Journal of Applied Research in Memory and Cognition 9 (2020) 419–424

Contents lists available at ScienceDirect

Journal of Applied Research in Memory and Cognition

journal homepage: www.elsevier.com/locate/jarmac

Commentary

Process Overlap Theory, Executive Functions, and the Interpretation of Cognitive Test Scores: Reply to Commentaries☆

Kristof Kovacs*
ELTE Eotvos Lorand University

Andrew R.A. Conway
Claremont Graduate University

In a previous issue of JARMAC, we published a paper discussing the separation of the two disciplines of Psychology, the correlational and the experimental, presented our vision of their unification, and outlined process overlap theory (POT), an explanation of the positive manifold of intelligence (i.e. the all-positive correlations between ability tests; Kovacs and Conway, 2019). In short, POT proposes that one employs both domain-general and domain-specific cognitive processes to solve mental ability tests and that domain-general processes overlap with domain-specific ones more often than the specific processes overlap with one another. Largely influenced by research on working memory, POT specifies the domain-general set of processes that are required by a large number of tests as executive functions. These processes are crucial for following instructions, monitoring goals, and focusing attention through inhibiting irrelevant stimuli.

Seven commentaries on our paper appeared in the same issue and elaborate on the ideas that appear in it or offer perspectives that are beyond our original writing (Hambrick, 2019; Maassen and Wicherts, 2019; McFarland, 2019; Oswald, 2019; Schneider and McGrew, 2019; Schubert and Rey-Mermet, 2019; Stankov, 2019). We are greatly honored by these commentaries, yet the topics they discuss are so diverse that it would be nearly impossible to address all of them in a single reply. Therefore, after highlighting the applied importance of the POT approach, we will focus on issues that seem recurring in the commentaries: Is POT just an extension of Thomson's sampling model? Why does not POT provide a list of executive functions (EFs) and without doing so why is it even a theory? Does POT claim that $g = EF$? Does POT focus solely on complex span tasks? Are all factors not formative?

Implications for Applied Ability Testing

POT was born as a theoretical endeavor, with the purpose of explaining the most replicated empirical finding in intelligence research: the positive manifold. Its explanation of the positive manifold provided a new interpretation of the general factor, g. While explaining the positive manifold with overlapping executive functions, the message of POT is not that executive functions are the most important aspects of intelligence. On the contrary, by explaining the positive manifold without general intelligence, the emphasis is shifted to specific abilities, like the broad abilities of the CHC (Cattell-Horn-Carroll) model (McGrew, 2009).

As a consequence, the focus of attention should shift from a global score such as IQ to a profile of relative strengths and weaknesses in these specific abilities. Importantly, this includes profiles of both a normative and ipsative nature: relative strengths and weaknesses compared to others (normative) as well as relative strengths and weaknesses compared to oneself (ipsative). It is possible that one's relative strength is below the average of a norm group, but such information on intra-individual patterns might still be useful for instruction and development. Therefore POT is in agreement with Kaufman's idiographic *intelligent testing* approach that emphasizes an ipsative, profile-based analysis (Kaufman, 1994; Kaufman and Lichtenberger, 2006).

The difference between focusing on global scores versus specific ability patterns manifests itself in different cognitive test batteries, too. For instance, the Wechsler Scales of Intelligence

Author Note

* Correspondence concerning this article should be addressed to Kristof Kovacs, ELTE Eotvos Lorand University. Contact: kristof340@googlemail.com

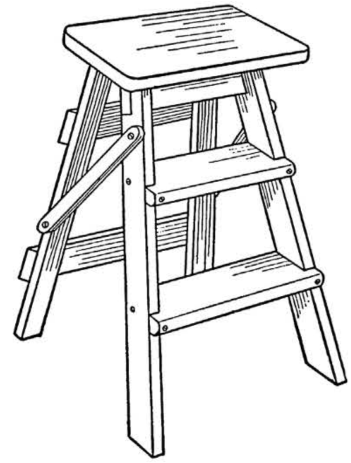

Figure 1. Stepladder of abstraction applied to WJ IV COG interpretation (based on Schrank, 2016).

were constructed under the idea that "the subtests are different measures of intelligence, not measures of different kinds of intelligence" (Wechsler, 1958, p. 64). Naturally, POT is in contrast with such an approach.

More recent versions of the Wechsler Scales include four broad ability indices besides Full Scale IQ scores. Other tests offer a larger number of specific ability indices; for instance, the Woodcock-Johnson Tests of Cognitive Abilities (WJ-COG) measures seven ability clusters in the CHC framework. Therefore, there are different levels of interpretation of test results. In the case of the WJ-COG this is illustrated by the stepladder analogy (Figure 1).

At the lowest level of abstraction are the individual tests of the battery. One can evaluate results at this level and compare the student's performance to a norm group in each test or look for intra-individual profiles at the test level. However, the reliability of results is also the lowest at this level and, relatedly, raw scores necessarily include measurement error.

At the middle level of abstraction are the cluster scores, the scores for the broad CHC ability constructs measured by the test: Comprehension-Knowledge, Fluid Reasoning, Cognitive Processing Speed, etc. From a POT perspective this is the optimal level of analysis, provided that each of these constructs is measured with (at least) two tests and factor scores are obtained. The calculation of such factor scores by hand is not impossible, but certainly tedious (Schneider, 2013); as the scoring of such batteries becomes more and more computer based, factor score calculation and interpretation will become available for more and more test users.

At the highest level of abstraction are global indices, such as the Global Intellectual Ability (GIA) index in the WJ IV, a proxy for *g*. This level represents a large step from the lower two:

> Unlike the WJ IV tests and clusters, *g* simply cannot be described in terms of information content. That is, there is no singular defining characteristic of *g* that can be stated in psychological terms. Much like the construct of *g*, the WJ IV COG GIA score cannot be defined as a distinct cognitive ability because it is an amalgam of several important cognitive abilities, functions, or processes into a single-score index. (Schrank, 2016, p. 204)

According to POT, the positive manifold is an emergent property resulting from the overlap of processes tapped by different tests and *g* is interpreted as a formative, rather than reflective variable. Hence global indices such as IQ or GIA are reflections of *intelligence in general* rather than a proxy for *general intelligence,* and the above approach is more in agreement with POT than the one under which different tests all measure the same intelligence.

As discussed in more detail in the target article, under POT, IQ has the same theoretical status as the Global Competitiveness Index (GCI) in economics, an index score calculated from a dozen different indicators of a country's economy. The GCI is useful for global ranking and for statistical prediction. Similarly, if one adheres to an *actuarial view* of ability testing (Canivez, 2013), where the sole purpose of psychological measurement is the statistical prediction of a target outcome, IQ can be as useful as GCI. But global indices are much less useful for treatment or intervention purposes: when a government attempts to improve the competitiveness of the country's economy, they do not target the GCI, but rather its constituents, like macroeconomic stability or financial market efficiency. The same is the case with IQ and its more specific components. Additionally, the same global index score, such as IQ, can arise from different idiosyncratic patterns: high verbal and average spatial in one person and vice versa in another. When relying solely on global indices such information about relative strengths and weaknesses is lost.

The history of intelligence test interpretation saw the influence of theories of cognitive abilities only recently, in what is usually called the 4th and currently last wave (Kamphaus et al., 1997; Schneider and Flanagan, 2015). Therefore, providing theoretical frameworks that might inform test constructors is an advantage in itself. Moreover, such theoretical considerations also influence the correct methodology for evaluating the validity of global versus specific scores as predictors of real life outcomes, such as job or school performance. Those who argue that practically all of the predictive validity of cognitive ability tests stems from *g* with little contribution from specific abilities usually rely on incremental validity analysis and enter global scores in hierarchical regressions first. Yet, "it is theoretically justifiable to enter GMA [general mental ability] in hierarchical regressions prior to specific abilities only if GMA is treated as a cause of variance in those abilities," and "when the association between GMA, specific abilities, and work outcomes is examined in accordance with these latter models [such as POT and other non g based models] it is inappropriate to conduct incremental validity analyses" in the first place (Lang and Kell, 2019, p. 5).

Is POT Just an Extension to Thomson's Sampling Model?

When publishing the theory (Kovacs and Conway, 2016b) we emphasized the influence of Thomson's (Thomson, 1916) work on our views and several commentators of that paper as well as of Kovacs and Conway (2019) have depicted POT as a modern sampling theory. While in general we agree with this, and do admire Thomson's pioneering work in providing an alternative to *g*-theory, we think that POT simply being "a reformulation and extension of Thompson's (1916) sampling theory" (Schubert and Rey-Mermet, 2019, p. 277) is exaggerated.

POT differs from Thomson's model in crucial ways. For instance, in Thomson's model processes are additive and thus the correlation between tests is the linear function of the ratio of shared and non-shared processes. In the formalized model corresponding to POT the general and specific components of tests are conceptualized as different dimensions, all of which need to be solved in order to arrive at a correct answer. As a consequence, executive processes function as a bottleneck, limiting performance in a number of different areas, regardless of the ability level of the specific processes involved. Also, Thomson's model suffered from a number of shortcomings (i.e., empirical phenomena it could not account for; Eysenck, 1987; van der Maas et al., 2006), but for which POT can account and indeed directly addresses (see Kovacs and Conway, 2016b).

More importantly, in our view sampling stands for a family of models that propose a large number of casual factors determining cognitive performance (typically much larger than what can be meaningfully included in latent variable models) and also propose that the correlation between tests are ultimately caused by shared resources, that is, processes being tapped by more than one kind of test. Therefore, POT is a simple reformulation and extension of Thompson's sampling theory only as much as Vernon's VPR model or the CHC model are reformulations and extensions of Spearman's two-factor model. The VPR and the CHC are factorial models, just like Spearman's, and POT is a sampling theory, just like Thomson's.

The reason we often encounter this label is probably due to the fact that unlike the prolific factor analytic approach, sampling was more or less—but not completely (Maxwell, 1972; McFarland, 2012)—discontinued. While honored to be held a successor of Thomson, we believe POT is different enough to not be labeled an extension or reformulation. Also, as we have pointed out (Kovacs and Conway, 2016a), POT was also greatly influenced by the systems theory of intelligence (Detterman, 1994), too.

Why Does not POT Specify the EFs that Overlap?

Sometimes it is questioned whether POT is a *real* theory without specifying EFs, for instance: "While [the mathematical formalization] provides a quantitate expression of their theory it is not complete until the identity of the components that make up the process scores are defined" (McFarland, 2019, p. 302).

The area is a controversial one, with different researchers having different positions about the nature of executive functions. For instance, while in Baddeley and Hitch's multi-component model the central executive was one of the components of working memory, today more and more often working memory itself is conceptualized as an executive function. We also completely agree that "Attentional control—also referred to as executive attention, cognitive control, executive control, inhibitory control, or executive functions—is an umbrella term that describes a wide variety of cognitive processes" (Schubert and Rey-Mermet, 2019, p. 277). We have repeatedly argued for a multi-mechanism view of working memory and executive functions, but POT deliberately does not include a list of EFs.

Generally speaking, we disagree that POT has to specify actual EFs in order to be a complete theory. Darwin's theory of evolution did not specify the mechanisms of the inheritance of traits; that was something that followed long after and not by Darwin himself. This hardly means that the theory of evolution was incomplete because it did not specify mechanisms of inheritance. Make no mistake: we are not, by any means, comparing our intellectual achievement to Darwin's. On the contrary, we use the example of the theory of evolution because it is probably one of the most elegant and most influential theories ever constructed. Yet it provided a casual explanation of a phenomenon (the diversity and origin of species) with a mechanism (evolution by natural selection), by assuming a vehicle (the inheritance of traits) that was unspecified, but for the existence of which there was ample empirical evidence. With POT our aim was similar: to provide a casual explanation of a phenomenon (the positive manifold) with a mechanism (overlapping processes), by assuming a vehicle (executive processes) that is unspecified, but for the existence of which there is ample empirical evidence. In other words,inheritance is crucially important for the theory of evolution, yet it does not include an actual theory of inheritance.

Similarly, EFs are crucially important for POT, yet it does not include an actual theory of executive functioning. Having said that, POT does make a number of claims about, and capitalizes on, empirical findings related to executive functions:

- It conceptualizes EF as independent from storage in WM tasks and points to SEM studies that separated the EF component from storage and retrieval.
- It points out that WM capacity and fluid intelligence share half of their variance and this is due to the executive, not the storage component of working memory tasks.
- It cites studies that demonstrate that executive processes and fluid intelligence share a large part of the neural substrates in what is called the frontoparietal control network.
- It cites evidence suggesting that these brain regions have a central role in the sense that they are involved in implementing a variety of distinct task demands and, relatedly, that they function as connector hubs linked to modular brain networks involved in more specific types of processing.
- It points to studies of goal neglect, a kind of executive failure, that demonstrate that people in the bottom 15–20% of the fluid intelligence distribution manifest behavior similar to prefrontal patients.

Overall, we believe that POT firmly establishes that there are psychological processes that contribute to goal-directed behavior in a multiplicity of tasks, and these processes form a network rather than a single, unitary system. The point we tried to make is that a set executive processes indeed overlap with more specific processes and, correspondingly, there are generalist brain regions that functionally overlap with more specialized regions.

POT argues that different executive processes are involved, to differing extents, in virtually all specific abilities, and EFs are mostly, but far from exclusively, related to the fluid intelligence factor, Gf. A factor analytic study that employed the CHC framework to executive functions found that a separate executive factor could not fit because the tests that measured EF were involved in all CHC abilities:

> The putative executive function tests were distributed across the CHC constructs... In other words, tests commonly grouped under the executive function rubric do not load on the same construct. This finding of heterogeneous construct loadings has two important implications. First, the results suggest that there is no unitary executive function construct underlying all executive function tests... Second, the results suggest that equating executive function with Gf..., may be misleading, as not all executive function tests are Gf tests. (Jewsbury et al., 2017, p. 560)

It seems that a structural model does not directly represent that EFs are causal in the positive manifold exactly because they are distributed in all ability factors, just like POT claims.

Does POT Replace g with Executive Functions?

This question appeared in several commentaries, for instance, "we will critically discuss the underlying assumption that attentional control is the unique domain-general process and can be established as a psychometric construct" and "POT's assumption that individual differences in domain general attentional processes give rise to individual differences in general intelligence" (Schubert and Rey-Mermet, 2019, pp. 278–279). Under this view, POT is conceptualized as basically offering executive function as some kind of *replacement* of *g*, or, ultimately, intelligence. If this were the case then POT would translate to either a higher-order model with a reflective *g* on the apex or a bifactor model where executive functions have a direct effect on the performance of all tests, along with—residualised—specific factors.

So, if POT claims that it is the overlap of EFs that cause the positive manifold, why is not *g* identified with EFs? First, according to POT, there need not be a single executive process shared between *all* ability tests for the positive manifold to emerge (this aspect is shared with Thomson's model). Therefore, such a reflective EF factor would not represent a real entity. Second, the positive manifold is strongest at lowest ability levels, hence *g* accounts for most variance in low ability samples. POT explains this with a bottleneck effect: if one fails the executive dimension on several items then they will correlate strongly, yet if that dimension is passed performance are primarily determined by specific processes and correlations are lower. Therefore, the appropriate factor would be a *lack of EF*, which seems somewhat inappropriate. This could also lead to misunderstandings in applied cognitive measurement: if *g* is interpreted as EF then it would look reasonable for EFs to be the focus of measurement. Instead, POT emphasizes specific abilities.

Since EFs are not conceptualized as the basis of a reflective (causal, explanatory) *g,* the reflective part of POT translates to an oblique model, one with correlated specific abilities and without a higher-order factor that would statistically explain their correlation. EFs are not represented in this model, they dissolve in the specific factors, all of which—according to POT—represent EFs to varying extents.

Does POT Focus Solely on Complex Span Tasks?

A related issue is whether POT attributes exclusivity in complex span tasks to explain the working-memory intelligence relationship. For instance:

> There is substantial evidence that simultaneous storage and processing demands..., are not necessary to observe a correlation between working memory capacity and intelligence... Both in the presence and in the absence of simultaneous processing and storage demands, the ability to build and maintain relational representations through temporary bindings has been shown to be strongly related to intelligence... Therefore, Kovacs and Conway (2019) present a one-sided view of a complex research area by discussing no viable alternatives. (Schubert and Rey-Mermet, 2019, p. 278)

In our recent JARMAC paper, for reasons of brevity, we focused our introduction of the WM-intelligence relationship to complex span tasks. The paper presenting the theory put more emphasis on other important kinds of tasks:

> Results with working memory tests other than complex span indeed suggest that it is not the dual-task nature of complex span tests (i.e., processing and storage) per se that is necessary for a working memory test to be predictive of Gf; instead, it is the involvement of executive processes, achievable in different ways—including but not restricted to dual tasking—that is common to these tasks, and what drives their relation with fluid intelligence (Kovacs and Conway, 2016b, p. 160).

We also emphasized that the variance of different EF tasks (array comparison, coordination and transformation, n-back, simple span with long lists, and running span) is not the same as the variance explained by complex span tests, hence the WMC-Gf correlation is driven by multiple, independent EFs, and complex span tasks tap only a part of the related variance. At the same time, we prefer complex span tasks to other working memory tasks because each complex span task has a baseline: a simple span task, so that complex span requires parallel storage and processing whereas simple span primarily requires storage and retrieval. For instance, in reading span one has to read sentences and remember their last word, whereas in word span one simply recalls a list of words. This makes complex and simple span optimal for latent variable modeling, since the storage component can be controlled for. This, in turn, makes it possible to study executive functions conceptualized as what complex span measures *beyond storage and retrieval*.

Studying executive functions with latent variable models instead of manifest tasks is useful because of issues with the reliability of tasks measuring executive functions. Most such tasks were designed for within-subject experiments and therefore their reliability is far from adequate (Hedge et al., 2018). Latent variables are free from measurement error, and therefore latent EF variables are much better than the—unfortunately unreliable—manifest EF tasks to unravel the connections between EF and cognitive abilities. Indeed, such studies have provided ample evidence for the connection between EF and fluid reasoning (Conway et al., 2002; Kane et al., 2004).

We completely agree that complex span tasks or, more precisely, what they measure beyond storage, do not cover the entirety of executive functions. Executive functions seem to be diverse and it is difficult to establish a unitary latent variable of executive control (Rey-Mermet et al., 2019). This is exactly the reason why *complex span minus simple span* is a useful way for operationalizing executive functions in latent variable models.

Are all Factors not Formative?

A recurring question related to POT, and one that appeared in a number of the commentaries (McFarland, 2019; Schneider and McGrew, 2019; Stankov, 2019) is whether the formative argument of POT is relevant for all factors, not only *g*. This view questions the status of all latent variables, or at least broad ability factors. Do they indeed reflect some underlying psychological property or are they the result of the overlap of lower-level abilities or processes?

Probably not all factors are created equal in this respect. It appears that latent constructs representing short-term memory or vocabulary do seem to reflect *real* entities, ones that would exist without measurement. For it appears that some people do have a larger mental lexicon than others and this manifests itself in their verbal behavior: they comprehend more words and they express themselves with a larger vocabulary in speech and writing. Similarly, some people are apparently able to keep in mind more things at the same time than others. Yet other, very broad second order ability factors might indeed allow for a formative interpretation—most importantly Gc, or crystallized intelligence, which involves general knowledge, comprehension, vocabulary, etc., and which seems to primarily reflect both "exposure to information via education and verbal comprehension" (Kan et al., 2011, p. 296) rather than a cognitive ability in the traditional sense.

At the global level, an advantage of the formative approach is that it provides more freedom for the composition of test batteries than a reflective one. This not only allows more space for cultural approaches to intelligence, acknowledging that abilities appreciated in Western societies might be less important elsewhere (Sternberg and Grigorenko, 2004), but even within the schooling system of Western societies it might provide more space to previously ignored abilities like those involved in decision-making (Stankov, 2017) or visuospatial cognition (Lubinski, 2010; Webb et al., 2007).

Conclusion

While POT was not meant to provide direct applications, let alone form the basis of recommendations for testing policy, its interpretation of the positive manifold and the general factor of intelligence do have important applied consequences. For over a century, the strongest argument for the overarching importance of *g*, and consequently global IQ indices as proxies for *g*, was the positive manifold: if abilities are indeed specific and worth profiling individually, and if all tests do not measure the same underlying construct—so goes the *g*-theorist's argument—then why do they correlate? We hope that POT has provided an adequate answer to this question and thus can be the theoretical basis of a shift of focus to specific abilities, both in basic research and in applied settings.

Author Contributions

K.K. and A.C. both contributed to the writing of the manuscript with K.K. taking on the role of lead author. K.K. wrote the first draft and both K.K. and A.C. wrote revisions.

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgment

The first author received funding by the National Research, Development and Innovation Office of Hungary: Grant PD-17-125360 and Grant KH-18-130424.

We would like to acknowledge Dennis McFarland for his commentary on our target article. We are deeply saddened to share that Dennis passed away in the Spring of 2020. In his career, Dennis made several important contributions to the field of cognitive science and he provided us with excellent feedback on the POT model. We would like to acknowledge here his contributions to the field. He will be sorely missed.

Keywords: Intelligence, IQ, Ipsative testing, Executive function, Cognitive ability.

References

Canivez, G. L. (2013). Psychometric versus actuarial interpretation of intelligence and related aptitude batteries. In D. H. Saklofske, C. R. Reynolds, & V. L. Schwean (Eds.), *Oxford library of psychology. The Oxford handbook of child psychological assessment* (pp. 84–112). Oxford University Press. http://dx.doi.org/10.1093/oxfordhb/9780199796304.013.0004

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*(2), 163–183. http://dx.doi.org/10.1016/S0160-2896(01)00096-4

Detterman, D. K. (1994). Theoretical possibilities: The relation of human intelligence to basic cognitive abilities. In D. K. Detterman (Ed.), *Current topics in human intelligence volume 4: Theories of intelligence* (pp. 85–115). Ablex Publishing.

Eysenck, H. J. (1987). Thomson's "bonds" or Spearman's "energy": Sixty years on. *Mankind Quarterly*, *27*, 259–274.

Hambrick, D. Z. (2019). Improving prediction of real-world performance: A process-overlap perspective. *Journal of Applied Research in Memory and Cognition*, *8*(3), 293–295. http://dx.doi.org/10.1016/j.jarmac.2019.06.008

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods*, *50*(3), 1166–1186. http://dx.doi.org/10.3758/s13428-017-0935-1

Jewsbury, P. A., Bowden, S. C., & Duff, K. (2017). The Cattell–Horn–Carroll model of cognition for clinical assessment. *Journal of Psychoeducational Assessment*, *35*(6), 547–567.

Kamphaus, R. W., Petoskey, M. D., & Morgan, A. W. (1997). A history of intelligence test interpretation. In *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 32–47).

Kan, K.-J., Kievit, R. A., Dolan, C., & van der Maas, H. L. J. (2011). On the interpretation of the CHC factor Gc. *Intelligence*, *39*(5), 292–302. http://dx.doi.org/10.1016/j.intell.2011.05.003

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & 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*(2), 189–217. http://dx.doi.org/10.1037/0096-3445.133.2.189

Kaufman, A. S. (1994). *Intelligent testing with the WISC-III*. Wiley.

Kaufman, A. S., & Lichtenberger, E. O. (2006). *Assessing adolescent and adult intelligence* (3rd ed.). Wiley.

Kovacs, K., & Conway, A. R. A. (2016a). Has g gone to POT? *Psychological Inquiry*, *27*(3), 241–253. http://dx.doi.org/10.1080/1047840X.2016.1202744

Kovacs, K., & Conway, A. R. A. (2016b). Process overlap theory: A unified account of the general factor of intelligence. *Psychological Inquiry*, *27*(3), 151–177. http://dx.doi.org/10.1080/1047840X.2016.1153946

Kovacs, K., & Conway, A. R. A. (2019). A unified cognitive/differential approach to human intelligence: Implications for IQ testing. *Journal of Applied Research in Memory and Cognition*, *8*(3), 255–272. http://dx.doi.org/10.1016/j.jarmac.2019.05.003

Lang, J. W. B., & Kell, H. J. (2019). General mental ability and specific abilities: Their relative importance for extrinsic career success. *Journal of Applied Psychology*, *1*(999) http://dx.doi.org/10.1037/apl0000472

Lubinski, D. (2010). Spatial ability and STEM: A sleeping giant for talent identification and development. *Personality and Individual Differences*, *49*(4), 344–351. http://dx.doi.org/10.1016/J.PAID.2010.03.022

Maassen, E., & Wicherts, J. M. (2019). Distinguishing specific from general effects in cognition research. *Journal of Applied Research in Memory and Cognition*, *8*(3), 288–292. http://dx.doi.org/10.1016/j.jarmac.2019.06.007

Maxwell, A. E. (1972). Factor analysis: Thomson's sampling theory recalled. *British Journal of Mathematical and Statistical Psychology*, *25*(1), 1–21. http://dx.doi.org/10.1111/j.2044-8317.1972.tb00474.x

McFarland, D. J. (2012). A single g factor is not necessary to simulate positive correlations between cognitive tests. *Journal of Clinical and Experimental Neuropsychology*, *34*(4), 378–384. http://dx.doi.org/10.1080/13803395.2011.645018

McFarland, D. J. (2019). Considering complex models of cognitive abilities. *Journal of Applied Research in Memory and Cognition*, *8*(3), 301–304. http://dx.doi.org/10.1016/j.jarmac.2019.05.004

McGrew, K. S. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence*, *37*(1), 1–10. http://dx.doi.org/10.1016/j.intell.2008.08.004

Oswald, F. L. (2019). Measuring and modeling cognitive ability: Some comments on process overlap theory. *Journal of Applied Research in Memory and Cognition*, *8*(3), 296–300. http://dx.doi.org/10.1016/j.jarmac.2019.06.009

Rey-Mermet, A., Gade, M., Souza, A. S., von Bastian, C. C., & Oberauer, K. (2019). Is executive control related to working memory capacity and fluid intelligence? *Journal of Experimental Psychology: General*, *148*(8), 1335–1372. http://dx.doi.org/10.1037/xge0000593

Schneider, W. J. (2013). What if we took our models seriously? Estimating latent scores in individuals. *Journal of Psychoeducational Assessment*, *31*(2), 186–201. http://dx.doi.org/10.1177/0734282913478046

Schneider, W. J., & Flanagan, D. P. (2015). The relationship between theories of intelligence and intelligence tests. In *Handbook of intelligence: Evolutionary theory, historical perspective, and current concepts*. pp. 317–340. Springer New York. http://dx.doi.org/10.1007/978-1-4939-1562-0_21

Schneider, W. J., & McGrew, K. S. (2019). Process overlap theory is a milestone achievement among intelligence theories. *Journal of Applied Research in Memory and Cognition*, *8*(3), 273–276. http://dx.doi.org/10.1016/j.jarmac.2019.06.006

Schrank, F. A. (2016). How to interpret the WJ IV COG. In F. A. Schrank, S. L. Decker, & J. M. Garruto (Eds.), *Essentials of WJ IV cognitive abilities assessment* (pp. 144–221). Wiley.

Schubert, A. L., & Rey-Mermet, A. (2019). Does process overlap theory replace the issues of general intelligence with the issues of attentional control? *Journal of Applied Research in Memory and Cognition*, *8*(3), 277–283. http://dx.doi.org/10.1016/j.jarmac.2019.06.004

Stankov, L. (2017). Overemphasized "g". *Journal of Intelligence*, *5*(4), 33. http://dx.doi.org/10.3390/jintelligence5040033

Stankov, L. (2019). Working memory, attention, and g as a weak formative construct. *Journal of Applied Research in Memory and Cognition*, *8*(3), 284–287. http://dx.doi.org/10.1016/j.jarmac.2019.06.003

Sternberg, R. J., & Grigorenko, E. L. (2004). Intelligence and culture: How culture shapes what intelligence means, and the implications for a science of well-being. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *359*(1449), 1427–1434. http://dx.doi.org/10.1098/rstb.2004.1514

Thomson, G. H. (1916). A hierarchy without a general factor. *British Journal of Psychology, 1904–1920*, *8*(3), 271–281. http://dx.doi.org/10.1111/j.2044-8295.1916.tb00133.x

van der Maas, H. L. J., Dolan, C. V., Grasman, R. P. P. P., Wicherts, J. M., Huizenga, H. M., & Raijmakers, M. E. J. (2006). A dynamical model of general intelligence: The positive manifold of intelligence by mutualism. *Psychological Review*, *113*(4), 842–861. http://dx.doi.org/10.1037/0033-295X.113.4.842

Webb, R. M., Lubinski, D., & Benbow, C. P. (2007). Spatial ability: A neglected dimension in talent searches for intellectually precocious youth. *Journal of Educational Psychology*, *99*(2), 397–420. http://dx.doi.org/10.1037/0022-0663.99.2.397

Wechsler, D. (1958). *The measurement and appraisal of adult intelligence*. Williams & Wilkins.

Received 13 January 2020;
received in revised form 21 April 2020;
accepted 21 April 2020
Available online xxx