Self- and Social-Regulation

Social Interaction and the Development of Social Understanding and Executive Functions

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Executive Function: Description and Explanation

ANTHONY STEVEN DICK AND WILLIS F. OVERTON

The concept of "executive function," which has broadly referred to the psychological processes involved in the conscious control of action and thought (Anderson, 1998; Zelazo & Müller, 2002), has come to occupy a central place in the study of cognition and cognitive development. However, while adequate as an initial working definition, this understanding is vague and imprecise. At this point in its history "executive function" requires some conceptual analysis and clarification if it is to continue to operate as a fruitful framework for empirical research projects. While virtually every paper published on the topic of executive function presents some form of definition, both historical and contemporary attempts to detail a precise understanding of the concept have been seriously flawed by its vagueness and the ambiguity that this vagueness fosters. This ambiguity arises primarily through the fact that proposed definitions conflate several alternative possible uses of the concept. Specifically, the use of the concept as a description has been conflated with its use as an explanation, and its use as an explanation has conflated several levels of explanation, especially biological and psychological levels. In many cases this conflating of uses is not recognized, although there are exceptions (e.g., for exceptions, see Rabbitt, 1997; Stuss, 1992; Welsh, Pennington, & Grossier, 1991; Zelazo, Carter, Reznick, & Frye, 1997). The ambiguity generated by these conflations ultimately impacts the empirical methods, findings, and conclusions of research on executive function. Our initial task then is to more precisely clarify and disentangle the nature of these conflating meanings.

Explanation begins with description, which operates at the behavioral level of analysis. Here, inquiry focuses on details of cognitive task performance.

Behavioral descriptions are obviously necessary, but their primary function is to serve as vehicles for making inferences about underlying structures and processes. Confusion begins when behavioral descriptions fuse with psychological explanations. Thus, for example, common executive function measures such as the Stroop task (Stroop, 1935) and the Wisconsin Card Sort Test (WCST; Berg, 1948) often are presented as explanatory "measures of cognitive flexibility" without evidence for such flexibility beyond performance on the task itself. This practice is most commonly found in approaches that define executive function as a list of component functions (see, e.g., Bennetto & Pennington, 2003; Levin et al., 1991; Lezak, 1995; Pennington & Ozonoff, 1996; Shute & Huertas, 1990; Stuss & Benson, 1986; Tranel, Anderson, & Benton, 1994).

Legitimate psychological explanations of cognitive phenomena are found not at the behavioral but at the psychological level of analysis. At this latter level, the focus is on inferences drawn concerning the mental organization, structures, or processes that account for the conscious control of action and thought. Behavioral description constitutes the ground from which these inferences are drawn, but behavioral descriptions are themselves not explanations. The movement from description to explanation occurs when structures or processes are inferred and these inferences yield differential predictions that move significantly beyond currently observed behaviors.

Biology represents a second level of analysis that generates explanations. Here, the focus is on biological correlates of task performance. The biological approach is generally undertaken with the assumption that these correlates represent necessary or necessary and sufficient conditions for the mental structures. This level becomes reductionistic, and reductionism becomes problematic, when psychological events are understood *as nothing but* neurological events (Miller, 1996; Searle, 1992), or when biological explanations are presented as replacements for psychological explanations (Miller & Keller, 2000). In the executive function literature, executive function defined as the functions of the prefrontal cortex illustrates a reductionism when these functions are presented as necessary and sufficient causal conditions for task performance. Establishing the neurophysiological organization necessary for cognitive functioning is an essential part of the explanatory process, but a necessary biological condition, in and of itself, provides little information about the psychological meaning of the constructs under investigation (for similar discussions, see Pennington & Ozonoff, 1996; Stuss, Eskes, & Foster, 1994; Tranel et al., 1994).

The present essay critically examines several contemporary approaches to the development of executive function as they operate as behavioral descriptions and as biological or psychological explanations. Here, we explore executive function from a relational perspective (Overton, 2006) emphasizing that description and multiple explanatory levels of analysis are fundamental features of a complete understanding and explanation of this field of enquiry. Within a relational approach, analyses at different levels of explanation are complementary. Thus, any complete explanation may entail all levels—including, for example, a level not discussed further in this paper, the cultural level—but no level represents a competing alternative to other levels.

Within this relational context, we will examine contemporary research on executive function. We will highlight the conceptual confusions that operate in this arena, and we will offer clarifications that will hopefully be helpful in advancing scientific knowledge. In the following, we first outline a general relational approach to research questions. Within this context we then explore the advantages that accrue to executive function research by clearly identifying the operation of complementary levels of analysis. And we conclude with suggestions uniting the levels into an integrated system of explanation.

Split and Relational Metatheories

Metatheoretical assumptions are a constitutive feature of any field of enquiry. These often silent background assumptions form the defining context within which theoretical and methodological concepts are formulated. Accordingly, metatheory determines the meaningfulness/acceptability or meaninglessness/nonacceptability of any substantive scientific concept. This effect includes the formulation of descriptive and explanatory concepts that guide the research agenda. Two broad metatheoretical approaches have been termed the "split" and the "relational" (Overton, 2003, 2006). Split and relational metatheories order the world in different ways; split metatheory orders the world as aggregates of additive elements, while relational metatheory orders the world as systems of dynamic changing part-whole relations.

SPLIT METATHEORY

This perspective originated in the Cartesian thesis that subject and object (mind and body) constitute two pure and, hence, independent forms—thus being split from each other—and the further thesis that beyond the flux of the manifest world of appearance could be found a rock bottom base or "foundation" of reality, hence a "foundationalism." The consequence of these theses is that the world becomes dichotomized, with one member of the dichotomous pair being elevated to a privileged position while the other is marginalized and treated as mere appearance (e.g., the antinomies such as subject-object, mind-body, and nature-nurture). This is, in fact, the framework for a reductionistic approach to enquiry, whereby the concepts of one domain are defined in terms of another domain so that the meaning of one domain is completely captured by the other, with the result that the reduced term becomes unnecessary (i.e., mere appearance; Miller & Keller, 2000). Of central relevance to definitions of executive function are attempts to reduce psychological definitions to biological definitions—that is, to redefine psychological definitions of executive function in terms of the functions of specific brain regions. This reductionism is often implicit, as when investigators use terms such as "underlie" to describe the relation between biology and psychology. The implication here is that the biological explanation is foundationally more basic.

RELATIONAL METATHEORY

This perspective rejects the Cartesian theses of pure forms, splitting, and rock bottom foundations. A relational perspective casts all explanations, including the biological and the psychological, as a set of differentiated but indissociable complementarities. The challenge for relational metatheory is to demonstrate how such seemingly disparate explanatory frames can, in fact, be integrated as indissociable complementarities, while at the same time maintaining their individual identities.

The relational approach is above all else a commitment to *holism*. As distinct from elements (pure forms) and the addition of elements into aggregates of the split metatheory, the relational approach represents the basic units of analysis as parts of a dynamic functioning system. Part-whole analyses rather than atomistic reductionism constitute the broad methodological center of this metatheory. The identity of any event or object of enquiry is the consequent of the relational context or system of parts in which it is embedded (for an extended discussion, see Overton, 2006; Overton & Ennis, 2006). Each part of the system both defines and is defined by the others and by its relation to the whole. Given this commitment to holism there are three subsidiary principles that constitute the operational methodology of relationism.

1. *The identity of opposites*: While we generally picture the world according to the Aristotelean law of identity (A cannot equal not A), within a relational perspective a first moment of analysis entails changing orientation and picturing the world according to a dialectical logic in which the law of identity is replaced with an identity of opposites (A equals not A). Within this moment of analysis pure forms cease to operate, and categories flow into each other. The most

vivid examples of how this moment of analysis functions come from various perceptual "illusions." For example, in the famous sketch by M.C. Escher titled "Drawing Hands" the sketch of a left and a right hand assume a relational posture according to which each is simultaneously drawing and being drawn by the other. Each hand is identical with the other in the sense of each drawing and each being drawn (identity). At the same time each hand preserves its own identity in the sense of there being a left and a right hand (opposites).

Within the framework of this principle, traditional polar opposites (e.g., mind-body, subject-object, and nature-nurture) are transformed into indissociable complementarities, and questions of causality are simultaneously transformed into reciprocal interpenetrating determinates. The most immediate implication here for present purposes is that, to paraphrase John Searle (1992), the fact that a behavior is biologically determined does not imply that it is not psychologically determined, and, the fact that it is psychologically determined does not imply that it is not biologically determined. The relational principle of the identity of opposites establishes the metatheoretical position that biology and psyche, like culture and psyche, operate in a truly *interpenetrating* manner, and not as a conventional interaction of elements of each.

2. *The opposites of identity.* Suspending the law of identity establishes the interpenetration of causal forces across various explanatory levels—biological, cultural, psychological. However, reasserting this law in a second moment of analysis is necessary both to avoid a complete relativism and to establish relatively stable bases or *standpoints* for inquiry. This is the moment at which precision and clear distinctions become figure over the dialectical background. At this moment the focus switches back to the oppositional quality of the relational pair; the identity fades to background, the opposite or differentiating qualities become figure. Despite the identity of the two, there are differences; the left hand of the Escher sketch *is* the left hand and *not* the right, and one may examine the whole from either the standpoint of the left hand or the standpoint of the right. Each standpoint will present a different, but interrelated, perspective on the same whole. Another example is that of two people standing at opposite sides of a room. Each has a view of the whole room, but each sees the room differently as well. Truth lies in the coordination of their perspective and not in denying one or the other view. In a similar fashion, despite their identities, biological explanation is biological explanation and not psychological, and one may examine executive function from either the biological explanatory standpoint or the psychological explanatory standpoint without privileging either. Adequate explanation resides in the coordination of these explanations, not in the reduction of one to the other.

3. *The synthesis of wholes*. This principle is fundamentally a reminder that for any relational pair there is invariably a third member that serves to coordinate the two. Thus, for example, when biological and psychological explanations are understood relationally, it is the social world or culture that joins these two. It is only in the context of culture that we have biological and psychological explanation. In a similar fashion cultural explanation and psychological explanation are coordinated by biology, while the psychological perspective coordinates biological and cultural explanations. The impact of this principle is recognition that the complete explanation of any phenomenon, including executive function, entails the coordination of multiple perspectives—or here "levels" of analysis—and not the reduction of the many to a single standpoint. In the following we consider executive function in the context of three standpoints—the behavioral, the biological, and the psychological.

Approaches to Defining Executive Function: Behavioral Description

With the principles of a relational metatheory as background, we can now examine common approaches to defining executive function and attempt to differentiate and order behavioral description and explanation on the one hand and psychological explanation and biological explanation on the other. Our first step, then, will be to elaborate the issue of the conflation of description and explanation, by exploring descriptive definitions of executive function.

A common definition of executive function entails a list of higher-order component functions required to control and coordinate performance on complex problem-solving tasks. For example, in a recent review, Bennetto and Pennington (2003) describe executive function as a range of skills including organization, planning, working memory, inhibiting inappropriate responses, and switching flexibly from one task or strategy to another. Similarly, Pennington and Ozonoff (1996) offer the functions of set shifting or cognitive flexibility, planning, working memory, contextual memory, inhibition, and fluency. Other functions that appear in such lists include anticipation, goal establishment, performance monitoring, set maintenance and evaluation, impulse control, and judgment and decision making (Levin et al., 1991; Lezak, 1993, 1995; Shute & Huertas, 1990; Stuss & Benson, 1986; Tranel et al., 1994).

It is only rarely acknowledged that many of these "functions" (e.g., planning, inhibition, decision making, etc.) are, in fact, descriptions of behavioral outcomes and not explanations. For example, consider a recent explanation of the 3-year-old's difficulty on problem-solving tasks involving conditions of conflict. Often in these tasks, children perseverate (i.e., get stuck) on an irrelevant task rule or method of responding. As an explanation for this perseveration, Diamond, Kirkham, and colleagues (Diamond & Kirkham, 2005; Kirkham, Cruess, & Diamond, 2003) point to the child's problem with "Attentional Inertia." That is, the authors argue that "children of 3 years have difficulty inhibiting their focus on the first aspect of a stimulus … that was relevant for their behavior …" (Kirkham et al., 2003, p. 451). This essentially describes the problem (i.e., young children have difficulty shifting), but it is not clear how this could serve to predict performance on other tasks involving conflict, or how the older child or adult is able to overcome this "Attentional Inertia." A development of the ability to inhibit has been presented as an explanation (Kirkham et al., 2003), but this suffers from many of the same problems. That is, the behavioral outcome—the older child or adult's inhibition, or suppression, of the irrelevant aspect of the task—is presented as an explanation for success. This explanation, though, is viciously circular and unfalsifiable. One is hard pressed to imagine a situation that could possibly refute the stated explanation that the young child fails to inhibit because they lack the ability to inhibit.

In addition to the list component "inhibition," many other list components masquerade as explanatory concepts. In exploring executive function, investigators have attempted to distill components by grouping tasks that prima facie make similar cognitive demands. They have then used statistical tools, such as factor or principal components analysis, in an attempt to isolate latent variables. Arguably, the use (or rather misuse) of these statistical tools has exacerbated the tendency to map behavioral descriptions to explanations. The primary mistake that many investigators make lies in the assumption that the isolation and labeling of latent variables, in and of itself, provides an explanation (for a similar criticism, see Zelazo & Müller, 2002).

A brief review of this approach illustrates the problem. In one developmental study, Welsh and colleagues (1991) examined associations among a number of common executive function tasks, including the Wisconsin Card Sort Test (WCST; Berg, 1948) and two versions of the Tower of Hanoi (ToH; Simon, 1975). A principal components analysis revealed three dissociable factors across eight tasks. Most studies that have used factor analysis to assess executive function are consistent with Welsh and colleagues and report multiple components (e.g., Brookshire, Levin, Song, & Zhang, 2004; Carlson & Moses, 2001; Hughes, 1998; Levin et al., 1991, 1996; Mariani & Barkley, 1997; Miyake et al., 2000; Pennington, 1997; Shute & Huertes, 1990; Welsh et al., 1991).

Observation of more than one factor implies a differentiation of cognitive components (Greve, Ingram, & Bianchini, 1998), supporting the intuitive differences among these tasks and the idea of dissociable, separable functions.

However, two problems significantly handicap the ability of the latent variable approach as a method of providing explanatory concepts. First, when multiple factors are reported, there is inconsistency in the number of reported components, and in the way in which tasks load on multiple factors. Many studies find three-factor models (Levin et al., 1991; Miyake et al., 2000; Patton, Stanford, & Barratt, 1995; Pennington, 1997; Spinella, 2005; Welsh et al., 1991), but some analyses return four-factor (Mariani & Barkley, 1997; Shute & Huertes, 1990) and five-factor models (Amieva, Phillips, & Della Sala, 2003; Brookshire et al., 2004; Levin et al., 1996; Pineda & Merchan, 2003).

Two clear sources of the differences in the number of reported factors are the selection of tasks with which to measure executive function, and the selection of the population that performs the tasks (e.g., normal vs. clinical vs. children vs. elderly). The use of different tasks should be expected to result in different factor structures, and differing populations surely add variation. However, although many of these studies use similar tasks and sample from the same populations, the same tasks have loaded on different factors across studies. For example, the WCST and Tower tasks have loaded on the same (Brookshire et al., 2004) and separate factors (e.g., Levin et al., 1991, 1996; Welsh et al., 1991). To be fair, these tasks likely require multiple cognitive functions (e.g., the WCST; Barcelo & Knight, 2002). In addition, as executive functions are higher-level control functions, tasks designed to assess them are often confounded with what would seem on the face of it to be nonexecutive processes, which makes them susceptible to a high degree of task impurity (Friedman et al., 2006). It is thus often difficult to determine whether a task or set of tasks assesses a single executive component, or the interaction of several subcomponents. In defining executive processes, we must also consider how cognitive processes that might be considered nonexecutive (e.g., long-term memory) interact with executive processes.

If we were to solve these problems, a second obstacle, that of interpretation of the statistical output, still severely handicaps the latent variables approach. Despite considerable investigation, there has been no clear agreement about how to understand the factors discovered via these analyses. Even if we consider only factor studies that have used the WCST, we find that this task has loaded on factors diversely labeled Impulse Control (Welsh et al., 1991), Shifting (Miyake et al., 2000; Pennington, 1997), Perseveration/Disinhibition (Levin et al., 1991), Conceptual Productivity (Levin et al., 1996), Problem Solving (Brookshire et al., 2004), Organization and Flexibility (Pineda & Merchan, 2003), and Executive Memory (Burgess, Alderman, Evans, Emslie, & Wilson, 1998). Scoring of the WCST itself results in multiple outcome variables, such as perseverative errors, categories achieved, and maintenance of set. These subscores of the WCST have loaded on both a single factor (Bowden et al., 1998) and separate factors (Greve, Stickle, Love, Bianchini, & Stanford, 2005; Kizilbash & Donders, 1999). Inconsistency here reveals some of the difficulties with this approach to understanding executive function.

The problems of making psychological interpretations based on the analysis of latent variables are not new. Consider, for example, the debate surrounding the meaning of the "Big-Five" latent personality variables in the personality psychology literature (Block, 1995a, 1995b). A fundamental criticism that arises in this literature is the fact that "factor analysis by itself cannot be empowered to make paramount and controlling decisions regarding the concepts to be used in the field …" (Block, 1995a, p. 209). The lesson to be learned in the executive function literature is this: we might be comfortable with asserting that latent variable analyses have broadly supported the understanding of executive function as a set of separable, but still associated, components (Friedman & Miyake, 2004; Miyake et al., 2000; Stuss & Alexander, 2000; Teuber, 1972), but latent variable analyses tell us nothing about the nature of these components. To assume that latent variable analyses directly generate psychological explanations is to conflate levels of analysis.

The conflation of description and explanation is an ever present danger to any list approach to the definition of executive function. Although lists facilitate the focusing of research questions and grouping of seemingly similar experimental tasks, their utility is limited to the taxonomy of task demands. Rabbitt (1997) has articulated the conclusions of several investigators (Parkin, 1998; Pennington & Ozonoff, 1996; Reitan & Wolfson, 1994; Stuss et al., 1994; Tranel et al., 1994) that executive function lists are handicapped by their descriptive, rather than explanatory, nature.

> When these criteria are listed together it becomes clear that they all describe the *outcomes*, but not the *functional aetiology* of the cognitive activities that we hope to understand. They are consensus descriptions … Such descriptions are intuitively appealing, and even illuminate our subjective experience, but are untrustworthy guides as to how to investigate function. (Rabbitt, 1997, p. 7)

Lists fail as explanation because they entail behavioral descriptions of the outcomes of cognitive processes, not the processes themselves. It is likely that many list components (e.g., planning, inhibition, and cognitive flexibility) represent emergent functions of interactions among specialized psychological and/or biological subsystems (Robbins, 1996). That said, a list approach is a useful point of departure, but does not, in and of itself, constitute explanation.

EXPLANATION

If component lists function as descriptive summary statements, what constitutes the movement from this arena to the arena of explanation? Here a brief conceptual orientation to the changing nature of scientific explanation is needed. From the metatheoretical split position, which framed an earlier neo-positivistic methodology, scientific explanation was narrowly identified with issues of contingent causality (i.e., a search for causal antecedents and only causal antecedents). These causal antecedents were classically defined as efficient and material causes and/or necessary and sufficient antecedent conditions of the phenomenon of enquiry. With the demise of neo-positivism and the rise of an increasingly relational methodology (Overton, 2006), the articulation of dynamic patterns, systems, or processes that underlie the phenomenon of enquiry has come to be recognized as a feature of any scientific explanation that is as fundamental as, and logically prior to, the discovery of contingent causes (Bunge, 1962, 2004; Cartwright, 1980; Hanson, 1958; Kitcher, 1981; Laudan, 1996; Overton & Reese, 1981; Putnam, 1983; Toulmin, 1953).

Hanson (1958) describes the relational quality of this approach to explanation in a discussion of Galileo's approach to the law of falling bodies.

> He [Galileo] seeks not a descriptive formula; nor does he seek to predict observations of freely falling bodies. He already has a formula … He seeks more: an *explanation* of these data. They must be intelligibly systematized … He has no confidence in observations which cannot be explained theoretically. Galileo was not seeking the cause of the acceleration; that was Descartes' program. Galileo wished only to understand. His law of constant acceleration (1632) is not a causal law. (p. 37)

Pattern or system explanation entails the discovery and specification of both *formal* (i.e., the dynamic form or organization of a phenomenon) and *final* (the direction of change of the phenomenon across time) patterns that systematize the phenomenon of interest. Each of these pattern explanations constitutes a principle of intelligibility (Randall, 1960; Taylor, 1995), rather than a cause. That is, each establishes the (immediate and temporal) meaning of the object of study and offers an intelligible context within which further empirical investigation proceeds. Formal principles establish order, constancy, and coherence of an activity at particular points in time, while final principles do the same across temporal sequences. This distinction is especially important for developmental theories as final principles are explanations of why development occurs (i.e., movement toward a specified end), and formal principles are explanations of what develops.

A further contrast between dynamic pattern explanation and casual explanation is that pattern principles are arrived at and assessed through an abductive or retroductive process, while causal determinants are inductive in origin. In fact, causal explanation can proceed only within the intelligible context provided by pattern explanation. Examples of both formal and final pattern explanations can be found in the natural sciences (e.g., the structure of the atom, the structure of DNA, and the structure of the universe), and in the biological and psychological sciences (e.g., the biological structure of consciousness: Edelman & Tononi, 2000; reasoning and decision making: Damasio, 1994; conceptual and cognitive development: Case, 1985; Piaget, 1952; Werner, 1957, 1958). In these and all other pattern explanations a model (system) is initially proposed to account for the activity of interest. The model is empirically assessed through observations of the fit between the model and data sets that extend beyond that data set that formed the basis for the original pattern inferences. To the extent that the novel data sets are consistent with the model, the pattern explanation is supported. Extending the scope (novel data sets) as well as assessing the precision of the model strengthens the claims of the model as a rich, powerful, and valid explanation. Failure to observe a fit between model and data sets weakens support for the model and may lead to its modification or abandonment.

With this orientation to explanation in contemporary scientific thinking as background we may now turn to the explanation of executive function at both the biological and psychological levels of analysis. Before making this turn, however, we need to note that with the introduction of pattern or system explanation a sharp dividing line between description and explanation begins to fade. If pattern explanations are inferences designed to give meaning to the phenomena under investigation, would not component lists be both descriptive and explanatory? It is difficult here to not give "descriptions" some explanatory value. On the other hand, list descriptions of executive function are so close to common sense intuitions, so devoid of the attributions of process, and so lacking in any potential explanatory power that it is best to again note that they are better considered a point of departure for explanation, rather than explanation itself.

Explanatory Approaches to Executive Function

BIOLOGICAL EXPLANATIONS

Following from the assumption of a split metatheory, the refusal to acknowledge pattern explanation as a legitimate explanatory form strongly impacts on the analysis of executive function at both the psychological and the biological levels of explanation. When biology is the standpoint of enquiry a restriction of explanation to contingent causality promotes the tendency to identify descriptive components with specific brain locations. This strategy opens two issues: (a) a *reductionism* issue discussed earlier with respect to split metatheory (here the issue concerns the relation of biological explanation to psychological explanation) and (b) a *localization* issue, which is an issue of understanding function at the biological level itself. Reductionism enters when the suggestion is raised that biological explanation can ultimately replace or substitute for psychological explanation. Localization arises with the suggestion that specific brain regions will ultimately explain the behavior associated with descriptive component features of executive function.

Both reductionism and brain localization emerge from the split metatheoretical assumption of wholes as additive aggregates that are ultimately decomposable into foundational fixed elements, and the further assumption that movement and change of these elements are fully explained physical forces termed causes. The suggestion that discrete anatomical regions of the prefrontal cortex (e.g., dorsolateral prefrontal cortex) constitute necessary and sufficient causes—and hence a complete explanation—of performance on executive function tasks illustrates the commitment to an explanatory approach that encompasses both reductionism and to localization. Here the psychological level of analysis is treated as a set of behaviors to be explained by the biological and psychological explanations, if they are acknowledged at all, function as derivative summary statements for an underlying biological foundation. In the executive function literature, this reductionism is often implicit. For instance, the term "prefrontal task" has come to be synonymous with tasks that assess executive cognitive functions, and it is common for executive functions to be relabeled and defined as prefrontal functions (e.g., Daigneault, Braun, & Whitaker, 1992; Roberts, Hager, & Heron, 1994; for similar criticisms, see Stuss, 1992). But executive function should not be defined solely in terms of the functions of the prefrontal cortex—these terms are not interchangeable (Robbins, 1996). Rather, the emerging view is that, while the prefrontal cortex plays a central role, the integrity of other brain regions is necessary for intact executive function (Anderson, 1998; McIntosh, 1999).

Localization itself implies that (a) specific brain regions function largely independently of other brain regions (i.e., the brain is an additive aggregate of elements), and (b) functions formulated from behavioral descriptions (e.g., inhibition, planning, working memory, etc.) find their causal nexus within these particular brain regions. Empirical data are far from supportive of localization for higher-order functions such as executive function. For example, lesion findings (Bechara, Damasio, Damasio, & Anderson, 1994; Milner, 1963;

Shallice, 1982; Stuss et al., 2000) are often cited to support a picture of localization, but replication has been inconsistent (Anderson, Damasio, Jones, & Tranel, 1991; Corcoran & Upton, 1993; Grafman, Jonas, & Salazar, 1990; Reitan & Wolfson, 1995; Teuber, Battersby, & Bender, 1951; van den Broek, Bradshaw, & Szabadi, 1993). In some studies, patients with frontal damage have actually performed better than those without frontal damage (Corcoran & Upton, 1993; Teuber et al., 1951; van den Broek et al., 1993), and patients with damage outside the prefrontal cortex also show executive deficits (Axelrod et al., 1996; van den Broek et al., 1993; for reviews, see Demakis, 2003, 2004; Reitan & Wolfson, 1994).

As stated earlier, the relational alternative to reductionism, and localization as well, begins with holism. Holism encourages a view of the psychological organism and brain as interpenetrating part systems of the embodied agent actively engaged in the world. These part systems, like other part systems of the embodied agent, are dynamic and self-organizing in character, and not decomposable into foundational elements. Explanation is not found in independent causes, but in formulating models that account for system functioning at each level of analysis, further exploring the systemic relations among levels and, within this context searching for specificity of conditions. At the biological level, the brain is a self-organizing system that functions in the context of the psychological and other biological (e.g., body) systems. From this assumptive perspective it would be expected that neural organization of complex cognitive functions would be best characterized in terms of a broad distribution of function at multiple neural levels rather than a physiologically elementaristic notion of localization of function (Damasio & Damasio, 1989). Thus, as Fuster (2001, p. 319) suggests from this perspective, "any hypothetical modularity of the prefrontal cortex … [would be] functionally meaningless if taken out of wide-ranging networks that extend far beyond the confines of any given prefrontal area."

Empirical support for this view is growing, with more recent work in the neurosciences supporting a model of the brain as a self-organizing system characterized by a broad distribution of function at multiple neural levels. Several imaging studies (e.g., PET and fMRI) find that more posterior areas, such as posterior parietal cortex, are also an important component of a distributed executive system (D'Esposito et al., 1998; Smith & Jonides, 1999; Sohn, Ursu, Anderson, Stenger, & Carter, 2000; see Carpenter, Just, & Reichle, 2000). These imaging findings are consistent with findings from research with nonhuman primates, indicating that executive function requires the coordinated participation of multiple brain regions (Fuster, 1997; Goldman-Rakic, 1987). Such a holistic understanding of a distributed neurological system for executive function is, in fact, familiar to many investigators who work primarily in the neurosciences. Luria (1966) is particularly explicit about such an understanding of neurological functions defining them specifically as functional *systems*, which are both dynamic and situated at multiple levels of the nervous system.

Other investigators in the neurosciences are approaching biological investigations from the perspective that brain representations are complex and distributed at multiple levels, and rejecting traditional notions of structure and function, where there is a clear one-to-one mapping between them (e.g., Carpenter & Just, 1999; Carpenter et al., 2000; McIntosh, 1999; Mesulam, 1998; Stuss, 1992). Poeppel and Hickok (2004) have synthesized such a biological systems understanding of biological function into a kind of mantra to guide empirical investigations: "if we must work locally, we should … at least think globally" (p. 2). Investigation of executive function at the biological level should take seriously this principle of holism, and concede both the anatomical and functional heterogeneity of the prefrontal region, and its role within a distributed neurological system that includes both cortical and subcortical regions of the brain, as well as sensory-somatic systems of the body proper. It is only in this context, and in the establishment of systemic regulative principles, that these biological approaches constitute sufficient explanations.

PSYCHOLOGICAL EXPLANATIONS

In turning to a review of psychological explanations of executive function we must face important conceptual distinctions. Just as the biological and psychological explanations constitute a relational whole, which can be analyzed only as the opposites of identity, psychological explanation itself is composed of several relational levels. In the broadest terms psychological explanation is distinguished by a personal and a subpersonal level (Elton, 2000; Bruun & Langlais, 2003; Dennett, 1986; Müller & Carpendale, 2001; Russell, 1999). The personal level is the phenomenological level, and it is constituted by genuine psychological concepts (e.g., acts, thoughts, feelings, desires, and wishes) that have intentional qualities, are open to interpretation, and are available to consciousness (Shanon, 1993); or in other words, have psychological meaning.

The subpersonal level entails the articulation of mechanisms. Here, however it must be understood that "mechanism" does not necessarily commit one to a mechanistic metatheory. The fact of the matter is that "mechanism" can be identified both as a "method" ("the agency or means by which an effect is produced or a purpose is accomplished" [mechanism; dictionary.com]), and as a set of contingent causes or functional input–output relations. This distinction is important because it suggests that there are at least two sublevels of the subpersonal. The first sublevel, call it the subpersonal *system* level, again brings us back to the earlier discussed idea of pattern explanation, for here the agency or means by which an intention or end is accomplished consists of some noncausal pattern or system. Thus, "action systems," "dynamic systems," "self-organizing systems," "mental structures," as well as more narrowly defined "schemes," "operations," "attachment behavioral system," and "self system" are all examples of the lexicon employed at this subpersonal system level. The second sublevel, call it the subpersonal *functional* level, engages terms such as "input," "output," "computation," "information processing," "antecedent cause," and "network." Some have incorporated biological explanation into the taxonomy of subpersonal levels of explanation (e.g., Müller & Carpendale, 2001). However, as discussed earlier conflating psychological and biological explanations should be avoided, and as a consequence we will not include the biological among these subpersonal levels.

The distinctions among these various levels, including the biological, are of course, easier to make in theory than in practice. For example, it is quite possible that an approach calling itself "dynamic systems"—the subpersonal system level—in fact, on analysis, relies heavily on input–output explanations—the subpersonal functional level. Despite such ambiguities, and others that may arise, beginning analysis with unambiguous conceptual distinctions permits further clarification of these ambiguities, while avoiding conceptual clarification simply ensures confusion. We reiterate that, although it deserves much greater discussion and analysis than is possible here, a relational metatheory argues for the interdependence without reductionism of all of these psychological levels, and the same interdependency between the biological and psychological levels. But, again, it serves analysis best to be clear conceptually at the beginning and move from there to the hard work of articulating the nature of the interdependencies as opposed to beginning and ending with the confusion of vagueness and imprecision.

With the personal–subpersonal levels distinctions in hand we move to a review of several explanations of executive function at reside primarily at the psychological level. As noted earlier, a good deal of what is offered as psychological explanation is, in fact, little more than observational generalization and description. There are, however, a number of exemplars of work that do offer legitimate psychological explanations of executive function. We will examine these and relate them to other levels of explanation, such as the biological. In this section, we largely restrict our discussion to recent developmental explanations.

In an effort to avoid what has been termed the "homunculus" problem in executive function, various developmental theories have incorporated a system-level psychological explanation. The homunculus problem arises when functions that should be considered as the output of an organized system as a whole are instead construed as the output of a smaller component of that system. For example, consider approaches that view executive control as an aspect or component of working memory, an approach that has gained popularity in both the developmental (Baddeley & Hitch, 2000; Case, 1985; Demetriou, Christou, Spanoudis, & Platsidou, 2002; Gordon & Olson, 1998; Pascual-Leone, 2000) and adult literatures (for a recent review of the adult literature, see Miyake & Shah, 1999). In such cases, the executive component of the working memory system is often poorly specified. Instead, there is an appeal to a global administrative component of executive control, such as the "central executive" of Baddeley and Hitch (Baddeley & Hitch, 1974), the Supervisory Attentional System of Norman and Shallice (1986), Pascual-Leone's "mental attention" (Pascual-Leone & Baillargeon, 1994), Case's "total processing space" (Case, 1985), or the "Working Hypercognition" of Demetriou and colleagues (2002). This executive component is taken to perform most of the functions that are logically necessary for the other aspects of the model to be effective (e.g., to direct attention, to plan, or to suppress prepotent or irrelevant responses), but there is little specification of how they are implemented.

In these global conceptualizations, the theoretical construct of executive function is taken out of the context of the system itself—it is presented as a static component or a set of processes that act on information from the system, but largely in isolation from the system. As a result, appeals to such components have been criticized for invoking a homunculus to explain how these functions are carried out (Parkin, 1998). This problem is avoided by situating executive function within a broader psychological organization (i.e., a system-level explanation). Russell (1999, p. 253) is unequivocal about how to conceptualize executive function within the broader psychological system: "the knowing system—the system of concepts and reasoning … cannot be understood apart from the functioning of [the] executive system."

This understanding is gaining increasing support in the developmental literature on executive function. Prominent are accounts that are offered under the umbrella of dynamic systems, connectionism, and complexity. However, even at this global system-level, explanations differ markedly in a number of respects. Some theoretical perspectives incorporate personal level concepts of mental representation, and specify cognitive structure or organization at the subpersonal systems level (e.g., complexity theories). Others marginalize mental concepts, or eschew them as altogether unnecessary (e.g., some flavors of connectionism or dynamic systems), and instead focus their efforts at the subpersonal functional level of analysis.

Our discussion of the similarities and differences among contemporary theories of executive function development is best considered within the context of the tasks that are typically used to assess the predictions derived from the theories. One task that has received extensive attention in the executive function literature is Piaget's A-not-B task (Piaget, 1954). In the canonical version of the A-not-B task, the infant watches as an object is hidden in one of two hiding places. A few seconds later, the infant is allowed to reach for and retrieve the object, and after a few retrievals at the first location (A), the object is moved, in full view of the infant, to a second location (B). Despite witnessing the movement of the object to the B location, with standard delays between hiding and searching younger infants perseverate and continue to reach to the A location (i.e., they commit the A-not-B error) until about 10–12 months (for a review, see Wellman, Cross, and Bartsch, 1986).

Piaget's original explanation for this phenomenon was situated at both the personal and subpersonal level of psychological explanation. At the personal level, Piaget pointed to the immaturity of the object concept (i.e., the understanding that objects can continue to exist when they are out of sight) to explain the younger infant's poor performance. Explanation of the child's acquisition of the object concept was, on the other hand, at the level of the subpersonal systems, namely those of assimilatory cognitive structures. To clarify, the notion of object-permanence meets all the criteria for being at the personal level (e.g., it is available to consciousness), but explanation of object permanence in terms of "operations" and the integration of operations is at the subpersonal systems level. An action is at the personal level, but action systems are at the subpersonal systems level. An act may be explained in terms of intentionality, all acts entail a goal, but assimilation is a part of an operational system and this is the subpersonal systems level.

Two recent explanations that attempt to explain executive function at a global system level can be understood at both a personal and a subpersonal systems level. Originating from a complexity perspective, the two theories, relational complexity and cognitive complexity, explain children's development in problem solving in terms of the nature of the organization of representations that the child is able to process. The personal level notion of representation used in this sense generally refers to something that stands for something else and is available to consciousness (e.g., the word "dog" refers to a dog; a "rule" specifies antecedent consequent relations; a "cognitive map" reflects spatial relations in the environment; see Bermudez, 2000). An important conceptual distinction is raised, however, when complexity theories attempt to explain developments in executive function by referring to changes in the structure of representational systems. When the form or organization of a system of representations is the focus of explanation, this explanation is now formulated at a subpersonal level, specifically the subpersonal systems level. This should not, however, be construed to imply that the subpersonal systems explanation replaces the personal level explanation; rather, subpersonal and personal level explanations are relational and nonautonomous. Useful and indispensable explanations occur on both sides of the table, but this does not mean that these differences warrant the demarcation of completely autonomous domains of explanation (Bermudez, 2000).

In the context of the A-not-B task, the two broadly compatible complexity theories (relational complexity and cognitive complexity) explain task difficulty by pointing to the number of individual representations that must be integrated into a single cognitive representation to solve the problem. Thus, the younger infant has trouble because she/he cannot consider the relation between the two hiding locations and integrate these into a single representation to guide action (relational complexity; Halford, Wilson, & Philips, 1998), or coordinate representations in a conscious representational system in order to overcome a response-based system activated by motor output (cognitive complexity; Marcovitch & Zelazo, 1999). Both theories also extend to executive function development in the preschool period and later childhood, arguing that the number of representations that can be integrated into a single representation increases with age, allowing for more successful problem solving on more complex tasks (Andrews, Halford, Bunch, Bowden, & Jones, 2003; Frye, Zelazo, & Palfai, 1995; Halford et al., 1998).

In the above examples, the concept of "representation" was incorporated as a personal level explanation. However, the notion of representation can be ambiguous (Markman & Dietrich, 2000), sometimes being used as above, but sometimes being defined at the subpersonal level, as for example, in connectionist and dynamic systems models. The notion of representation in connectionist and dynamic systems models is categorically different from the more traditional notion used in most cognitive theories (Fodor & Pylyshyn, 1988). For example, in connectionist models, representation is defined broadly as "patterns of activation across a pool of neuron-like processing units" (Elman et al., 1996, p. 25). Activation patterns on a layer of the network might be offered as "representing" categories because the modeler can understand that these patterns are stable patterns in relation to outputs of the network, but this is clearly not a personal level "representation" directly relevant to the child's conscious understanding of the world (Smith & Samuelson, 2003). Representations in this example are thus not viewed as the "standard symbolic variety" (van Gelder, 1995; i.e., internal models of external conditions). Consequently, this understanding of "representations" is situated at the subpersonal, not the personal level of explanation (Keijzer, 2002).

Examples of approaches in the executive function literature that understand representation at the subpersonal level are Thelen and colleagues' dynamic systems model (Thelen, Schöner, Scheier, & Smith, 2001; Thelen & Smith, 1994) and the connectionist model presented by Munakata and colleagues (Morton & Munakata, 2002; Munakata, 1998). These approaches have rejected personal level symbolic representational systems. Despite the phrase "dynamic systems" in one of these approaches, both have favored bottom-up or emergentist explanations that concentrate on causal mechanisms (i.e., subpersonal functional level). For example, the dynamic systems explanation of the A-not-B error views perseveration as an emergent outcome of the interaction of dynamic processes, specifically of online visually guided reaching processes, and memory processes that encode the history of the child's behavior. Development here is modeled by changes in parameters that contribute to the model (e.g., changes in the motor planning process). For this model, structure is *outside the organism*; behavior is the focus, and there is no emphasis on mental organization of the organism (Thelen & Bates, 2003). Although this model has aspects of a pattern explanation in that it is dynamic and emergent, its rejection of explanation in terms of mental organization, and subsequent emphasis on causal connections and input–output relations, situates the explanation at the subpersonal functional level of analysis.

Munakata and colleagues' connectionist model (Morton & Munakata, 2002; Munakata, 1998) is also at the subpersonal functional level; the emphasis is on modeling information-processing mechanisms and causal relations among units in a connectionist network. The model specifies two components, active and latent representations, which compete to determine behavior, and developmental improvement is understood as reflecting the ability of the active representation to compete with and overcome the latent representation (Morton & Munakata, 2002; Munakata, 1998). Here again, the term "representation" is not offered at the personal level; this form of representation has no direct meaning for the child.

Although these dynamic systems and connectionist examples offer psychological subpersonal explanations, this fact does not preclude the possibility of personal level explanations within the same models. That is, the use of, for example, subpersonal functional explanations does not suggest a necessary incompatibility between these and other levels of explanation of the same phenomenon. Incompatibility occurs only when reductionism is an auxiliary hypothesis in the model or when the different explanations make different predictions or specify different models. Thus, Thelen and Bates (2003) may be correct when they argue that nothing in a dynamic systems framework precludes the analysis of mental representation at the personal level, and Müller and Carpendale (2001) may similarly be correct when they argue that

Piaget's account and the dynamic systems account of the A-not-B error may be seen as compatible explanations pitched at different levels of explanation. Several models in the literature have in fact integrated explanatory concepts across levels. These include van Geert's (1994) and Bidell and Fischer's (2000) models that incorporate a relational developmental systems perspective with personal level aspects of mental structure, and models presented from a complexity perspective by Zelazo and colleagues (Müller, Dick, Gela, Overton, & Zelazo, 2006; Zelazo, Müller, Frye, & Marcovitch, 2003) that have analyzed component cognitive mechanisms (e.g., inhibition and working memory) to supplement the analysis of mental organization. From our relational perspective, the psychological levels of analysis, along with the biological level, all represent potential standpoints from which to converge on a broad, but precise understanding of executive function without engaging in the zero sum game of reductionism.

Conclusions

In the present chapter, we have argued that definitions of executive function suffer from a vagueness and ambiguity that impacts on empirical methods, findings, and conceptual conclusions of research in this area. Part of this confusion grows from the fact that many researchers fail to explicitly acknowledge that the construct of executive function can be explored from different standpoints. Further, researchers fail to acknowledge that descriptions as summary statements do not constitute explanations. We have argued that the rejection of a split metatheory in favor of a relational metatheory represents a necessary step in clarifying the executive function construct. Recast within a relational metatheory, description and explanation are at the same time distinguished to clarify each individual concept, and integrated to form a framework for empirical and theoretical investigation. A relational metatheory also frames the explanatory standpoint, where pattern and causal explanation form complementary relations. Similarly, biological and psychological explanations are taken as legitimate standpoints from which to investigate executive function, but also represent integrated explanatory constructs within a relational matrix. Within this relational metatheory, the commitment to the principle of holism understands basic units of analysis as parts of a dynamic functioning system. From such an understanding, pattern or system-level explanation is a necessity at both the psychological and biological levels of analysis. At the psychological level, recognition and distinction of both personal and subpersonal level explanation allows for an increasing conceptual clarity in the field of executive function research.

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