Exploring Functions of Working Memory Related to Fluid Intelligence: Coordination and Relational Integration

Joel E. Bateman (jbat2136@uni.sydney.edu.au)[1]
Damian P. Birney (damian.birney@sydney.edu.au)[1]
Vanessa Loh (vanessa.loh@sydney.edu.au)[1]

[1]School of Psychology, University of Sydney
Sydney, NSW, 2006, Australia

Abstract

Two hypothesized functions of working memory – coordination (ability to maintain unrelated storage loads during processing) and integration (ability to integrate multiple elements into a relation) – were explored and compared to fluid intelligence. In Experiment 1, 130 participants completed a modified Latin-Square Task (LST) which experimentally added or reduced storage load. Results suggested that pure integration (with no storage load) could predict Gf, but no difference was found between coordination and integration. Experiment 2 employed the Arithmetic Chain Task (ACT), again with modifications to storage load. Results support replication of LST findings, though a distinction was found between coordination and integration when storage material could not be easily rehearsed. Findings from both experiments support a distinction between coordination and integration tasks in understanding the WM-Gf association.

Keywords: working memory; fluid intelligence; relational integration

Introduction

Working memory *(WM)* has consistently been linked to fluid intelligence *(Gf)*, yet the intricacies underlying this relationship are not fully understood. This is in part because neither *WM* nor *Gf* reflect a single cognitive process. Rather, *WM* is a complex system responsible for processing and maintaining information, attention, and multi-tasking. *Gf* is similarly multi-dimensional, variously reflecting reasoning and the capacity to deal with novelty. Many *WM* tasks (such as complex-span tasks; CSPANs) draw on *coordination*, in that information from one aspect of the task must be maintained in storage while performing a simultaneous but unrelated processing task. Conversely, many prototypical *Gf* tasks require *relational integration* (henceforth 'integration'; Halford, Wilson, & Philips, 1998). Integration entails the ability to combine multiple representations and is critical to reasoning. In this report, we argue that advances in understanding the *WM-Gf* link have been slowed by the overrepresentation of coordination in *WM* tasks, and the failure to consider integration as a component of *WM*.

We aim to redress this using two experiments. In Experiment 1, we modify the integration-based Latin-Square Task (LST; Birney, Halford, & Andrews, 2006) by adding or removing storage load. In Experiment 2, we investigate the same processes in an arithmetic task (Oberauer, Demmrich, Mayr, & Kliegl, 2001). We begin with an exposition of coordination and integration.

Two Functions of Working Memory

Coordination *WM* tasks typically involve some combination of *processing* and *storage*, reflecting the two components of *WM*. Coordination can be defined as the ability to coordinate stored elements with unrelated processing. CSPANs, such as the operation span, are examples of coordination tasks, because storage capacity is the primary outcome (e.g., the number of words that can be recalled) and processing (e.g., verifying the veracity of a math operation) is included to fulfil the simultaneous processing-storage conceptualization of *WM* (Baddeley & Hitch, 1974). While a failure of either component does not represent a failure of the other, if both components are not given equal priority, the extent that CSPAN measures *WM* is brought into question. However, even when processing is ensured (e.g., with an 85% threshold for operation verifications), the only measure indexing *WM* is the recall. Because the processing is somewhat trivialized, it tells us little about how processing *ability* influences performance on *WM* tasks. This does not, however, take away from the fact that coordination tasks are excellent for linking *WM* and *Gf* (Ackerman, Beier, & Boyle, 2005).

Integration Process-oriented accounts of *WM* have led to the development of tasks that measure the ability to *integrate* representations into higher-order relational structures (Oberauer Süß, Wilhelm, and Wittman, 2008). All processing subtasks typically require some form of integration (e.g., integrating two digits to derive a sum), though some researchers have attempted to provide formalized accounts of processing tasks. Oberauer et al. (2008) employed the *finding squares* task, where participants monitored a 10x10 grid filled with 10 dots. Every few seconds, some dots would change position. The task was to monitor the dots and respond if a collective set of dots formed a square. Although tasks such as these have no storage requirements, they are still good predictors of *Gf* (Oberauer et al., 2008). This has led to the suggestion that integration forms the core of *WM* (Oberauer, Süß, Wilhelm, & Sander, 2007); and that rather than a 'storage capacity' limiting *WM*, constraints are instead dictated by the strength of bindings between integrated representations.

Halford and colleagues provide an alternate process-oriented account of *WM* limitations in terms of relational complexity (Halford et al., 1998), that formalizes individual capacity for integration. *WM* is framed not as a limitation in the *number* of elements, but by the *complexity* of relations between elements to-be-integrated. Complexity metrics have been shown to capture constraints in processing capacity (Birney et al., 2006).

Aims There is evidence that both coordination and integration can be implicated in the *WM-Gf* association. However, it is difficult to directly compare these functions, as they are typically operationalised in different tasks. The current research aims to compare coordination and integration within single tasks, experimentally.

Experiment 1

One way to explore coordination and integration within a task is to consider a variant of a typical processing task, with reduced or additional storage load requirements. If the reduced storage load condition still associates with *Gf*, it would suggest a role of pure integration within the *WM-Gf* link, as only the processing remains. Conversely, if the additional storage load condition associates with *Gf*, it would suggest a role of coordination. This is the approach we used in Experiment 1, employing the LST as a processing task.

The LST was designed following the principles of relational complexity theory (Birney et al., 2006). The LST presents participants with an incomplete matrix of 4x4 cells with the governing rule that each row and column may contain only one element from a set of 4 elements. Complexity is manipulated by the number of rows and columns that must be considered in order to deduce a target cell (see Figure 1). In some items, participants must also solve interim cells, using information from those cells to solve the target. Thus, although the task is processing-focused, there is some storage costs associated with holding interim cell information. Birney et al. (2006) found that complexity captures 64% of variability in item difficulty, while the number of interim cells captures 16%. Thus, 80% of difficulty variance is from identified processing and storage demands.

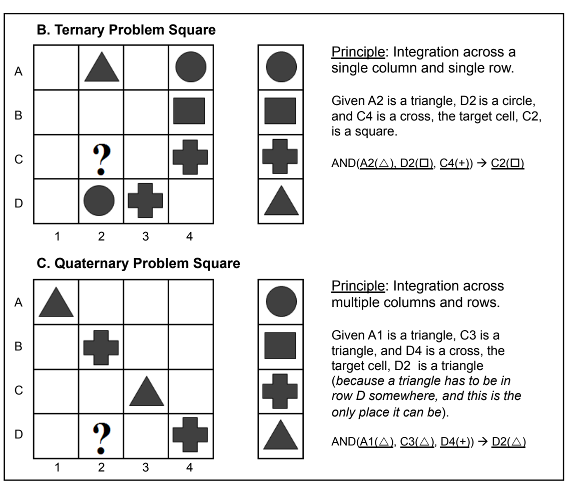

Figure 1. Example LST items

Because we were employing a variance-partitioning approach, it was possible to more directly compare the coordination condition with integration by varying whether the additional storage was processing-contingent or not. By partitioning out variance associated with the baseline task, we could derive variance associated solely with a coordination load and compare it to variance associated with an integration load, that were equivalent in task format and (potentially) difficulty. Thus, our four conditions for the LST were: basic, reduced storage, additional storage (coordination), and additional storage (integration); which were crossed with the standard manipulations of complexity and steps.

We hypothesized that the reduced storage condition would reduce the difficulty of the task, but maintain the association with *Gf*, because pure integration was still required of the baseline task. We also hypothesized that the additional storage conditions would increase the difficulty of the task to similar degrees, and each would represent a unique contribution to predicting *Gf*, as they represent the two functions of coordination and integration.

Method

Participants and Procedure In total 130 first-year students (83 females) at the University of Sydney participated in exchange for course credit. The mean age was 19.04 (SD = 1.6) years. Participants were tested in groups in 60m sessions.

Measures Three LST sets, each with 12 unique items equally distributed across complexity (2/3/4) and steps (1/2), were adapted from Birney and Bowman (2009). Thus, all sets included an equal distribution of complexity and steps. The *basic* set consisted of 12 standard items (as in Figure 1).

The *dynamic-completion* (DC) set consisted of 12 items which allowed participants to insert interim solutions. Instead of simply selecting an answer, participants could place shapes into empty cells of the matrix, before placing a shape into the target cell to indicate their overall response. In this way, participants were able to work through the problem, offloading storage demands associated with interim cells.

The final set was additional *load*, consisting of 12 items. Participants were randomly allocated to coordination or integration items for this set. The actual items were identical, but the procedures were different.

For coordination items, there was a 5s memory phase where participants viewed the matrix without the target indicated. During this phase, two shape-filled clue cells were coloured to indicate that they must be remembered. After this phase and a 2000ms interlude, the typical test phase began with the target indicated. After responding to the item, the recall phase began. In this phase, there was first a five-second downtime with a black screen stating to “recall the cells”. After this, a blank probe matrix appeared and the participant had to indicate the shapes and locations associated with the two marked cells (thus requiring *coordination* of stored elements and unrelated processing).

For integration items, a similar procedure was employed for coordination items except that the two marked cells during the memory phase were *removed* during the test phase. In this way, if the participants forgot the shapes in these cells, they would not be able to solve the problem (thus requiring *integration* of stored elements with related processing).

After the LST, participants completed a 20-item Raven's Advanced Progressive Matrices (Raven, 1941; APM; odd items + items 34 and 36). The use of a single task does define *Gf* narrowly, because we cannot be certain that correlations between the LST and APM are due to an overlap in *WM* functions or due to task-specific factors, such as modality. However, there is a large comparative literature base to draw on to understand implications of this limitation.

Results

Difficulty Effects Descriptive results are presented in Table 1. The overall LST-APM correlation was r = .47, p < .001, replicating prior work (Birney et al., 2012). Using a repeated measures ANCOVA, a complexity effect was investigated with APM entered as a moderator (covariate). Consistent with prior research (Birney & Bowman, 2009), complexity was a significant predictor of performance ($F_{2,256}$ = 94.73, *mse* = 0.485, p < .001, partial-η^2 = .425), but APM did not moderate the effect, suggesting increases in complexity does not result in increased demand on *Gf*-like resources.

A set (basic/DC/load) by complexity (2/3/4D) repeated-measures ANOVA was conducted to determine whether set affected performance. There was a significant main effect of set ($F_{2,242}$ = 43.17, *mse* = 0.56, p < .001, *partial*-η^2 = .26). As hypothesized, DC items were significantly easier ($F_{1,121}$ = 35.14, *mse* = 0.76, p < .001) and load items were significantly more difficult ($F_{1,121}$ = 14.66, *mse* = 1.48, p < .001). A significant set-complexity interaction ($F_{4,484}$ = 13.28, *mse* = 0.36, p < .001, *partial*-η^2 = .10) suggests complexity moderates the set effects. Simple-effect analyses suggest the difference between conditions, particularly the DC condition (DC vs basic x quadratic complexity effect: $F_{1,121}$ = 4.69, p = .03), is more pronounced for more complex items. Finally, separate analyses suggest that integration (M=3.12) and coordination (M=3.31) conditions were not significantly different, $F_{1,128}$ = 2.81, p = .10. Although this was as hypothesized, there was a trend towards integration items being more difficult.

The results of these tests indicate the LST sets were performing as expected. That is, the DC condition was aiding participants and the load conditions were burdening. The next set of analyses sought to test the hypotheses on the links of set to predicting *Gf*.

LST-Gf A series of multiple regressions were performed, regressing APM on LST set performance. Our first hypothesis was that DC should maintain the association with *Gf*, despite having reduced storage demands.

When basic and DC items were entered together, 14.2% of variability in APM performance was accounted for (R^2 = .142, $F_{2,127}$ = 10.49, p < .001). DC items explained 8% unique variance (β = .30, sr^2 = .084, p = .001), whereas basic items did not significantly account for any additional systematic variance (β = .14, sr^2 = .018, p > .05). As hypothesized, DC did sustain the link with *Gf*; and in fact, captured a larger proportion of variance in APM than basic items.

Table 1. LST and APM Descriptives

Scale (Total Scores)	Mean	(SD)	Range
LST combined	31.17	(3.42)	17 - 36
2D Items	11.42	(1.02)	7 - 12
3D Items	10.96	(1.14)	8 - 12
4D items	8.78	(2.11)	2 - 12
Basic Set	10.35	(1.50)	5 - 12
DC Set	11.17	(1.19)	6 - 12
Load: Integration (n1 = 65)	9.37	(1.98)	3 - 12
Load: Coordination (n2 = 65)	9.92	(1.78)	4 - 12
Recall Cell 1 (Coordination, n2 only)	10.78	(1.60)	4 - 12
Recall Cell 2 (Coordination, n2 only)	10.69	(1.98)	0 - 12
APM	13.35	(3.88)	2 - 20

The final regression aimed to test the hypothesis that additional coordination and integration conditions could provide unique contributions to APM. The basic set was entered first, followed by load (regardless of type), then a load interaction variable distinguishing coordination from integration. Load items did account for a significant proportion of variance in APM performance, β = .39, sr^2 = .14, p = .001, over and above basic items, β = .16, sr^2 = .02, p > .05. However, contrary to hypotheses, the regression lines were not different, β = .10, sr^2 = .01, p > .05.

Discussion

In Experiment 1, we flipped the typical *WM* operationalisation, which uses recall as a primary task, to have processing as the primary task. Under these conditions, a storage-loaded version of the LST, relative to basic items, predicted a greater proportion of differences in *Gf*, providing support for the notion that *WM* does not have to be restricted to recall as an outcome, or processing as a distractor. The inability to distinguish integration from coordination was unexpected, though clashed with the results of the DC condition, which implicated pure integration alone as the strongest link between *WM* and *Gf*. It is possible the impact of the additional load conditions was confounded by the use of a primary task already highly loaded on integration processes. The burden of performing novel integration may have attenuated differences between the load conditions.

To address this limitation, Experiment 2 employed a different experimental task, the *Arithmetic Chain Task* (ACT; Oberauer et al., 2001). The ACT requires participants to solve a series of simple equations using mental arithmetic under additional load conditions, while mitigating the potentially high integration present in the LST by having a constant level of complexity. Furthermore, because the ACT is non-visuospatial, it helps quell criticism that the modality overlap between the LST and APM was the core determinant of correlation. Although arithmetic is a form of integration

(3+5=? entails establishing the relation, *sums-to(3,5,?)*; Halford et al., 1998), we argue that completing a chain of simple arithmetic provides a cognitively simpler instantiation of integration than the LST, thus allowing stronger differences to emerge between additional load conditions.

Experiment 2

Oberauer et al. (2001) provided evidence for a distinction between coordination and integration in the ACT. They asked participants to complete a mental arithmetic task in which participants were shown an equation involving a number of digits, three of which were replaced by symbols (e.g., X, Y, and Z). In the control condition, participants were given a key showing the numerical values of *XYZ* for use in the equation. In the coordination condition, participants were briefly shown three additional numeric values associated with other symbols (A, B, and C). These variables were to be memorized and recalled later, though they were not relevant to the arithmetic. In the integration condition (dubbed 'access') however, *XYZ* was equated to *ABC*, necessitating both storage and integration (see Figure 2). The authors found that although the number of stored value mappings had little effect on performance in coordination; in the integration condition, higher levels of storage load produced declines in speed and accuracy. These diverging outcomes indicated the manipulations may have indeed tapped different functions.

In the current study, the ACT entails equations of six operations and seven addends. The format for control, coordination, and access from Oberauer et al. (2001) was used. We also introduced an additional condition, which modified the access condition to include fixed (e.g., ABC=XYZ) as well as random (e.g., ABC=YZX) mappings. Our complexity analysis (not reported here) suggests that random access imposes constraints on conceptual chunking, increasing the integration load, relative to access-fixed. In summary, the convenience of the serially ordered fixed mappings cannot be applied to random mappings, forcing participants to deconstruct and reconstruct the bindings holding the relation together – a critical source of demand in Oberauer et al.'s (2007) architecture of *WM*.

In addition to the ACT and APM, we employed the symmetry span as an additional criterion measure. We also aimed to replicate Experiment 1 by including the LST. If the LST-DC is indeed a measure of pure integration, it would provide a useful criterion measure.

Our primary hypothesis was that access and coordination aspects of the ACT should provide independent contributions to predicting APM variance. Further, we hypothesized that access-random should provide the strongest unique contribution, over-and-above other conditions, as it places the highest theoretical demand on a binding-based relational processing system of *WM*.

Method

Participants and Procedure The participants were 60 first-year students (44 females) at the University of Sydney who participated for course credit. The mean age was 19.22 (SD = 2.77). Participants were tested in groups in 90m sessions.

Measures The ACT required participants to solve arithmetic problems of six operations (additions/subtractions). Four blocks of problems (control, coordination, access-fixed, access-random) were generated such that all digits were between 1 and 7, and final answers, between -9 and +9. There were six items per block. Participants had practice with all conditions, then received the blocks in random order.

Control items were basic problems that entailed substituting variable-value mappings (e.g., X=2, Y=1, Z=4) provided in the top half of the screen into equations where each operand was displayed one-at-a-time at a pace controlled by participants. After all 7 operands had been displayed, a textbox would appear prompting the participant for an answer. Feedback was then displayed.

Coordination items were identical to control items, with the exception that participants were given 6s to memorize three variable-value mappings (e.g., A=6, B=3, C=1) to be recalled at the end of the trial.

Access-fixed items were similar to coordination items, except the *XYZ* variable-value mappings were directly linked to the *ABC* mappings (e.g., A=6, B=3, C=1; and always, X=A, Y=B, Z=C). Again, participants were asked to reproduce the digits corresponding to *ABC* after the equation had been solved. Thus, unlike the coordination condition, the *ABC* mappings were required for the arithmetic. *Access-random* items were similar but the *XYZ* mappings were randomly linked to the *ABC* mappings (e.g., A=6, B=3, C=1; and say, X=B, Y=C, Z=A).

Participants also completed the symmetry span, as in Kane et al. (2004), with set sizes of two to five (two of each). The

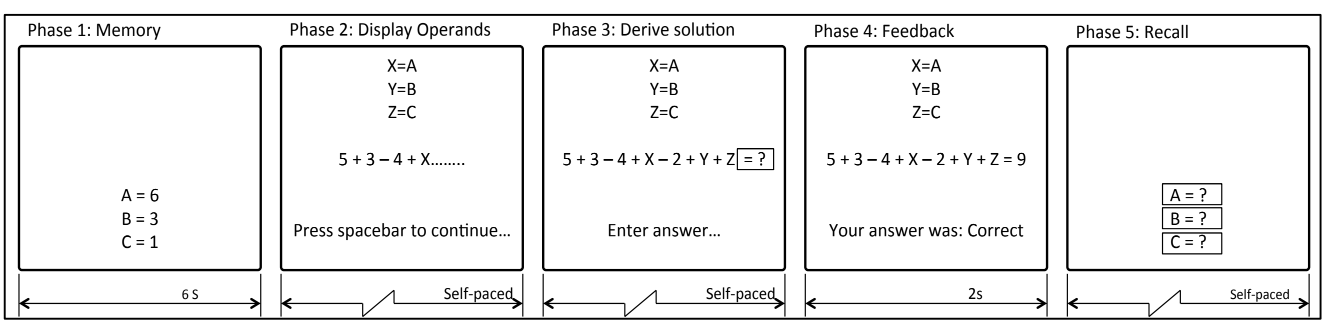

Figure 2. Example of Access condition of the Arithmetic Chain Task (adapted from Oberauer et al., 2001)

score analyzed was total number of recalled squares (0-28). The LST and APM were administered as in Experiment 1.

Results

Difficulty Effects A repeated-measures ANOVA indicated differences in performance across conditions were significant ($F_{3,180}$ = 23.99, *mse* = 1.51, $p < .001$, *partial*-η^2 = .29). Control performance (*M* = 5.20, *SD* = 1.01) was not significantly different to coordination performance (*M* = 5.00, *SD* = 1.34), t_{59} = 1.07, *p* = .29. However, control performance was significantly higher than the access conditions on average (Access-fixed: *M* = 3.98, *SD* = 1.75; Access-random: *M* = 3.60, *SD* = 1.89), t_{59} = 7.58, $p < .001$. Although in the expected direction, the difference between fixed and random did not reach statistical significance, t_{59} = 1.60, *p* = .12.

In summary, the ordering of performance was as expected. Recall was high for all conditions (coordination: 86.67%, access-fixed: 92.59% and access-random, 90.37%), meeting the criterion of the secondary task in CSPANs, though there was some evidence to suggest recall under conditions where the information was critical (access) is better than when it was irrelevant (coordination).

ACT Correlates The ACT correlated well with the APM, sharing 22% of variance (*r* = .47). The total ACT-recall component correlated with the CSPAN (*r* = .46), but was not related to either LST-DC or APM.

In efforts to understand the relationships among the data, step-wise analyses regressing each criterion measure (CSPAN, LST-DC, APM) on ACT were conducted. Results suggest different sets of unique predictors for each criterion in ways as might be expected. For CSPAN, the only ACT predictor accounting for significant variance was coordination recall. For both LST-DC and APM, control and access-random performance were unique predictors. In second models, the criterion measures not being predicted were added, but the results remained unchanged.

In order to fully explicate the ACT-*Gf* model, a hierarchical regression was conducted, with each condition predicting APM. Model 1, with just control items, predicted 15.3% of variance in APM. Contrary to expectations, the coordination predictor did not account for additional unique variance in the second model (ΔR^2 = .009, $F_{1,57}$ = .63, *p* = .431). Model 3 with access-fixed also failed to result in a significant change (ΔR^2 = .032, $F_{1,56}$ = 2.19, *p* = .144), with control items and shared variance taking the majority of the contribution. However, model 4 with access-random added 6.4% of unique APM variance predicted – a significant contribution over-and-above all other variables, (ΔR^2 = .064, $F_{1,55}$ = 4.77, *p* = .03).

Discussion

The findings for LST-DC and APM support the notion that integration is a key component of each of these tasks, drawing both on the control arithmetic (which is basic arithmetical integration) and access-random (which has the highest theoretical integration demands). CSPAN, which we have argued as capturing coordination, was related to recall in the coordination aspect of the ACT.

General Discussion

The extant literature makes a distinction between coordination and integration functions of *WM*. We adopt a conceptualisation of *coordination* as the *WM* function underlying dual-task requirements, where a storage load must be maintained despite ongoing, unrelated processing. This paradigm remains by far the most common used in investigations of the *WM-Gf* link (Ackerman et al., 2005). Process-oriented accounts of *WM* instead focus on the capacity for *integration*: combining multiple representations into higher-order relational structures. Integration as a concept has been linked conceptually and empirically to *Gf* (Oberauer et al., 2008). The current work contributes to this research by investigating coordination and integration functions of *WM* and their relationship to *Gf*. A feature of our approach has been to focus on measures where the primary task is processing, rather than recall.

The LST provided mixed results on a distinction between coordination and integration. While additional load overall was incrementally predictive of *Gf*, the load effect did not

Table 2. Significant stepwise correlates of cognitive criterion variables.

	Model **CSPAN**			Model **LST-DC**			Model **APM**		
Predictor	**b**	**t**	**p**	**b**	**t**	**p**	**b**	**t**	**p**
Control	-	-	-	.39	3.23	.002	.27	2.22	.030
Coordination	-	-	-	-	-	-	-	-	-
Coordination Recall	.42	3.54	.001	-	-	-	-	-	-
Access-Fixed	-	-	-	-	-	-	-	-	-
Access-Fixed Recall				-	-	-	-	-	-
Access-Random	-	-	-	.24	2.03	.047	.34	2.73	.008
Access-Random Recall	-	-	-	-	-	-	-	-	-
Symmetry Span	***	***	***	-	-	-	-	-	-
LST-DC	-	-	-	***	***	***	-	-	-
APM	-	-	-	-	-	-	***	***	***
	R^2 = .18; $F_{1,58}$=12.54, p < .001			R^2 = .28; $F_{2,57}$=10.99, p < .001			R^2 = .25; $F_{2,57}$=9.56, p < .001		

Note: The set of arithmetic variables were entered first, then cognitive variables second. *** = not included in the model (because it was the DV). b = standardised regression coefficient; t = t-test value; p = significance value.

depend on whether the recalled items were unrelated or related to the LST solution. However, evidence for integration was found in the DC condition, which exceeded expectations as a predictor of *Gf*, improving performance while also increasing the association with APM. We replicated this in Experiment 2. This could be explained as a means of 'purifying' the LST into an assessment of raw integration, minimizing the impact of obfuscating storage demands associated with holding interim processing outcomes. DC may be a valuable tool for future use of processing tasks, in order to amplify the effect of integration.

We argued that one issue with the LST was the high integration load present in all manipulations, potentially swamping our additional load conditions by task-specific characteristics. This is especially plausible given the power of DC. The ACT was selected for Experiment 2 because those characteristics are less apparent. The ACT conditions were predictive of the criterion measures consistent with an account for a distinct coordination and integration. However, the coordination link to CSPAN only became apparent when using the recall portion of the ACT, indicating the relationship may have more to do with the outcome measure (i.e., recall) rather than a coordination function *per se*.

The results of the experiments support a compelling case for differentiating a specific role of integration in *Gf* over-and-above conceptualisations of *WM* defined by CSPANs. The absence of storage in the LST-DC and other integration-based tasks (Oberauer et al., 2008) contributes to the notion that storage maintenance is not a pre-requisite for *WM* to be associated with *Gf*, and supports process-oriented accounts of *WM* (Halford et al., 1998; Oberauer et al., 2007). Further, specific processing limits were alluded to in the results of access-random. That is, consistent with a relational binding approach (Oberauer et al., 2007), the random ordering forced participants to quickly and flexibly deconstruct and reconstruct the variable-value mappings from the way they were first presented into an order consistent with the way they were presented on the screen at the time of the equation. Because only this single condition could indicate binding as an ability, further research is needed to determine what processes contribute to the capacity for relational binding.

One limitation with the current results was that the DC variance could have represented a general task navigation ability (i.e., to apply the advantages of DC), as opposed to pure integration *per se*. It seems unlikely that such a strong unique effect (equal to 8.4% of variance in APM) could be attributed solely to DC (as opposed to any other condition), though there is no way to disprove such an explanation with the current data. Because participants could fill as many cells as they wished, we could not distinguish which cells were filled through trial-and-error and which were used as actual planning steps. This task navigation component could be explored using a variant of DC where participants are allowed only a limited number of cells to fill.

Another limitation was the LST and ACT both being integration-based tasks. While we have attempted to reconcile this by holding processing load constant in the ACT, it is worth considering alternatives for future work. For one, it would be helpful to consider both a storage-based and a processing-based primary task, each with coordination and integration conditions. For instance, an integration version of the operation span could use numbers for the storage component, and these numbers could then be used in the processing component. While this does remove the ability to keep comparisons within a single task, it may at least provide some evidence of a coordination-integration dichotomy not restricted to processing-based tasks.

In conclusion, the current results offer mixed support for a strict coordination-integration functional dichotomy within *WM*. They do, however, provide evidence of a relational integration ability implicated within *Gf* across multiple task formats, with the storage-stripped DC set offering perhaps the strongest support. Further work is needed to determine the extent of integration across tasks; and to determine if coordination can be distinguished from mere recall.

References

Ackerman, P.L., Beier, M.E., & Boyle, M.O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin, 131*, 30-60.

Baddeley, A.D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47-89). New York: Academic Press.

Birney, D.P., & Bowman, D.B. (2009). An experimental-differential investigation of cognitive complexity. *Psychology Science Quarterly, 51*, 449-469.

Birney, D.P., Halford, G.S., & Andrews, G. (2006). Measuring the influence of complexity on relational reasoning: The development of the Latin Square Task. *Educational and Psychological Measurement, 66*, 146-171.

Halford, G.S., Wilson, W.H., & Philips,S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral and Brain Sciences, 21,* 803-865.

Kane, M.J., Hambrick, D.Z., Tuholiski, S.W., Wilhelm,O., Payne,T., & Engle, R.W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*, 189-217.

Oberauer, K., Demmrich, A., Mayr, U., & Kliegl, R. (2001). Dissociating retention and access in working memory: An age-comparative study on mental arithmetic. *Memory & Cognition, 29,* 18-33.

Oberauer, K., Süß, H.M., Wilhelm, O., & Sander, N. (2007). Individual differences in working memory capacity and reasoning ability. In R.A. Conway, C. Jarrold, M.J. Kane, A. Miyake, & J.N. Yowse (Eds.), *Variation in Working Memory*. New York: Oxford University Press.

Oberauer, K. Süß, H.M., Wilhelm, O., & Wittman, W.W. (2008). Which working memory functions predict intelligence? *Intelligence, 36,* 641-652.

Raven, J. C. (1941). Standardisation of progressive matrices. *British Journal of Psychology, XIX,* 137-150.