Working Memory Capacity and Fluid Intelligence Are Strongly Related Constructs : Comment on Ackerman, Beier, and Boyle (2005)

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Abstract:

The authors agree with P. L. Ackerman, M. E. Beier, and M. O. Boyle (2005) that working memory capacity (WMC) is not isomorphic with general fluid intelligence (Gf) or reasoning ability. However, the WMC and Gf/reasoning constructs are more strongly associated than Ackerman et al. (2005) indicate, particularly when considering the outcomes of latent-variable studies. The authors' reanalysis of 14 such data sets from 10 published studies, representing more than 3,100 young-adult subjects, suggests a strong correlation between WMC and Gf/reasoning factors (median *r* = .72), indicating that the WMC and Gf constructs share approximately 50% of their variance. This comment also clarifies the authors' "executive attention" view of WMC, it demonstrates that WMC has greater discriminant validity than Ackerman et al. (2005) implied, and it suggests some future directions and challenges for the scientific study of the convergence of WMC, attention control, and intelligence.

Article:

Theorists have recently speculated that individual differences in working memory capacity (WMC) may explain reasoning ability, general intelligence (Spearman's g), or both (e.g., Engle, 2002; Kyllonen & Christal, 1990; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). In response to these claims, Ackerman, Beier, and Boyle (2005) conducted a critical review and meta-analysis of the literature and rejected the notion that WMC is isomorphic to g, general fluid intelligence (Gf), or any other cognitive ability. Indeed, they remained generally skeptical that WMC research would significantly advance either the understanding or measurement of human intelligence. Perhaps it is surprising, then, that we find several points of agreement with Ackerman et al. (2005), despite our position that WMC and Gf are closely related and that exploring this relationship will yield important theoretical insights into the nature of normal cognitive variation (e.g., Conway, Kane, & Engle, 2003; Engle & Kane, 2004; Engle, Kane, & Tuholski, 1999; Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2002).

We concur with Ackerman et al. (2005) on three main conclusions: (a) WMC is not equivalent to g, Gf, or reasoning ability; (b) WMC is primarily a domain-general construct; (c) WMC is more closely related to Gf and reasoning than is short-term memory (STM). The latter two arguments are now well supported by large-sample, latent-variable studies. WMC tasks correlate strongly with each other and with a wide range of cognitive abilities regardless of their surface characteristics, and WMC and Gf share substantial variance that is independent of STM (for reviews, see Daneman & Merikle, 1996; Kane et al., 2004). Regarding the central issue of a WMC-intelligence isomorphism, Ackerman et al.'s (2005) meta-analysis suggests that individual tests of WMC and Gf (or reasoning) share only about 20% of their variance, on average, and so these constructs are not synonymous (see also Ackerman, Beier, & Boyle, 2002). We have similarly argued in recent reviews of latent-variable studies that the correlations between WMC and Gf constructs do not approach 1.0, even when both are measured broadly, and so speculations about isomorphism are falsified (Conway et al., 2003; Kane et al., 2004).

Nonetheless, we also find major points of disagreement with Ackerman et al. (2005) and discuss them below. Namely, when we consider the data from latent-variable studies, we find that the WMC-Gf association is much stronger than they suggested. WMC also shows greater discriminant validity than Ackerman et al. (2005) admitted, correlating more strongly with some constructs than with others, and so WMC represents much more than a “crud factor” (p. 52) in its association with other cognitive abilities. Finally, the link between WMC and attention control is potentially important to a complete understanding of intelligence, but it also presents considerable challenges for future theoretical and empirical work that we discuss—particularly regarding measurement. To put our critique in proper context, however, we first present an overview of our theoretical perspective. We also hope that this review clarifies aspects of our position that seem to have promoted some misunderstanding.

An Executive Attention View of WMC

Our view of WMC derives from correlational, experimental, and quasi-experimental studies of WMC variation (for more detailed reviews, see Engle & Kane, 2004; Engle, Kane, & Tuholski, 1999). Much of this research is based on “complex span” tasks, such as Daneman and Carpenter's (1980) reading span task, which present short lists of stimuli for immediate recall. In contrast to “simple” STM span tasks, the presentation of the memory items is interpolated with a secondary processing task such as verifying mathematical equations. The most critical findings for our perspective are that individual differences in performance of WMC tasks predict a variety of higher order cognitive abilities, from learning to comprehension to reasoning, even when the WMC and ability tests bear no surface similarity to each other. Moreover, statistical or experimental control of subjects' mnemonic strategies, processing skills, or motivation does not eliminate—or even attenuate—WMC-ability correlations, and so these factors cannot account for the relationship. STM storage and rehearsal factors cannot either. WMC and STM tasks yield correlated but separate factors when factor analyzed, and the WMC factor is more strongly associated with Gf than is STM.

If the storage, rehearsal, processing, and strategic processes tapped by WMC tasks do not drive the correlations with ability, then what does? We have inferred that the residual “secret ingredient” is an attention-control capability that is elicited by WMC tasks to a greater degree than by STM tasks. To wit, WMC tasks require subjects to maintain or recover access to stimulus representations in the face of (a) proactive interference from prior test trials and (b) mandatory shifts of conscious focus away from those memory representations to the secondary processing task. Direct support for our attention hypothesis comes from findings that extreme groups of high and low WMC span scorers differ in the performance of prototypical “attention-control” tasks such as dichotic listening, Stroop, antisaccade, and flanker tasks and that high WMC individuals often can be made to perform like low WMC individuals by dividing their attention. In short, people with lower WMC show poorer control over thought and action than do those with higher WMC by failing more often to prevent or recover from prepotent responses and by showing slower and less flexible allocation of visual attention to objects in space.

These findings lead us to the following view: The WMC construct reflects primarily a domain-general attentional capability to sustain or recover access to (or activation of) representations of task-relevant stimuli, goals, or response productions, and to control the influences of interference and competition on goal-directed thought and behavior. However, one must be mindful that WMC tasks are complex and multiply determined. They measure some attention-control capabilities and other capabilities as well (e.g., storage, processing skill, mnemonic strategies). Moreover, although WMC tasks are more influenced by attention-control processes than by storage and rehearsal, whereas the reverse seems true for STM tasks, both WMC and STM tasks tap executive and storage processes to some degree. Finally, the WMC construct and WMC tasks do not account for, or perfectly measure, the full extent of possible attention and executive capabilities and processes. That is, WMC does not fully explain all manner of attentional or executive variance. Indeed, our labs have discovered several “attentional” domains that are unrelated to WMC variation (Kane, Poole, Tuholski, & Engle, 2003). So, when we argue that WMC is tied to attention control, we mean that WMC's domain-general predictive power reflects primarily, but not uniquely, variance attributable to attention-control capabilities. Most of the variance that WMC shares with the common abilities underlying complex cognition, such as reasoning, reflects domain-general attentional processes of maintenance and control.

The Strength of the WMC-Gf Correlation

Despite Ackerman et al.'s (2005) suggestion of a “jingle fallacy” (p. 51), researchers have not considered WMC a candidate mechanism of general intellectual ability simply because our theories use language similar to Spearman's (1927). Rather, pursuit of a WMC-Gf association led from the facts that nomothetic models of cognition accord working memory a central role (e.g., Anderson, 1993; Meyer & Kieras, 1999) and that WMC variation predicts cognitive abilities very broadly. As well, computational models suggest that *g* is more easily implemented at the domain-free, stable, architectural level of a system rather than at the domain-specific, malleable levels (Ohlsson, 1998), and neuroscience data suggest that common prefrontal cortex circuitry is involved in working memory, attention control, and novel reasoning (Duncan, 1995; Kane & Engle, 2002). WMC and control processes are therefore natural candidates for those underlying general intellectual abilities.

Although WMC is not equivalent to Gf or reasoning ability, we believe that the association between WMC and these constructs is stronger than Ackerman et al. (2005) suggested. Our argument hinges on whether one should draw inferences about hypothetical constructs from individual tasks or, instead, from latent variables derived from multiple tasks. We think it is unwise to base arguments about the association between underlying constructs on modest correlations between tasks. Two tasks that reflect, in part, highly related constructs might nonetheless correlate weakly because of other sources of variability (i.e., measurement error). In contrast to Ackerman et al. (2005), then, we place more stock in findings from latent-variable studies, which eliminate the measurement error that confounds interpretation of individual tasks and their correlations. 1 Latent-variable procedures, such as confirmatory factor analysis, statistically isolate the shared variance among tasks that are thought to reflect a hypothetical construct, such as WMC or Gf. In doing so, they eliminate error variance that is unique to any one test and yield a purer measure of the construct. For example, a Gf latent variable based on syllogistic and analogical reasoning tests is free of deduction- and induction-specific ability; a WMC latent variable based on tests for words and for arrows is free of content-specific storage. As Ackerman et al. (2005) argued with respect to g, construct measurement based on multiple, varied tests is always more valid and reliable than that based on any individual, multidetermined test, regardless of the construct in question—including WMC.

In Ackerman et al.'s (2005) analyses, individual WMC and Gf/reasoning tests correlated around .45, indicating 20% shared variance (see their Table 1, “Average WM” row).[2] In contrast, latent-variable studies of young adults, using confirmatory factor analysis or structural equation modeling, generally produce path estimates of.60–.80 between WMC and Gf, indicating approximately 35%–65% shared variance (Ackerman et al., 2002; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, et al., 1999; Hambrick, 2003; Kane et al., 2004; Kyllonen & Christal, 1990; Mackintosh & Bennett, 2003; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Süß et al., 2002). Interpreting the WMC-Gf associations across these studies is difficult, however, because the models were structured differently from each other and many included additional constructs in their models (e.g., knowledge, speed, STM) that could affect the WMC-Gf path estimates.

Table 1

Correlations Between WMC and Gf/Reasoning Factors Derived From Confirmatory Factor Analyses of Data From Latent-Variable Studies With Young Adults

Study	WMC tasks	Gf/reasoning tasks	*r*(95% CI)
Kyllonen & Christal (1990)			
Study 2: *n* = 399	ABC numerical assignment, mental arithmetic, alphabet recoding	Arithmetic reasoning, AB grammatical reasoning, verbal analogies, arrow grammatical reasoning, number sets	.91 (.89, .93)
Study 3: *n* = 392	Alphabet recoding, ABC21	Arithmetic reasoning, AB grammatical reasoning, ABCD arrow, diagramming relations, following instructions, letter sets, necessary arithmetic operations, nonsense syllogisms	.79 (.75, .82)
Study 4: *n* = 562	Alphabet recoding, mental math	Arithmetic reasoning, verbal analogies, number sets, 123 symbol reduction, three term series, calendar test	.83 (.80, .85)
Engle, Tuholski, et al. (1999; *N* = 133)	Operation span, reading span, counting span, ABCD, keeping track, secondary memory/immediate free recall	Raven, Cattell culture fair	.60 (.48, .70)
Miyake et al. (2001; *N* = 167)	Letter rotation, dot matrix	Tower of Hanoi, random generation, paper folding, space relations, cards, flags	.64 (.54, .72)
Ackerman et al. (2002; *N* = 135)	ABCD order, alpha span, backward digit span, computation span, figural-spatial span, spatial span, word-sentence span	Ravens, number series, problem solving, necessary facts, paper folding, spatial analogy, cube comparison	.66 (.55, .75)
Conway et al. (2002; *N* = 120)	Operation span, reading span, counting span	Raven, Cattell culture fair	.54 (.40, .66)
Süß et al. (2002; *N* = 121[a])	Reading span, computation span, alpha span, backward digit span, math span, verbal span, spatial working memory, spatial short-term memory, updating numerical, updating spatial, spatial coordination, verbal coordination	Number sequences, letter sequences, computational reasoning, verbal analogies, fact/opinion, senseless inferences, syllogisms, figural analogies, Charkow, Bongard, figure assembly, surface development	.86 (.81, .90)
Hambrick (2003; *N* = 171)	Computation span, reading span	Raven, Cattell culture fair, abstraction, letter sets	.71 (.63, .78)
Mackintosh & Bennett (2003; *N* = 138[b])	Mental counters, reading span, spatial span	Raven, mental rotations	1.00
Colom et al. (2004)			
Study 1: *n* = 198	Mental counters, sentence verification, line formation	Raven, surface development	.86 (.82, .89)
Study 2: *n* = 203	Mental counters, sentence verification, line formation	Surface development, cards, figure classification	.73 (.66, .79)
Study 3: *n* = 193	Mental counters, sentence verification, line formation	Surface development, cards, figure classification	.41 (.29, .52)
Kane et al. (2004; *N* = 236)	Operation span, reading span, counting span, rotation span, symmetry span, navigation span	Raven, WASI matrix, BETA III matrix, reading comprehension, verbal analogies, inferences, nonsense syllogisms, remote associates, paper folding, surface development, form board, space relations, rotated blocks	.67 (.59, .73)

Note. WMC = working memory capacity; Gf = general fluid intelligence; 95% CI = the 95% confidence interval around the correlations; WASI = Wechsler Abbreviated Scale of Intelligence.

[a] *N* with the complete data set available (personal communication, K. Oberauer, July 7, 2004). [b] *N* for each pairwise correlation ranged from 117 to 127.

We therefore reanalyzed the data from published latent-variable studies that tested at least 100 healthy young adults on multiple measures of both WMC and Gf and that reported enough information for us to conduct our own confirmatory factor analyses on the data (i.e., they reported standard deviations for each measure along with all the relevant pairwise correlations, which allowed us to recover the covariance matrices to be used as input for the analyses). For each data set, we specified two separate factors (using maximum likelihood estimation) from the WMC and Gf tests and allowed them to correlate. Table 1 lists the tasks we factor analyzed from each study. We included all the immediate-memory tasks labeled working memory tasks by the original authors and all the novel reasoning tasks originally labeled as Gf or reasoning tasks (i.e., we dropped tasks that reflected primarily STM or crystallized abilities). Table 1 also presents the WMC-Gf correlations, which ranged from.41 to 1.00 with a median value of.72. These correlations, representing 3,168 subjects from 14 different samples, suggest that WMC and Gf/reasoning constructs share approximately half of their variance. Moreover, this estimate is conservative because many of these studies tested undergraduates, who likely represented restricted ranges of both WMC and Gf. In addition, some studies administered WMC and Gf tasks in different sessions, and so the extent to which WMC and Gf fluctuate over days also attenuated the correlation. Finally, many of the studies sampled WMC and Gf tasks with very different bandwidths, using limited types of WMC tasks but a broad variety of Gf tasks, or vice versa. As Ackerman et al. (2005) noted, bandwidth asymmetry attenuates correlations between factors (see also Süß et al., 2002). But even without considering any such attenuation, it is clear that our estimate of 50% shared variance between WMC and Gf is considerably greater than the 20% estimate provided by Ackerman et al. (2005).

Discriminant Validity and the “Crud Factor” Criticism

Psychologists often validate their hypothetical constructs through a process of triangulation (e.g., Campbell & Fiske, 1959). For example, if putative tests of Construct A correlate more strongly with each other than with tests of Construct B, then Construct A is said to exhibit discriminant validity. Ackerman et al. (2005) argued that WMC measures “do not show substantial discriminant validity—meaning that they correlate significantly and substantially with many different abilities, rather than with one or two key abilities” (p. 52). We agree that WMC measures correlate positively with many cognitive variables, but we also emphasize that discriminant validity is a complex issue with respect to Gf because its marker tests must, by definition, correlate broadly with many other abilities. If a construct, such as Gf or WMC, is truly pervasive in complex cognition, then it simply cannot correlate with only “one or two key abilities.” Instead, discriminant validity will be indicated if tests of the ostensibly pervasive construct correlate more strongly with some constructs than with others.

This is precisely the pattern that WMC shows. With respect to narrowly defined tasks, we find WMC variation to be unrelated to (a) delayed memory for supraspan lists in the absence of interference (Conway & Engle, 1994; Kane & Engle, 2000), (b) stimulus-driven visual orienting (Kane, Bleckley, Conway, & Engle, 2001), (c) identification of masked letters via a novel response mapping (Kane et al., 2001), (d) subitizing one to three visual items (Tuholski, Engle, & Baylis, 2001), and (e) some varieties of task-set switching and inefficient visual search (Kane et al., 2003). [3] In contrast, as we noted above, WMC does correlate with attention and memory tasks provoking substantial interference and conflict, and so WMC is important to only some basic cognitive capacities. With respect to more broadly defined abilities, Ackerman et al.'s (2005) meta-analysis shows that WMC correlates considerably more strongly with nonverbal reasoning and ECTs than with perceptual speed or knowledge. Similarly, Süß et al. (2002) found that WMC correlated more strongly with reasoning than with creativity, speed, or even memory factors. It appears to us that Ackerman et al. (2005) contradicted themselves, for in arguing elsewhere in their article that WMC and reasoning are not isomorphic, they relied on Kyllonen and Christal's (1990) finding that WMC correlated more strongly with speed than did reasoning whereas reasoning correlated more strongly with knowledge than did WMC. We suggest that if this is the case, then WMC demonstrates discriminant validity. WMC is not uniformly promiscuous in its associations with other constructs. Coupled with the fact that WMC and Gf-reasoning constructs share about half of their variance, WMC represents much more than a crud factor in the study of cognitive ability.

WMC, Gf, and Attention Control

Our argument so far is that WMC represents a distinct cognitive-ability construct that is strongly related to Gf and novel reasoning. In addition, we believe that executive attention processes mediate this strong WMC-Gf association. This does not mean that attention control completely explains Gf but only that it is largely responsible for the shared variance between WMC and Gf. In making this argument, however, we realize that our evidence is provisional, and we appreciate Ackerman et al. (2005) pointing out some of its limitations. Our work has demonstrated significant performance differences between high and low WMC individuals across a number of different “simple” attention tasks, but these extreme-groups designs cannot quantify the strength of the WMC-attention association, nor can they determine whether WMC-related attention differences correspond to WMC-related Gf differences. We therefore may be making much theoretical hay out of a relatively modest correlation that is independent of the WMC-Gf association. What the field needs now, then, is a latent-variable approach to the problem, in which many subjects complete many marker tests of WMC, Gf, and attention control. These studies should report the magnitude of the WMC-attention correlation and examine whether the shared variance between WMC and attention accounts for substantial Gf variance (and more Gf variance than is accounted for by residual variance from WMC or attention constructs).

Our attentional view has empirical support, but it also poses a significant challenge that was familiar to Spearman (1937, see especially p. 133), who argued that attention could be as vague a construct as intelligence. If the examination of a WMC-ability link is to move beyond a simplistic consideration of tasks (such as WMC span vs. STM span) and toward a deeper understanding of underlying constructs, then the attentional/executive contributions to WMC and Gf must be specified. Quasi-experimental tests for WMC-related differences in attention tasks are a good place to begin narrowing the field. An additional tack is to consider the attentional demands of WMC and Gf tasks themselves. For example, Unsworth and Engle (2004) argued that (a) WMC span tasks require attention control because the processing component displaces the memory items from attentional focus, which then must be retrieved from secondary memory in the face of proactive interference (see also Miyake, Friedman, & Saito, 2003); (b) if the focus of attention is limited to 4 ± 1 items (Cowan, 2001), then STM span tasks presenting lists of 4 or more items also require some secondary-memory retrieval and its attendant control processes. In support of these arguments, Unsworth and Engle factor analyzed two verbal WMC tasks (with list lengths 2–5) and two STM span tasks (with list lengths 2–7), which yielded three factors: STM lengths 2–4, STM lengths 4–7, and WMC lengths 2–5. The latter two factors correlated.67 (vs..39 between WMC and STM 2–4), suggesting that WMC span and long STM lists measured a similar construct. Moreover, recall on WMC list lengths 2, 3, 4, and 5 all correlated equivalently with Gf, but only performance on the long STM lists correlated with Gf as strongly. Finally, the variance shared by WMC span and long STM lists accounted for 18% of the variance in Gf, and each accounted for only 5% unique variance. These findings reinforce the point that immediate memory tasks cannot be dichotomized as reflecting either STM or WMC; all these tasks rely on storage and attentional processes. The challenge is in assessing their respective contributions.

A related challenge to investigating the WMC-Gf association is constructing reliable WMC tasks that maximize executive-attention demands. We think that the tasks should require maintaining rapid access to information that is at least momentarily outside the limited, conscious focus of attention. (This would also seem relevant to successful reasoning.) Dual-task procedures provide one such methodology—but not the only one. Ackerman et al. (2005) claimed that “nearly all” WMC tasks are dual tasks and complained that “far too little information is available that provides an account of how overall performance should be assessed” (p. 50). We disagree on both counts. First, many WMC tasks included in their meta-analysis are not dual tasks (e.g., Kyllonen & Christal, 1990; Süß et al., 2002), and several nondual-task measures of immediate memory correlate strongly with Gf, such as spatial STM tasks (Miyake et al., 2001), coordination and transformation tasks (Süß et al., 2002), and verbal STM tasks with long lists (Unsworth & Engle, 2004). Second, the problem of a dual-task assessment of WMC is ameliorated when a latent variable is derived from both dual and nondual tasks; indeed, the WMC-Gf correlation does not seem to vary much whether one obtains the WMC construct from dual tasks or from a mixture of dual tasks and nondual tasks (e.g., Süß et al., 2002). An important goal for research in this area, then, will be to clarify the shared processes among dual- and nondual-task measures of the WMC construct and to determine whether our idea that they reflect an attention-control capability holds up.

As a final methodological note, we consider Ackerman et al.'s (2005) argument that WMC span tasks are problematic because they are typically scored only for the storage component of the task and thus people who differ in accuracy on the processing component by 5% or more are indistinguishable. In fact, it is extremely rare for individuals to differ this much on the processing component of a WMC span task because performance is generally at ceiling. For example, during the Spring of 2003, 420 students at the University of Illinois at Chicago completed two verbal WMC tasks, and the mean numbers of processing errors, out of 42 total trials, were only 1.2 (SD = 1.5) and 1.3 (SD = 1.5), respectively. One might be tempted to argue from this that the time to perform the processing component may be more important, or more sensitive to trade-off, than accuracy. However, statistically or experimentally controlling time on the processing component does not diminish the correlation between WMC span and complex cognition, and it sometimes increases it (Conway & Engle, 1996; Engle, Cantor, & Carullo, 1992; Friedman & Miyake, 2004). Thus, the correlation between WMC and ability is not impacted by the fact that many WMC tests are dual tasks, and so we think that the norm of scoring only the storage component of WMC span tasks is well justified. Future experimental and correlational research will determine whether our attentional view of WMC and Gf is equally well justified.

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Footnotes

1 Ackerman et al. (2005) did point out that latent-variable analyses of meta-analytic data, which are what they had to work with, are potentially problematic and should be interpreted with caution.

2 Note that, by way of contrast, the meta-analytic correlations between individual STM and Gf/reasoning tasks averaged.30, indicating only 9% shared variance. This low estimate is consistent with findings from latent-variable studies (e.g., Conway et al., 2002; Engle, Tuholski, et al., 1999). However, Ackerman et al.'s (2005) confirmatory factor analyses, depicted in their Figures 2 and 4, seem to provide an exception to this trend: Their model for WMC and ability factors yielded a.50 working memory–g correlation, and a parallel model for STM yielded a.49 STM–g correlation. The apparent similarity is misleading, however, because the g factors were defined very differently between the two models. In particular, the g factor in the WMC analysis (Figure 2) was based primarily on Gf/reasoning indicators, whereas the g factor in the STM analysis (Figure 4) was based equally on Gf/reasoning and knowledge-crystallized ability indicators (note also the different g loadings for the Reasoning factor between the hierarchical models for the WMC and STM data sets, depicted in their Figures 1 and 3, respectively). Thus, the strong association here between STM and g is not particularly surprising because STM factors often have been observed to correlate with crystallized ability even after controlling for WMC (e.g., Engle, Tuholski, et al., 1999). Furthermore, WMC and g demonstrate a stronger relation in the hierarchical factor model depicted in their Figure 1 (where WMC has a g factor loading of.89) than STM and g do in the hierarchical model depicted in their Figure 3 (where STM has a g factor loading of.51). The Ackerman et al. (2005) findings therefore do not compromise the general view that WMC is more strongly associated with Gf than is STM.

3 Many of these tasks represent those that Ackerman et al. (2005) would classify as “elementary cognitive tasks” (ECTs), thus complicating any interpretation of the WMC-ECT relationship. We suggest that analyses of ECTs' attention demands will be critical to understanding their correlations (see Conway, Kane, & Engle, 1999; but see Ackerman et al., 2002). We also note that three of the nine tasks classified by Ackerman et al. (2005) as ECTs were titled “reasoning” tasks by the original authors, and so they may have had reasonably high Gf loadings. This could explain, in part, their strong association with WMC.

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