = 116$  for the constructive matching condition). Descriptive statistics for all measures are presented in Table 1; all variables were close to a normal distribution. To confirm the reliability of the modified version of the APM used in the present study, the Kuder-Richardson Formula 20 coefficient (equivalent to a Cronbach's alpha coefficient for binary measures) was computed across all trials. The reliability of the APM task was satisfying in both the control condition ( $KR20 = .76$ ) and the constructive matching condition ( $KR20 = .72$ ). Participants assigned to the control condition and to the constructive matching condition had comparable WMC,  $t(248) = 0.11, p = .913$ .

The effect of the experimental manipulation on the relationship between WMC and accuracy on the APM was tested with a general linear model analysis, with WMC treated as a continuous variable and the experimental condition treated as a between-subjects categorical variable. We expected to observe a two-way interaction between WMC and experimental condition, indicating that the correlation between WMC and performance on the APM differed as a function of strategy instructions. The main effect of WMC was significant,  $F(1, 246) = 22.64, MSE = 9.04, p < .001, \eta^2_p = .08$ , indicating that WMC was on average predictive of performance on the APM. The main effect of the experimental condition was also

significant,  $F(1, 246) = 37.40$ ,  $MSE = 9.04$ ,  $p < .001$ ,  $\eta^2_p = .13$ , reflecting the fact that performance was higher in the constructive matching condition ( $M = 12.77$ ,  $SD = 2.35$ ) than in the control condition ( $M = 10.45$ ,  $SD = 3.70$ ). Critically, the two-way interaction was significant,  $F(1, 246) = 4.80$ ,  $MSE = 9.04$ ,  $p = .029$ ,  $\eta^2_p = .02$ , indicating that the correlation between WMC and performance was significantly different in the two experimental conditions.

Table 1

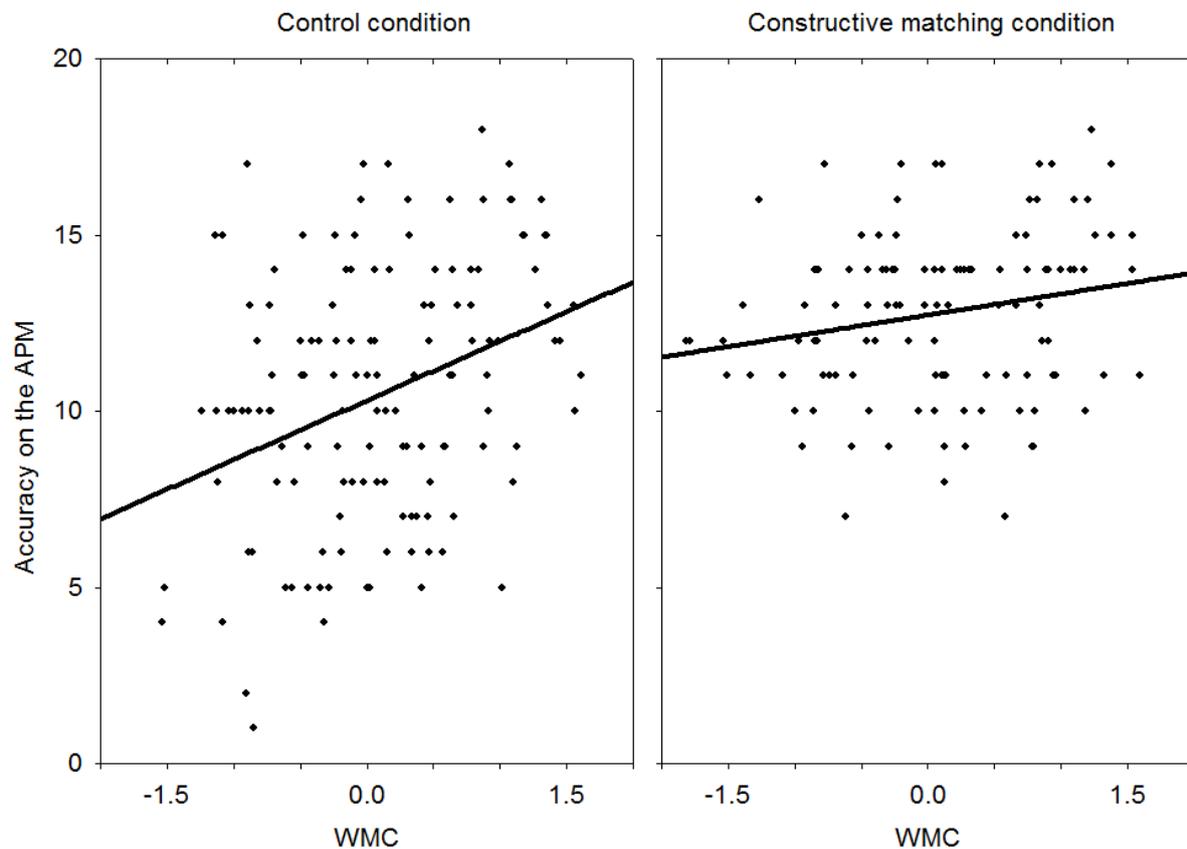
*Descriptive statistics for all measures*

Condition	Measure	<i>M</i>	<i>SD</i>	Range	Skewness	Kurtosis
Control	Composite WMC	0.08	0.75	-1.54 – 1.61	0.06	-0.76
	Total APM	10.45	3.70	1.00 – 18.00	-0.14	-0.71
Constructive matching	Composite WMC	0.07	0.80	-1.81 – 1.59	-0.18	-0.67
	Total APM	12.77	2.35	7.00 – 18.00	-0.11	-0.43

*Note.* Since the composite WMC score is expressed as an average of standardized scores, the value 0 corresponds to the mean of the population. Possible values range from 0 to 18 for the total APM score.

Decomposing this interaction revealed that WMC was predictive of performance in the control condition,  $r(132) = .34$ ,  $p < .001$  (see Figure 1A). The magnitude of this correlation was comparable to the results generally observed with equivalent tasks (Ackerman et al., 2005; Gonthier et al., 2015; Redick et al., 2012). WMC was still predictive of performance in the constructive matching condition, but the relationship was much weaker,  $r(114) = .20$ ,  $p = .028$  (see Figure 1B). In other words, the percentage of shared variance between WMC and performance on the APM dropped from 11.6% in the standard condition with unconstrained strategy use to 4% in the constructive matching condition, corresponding to a 66% decrease. These results are consistent with the hypothesis that strategy use contributes to the relationship

between WMC and performance, but they are incompatible with the hypothesis that strategy use constitutes irrelevant noise in this relationship.



*Figure 1.* Relationship between working memory capacity and performance on Raven's APM as a function of experimental condition.

Closer examination of the regression coefficients revealed that participants with high WMC were relatively unaffected by the strategy instructions. For participants 1 standard deviation above the average WMC, predicted accuracy on the APM was 12.00 in the control condition and 13.32 in the constructive matching condition. On the other hand, the use of constructive matching seemed to significantly improve the performance of participants with low WMC: for participants 1 standard deviation below the average WMC, predicted accuracy on the APM was 8.63 in the control condition and 12.13 in the constructive matching condition.

In other words, the two-way interaction between WMC and experimental condition was driven by an increase in the performance of participants with low WMC in the constructive matching condition. These results are compatible with the idea that the lower performance of participants with low WMC in the control condition hinged on the use of the inefficient response elimination strategy by these participants. They are also interesting in showing that participants with low WMC can benefit from strategy training to some extent, congruent with prior studies (e.g. Turley-Ames & Whitfield, 2003).

## **Experiment 2**

The results of Experiment 1 showed that constraining strategy use decreased the correlation between WMC and accuracy on the APM. This finding supports the idea that strategy use plays a determinant role in the relationship between WMC and performance on the task. The results are also critical in ruling out the possibility that strategic behavior only constitutes irrelevant noise (Friedman & Miyake, 2004; Lépine et al., 2005; St Clair-Thompson, 2007; Turley-Ames & Whitfield, 2003): if strategies do not play any role, it is difficult to envision an explanation for the fact that an experimental manipulation of strategy use decreases the correlation between WMC and performance. Thus, it seems that the strategy-as-noise hypothesis cannot be applied to the context of strategic behavior in the APM task.

However, Experiment 1 constituted only one step in testing our hypothesis: experimentally manipulating strategy use did not allow us to closely examine individual differences in strategic behavior as a function of WMC, and it is difficult to ensure that the experimental induction of constructive matching did not affect other components of performance in the task. The second step in testing the role of strategic behavior in the relationship between WMC and the APM was to obtain a direct measure of spontaneous strategy use, and to determine whether strategy use statistically mediates the correlation

between the two constructs. To this end, Experiment 2 measured the participants' use of constructive matching and response elimination in the APM with a verbal strategy report. This approach has been successfully used in multiple studies relating strategy use to WMC (e.g. Beilock & DeCaro, 2007; Dunlosky & Kane, 2007), as well as in studies investigating the use of constructive matching and response elimination in reasoning tasks (Bethell-Fox et al., 1987; Mitchum & Kelley, 2010; Snow, 1980). Critically, measuring strategic behavior made it possible to directly test the possibility of a mediation: strategy use was predicted to fully mediate the correlation between WMC and performance on the APM.

## **Method**

### **Participants.**

Ninety-five undergraduates<sup>3</sup> at the University of Savoy participated for course credit (14 males and 81 females; mean age = 20.02 years,  $SD = 1.69$ ). All participants were native French speakers, and none of them had completed Raven's APM before.

### **Materials.**

WMC was measured with the CCS (Gonthier et al., 2015), as in Experiment 1. The APM task was identical to the control condition in Experiment 1: participants had 30 minutes to complete the 18 odd-numbered items in set II of the APM, without any instructions about strategy use.

### ***Strategy questionnaire.***

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<sup>3</sup> The required sample size to detect a mediation effect has been estimated by Fritz and MacKinnon (2007). In the present case, it depended on the size of the correlations between WMC and strategy use and between strategy use and performance on the APM. Prior results suggest that the correlation between WMC and strategy use in the APM may be of moderate size ( $r = .38$  for the correlation between WMC and the proportion of time spent looking at the possible responses; Jarosz & Wiley, 2012); strategy use seems moderately correlated with performance on the APM (Vigneau et al., 2006). These two points suggest that a sample size of 71 participants should be sufficient to achieve .80 power with the type of analysis used in the present study (Fritz & MacKinnon, 2007).

The strategy questionnaire was similar to the two-items measure used by Mitchum and Kelley (2010), which demonstrated convergent validity with eye-tracking measures of strategic behavior. Our version of the questionnaire consisted of eight items. Participants had to rate their agreement with each item on a scale from one (*not at all true*) to nine (*completely true*). The questionnaire included four filler items (e.g., "Overall, I was confident in my answers") and four questions regarding strategy use: two questions assessing constructive matching ("I took the time to examine the drawing and to think about the answer before examining the response alternatives"; "After examining the drawing, I imagined the missing piece and then looked for it among the possible answers"), and two questions assessing the response elimination strategy ("After examining the drawing, I ruled out the response alternatives that did not match until only one remained"; "I successively examined each possible answer to decide whether it could be the missing piece"). The items were presented in random order, with each strategy item followed by a filler item.

The validity of this strategy questionnaire was confirmed in an independent experiment (see Supplemental materials). The results of this experiment indicated that the questionnaire demonstrated a two-factor structure, with the two constructive matching questions loading on a common factor and the two response elimination questions loading on another factor. All four items were highly correlated with a longer version of the scale, with correlations ranging between .57 and .86. Experimental manipulations inducing participants to use a constructive matching or a response elimination strategy had a large effect on responses to the questionnaire (all  $\eta^2_p$ s > .50). Lastly, participants reported that the questionnaire adequately reflected their strategy use in the task (mean agreement = 7.09 on a 9-point Likert scale,  $SD = 1.06$ ).

### **Procedure.**

All participants provided written informed consent prior to the experiment. They performed the experiment individually in a university testing room. The first task of the

experimental session was the CCS. After a short break, participants completed two training items from set I of the APM, followed by the rest of the task. Participants completed the strategy questionnaire immediately after the APM. The whole experimental session lasted approximately 60 minutes.

## **Results and discussion**

The data were screened for outliers using Cook's distance in each analysis. Two participants were excluded from the sample on this basis, yielding a final sample size of 93 participants. A preliminary analysis examined the psychometric qualities of the strategy questionnaire. The correlation matrix presenting the relationships between the four items of the questionnaire and the total strategy scores is displayed in Table 2. The two constructive matching questions were significantly correlated, as were the two response elimination questions; the pairs of questions were averaged for subsequent analyses, yielding a single score per strategy. Total scores for the two strategies were negatively correlated, indicating that participants who used one strategy were less likely to use the other.

As a complementary way to ensure the validity of the strategy questionnaire, we examined the correlations between the two strategy scores and average response times in the APM: indeed, it has been observed that participants using the relatively simple response elimination strategy tend to demonstrate faster response times, whereas participants using the more complex constructive matching strategy tend to demonstrate slower response times (see Vigneau et al., 2006). This is precisely what we observed. The constructive matching score was positively correlated with response times,  $r(91) = .38, p < .001$ , whereas the response elimination score was negatively correlated with response times,  $r(91) = -.32, p = .001$ . In other words, the strategy questionnaire demonstrated convergent validity with an objective behavioral measure.

Table 2

*Matrix of correlations for the strategy questionnaire*

Measure	1.	2.	3.	4.	5.	6.
1. Constructive matching question 1	–					
2. Constructive matching question 2	<b>.21</b>	–				
3. Response elimination question 1	-.09	-.16	–			
4. Response elimination question 2	-.14	-.11	<b>.31</b>	–		
5. Total constructive matching	<b>.74</b>	<b>.81</b>	-.16	-.16	–	
6. Total response elimination	-.14	-.17	<b>.83</b>	<b>.79</b>	<b>-.21</b>	–

*Note.* Total constructive matching = average of the two constructive matching questions; Total response elimination = average of the two response elimination questions. Significant correlations are in bold.

Descriptive statistics for all measures are presented in Table 3. All variables were close to a normal distribution, although the constructive matching score demonstrated a slight negative skewness, suggesting that most participants implemented this strategy to some degree. To confirm the reliability of the shortened version of the APM, the Kuder-Richardson Formula 20 coefficient was computed across all trials. The task demonstrated satisfying reliability ( $KR20 = .77$ ).

Table 3

*Descriptive statistics for all measures*

Measure	<i>M</i>	<i>SD</i>	Range	Skewness	Kurtosis
Composite WMC score	0.05	0.77	-1.84 – 1.61	-0.03	-0.56

Total APM score	9.88	3.56	1.00 – 17.00	-0.10	-0.60
Constructive matching score	7.56	1.33	3.50 – 9.00	-0.75	-0.15
Response elimination score	4.17	2.41	1.00 – 9.00	0.20	-1.15

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*Note.* Since the composite WMC score is expressed as a sum of standardized scores, the value 0 corresponds to the mean of the population. Possible values range from 0 to 18 for the total APM score, and from 1 to 9 for the constructive matching and response elimination scores.

The main analysis examined the relationships between WMC, strategy use and performance. As expected, the use of the constructive matching strategy was positively correlated with performance on the APM,  $r(91) = .45$ ,  $p < .001$ , whereas the use of response elimination was negatively correlated with performance,  $r(91) = -.40$ ,  $p < .001$ . WMC was positively correlated with constructive matching,  $r(91) = .29$ ,  $p = .004$ , and negatively correlated with response elimination,  $r(91) = -.33$ ,  $p = .001$ . In other words, participants with high WMC were both more likely to use the effective strategy and less likely to use the ineffective strategy. WMC was positively correlated with performance on the APM in a simple regression,  $r(91) = .33$ ,  $p = .001$ . Critically, the correlation between WMC and performance on the APM was no longer significant in a multiple regression controlling for the constructive matching and response elimination scores,  $r(89) = .13$ ,  $p = .184$ . In other words, WMC and performance on the APM shared 10.9% of their variance in a simple regression; this shared variance dropped to 1.7% when controlling for strategy use, which indicates that strategy use accounted for 84.5% of the correlation between WMC and performance on the APM. In summary, Baron and Kenny's (1986) four criteria for a complete mediation were fulfilled: WMC correlated with performance on the APM, strategy use correlated with both WMC and the APM, and the relationship between WMC and performance on the APM disappeared when controlling for strategy use. These results are summarized in Figure 2.

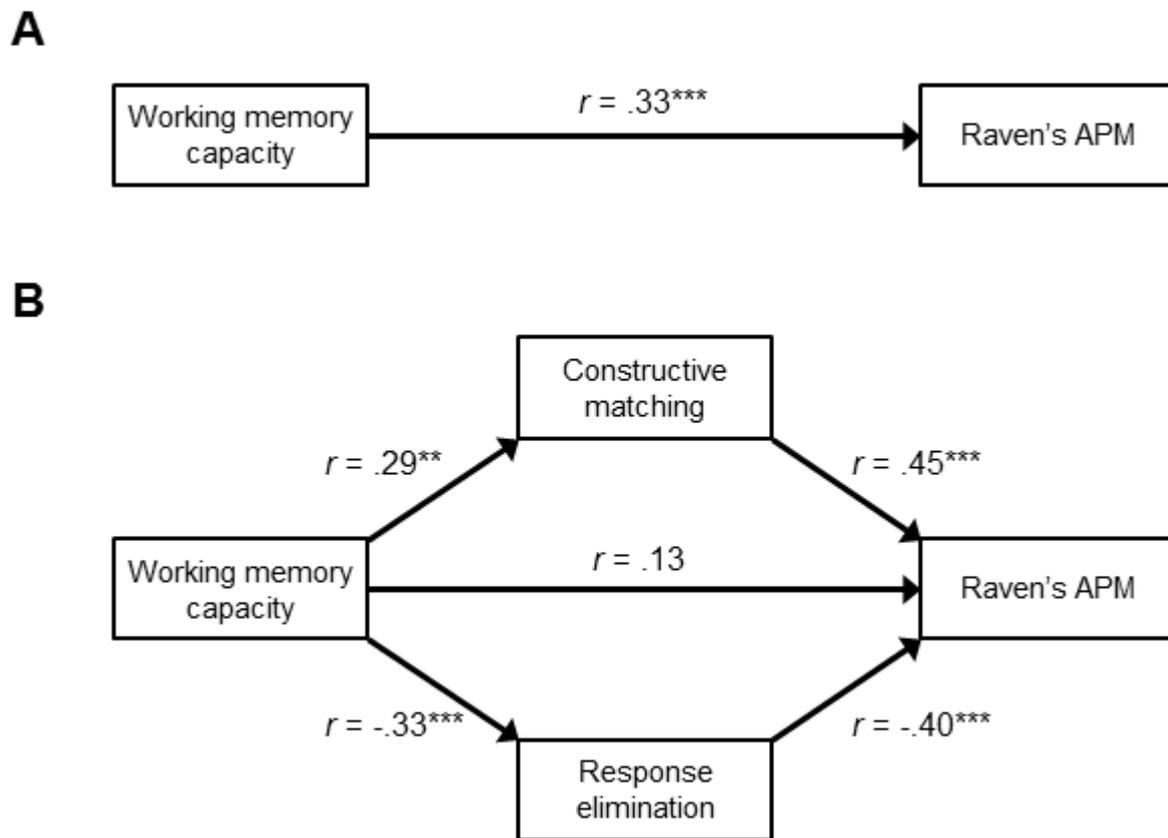


Figure 2. Relationship between working memory capacity and Raven's APM in a simple regression (A) and in a multiple regression controlling for strategy use (B).

\*\*  $p < .01$ , \*\*\*  $p < .001$ .

In order to confirm the existence of a mediation by strategy use, a multiple mediator model was tested using the procedure developed by Preacher and Hayes (2008). This approach is conceptually similar to a Sobel (1982) test, except that it allows for the simultaneous test of multiple mediators. Bootstrapping is also used to obtain a better estimate of the indirect effects associated with the mediators. This approach yields a confidence interval for the total indirect effect of the independent variable on the dependent variable through the mediators; a multiple mediation exists if this confidence interval does not include zero. The multiple mediator model

was tested using the *INDIRECT* macro for SPSS provided by Preacher and Hayes (2008). We computed bias-corrected and accelerated 95% confidence intervals, two-tailed, with 20,000 bootstrap resamples. The indirect effect was highly significant (total indirect effect = .99,  $SE = .29$ , 95% CI [.48, 1.63]), confirming that strategy use mediated the relationship between WMC and performance on the APM.

### **General Discussion**

The present research aimed to test the hypothesis that strategy use drives the relationship between WMC and performance on Raven's APM. Experiment 1 showed that inducing all participants to use the same strategy decreased the relationship between WMC and performance on the APM. This finding strongly supports the view that strategies play a critical role, but it is difficult to reconcile with the view that strategies constitute unwanted noise. Experiment 2 showed that participants with high WMC were both more likely to use the effective constructive matching strategy, and less likely to use the ineffective response elimination strategy. These results are highly compatible with prior findings obtained with eye-tracking (Jarosz & Wiley, 2012) and demonstrate that WMC is related to effective strategy use in fluid intelligence tests, similar to other high-level cognitive tasks such as arithmetic (Beilock & DeCaro, 2007), syllogism (Copeland & Radvansky, 2004; Verschueren et al., 2005) or verbal fluency tasks (Schelble et al., 2012; Unsworth et al., 2013). Critically, the relationship between WMC and fluid intelligence was no longer significant when controlling for strategy use. Taken together, the results indicate that the use of effective strategies fully mediates the relationship between WMC and Raven's APM.

Importantly, the idea that strategy use drives the relationship between WMC and performance on Raven's APM is by no means incompatible with the role of primary memory, secondary memory and controlled attention advocated by the literature (e.g. Unsworth et al.,

2014). On the contrary, it is likely that individual differences in the use of effective strategies associated with WMC are directly due to individual differences in attentional control or memory (for a similar point, see Schunn & Reder, 1998). For example, the use of the constructive matching strategy in the APM relies on the construction of a mental representation of the solution, which requires participants to follow a systematic multi-step process and to integrate interim mental representations into a complete answer (Carpenter, Just, & Shell, 1990). Such a process necessarily makes heavy demands on attentional control and primary memory (Carpenter et al., 1990; Wiley & Jarosz, 2012; see also Bethell-Fox et al., 1984). As a consequence, participants with high WMC may engage in more effective strategies simply because they are able to do so more easily or more effectively.

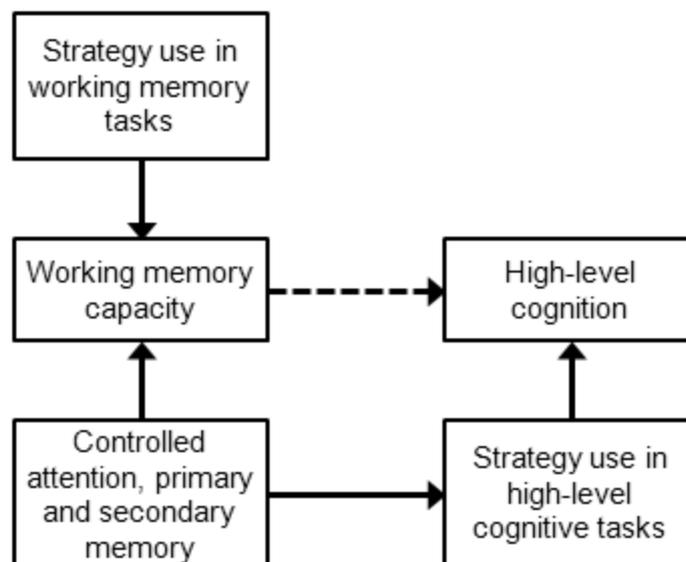
In this view, strategy use may be just one causal step in the relationship between WMC and fluid intelligence: participants with high WMC have better attentional control and primary memory, which leads them to use more effective strategies, which in turn elicits better performance on fluid intelligence tests. This explains why both strategy use and cognitive abilities such as attentional control and primary memory are observed to mediate the relationship between WMC and high-level cognition: these simply represent different steps in the same causal process. In sum, the strategic approach and the traditional approach based on cognitive abilities need not be opposed (Schunn & Reder, 1998). On the contrary, the strategic approach plays a critical role in providing a mechanistic account of how abilities such as attentional control can influence performance on fluid intelligence tasks.

This conclusion may seem at odds with the multiple studies reporting that strategy use does not play a role in the relationship between WMC and high-level cognition (Turley-Ames & Whitfield, 2003; Friedman & Miyake, 2004; Dunlosky & Kane, 2007; St-Clair Thompson, 2007; Bailey, Dunlosky, & Kane, 2008). This apparent inconsistency is resolved by the fact that all these studies have measured strategy use in working memory tasks, rather than in the

high-level cognitive tasks themselves (see Thomassin et al., 2014, for a discussion of this point). Since strategies tend to be task-specific (e.g. Bailey, Dunlosky, & Kane, 2008), strategic behavior in working memory tasks cannot be expected to bear a relationship to high-level cognitive tasks. The strategies at play in working memory tasks are also relatively simple – for instance, the most prominent strategy in complex spans seems to be subvocal rehearsal (Friedman & Miyake, 2004; Dunlosky & Kane, 2007) – which suggests that they might not critically depend on abilities such as attentional control. For these two reasons, it is not surprising that strategy use in working memory tasks are not involved in the relationship with high-level cognition: on the contrary, if the strategies used in working memory tasks influence WMC without being related to high-level cognition, they can be expected to actually decrease the strength of the relationship between WMC and fluid intelligence – which is exactly what is observed in practice (Friedman & Miyake, 2004; Lépine et al., 2005; St-Clair Thompson, 2007; Turley-Ames & Whitfield, 2003). In other words, researchers should distinguish between strategy use in high-level cognitive tasks, which plays a critical role in the relationship with WMC, and strategy use in working memory tasks, which represents a nuisance parameter. This model is summarized in Figure 3.

To conclude, it is important to note that the APM are by no means the only test that measures fluid intelligence. This is actually a critical point, as the vast majority of studies interested in the predictive value of WMC have assessed fluid intelligence with a version of Raven's matrices (Ackerman et al., 2005). Since strategies are not transferable from one task to another (Bailey et al., 2008), the two basic strategies described in the APM may not exist at all in a different task. For instance, other fluid intelligence tasks may only allow for a single strategy, or conversely they may encourage a wide range of different strategies; the role of strategy use as a mediator might well be different in that case. For this reason, future studies should investigate the relationship between WMC and strategy use in intelligence tasks other

than Raven's matrices. Importantly, this does not question the role of strategic behavior in the relationship between working memory and high-level cognition: given the very wide variety of tasks in which WMC has been shown to predict strategy use, it is likely that strategies constitute a very general mediator for the predictive value of WMC.



*Figure 3.* A model of the relationships between working memory capacity, high-level cognition and strategy use.

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