# Framing Executive Function as a Construct and its Relation to Academic Achievement

**Paul T. Cirino, Ph.D**
University of Houston

## Abstract

The goal of this work is to provide a framework for understanding the relationship of executive function (EF) to reading and other academic achievement to promote future work in this area. After briefly reviewing extant theoretical and empirical support about what is known in this area, we then more deeply evaluate the construct of EF itself. This is necessary because EF means any number of things to any number of individuals, scientists included. Review of several pertinent conceptualizations of EF, including our own, reveals agreement that EF is domain general (although the meaning of domain generality is varied); additional commonalities include a focus on control/management and goal direction. However, there is less agreement on whether EF is singular or plural, or whether EF is one or more "thing(s)" versus process(es). These alternatives are discussed with a focus on the implications for understanding the role of EF for important functional outcomes.

## Lay Abstract

Executive function can be a confusing term, but it is known to relate to important things like academic achievement. Therefore, we reviewed different perspectives on executive function, including our own, finding common (and not so common) ground. We then attempt to resolve some issues in this regard. It is necessary to do this in order to advance our understanding and move in new directions about how executive function relates to academic achievement.

### Keywords

Executive Function; Framework; Achievement; Reading; Math

There is no agreed-upon definition of executive function (EF), and this literature can be confusing. Somewhat tongue-in-cheek, three subgroups of scientists might be delineated in how they view EF. One subgroup might adopt a definition or synonym commonly cited in extant literature, and use one or more of the most common measures. Another subgroup might say, "I don't know what it is", and so are agnostic towards EF, referring to it and or

Paul T. Cirino, Ph.D., Department of Psychology, University of Houston, TIMES, Health 1, Room 373, 4349 Martin Luther King Blvd., Houston, TX 77204-6022. pcirino@uh.edu.

Conflict of Interest Statement:
The authors have no conflicts of interest to disclose.

Informed Consent Statement:
Human subjects were not directly involved in this review.

measuring it as convenient. A third subgroup might be described as "atheist" – finding the construct unnecessary, too abstract, or too complicated, preferring instead to deal with more specific constructs. Conceptual clarity is important for any research domain (Bringmann, Elmer, & Eronen, 2022), but particularly for EF as there are many accepted meanings. There is also debate with regard to dyslexia or reading disability, but that debate seems more tractable than EF, since it is at least more apparent what is in versus outside the domain of reading. We first review evidence for how EF is "attached" to reading and other academic skills (primarily math), but spend the bulk of the work evaluating the construct of EF itself, presenting our own framework, highlighting similarities and differences with others prevalent in the literature. We seek to use this framework to help develop an agenda for novel ways in which EF might be considered and studied.

## EF and Achievement: Current Status

In order to discuss the relation of EF and achievement, it is helpful to first evoke an *idea* of how EF is often considered (even overly broadly and overly simplistically); that is, as a "higher order" complex construct supporting goal-directed behavior. We do so as a placeholder of sorts, as the bulk of this work focuses on the nature of EF as construct per se.

### Reading

When viewed in this placeholder manner, then a rationale for why EF relates to reading can be described that is relevant to most conceptualizations of EF. Three strands can be discerned including logic, reading theory, and cognitive theory. Logically, the act of reading is complex. Even for single words (or nonwords) in isolation, it is necessary to integrate orthography, phonology, and semantics (Siedenberg & McClelland, 1989). Learning these associations to automaticity requires consistent and broad exposure, and where this is not possible (e.g., sounding out less familiar words), a means of decoding must also be available, which must be done quicky to allow for fluent reading. Finally, for reading comprehension, it is necessary to connect meaning within and across sentences and paragraphs. Thus, a complex learned skill like reading might benefit from a construct like EF.

Second, multiple theories of reading (comprehension) invoke EF, as eloquently argued elsewhere (Butterfuss & Kendeou, 2017). Though many such models (e.g., Construction-Integration (Kintsch, 1988; 1998); Structure Building (Gernsbacher, 1991); Landscape (van den Broek et al., 1999)) do not use the words "EF", they commonly reference cognitively complex operations that fall under the rubric of EF.

Third, cognitive models beyond reading have elements that can be seen to "ally" with EF for complex skills like reading. For example, dual process theory (Evans & Stanovich, 2013) differentiates autonomous and controlled processes. More complex skills are less likely to be readily automatized, and therefore reading (particularly comprehension), which relies on controlled processes, is likely to benefit from the support of EF. Cognitive Load theory (Chandler & Sweller, 1991; Sweller, 2011) differentiates extrinsic from intrinsic load, and higher intrinsic load means increased reliance on working memory (which is often associated with EF). Because reading comprehension is complex, it carries a high intrinsic load.

Beyond the above rationale, there is also tremendous empirical evidence relating EF to reading. Meta-analyses show that EF is related to decoding (Ober, Brooks, Homer, & Rindskopf, 2020; $r = .28$ to .34) and to comprehension (Follmer, 2017; $r = .36$), and working memory in particular relates to all types of reading (Peng, Barnes, et al., 2018, $r = .29$). When students with and without reading difficulty are compared on cognitive factors, group differences are similarly (moderately) sized (Kudo, Lussier, & Swanson, 2015; $d = .67$; Peng et al., 2022; $d = .48$ to .60). EF shows these effects, even with a range of other factors controlled, and EF may also interact with Simple View of Reading (Gough & Tumner, 1986) variables (Cirino, Miciak et al., 2019).

## Other Achievement Domains

Written language includes reading and writing, and like reading, writing is rooted in language. Despite some work relating EF to writing (Ahmed et al., 2022; Altemeier, Abbott & Berninger, 2008; Hooper et al., 2002; Kim & Schatschneider, 2017), the literature is richer with regard to math. On the surface, math and reading are quite different, though they are strongly related, and difficulties frequently co-occur (Cirino, Child, & Macdonald, 2018; Morsanyi et al., 2018; Peterson et al., 2017). Because both math and reading are complex developmental goal-directed behaviors, many arguments for how or why EF relates to math are similar to those invoked for reading (e.g., logic, math theory, and cognitive theory). First, math requires a cumulative acquisition of facts, procedures, and applications of increasing complexity. In addition, new math learning requires a combination of build-upon learning, and sometimes unlearning (e.g., whole number bias; Ni & Zhou, 2005; van Hoof et al., 2017). Particular domains of math, such as word problems, also rely on reading comprehension (Fuchs et al., 2015). Thus, EF resources are highly valued for math development.

Second, math theories reference EF either indirectly or directly. For example, math facts are often considered a “bottleneck” for later math development (Fleishner et al., 1982; Geary et al., 1987), where math fact mastery frees up resources (e.g., working memory) for more complex procedures. Geary (2004) specifies a model wherein the working memory system (highlighting the central executive) undergirds procedural and conceptual mathematics; Geary (2013) also notes that the mapping of nonsymbolic magnitude to explicit number knowledge early in development is governed by attentional control. von Aster and Shalev (2007) posit a model wherein math development affords a representational re-description of the mental number line, which is accomplished via increasing working memory resources. Working memory plays the dominant role in how EF relates to math, whereas for reading, EF is considered more broadly.

Third, because the cognitive models noted above (Chandler & Sweller, 1991; Evans & Stanovich, 2013; Sweller, 2011) are not specific to academic achievement, they play a similar role for math as for reading. Math also involves the transition from controlled to more automatic operations (with many never being automatized), and also carries high intrinsic cognitive load.

The empirical evidence regarding the relation of EF to math is also well-developed. Peng et al. (2016) found that working memory was meta-analytically related to math ($r$ = .35), and not moderated by the type of working memory, or by the type of math, except to have weaker relations to early geometry. When students with and without math difficulty are compared on various cognitive factors, group differences are similarly (moderately) sized ($d$ = .76 for working memory, and $d$ = .50 for other EF components; Peng, Wang, & Namkung, 2018). Most of these studies involve younger students, though with more recent recognition that working memory is important for older students as they learn fractions, proportional reasoning, and algebra, with both direct and indirect effects (Cirino et al., 2016; Cirino, Tolar & Fuchs; 2019).

### Summary and Expansion

There is little doubt that EF is related to academic achievement, theoretically and empirically. There is also evidence regarding a role for EF where reading and math overlap (Child et al., 2019; Cirino et al., 2015; Peterson et al., 2019). In this vein, a recent meta-analysis (Spiegel et al., 2021) examined EF with regard to both reading and math. Overall effects were higher for math ($r$ = .36) relative to reading ($r$ = .30), and among EF measures, working memory had stronger effects relative to inhibition and shifting. However, relations of working memory were smaller for reading fluency and math fluency ($r$ = .21 and .25, respectively) than for decoding, comprehension, and calculations (range $r$ = .32 to .34); the highest relations of WM were with word problems ($r$ = .43). The bulk of EF-achievement relations generally are focused on working memory, and moreso in the math relative to reading literature. This can lead to the idea that EF “training” should improve achievement. There is sound evidence that particularly working memory can be improved (e.g., Sala & Gobet, 2020; Takacs & Kassai, 2019). Such effects are stronger when supports are provided (Schwaighofer, Fischer, & Buhner, 2015), which ironically could be seen as EF scaffolding. There is not yet strong evidence to conclude that such improvements transfer to academic achievement (Jacob & Parkinson, 2015; Melby-Lervåg, Redick, & Hulme, 2016; Sala & Gobet, 2017; Schwaighofer et al., 2015). Of note, however, other works in this Special Series provide new and exciting data in this regard.

## What is EF?

One possible reason that the state of the science regarding EF and achievement has not yielded obvious suggestions for the best way to leverage EF for reading and math is that EF is discussed and measured in many different ways that do not relate well to one another. We believe that a deeper evaluation of EF as a construct might yield new insights. One caveat should be noted. Although EF has traditionally been linked with the frontal lobes (as highlighted in multiple contributions to this Special Series), the present work focuses on EF as a psychological construct only.

We have previously provided a definition: “EF (1) ***is*** a (2) ***domain-general*** (3) ***control*** (4) ***process*** important for (5) ***managing*** (6) ***goal-directed behavior***” (Cirino, Ahmed et al., 2018). While this definition is not perfect, we can describe how it was formulated, and use it as an example of how to parse any EF definition and evaluate the implications for EF as a construct. We then compare this definition with others. The value is in prompting the asking of answerable questions that further interrogates and clarifies the construct and its relations to outcomes.

First, our definition is singular rather than plural (#1). This was a conscious choice in part because of the way EF is usually discussed (i.e., it is more common to ask "What is EF?" than to ask "What are EFs?"). Even when EF is used in the plural, it is less the construct itself than its *measurement* that is referenced (e.g., "EF consists of X, Y, and Z", rather than "X, Y, and Z are the EFs").

Second, EF is domain-general (#2). This too was a choice, in contrast to specificity that could arise from: (a) sensory modality (e.g., vision, hearing, touch, taste, smell); (b) stimulus content/material (e.g., words, shapes/locations, other symbols); (c) response output requirements (e.g., oral or manual); (d) outcome (e.g., reading, problem solving, social); or (e) any combination of the above. The most common distinction is with regard to stimulus content (b), such as the contrast between verbal versus visual working memory (WM). This distinction is sometimes made with reference to Baddeley's model (Baddeley, 2012; Baddeley & Hitch, 1974), though visual and verbal WM are not the same as the visual-spatial scratch pad (VSSP) and phonological loop (PL) components of that WM model. Rather, EF is more closely aligned to the central executive (CE) component of Baddeley's model (the limited capacity attentional mechanism; Baddeley & Logie, 1999). It is uncommon to distinguish CE or EF by stimulus content (e.g., verbal CE versus visual CE), or by outcome (e.g., reading EF, math EF, social EF). Even if EF *manifests* differently based on stimulus content or outcome, EF is expected to have the same *meaning* across domains, and it is in this sense that EF is domain general.

Third, EF requires control (#3). The implication is that there is control *of something*, thus aligning with a "higher order" nature of EF. Having higher-order things implies that there are lower-order things, and thus invokes a tiered set-up among cognitive skills. In other contexts, however, control implies a unidirectional relationship, where a given input always leads to a given output, and/or in maintaining homeostasis.

Fourth, EF is a process (#4), implying that it is not a static "thing" (or a collection of things), but rather is fundamentally an interaction among "things" (that are either specifically or generally relevant to the goal). Process also implies a sequence of cognitive actions that operate across contexts. EF unfolds when prompted by a problem; it is the behavior produced (whether and how well the problem is worked out), that determines whether or not EF is "good".

Fifth, EF manages (#5). Management and control (#3) have similarities in that both invoke a sense of being "in charge" as well as "higher order", but (good) management implies coordination and cooperation more than direct control, and thus may not strictly be "higher". Change based on feedback is also consistent with a dynamic process that may need to be repeated and/or altered; in this sense, management also implies a metacognitive aspect to EF.

Sixth and finally, EF is goal-directed (#6), representing the "class" of behaviors that require EF management – those that are challenging or effortful (either of high complexity or having many steps and not automatized), those that are novel (having no existing template), and/or requiring a delay (time/persistence). In contrast, EF is not needed for stimulus-response, or well-learned activities (even if a sequence/process is involved). The nature of developmental learning variably invokes EF. In many cases (e.g., riding a bike; learning to apply a math algorithm), the effort required during learning is quite high, but once established, the goal in these cases remains (e.g., not falling; completing the math problem), but becomes more implicit than explicit, and requires little conscious effort. EF is also not a purely cognitive or affective exercise – some action (behavior) must ensue (or else be withheld, if there are prepotencies involved). Goal-directed behavior can be in any domain (e.g., reading, math, or social), and this observable behavior can be considered the *result or manifestation of EF* (for good or ill). If Paul comes up with a solution to a problem or gets a tough job done, then he is adjudged to have good EF. But if he makes mistakes (especially if not remedied), then Paul is adjudged to *not* have good EF.

## Comparison of Several Definitions of EF

The array of terms used or substituted for EF is dizzying – Packwood, Hodgetts, and Tremblay (2011) identified 68 components in the literature. Because the overlap and distinctions are near endless, we more parsimoniously chose six models/frameworks. Each is well-represented in the literature, well-articulated theoretically, and with plentiful empirical support (none of which is disputed here; indeed, our own ideas are strongly informed by this literature). Table 1 compares and contrasts these models with the one described above.

The Zimmerman model has three phases. Forethought includes identifying the issue/goal, generating a plan, and preparing oneself for implementation (which includes motivations, expectations, etc.). Performance includes focusing on the task at hand, following the steps of the pre-planned process, and considering the effects of the chosen strategies in the moment. Finally, self-reflection examines the result of implementation to see whether and how satisfactorily the strategy worked. As shown in Table 1, there is much overlap of this model with the definition discussed above. For example, the metacognitive component of self-reflection is aligned with management (#5), and forethought (#3) invokes control, preparing the action plan to be followed. The term SRL is typically used in the singular (#1) despite being measured in many ways, and the model does not specify a particular modality, content, or outcome, so it is domain general (#2). This model first focused on college students, but now includes correlational and experimental studies and younger students.

Second, Rothbart's model has three components related to personality constructs, but it is the effortful control (EC) portion that most closely aligns with EF. EC is related to the executive attention network (Rothbart, 2007) with sub-components of attention control, inhibitory control, perceptual sensitivity, and low-intensity pleasure. This model is focused on preschoolers. The overlap of this model with that above is somewhat ambiguous, as seen in Table 1.

Third, Zelazo described EF as a "macro-construct", requiring individual subfunctions (some executive and others automatic) to operate together for a common goal; executive resources are needed with novelty or when competing demands or interference are present. There is much overlap of this model with the definition earlier provided. The focus of this model is most frequently at the preschool ages and includes both correlational and experimental approaches.

Fourth, Engle's model combines elements of measurement with experimentation; it is focused on college students and young adults, and is typically assessed via complex span tasks. A key difference with the model above is that EF is not considered a process. It should be noted that although the model is of controlled attention, the key operationalization is of working memory; it is the "engine" that supplies the cognitive resources needed to control one's attention.

Fifth, Miyake's model recognizes that EF measures are complex, making it difficult to separate their components (the so-called *task impurity problem*). This model contrasts with the above model in that it is plural – the three functions are clearly separable though related. Miyake et al.'s (2000) definition of EF as "general-purpose control mechanisms that modulate the operation of various cognitive subprocesses and thereby regulate the dynamics of human cognition" (p. 50) clearly reflects control (#3) and management (#5), but not process (#4). This model initially focused on college students and young adults, but has since been expanded, and is typically utilized in individual differences or correlational fashion. Over the past 20 years, there has been increased homogeneity in the conceptualization of EF, aligned to the Miyake model. However, it is unclear to what extent this reflects true agreement versus practicability.

Zelazo and colleagues later define EF as "a specific set of attention-regulation skills involved in conscious goal-directed problem solving." (p. 2), and the components map (likely not coincidentally) onto the Miyake et al. (2000) components. Other works by Zelazo (Zelazo & Carlson, 2012) and others (Hongwanishkul et al., 2005; Prencipe et al., 2011) further differentiate among "hot" and "cool" EF, and describe functional and anatomical differences in these types of skills. These views seem a different approach relative to the earlier process-focused approach, particularly in terms of different categories of EF (hot/cool), and the shift from singular to plural, while avoiding the process component.

## Comparison Discussion

Even from this brief selective review and perusing of Table 1, a range of similarities and differences are apparent. For example, most frameworks emphasize that EF is domain general (#2), that it is in "control" (#3), that there is a need for "management" (#5), and that EF is associated with goal direction (#6). In contrast, there are substantial differences with regard to EF being singular versus plural (#1), or the consideration of EF as a process versus thing(s) (#4). Therefore, it is relevant to further evaluate the consequences of these options, and their implications for EF.

**EF as Singular versus Plural.—**The common empirical approach to the plurality (or not) of EF is factor analysis. A recent review of 40 such studies (Karr et al., 2018) found that the number of factors varied across preschool (one or two factors), younger school age (three), adolescence and adulthood (three, often nested), older adults (two or three). Our own work has found support for a bifactor model, with discrete factors beyond the typical three (Cirino, Ahmed et al., 2018). Beyond the findings per se, which Karr et al. noted to be quite variable, many studies were noted to be of low power, and in re-analysis, models failed to converge more often than not; further, only performance measures of EF (as opposed to self- or other-rating scales) were considered in this work. In addition, few studies evaluated indicators from *other than* the three most commonly referenced constructs (i.e., those of the Miyake model). Karr et al. (2018) highlight the need to consider alternative models, including additional purported elements of EF, while simultaneously lamenting the large number of potential EF measures (and also recognizing their low intercorrelations). Overall, support for the equating of EF to the three factors of cognitive flexibility/shifting, updating/working memory, and inhibition is more nuanced than may at first appear.

A second approach to plurality is separability along theoretical lines, such as "hot EF" and "cool EF". The use of these adjectives prior to the word EF suggests distinct individual differences (there are in fact low correlations between the two sets of measures). However, what varies is the setting within which EF is deployed, versus being non-overlapping cognitive resources. Although more cumbersome, a more accurate distinction may be 'EF measured in the context of an emotionally or motivationally valanced (versus a neutral) goal-state'. Even if the neuroanatomical circuitry is different/dissociable, to the extent that the purpose in both cases is to coordinate and deploy resources as needed to achieve a desired goal-state, then hot and cool can be considered different *contexts* as opposed to different *constructs*.

If EF is plural, it is necessary to demonstrate that each component is relevant for goal-directed behavior – in this regard, the evidence is very strong. Plural EF also implies that components are identifiable and discreetly measurable, which also appears to be the case. This affords several advantages, including making connections upstream (e.g., neurobiological and cognitive correlates) and downstream (e.g., their impact on goals/outcomes) more readily accessible. There is much data in these veins for each of updating/working memory, inhibition, and shifting/cognitive flexibility.

Despite strong advantages, at least three disadvantages are also apparent, in the form of begged questions. If there are multiple EFs, how do they operate jointly for their contribution to a purpose/goal-state? What is the mechanism that establishes how they operate or are deployed? Further, if there were such a mechanism, would it not be better to consider that mechanism itself to be EF? Also, if there are multiple EFs, what are the criteria for being or not being an EF?

Second, despite the strong evidence in favor of working memory, inhibition, and cognitive flexibility as being important for goal-directed tasks, it is not clear why EF needs to be restricted to these. Why are two EFs not sufficient, or why are four EFs too many? What about planning, or fluency/generativity, or processing speed, or attention and any of its varieties? In corollary, if hot and cool EF are also separable, are there then four EFs (three cool EFs and a singular hot EF) or six EFs (hot cognitive flexibility, cool cognitive flexibility, etc.)? Also, arguing for the *importance* of a given element to goal-directed behavior is different than arguing for its *<u>necessity</u>*. It is the case that models that stress plurality do not pre-specify that *all* three elements are both necessary and sufficient to produce *every* goal-directed behavior or functional outcome, but then it becomes less clear what is the commonality that makes them EFs per se. If these three cognitive constructs are instead considered to be "only" domain general individual differences, then it is easier to see them as belonging to a suite of potential resources that are selected for use depending on the goal-directed behavior, and/or on other domain-specific individual differences.

Third, at a conceptual level, if EF is only a label for a collection, then is it needed beyond its role as a communication heuristic? The key potential danger lies in a mismatch between the way that EF is *discussed* versus the way it is *measured*. This can be true of any construct, but the stakes are somewhat higher for EF because it is discussed so very broadly (in terms of educational, socio-emotional, or occupational outcomes), and yet is measured with a very wide range of performance tasks that may have weak psychometric characteristics that also relate weakly to one another.

EF being singular is parsimonious, but also aligns with the concept of EF as a general individual difference. It also removes the need to discuss how different EFs interact. Having EF as a single entity is easier to relate to functional outcomes. Considering EF as unitary also suggests shifts the question from "how many EFs are there?" but rather, "what does the construct of EF add beyond individual differences in domain general skills" (even if these include constructs like working memory and inhibition). However, to the extent that a single EF is too broadly defined, then it can be difficult to measure directly and consistently. Even if EF is a single factor-analytic based construct, this is limiting for research as well as practically and clinically, given the effort needed to attain multiple strong indicators. If EF is a singular process, then its components need to specified and measured, and because processes are by nature dynamic, additional measurement challenges pertain. Another disadvantage of a singular EF is that attempts to root this construct to neurobiological structure (at either macro- or micro- levels) or function (brain activity level) become more difficult to achieve.

**EF as a Thing(s) versus a Process.—**Whether EF is a process versus a thing (or things) may be constrained by the plurality of EF. If EF is singular, it could be a single process, a single cognitive construct, or a single superordinate cognitive construct (either theoretically, e.g., "metacognition", or empirically such as a unidimensional or bifactor model). As with plurality, considering EF as a thing(s) versus a process has advantages and disadvantages.

If each EF component has theoretical and empirical justification for goal-directed behavior (a safe assumption), then EF as a thing (or things) can be measured out of context, and directly. This means that stable individual differences can be identified/specified, and related to other things, including both functional outcomes and neurobiological substrates. On the other hand, EF necessarily becomes tied to the psychometric properties of particular performance tasks, making generalizability across those tests and to functional outcomes more difficult.

Considering EF to be a process also has pros and cons. EF as a process allows it to be considered in a way that is usually meant – as something that is more than the sum of its parts. However, at the same time, a process cannot be assessed outside of a given context/goal-directed behavior, and different contexts may require different combinations of domain specific and domain general resources. This is consistent with arguments made in other domains, such as attention, where context is essential rather than measurement error (Ristic & Enns, 2015). Even the same process (sequence of steps) can either work or not work, implying that EF in turn can *appear* better or worse, even if it is generally a stable individual difference. As before, EF as a process requires that the sequence is operationalized, and reflects that the steps of the process might be dynamic and influence one another.

**Domain Generality.—**Domain generality is one of the more agreed-upon aspects of EF across perspectives. However, the term usually means that it has utility for many outcomes (which does appear to be the case); cognitively, this can be considered via the lens of modularity (Endress, 2019; Fodor, 1983). However, in corollary, domain generality also means that the skill is not *privileged* for any particular outcome – that is, any given outcome does not depend solely on domain general construct(s). Domain specificity, in contrast, implies that it is more important for a given outcome *than other outcomes*, or else more important or proximal to a given outcome *relative to other predictors* (Endress, 2019). For example, in the math literature, domain specific skills are either foundational number or previously taught math skills, whereas domain general skills are not math skills per se, but relate to them in theoretically plausible ways (Cirino et al., 2021).

Domain general can also imply "higher order" via a hierarchy. To the extent that a function or a process is domain general, then it sits "above" domain specific things. Domain general also implies a one-to-many relation, although this tiered characterization of cognition can also be invoked by "control" or "management". Finally, saying that EF is domain general is not contradictory with EF being relevant only for certain *kinds* of outcomes (those that require goal-oriented problem solving) and not others (those that are routine, well-learned, or automatic). It does imply that the outcome/goal has "a say" in which domain-specific and domain general functions are most relevant.

## What is EF? (Reprise)

Given the above, our earlier definition is amended to say that **EF is a managerial process for coordinating domain general and domain specific resources during challenging goal-directed behavior.** Key changes are to: (a) drop the word "control" as it either overlaps with "manage" or where it differs, implies a more directive or inflexible homeostatic function; (b) explicitly highlight the need for both domain general and domain specific resources; and (c) specify that the goal-directed behavior must be challenging in some way (e.g., complex, difficult, novel). We retain the idea of a singular EF and EF as a process, in part because we perceive the downsides of a multiple EFs to be theoretically problematic. Downsides to a singular EF process are difficult as well, but reflective of the complexity that is often attributed to EF. There remain pressing issues, including: (1) how to juxtapose/resolve singular process versus componential models of EF; (2) how to specify/instantiate the process; (3) how to resolve apparent paradoxes (e.g., EF as singular but needing to be measured in-situ for a given goal-directed behavior); and (4) how to measure EF as a process.

First, how can the voluminous evidence that individual differences in working memory, inhibition, and cognitive flexibility are important for goal-directed behavior, be framed? Nothing about considering EF as a process disputes any such evidence. The key distinction is whether measures of those individual differences are EF itself (or themselves), versus whether they are grouped with other domain general and domain specific skills to produce EF in the service of goal-directed behavior. In order to enact a cognitive process, "space" is needed for that process to operate, and it may be that domain general factors such as working memory, inhibition, and cognitive flexibility help parameterize such a space. However, other domain general factors (e.g., processing speed, generativity, attention) might also be included. Further, the extent to which these domain general elements are needed may depend on what the goal-directed behavior is, and which domain specific elements are relevant for that behavior. Individual differences across *all* the domain general and specific resources for a given outcome are important, but the argument made here is that EF *per se* refers to whether and how these are deployed during the process of completing goal-directed behavior. Thus, different behaviors use different combinations and/or amounts of resources, and the same resource can be taxed to varying degrees, or not used at all, depending on context, rather than being both necessary and sufficient.

Second, a process includes an interactive sequence that needs specification. Much as is the case with other models both in development (e.g., Zelazo et al., 1997), education (e.g., Zimmerman & Schunk, 2011), and other domains such as rehabilitation (e.g., Levine et al., 2000; Ylvisaker & Feeney, 2002), elements of this process include at least three components: (a) *representation* of a problem; (b) *plan* development; and (c) *monitoring* during execution (or RPM). Representation is identifying the goal, and parameterizing its characteristics (e.g., with regard to complexity, novelty, etc.). Planning is necessary to develop the steps (and their order) that need to be completed, in order to reach the goal efficiently, and with knowledge of one's own strengths and weaknesses (e.g., if a good plan includes taking copious notes, alternatives would be needed if the act of writing is laborious). Finally, monitoring implies execution of the plan, and tracking its progress, including whether the existing plan needs tweaking (or scrapping); monitoring could also involve speeding up (if time is running out), or slowing down (if errors are being made), or simply persevering.

Third, if a process can only be evaluated during or in consideration of goal-directed behavior, and if each goal-directed behavior varies in terms of its domain general and specific resource requirements, then could it be that EF is *very* plural – that there are as many EFs as there are goal-directed behaviors? We do not believe so. If there is a single EF that has individual differences, then what makes EF, "EF" is how adept an individual is at the applying the RPM process across contexts (which implies that the relevant domain specific skill varies considerably with individual differences therein), or even across occasions of the same context that are achieved either better or worse than is typical (e.g., because of motivational or affective fluctuations). In many ways, this is analogous to viewing EF as a "trait" as well as a "state".

Perhaps the most thorny aspect of considering EF as a process is how it can be measured. In theory, it is possible to assess aspects of RPM separately. For example, a series of complex problems could be presented, where the first task is only to identify/articulate the issue; then, plans could be presented, with the task of identifying the most efficient solution; and finally, responses to feedback (real or hypothetical) based on implementing those plans can be evaluated via a rubric. Three additional routes are possible. First, if a particular goal-directed behavior is of interest, then an RPM task could be developed/evaluated directly in that context (along with key domain specific and specific resources for that outcome). Second, if EF is to be ascertained globally (as an individual difference), then it would seem to require accumulating RPM tasks over different contexts; such ascertainments would be expected to correlate robustly but incompletely. Third, it is possible to obtain ratings of the enactment of the RPM process across different contexts. One would assume modest correlations between this and the two more performance-based methods, in line with literature on EF (Toplak et al., 2013) and attention (Sims & Lonigan, 2011; Macdonald et al., 2021), but for academic achievement, the two approaches are likely complimentary (Gerst et al., 2017). Of course, any such rating scale must focus on the RPM process itself, and be separable from other constructs such as those assessing diagnostic symptomatology (e.g., of ADHD). From both a psychometric perspective, as well as time, money, and other resources, this last route (ratings) may be the most efficient place to begin.

## Summary and Future Directions

It would be ideal for EF to have an agreed upon meaning, to be easy to measure, to have clear brain correlates, to plausibly (theoretically) be related to important goal-directed behaviors (outcomes), to be predictive of those outcomes, to be malleable, and for any such malleability to have "downstream" impacts on important outcomes. However, few of the above criteria have currently been met. We suggest that key issues of how to consider EF, and thus how to measure it, need more convergence before it can be addressed how/whether EF is malleable, and if so, what the implications are to follow. We argue that what makes EF unique is its position as a meta-construct (Zelazo et al., 1997). Other individual differences (in domain general and specific resources) are important to the process, but crucially are *not* the process itself. To the extent that existing EF measures address components of the RPM process, then they ought to correlate with new measures specifically designed to assess EF as a process, be they rating scales or performance measures, notwithstanding method variance issues. It is at present unclear how best to measure that process, or if it is malleable (e.g., via strategy instruction), or if it is as-or-more relevant to a variety of goal-directed behaviors than other individual differences. But if so, this would expand the promise of EF, and should be investigated empirically for those reasons.

Fundamentally, work in EF must make careful choices between its levels of analysis and measurement, versus the inferences made. The more narrowly and discretely EF is measured, the easier it is to evaluate how EF is instantiated in the brain, and to establish and replicate relations (however strong or weak) to other constructs, including achievement. However, the inferences generated from such an approach must match the scale of measurement. Because EF is often discussed so very broadly and abstractly, there is a mismatch if it is not measured from a similarly broad perspective. This also applies at the level of outcomes (e.g., performance on computational measure of single-digit addition, versus a normed computational measure with many mixed operations, versus a math grade for the semester). Recognizing EF as a process with components that vary in their necessity according to the goal/functional outcome may promote a tighter link to more complex outcomes while at the same time promoting a better understanding of the mechanisms of failure and success at employing EF.

### Conclusion

EF is difficult to define, but the present work considers EF to be a managerial process for coordinating domain general and domain specific resources during challenging goal-directed behavior. In order to leverage EF for improving academic achievement, its nature (as a process) and complexity first needs to be embraced and measured, alongside traditional domain general and domain specific individual differences. At a "meta" level, this work serves to represent the problem facing EF, and provide a potential plan to establish EF in a way that is useful for important academic achievement outcomes. There is no doubt that enacting and monitoring progress towards that goal may require alterations. The present work views the road ahead as challenging but potentially highly rewarding.

## Acknowledgments

This research was supported in part by Award Number P50 HD052117, Texas Center for Learning Disabilities, from the *Eunice Kennedy Shriver* National Institute of Child Health & Human Development, and by Grant No. 1760760 from the National Science Foundation, both awarded to the University of Houston. The content is the sole responsibility of the author and does not necessarily represent the official views of the *Eunice Kennedy Shriver* National Institute of Child Health & Human Development, the National Institutes of Health, or the National Science Foundation.

## References

Ahmed Y, Kent S, Cirino PT, & Keller-Margulis M (2022). The not-so-simple view of writing in struggling readers/writers. Reading and Writing Quarterly, 38(3), 272–296.

Altemeier LE, Abbott RD, & Berninger VW (2008). Executive functions for reading and writing in typical literacy development and dyslexia. Journal of Clinical and Experimental Neuropsychology, 30, 588–606. DOI: 10.1080/13803390701562818.

Baddeley AD, & Hitch GJ (1974). Working memory. In Bower GA (Ed.), The Psychology of Learning and Motivation: Advances in Research and Theory, pp. 47–89. New York: Academic Press.

Baddeley AD (2012). Working memory: Theories, models, and controversies. Annual Review of Psychology, 63, 1–29. DOI: 10.1146/annurev-psych-120710-100422

Baddeley AD, & Logie RH (1999). Working memory: the multiple component model. In Miyake A, Shah P (Eds.), Models of Working Memory: Mechanisms of Active Maintenance and Executive Control, pp. 28–61. Cambridge, UK: Cambridge Univ. Press

Bringmann LF, Elmer T, & Eronen MI (2022). Back to basics: The importance of conceptual clarification in psychological science. Current Directions in Psychological Science, 1–7. DOI: 10.1177/09637214221096485

Butterfuss R, & Kendeou P (2017). The role of executive functions in reading comprehension. Educational Psychology Review, 30(3), 801–826. DOI: 10.1007/s10648-017-9422-6.

Child AE, Cirino PT, Fletcher JM, Willcutt EG, & Fuchs LS (2019). A cognitive dimensional approach to understanding shared and unique contributions to reading, math, and attention skills. Journal of Learning Disabilities, 52(1), 15–30.

Cirino PT, Ahmed Y, Miciak J, Taylor WP, Gerst EH, & Barnes MA (2018). A framework for executive function in the late elementary years. Neuropsychology, 32(2),176–189.

Cirino PT, Child AE, & Macdonald K (2018). Longitudinal overlap of reading and math and their predictors. Contemporary Educational Psychology, 54, 99–111.

Cirino PT, Fuchs LS, Elias JT, Powell SR, & Schumacher R (2015). Cognitive and mathematical profiles for different forms of learning disabilities. Journal of Learning Disabilities, 48(2), 156–175.

Cirino PT, Miciak J, Ahmed Y, Barnes, Marcia A, Taylor WP, & Gerst EH (2019). Executive function: Association with multiple reading skills. Reading and Writing, 32, 1819–1846.

Cirino PT, Tolar TD, & Fuchs LS (2019). Longitudinal algebra prediction for early versus later takers. Journal of Educational Research, 112(2), 179–191.

Cirino PT, Tolar TD, & Fuchs LS (2021). Domain general and specific contributions to algebra: A sequenced longitudinal path model. Contemporary Educational Psychology.

Cirino PT, Tolar TD, Fuchs LS, & Huston-Warren E (2016). Cognitive and numerosity predictors of mathematical skills in middle school. Journal of Experimental Child Psychology, 145, 95–119.

Chandler P, & Sweller J (1991). Cognitive load theory and the format of instruction. Cognition and Instruction, 8, 293–332. DOI: 10.1207/s1532690xci0804_2

Endress AD (2019). Duplications and domain-generality. Psychological Bulletin, 145(12), 1154–1175. DOI: 10.1037/bul0000213

Engle RW, Kane MJ, & Tuholski SW (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In Miyake A, Shah P (Eds.)., Models of Working Memory: Mechanisms of Active Maintenance and Executive Control, pp. 102–34. New York: Cambridge Univ. Press

Engle RW (2002). Working memory capacity as executive attention. Current Directions in Psychological Science, 11, 19–23. DOI: 10.1111/1467-8721.00160

Engle RW (2018). Working memory and executive function: A revisit. Perspectives on Psychological Science, 13(32), 190–193. DOI: 10.1177/1745691617720478.

Evans JSB, & Stanovich KE (2013). Dual-process theories of higher cognition: Advancing the debate. Perspectives on Psychological Science, 8(3), 223–241. DOI: 10.1177/1745691612460685

Fleishner JE, Garnett K, & Shepherd MJ (1982). Proficiency in arithmetic basic fact computation of learning disabled and nondisabled children. Focus on Learning Problems in Mathematics, 4, 47–56.

Fodor JA (1983). The Modularity of Mind. Cambridge, MA: MIT Press.

Follmer DJ (2017). Executive function and reading comprehension: A meta-analytic review. Educational Psychologist, 53, 42–60. DOI: 10.1080/00461520.2017.1309295.

Friedman NP, & Miyake A (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. Cortex, 86, 186–204. DOI: 10.1016/j.cortex.2016.04.023

Fuchs LS, Fuchs D, Compton D, Hamlett C, & Wang A (2015). Is word-problem solving a form of text comprehension? Scientific Studies of Reading, 19(3), 204–223. DOI: 10.1080/10888438.2015.1005745.

Fuchs LS, Powell SR, Seethaler PM, Cirino PT, Fletcher JM, Fuchs D, & Hamlett CL (2010). The effects of strategic counting instruction, with and without deliberate practice, on number combination skill among students with mathematical difficulties. Learning and Individual Differences, 20(2), 89–100.

Geary DC (2004). Mathematics and learning disabilities. Journal of Learning Disabilities, 37(1), 4–15.

Geary DC (2013). Early foundations for mathematics learning and their relations to learning disabilities. Current Directions in Psychological Science, 22(1), 23–27. DOI: 10.1177/0963721412469398

Geary DC, Widaman KF, Little TD, & Cormier P (1987). Cognitive addition: Comparison of learning disabled and academically normal elementary school children. Cognitive Development, 2, 249–269.

Gernsbacher MA (1991). Cognitive processes and mechanisms in language comprehension: the structure building framework. In Bower GH (Ed.), The Psychology of Learning and Motivation (pp. 217–263). New York: Academic Press.

Gerst EH, Cirino PT, Fletcher JM, & Yoshida H (2017). Cognitive and behavioral rating measures of executive function as predictors of academic outcomes in children. Child Neuropsychology, 23, 381–407. DOI: 10.1080/09297049.2015.1120860

Gough PB, & Tunmer WE (1986). Decoding, reading, and reading disability. Remedial and Special Education, 7, 6–10. doi:10.1037/0022-0663.99.2.311.

Hongwanishkul D, Happaney KR, Lee W, and Zelazo PD (2005). Assessment of Hot and Cool Executive Function in Young Children: Age-Related Changes and Individual Differences. Developmental Neuropsychology, 28(2): 617–644.

Hooper SR, Swartz CW, Wakely MB, de Kruif RE, & Montgomery JW (2002). Executive functions in elementary school children with and without problems in written expression. Journal of Learning Disabilities, 35(1), 57–68. DOI: 10.1177/002221940203500105

Jacob R, & Parkinson J (2015). The potential for school-based interventions that target executive function to improve academic achievement a review. Review of Educational Research, 85, 512–552. DOI: 10.3102/0034654314561338

Karr JE, Areshenkoff CN, Rast P, Hofer SM, Iverson GL, & Garcia-Barrera MA (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. Psychological Bulletin, 144(11), 1147. DOI: 10.1037/bul0000160

Kim YSG, & Schatschneider C (2017). Expanding the developmental models of writing: A direct and indirect effects model of developmental writing (DIEW). Journal of Educational Psychology, 109(1), 35–50. DOI: 10.1037/edu0000129

Kintsch W (1988). The role of knowledge in discourse comprehension: a construction-integration model. Psychological Review, 95(2), 163–182. DOI: 10.1037/0033-295X.95.2.163.

Kintsch W (1998) Comprehension: A Paradigm for Cognition. New York: Cambridge University Press.

Kudo MF, Lussier CM, & Swanson HL (2015). Reading disabilities in children: A selective meta-analysis of the cognitive literature. Research in Developmental Disabilities, 40, 51–62. DOI: 10.1016/j.ridd.2015.01.002

Levine B, Robertson IH, Clare L, Carter G, Hong J, Wilson BA, … Stuss DT (2000). Rehabilitation of executive functioning: An experimental-clinical validation of goal management training. Journal of the International Neuropsychological Society, 6, 299–312. DOI: 10.1017/S1355617700633052

Macdonald KT, Barnes MA, Miciak J, Roberts G, Halverson KK, Vaughn S, & Cirino PT (2021). Sustained attention and behavioral ratings of attention in struggling readers. Scientific Studies of Reading, 25(5), 436–451.

Melby-Lervåg M, Redick TS, and Hulme C (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer": Evidence from a meta-analytic review. Perspectives on Psychological Science, 11(4): 512–534.

Miyake A, & Friedman NP (2012). The nature and organization of individual differences in executive functions four general conclusions. Current Directions in Psychological Science, 21, 8–14. DOI: 10.1177/0963721411429458

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, & Wager TD (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. Cognitive Psychology, 41, 49–100. DOI: 10.1006/cogp.1999.0734

Morsanyi K, van Bers BM, McCormack T, & McGourty J (2018). The prevalence of specific learning disorder in mathematics and comorbidity with other developmental disorders in primary school-age children. British Journal of Psychology, 109(4), 917–940.

Ni Y, & Zhou Y-D (2005). Teaching and learning fraction and rational numbers: the origins and implications of whole number bias. Educational Psychologist, 40, 27–52. DOI: 10.1207/s15326985ep4001_3.

Ober TM, Brooks PJ, Homer BD, & Rindskopf D (2020). Executive functions and decoding in children and adolescents: A meta-analytic investigation. Educational Psychology Review, 32(3), 735–763. DOI: 10.1007/s10648-020-09526-0

Packwood S, Hodgetts HM, & Tremblay S (2011). A multiperspective approach to the conceptualization of executive functions. Journal of Clinical and Experimental Neuropsychology, 33, 456–470. DOI: 10.1080/13803395.2010.533157

Peng P, Barnes M, Wang C, Wang W, Li S, Swanson HL, Dardick W, & Tao S (2018). A meta-analysis on the relation between reading and working memory. Psychological Bulletin, 144, 48–76. DOI: 10.1037/bul0000124

Peng P, Namkung J, Barnes M, & Sun C (2016). A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. Journal of Educational Psychology, 108(4), 455–473. DOI: 10.1037/edu0000079

Peng P, Wang C, & Namkung J (2018). Understanding the cognition related to mathematics difficulties: A meta-analysis on the cognitive deficit profiles and the bottleneck theory. Review of Educational Research, 88(3), 434–476.

Peng P, Zhang Z, Wang W, Lee K, Wang T, Wang C, Luo J, & Lin J (2022). A meta-analytic review of cognition and reading difficulties: Individual differences, moderation, and language mediation mechanisms. Psychological Bulletin. DOI: 10.1037/bul0000361

Peterson RL, Boada R, McGrath LM, Willcutt EG, Olson RK, & Pennington BF (2017). Cognitive prediction of reading, math, and attention: Shared and unique influences. Journal of Learning Disabilities, 50(4), 408–421. DOI: 10.1177/0022219415618500.

Prencipe A, Kesek A, Cohen J, Lamm C, and Zelazo PD (2011). Development of hot and cool executive function during the transition to adolescence. Journal of Experimental Child Psychology, 108: 621–637.

Ristic J, & Enns JT (2015). The changing face of attentional development. Current Directions in Psychological Science, 24(1), 24–31.

Rothbart MK, Ahadi SA, & Hershey K (1994). Temperament and social behavior in childhood. Merrill-Palmer Quarterly, 40, 21–39.

Rothbart MK, Ahadi SA, & Evans DE (2000). Temperament and personality: Origins and outcomes. Journal of Personality and Social Psychology, 78(1), 122–135.

Rothbart MK (2007). Temperament, development, and personality. Current Directions in Psychological Science, 16(4), 207–212.

Rothbart MK, Sheese BE, & Posner MI (2007) Executive attention and effortful control: Linking temperament, brain networks, and genes. Child Development Perspectives, 1. DOI: 10.1111/j.1750-8606.2007.00002.x

Rothbart MK, & Derryberry D (1981). Development of individual differences in temperament. In Lamb ME & Brown AL (Eds.), Advances in Developmental Psychology (Vol. 1, pp. 37–86). Hillsdale, NJ: Erlbaum.

Sala G, & Gobet F (2017). Does far transfer exist? Negative evidence from chess, music, and working memory training. Current Directions in Psychological Science, 26, 515–520. DOI: 10.1177/0963721417712760.

Sala G, & Gobet F (2020). Working memory in typically developing children: A multilevel meta-analysis. Psychonomic Bulletin & Review, 27, 423–434. DOI: 10.3758/s13423-019-01681-y

Schunk DH, & Zimmerman BJ (1998). Self-regulated learning: From teaching to self-reflective practice. New York, NY: Guilford Press.

Schwaighofer M, Fischer F, & Bühner M (2015). Does working memory training transfer?: A meta-analysis including training conditions as moderators. Educational Psychologist, 50(2), 138–166.

Seidenberg MS, & McClelland JL (1989). A distributed, developmental model of word recognition and naming. Psychological Review, 96(4), 523–568.

Sims DM, & Lonigan CJ (2013). Inattention, hyperactivity, and emergent literacy: Different facets of inattention relate uniquely to preschoolers' reading-related skills. Journal of Clinical Child & Adolescent Psychology, 42, 208–219. DOI: 10.1080/15374416.2012.738453.

Spiegel JA, Goodrich JM, Morris BM, Osborne CM, & Lonigan CJ (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. Psychological Bulletin, 147(4), 329.

Sweller J (2011). Cognitive load theory. In Psychology of Learning and Motivation, Volume 55 (pp. 37–76). New York: Academic Press.

Takacs ZK, & Kassai R (2019). The efficacy of different interventions to foster children's executive function skills: A series of meta-analyses. Psychological Bulletin, 145(7), 653.

Toplak ME, West RF, & Stanovich KE (2013). Practitioner review: Do performance-based measures and ratings of executive function assess the same construct? Journal of Child Psychology and Psychiatry, and Allied Disciplines, 54, 131–143. DOI: 10.1111/jcpp.12001

Teuber HL (1972). Unity and diversity of frontal lobe functions. Acta Neurobiologiae Experimentalis, 32, 615–656.

van den Broek P, Young M, Tzeng Y, & Linderholm T (1999). The landscape model of reading: Inferences and the online construction of a memory representation. In van Oosterdorp H & Goldman SR (Eds.), The Construction of Mental Representations During Reading (pp. 71–98). Mahwah, NJ: Taylor & Francis.

van Hoof J, Vamvakoussi X, Van Dooren W, & Verschaffel L (2017). The transition from natural to rational number knowledge. In Geary D, Berch D, Ochsendorf R, & Mann Koepke K (Eds.), Acquisition of Complex Arithmetic Skills and Higher-Order Mathematics Concepts (pp. 101–123). San Diego, CA: Academic Press.

von Aster MG, & Shalev RS (2007). Number development and developmental dyscalculia. Developmental Medicine and Child Neurology, 49(11), 868–873.

Ylvisaker M, & Feeney T (2002). Executive functions, self-regulation, and learned optimism in paediatric rehabilitation: A review and implications for intervention. Developmental Neurorehabilitation, 5, 51–70. DOI: 10.1080/1363849021000041891

Zelazo PD (2006). The Dimensional Change Card Sort: A Method of Assessing Executive Function in Children. Nature Protocols, 1(1): 297–301.

Zelazo PD, Blair CB, and Willoughby MT (2016). Executive Function: Implications for Education (NCER 2017–2000). Washington, DC: National Center for Education Research, Institute of Education Sciences, U.S. Department of Education.

Zelazo PD, & Carlson SM (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. Child Development Perspectives, 6, 354–360.

Zelazo PD, Carter A, Reznick JS, & Frye D (1997). Early development of executive function: A problem-solving framework. Review of General Psychology, 1, 198–226. DOI: 10.1037/1089-2680.1.2.198

Zimmerman BJ (2002). Becoming a self-regulated learner: An overview. Theory Into Practice, 41(2), 64–70. DOI: 10.1207/s15430421tip4102_2

Zimmerman BJ, & Schunk DH (2011). Self-regulated learning: An introduction and an overview. In Zimmerman BJ & Schunk DH (Eds.), Handbook of Self-Regulated Learning and Performance. New York, NY: Routledge.

## Table 1.

Comparison of Models of EF

| Key Author/ Citation(s)* | Field | Key Features | Primary Measures | ***Single/ Plural*** | Domain General | Control | ***Process*** | Manage | Goal Direction |
|---|---|---|---|---|---|---|---|---|---|
| [1]Cirino | Neuropsychology | See text | Performance/ Ratings | *Singular* | Yes | Yes | *Yes* | Yes | Yes |
| [2]Zimmerman | Educational Psychology | Self-regulated learning; Forethought, Performance, and Self-Reflection | Strategy Use/ Ratings | *Singular* | Likely | Likely | *Yes* | Likely | Yes |
| [3]Rothbart | Developmental Psychology | Temperament; *Effortful Control*, Negative Affectivity, Extraversion/ Surgency | Ratings | *Unclear* | Likely | Yes | *No* | Yes | Likely |
| [4]Zelazo | Developmental Psychology | Problem-Solving Framework; Problem Representation, Planning, Execution, Evaluation | Performance | *Singular* | Yes | Yes | *Yes* | Yes | Yes |
| [5]Engle | Cognitive Psychology | Controlled/Executive Attention; Working Memory (and Fluid Intelligence) | Performance (WM Span) | *Singular* | Yes | Yes | *No* | Likely | Yes |
| [6]Miyake | Cognitive Psychology | Unity and Diversity; Updating, Shifting, Inhibition | Performance | *Plural* | Yes | Yes | *No* | Yes | Yes |
| [7]Zelazo | Developmental Psychology | Working Memory, Cognitive Flexibility, Inhibitory Control | Performance | *Plural* | Yes | Yes | *No* | Yes | Yes |

Note:

[*]Superscripts refer to seminal works that describe the model.

[1]Cirino, Ahmed, et al. (2018);

[2]Schunk & Zimmerman, 1998; Zimmerman (2002); Zimmerman & Schunk (2001);

[3]Rothbart (2007); Rothbart, Ahadi, & Hershey (1994); Rothbart, Sheese, & Posner (2007);

[4]Zelazo, Carter, Reznik, & Frye (1997);

[5]Engle (1999); Engle (2002); Engle (2018);

[6]Friedman & Miyake (2017); Miyake et al., (2000); Miyake & Friedman (2017);

[7]Zelazo, Blair, & Willoughby (2017). Performance = Psychometric Performance tasks; Ratings = Behavioral ratings based on observation/knowledge of individual. Columns in italics refer to areas where there is disagreement amongst models. WM = working memory.