Abstract: Executive functioning has been said to bear on a range of traditional philosophical topics, such as consciousness, thought, and action. Surprisingly, philosophers have not much engaged with the scientific literature on executive functioning. This lack of engagement may be due to several influential criticisms of that literature by Daniel Dennett, Alan Allport, and others. In this paper I argue that more recent research on executive functioning shows that these criticisms are no longer valid. The paper attempts to clear the way to a more fruitful philosophical engagement with findings on the central executive system.

Word count: 8,174

The Central Executive System[1]

Much progress in recent philosophy of mind has been due to reflection on results from empirical psychology. Reflection on perceptual constancies has advanced debates about vision, reflection on neural mechanisms of attention has advanced debates about visual experience, and reflection on the neuropsychology of motor imagery has advanced debates about intentional action. (Burge 2010; Block 2013, 2015; Butterfill & Sinigaglia 2012)

Similar advances should be expected from reflection on executive functioning. Executive functioning has been said to closely relate to consciousness, thought, and action.[2] In particular, executive functioning appears to be a central component in human problem-solving, flexible cognitive control, and goal-directed action. Each of these topics is, of course, of intrinsic philosophical interest.

Nor is the philosophical potential of research on executive functioning a secret. Daniel Dennett probably was the first philosopher to discuss research on executive functioning. (Dennett 1978, 1994, 2005) He points to the apparent potential of this research to "explain the dramatic increases in cognitive competence that we associate with consciousness: the availability to deliberate reflection, the non-automaticity, in short, the open-mindedness that permits a conscious agent to consider anything in its purview in any way it chooses." (Dennett 2005, 136)

So, if research on executive functioning has the potential to illuminate each of these *ur*-philosophical topics, why has there been so little positive philosophical engagement with executive functioning's scientific study?[3]

1 ACKNOWLEDGEMENTS SUPPRESSED

2 On the relation to consciousness, see, e.g. (Fuster 2015; Ardila 2016; Baddeley 1986), on thought (Zelazo et al. 1997; Richland & Burchinal 2012), on action (Passingham & Wise 2007; Kurzban 2013; Inzlicht & Schmeichel 2012).

3 Sebastian Watzl appeals to executive functioning in explaining the active nature of attention. (Watzl 2017) Watzl

When Daniel Dennett points to their apparent potential he, in the same breath, dismisses explanatory appeals to executive functioning as spurious. He maintains that the 'dramatic increase in cognitive competence' must be explained by "the accessibility [of specialized brain modules] to each other (and not to some imagined higher Executive or Central Ego)." (Dennett 2005, 136; also Dennett 1994, chapters 5 & 9, esp. pp. 256, 274ff.) Several philosophically-minded psychologists, prominently Alan Allport, have similarly criticized research on executive functioning. I suspect that philosophers' lack of positive engagement with this research may be due to the negative connotations attached to 'executive functioning' about 20 years ago. Possibly, philosophers still tacitly rely on these criticisms.

The situation with respect to research on executive functioning hence is more complicated than that regarding perceptual constancies, mechanisms of attention, or motor imagery. This latter research has at no point faced the all-out philosophical skepticism that research on executive functioning encountered. We must first overcome the skepticism before we can enjoy the benefits of this research.

I believe that it is time to re-evaluate the criticisms and to revise our verdict about this part of psychology in light of more recent developments and findings. In this paper I attempt to contribute to such re-evaluation and revision. I thus hope to promote a more fruitful philosophical engagement with the science of executive functioning.

In Section 1 I sketch the central executive system – a system of executive functions for the control of cognitive activity.[4] In Section 2 I describe and refute a first objection against the notion of an executive system. The objection relies on the claim that there is no specific part of the brain that realizes this system. From this claim the objector infers that there is no such system. Section 3 contains a discussion of another set of objections. According to these objections, the executive system does not yield genuine explanations. I address both the general claim about the explanatory value of the system and a more specific charge that this system constitutes an over-endowed homunculus. In both Section 2 and 3 I illustrate ways in which the executive system generates genuine psychological explanations and predictions. In

---

draws upon work by Denis Buehler who sketches an explication of agency in terms of executive functioning. Buehler 2014) Peter Carruthers mentions executive functioning in his book on working memory. (Carruthers 2015) Andy Clark points out the explanatory potential of appeals to executive functioning in reply to a negative review of this research by Catherine Stinson. (Stinson 2009; Clark 2009)

There has been much philosophical interest in a related phenomenon – the nature of attention. (Mole 2010; Wu 2014; Watzl 2017) To the extent that this literature engages with empirical research its focus tends to be on perceptual attention. It does not engage with the empirical literature on executive functioning.

[4] In what follows I will for brevity's sake often drop the 'central' and merely refer to the 'executive system.'

section 4 I conclude that the central executive system is a valid psychological construct and sketch two reasons why it warrants philosophical attention.

1 The Central Executive System

According to an especially fruitful line of research, stemming from Alan Baddeley's model of working memory, the executive system is a psychological system that functions to control cognitive processes. It helps initiate, sustain, and terminate them. The system organizes processing and storage resources for carrying out cognitive processes. It coordinates the processes' simultaneous or sequential execution. (Baddeley 1986; Norman & Shallice 1986; Miller & Cohen 2001; Miyake et al. 2001; Baddeley 2007; Passingham & Wise 2012; Fuster 2015)

The executive system controls a cognitive process by flexibly allocating central processing and storage resources for its completion. The *storage* resources that the system allocates prominently include those of working memory. Working memory holds states active during the execution of cognitive processes. It is a short-term memory system with limited storage capacity. Working memory comprises several sub-components.[5] These sub-components are devoted to storing different, often modality-specific, types of information, such as purely acoustic or visuo-spatial information deriving from individuals' perceptual systems. (Cf. e.g. Baddeley 2007, chapters 2 & 3; Brady et al. 2008, 2011)

But the executive system can also allocate *processing* resources that determine the speed and accuracy of a cognitive process, and the number of cognitive processes that can be performed concurrently. Sometimes this aspect of executive functioning is called 'executive attention.' Sometimes researchers generically appeal to 'executive attention' in referring to the executive system's activities. I here want to de-emphasize this component of the executive system in favor of the system's *organizing* and *allocating* resources (including 'executive attention'). (Baddeley 2007; Fougnie 2009; Fuster 2015)

The executive system organizes and allocates processing and storage resources by performing *executive functions*. Executive functions are signature competencies that characterize the system's operations. Switching of mental set, maintenance of relevant memories, and

[5] The precise nature of working memory is a matter of ongoing debate. Researchers disagree about the amount of information working memory can store and about what determines this amount. (Baddeley 2012, 15 & 20; Cowan 2005, 75ff & 80ff.; Cowan 1995; Alvarez et al. 2004; Brady et al. 2011).

inhibition of prepotent responses and interfering stimuli are the most frequently recognized executive functions. *Switching* of mental set consists in the process of abandoning one cognitive process, and initiating another. (A mental set is the suite of psychological states and events required for completing a cognitive process.) *Maintenance* consists in the activation and holding active of task-relevant information in working memory, as much as the encoding of incoming task-relevant information into working memory. *Inhibition* consists in the exercise of a competency to suppress dominant, automatic, or prepotent responses and distracting or interfering stimuli and information. (Miyake & Shah 1999; Jurado & Roselli 2007; Anderson et al. 2008; Baddeley 2007)

While different theories of the executive system postulate different executive functions, there is widespread agreement on these three basic executive functions. (Goldstein et al. 2014) They are fairly precisely defined. A series of well-studied, relatively simple tasks requires exercising these functions and thus allows their investigation. I will follow the science in focusing on these three executive functions. (Miyake et al. 2001)

Let me briefly illustrate the executive system's activity. Suppose that an individual adds the numbers 123,145 and 224,187. The executive system can initiate the addition by switching mental set to adding the numbers, and by therein allocating processing resources to it. The executive system can terminate the addition by switching set to some other cognitive process.

Adding the numbers 123,145 and 224,187 requires maintaining the mental set for adding the integers. Adding also requires maintaining the numbers 123,145 and 224,187 in working memory. When the individual adds the numbers, she has to carry 1 from the column of the units to the column of the tens. She has to carry 1 from the column of the tens to that of the hundreds. The executive system organizes these memory states so as to sustain the process of adding the numbers until its completion.

The executive system may also sustain the addition by suppressing interference from task-irrelevant stimuli and competing cognitive processes. The individual may be looking at the neon landscape of Hollywood Boulevard. Blinking lights attract her attention. The executive system may inhibit the lights' influence on the individual's addition and suppress the impulse of reading the advertisements. In these different ways, the executive system organizes the individual's resources for adding 123,145 and 224,187.

Suppose that the individual simultaneously engages in a conversation. The executive system coordinates the two tasks by switching from processes pertaining to one task to those pertaining to the other. The system may cue the tasks, first executing the conversation, then the addition. The system may distribute central resources among the tasks, allocating some of these resources to the addition, others to the comprehension of the interlocutor's utterances. In doing, so, the system enables the simultaneous completion of both tasks.

The processing and storage resources that the executive system allocates, are *central* resources partly because they are used for non-modular, intermodal processing. Modular processes are relatively encapsulated:[6] they take a very confined range of inputs and are not influenced by information outside this range. For example, the computation of surface lightness in the early visual system may rely exclusively on information about luminance contours, from the retina. The individual's higher cognitive states may not influence such computations. Processes are *non-modular* when a wide range of states from different psychological capacities enters into them. When an individual forms a perceptual belief that the apple in front of her is edible she may rely on her visual perception and background beliefs about the edibility of apples. Often, such processes are *intermodal* in that they rely on information from different modalities.[7] States and events realizing executive control typically result from the integration of information from different psychological faculties and enter into non-modular processes. I conjecture that such states and events are among the most widely integrated psychological states and events.

At the most basic level, the central executive system controls cognitive processes by allocating resources to them. *Switching*, *maintenance*, and *inhibition* are basic ways in which the executive system allocates resources. Psychology studies the central executive system (in part) by studying these executive functions.

2 The Objection from Neural Mechanisms

There are two main lines of objection against appeals to the central executive system. One argues that there is no such system. The other consists in the claim that appeals to this system do not yield genuine explanation. Both lines of objection have been called "*the*

[6] See Fodor 1983, 47ff.; Fodor 2001, 55. For a discussion of Fodor's notion of modularity, see Shea 2015, Firestone & Scholl 2016, and Block [MS]. I do not here take a stand in the debate about whether there are Fodorian modules in a strict sense, or whether Fodorian modules constitute an important psychological kind.
[7] Note that it seems at least in principle possible for intermodal propositional inference to be modular. Cf. the discussion in Burge 2010b, 49f.

homunculus-problem." It has sometimes gone unnoticed that the two objections are not equivalent. In the present section, I discuss the first line of objection. In the following section, I discuss the second.

The first objection denies the executive system's existence. Proponents of this objection typically assume, *first*, that empirical results have shown that the executive system cannot be identified with any narrowly circumscribed, precisely identifiable region or fully specified mechanism in the brain. *Second*, they assume that a coherent, principled account of the executive system requires identifying it with a narrowly circumscribed, precisely identifiable region or fully specified mechanism in the brain. They conclude that the executive system does not exist. (Allport 1993; Allport 2011; Dennett 1994; Dennett 2005; Stinson 2009) I discuss the two assumptions of this argument in the following two sub-sections.

2.1 The Neuroanatomic Realization of the Central Executive System

The *locus classicus* supporting the first assumption is Alan Allport's 1993 article. In this article, Allport points out a range of problems for research on executive functioning. Allport's criticisms had an important positive impact on the rigor with which executive functioning has subsequently been investigated.

Allport supports the first assumption by surveying then current results from neuroscience. Different executive processes correlate with neural activity in different parts of the brain. Allport points out, for example, that endogenous deployments of attention elicit neural activity spread over the parietal cortex, the frontal eye fields, the superior colliculus, and the lateral pulvinar nucleus of the thalamus. Task-preparation coincides with activations of different areas in the prefrontal cortex. (Allport 1993, 200/3) Allport concludes that the executive system could not plausibly be located at, or identified with, any narrowly circumscribed, precisely identifiable region or mechanism in the brain. He writes: "The results offered by … new techniques together with neuropsychological analyses of the effects of localized injury or disease on diverse executive functions, and neurophysiological data on nonhuman primates, make the idea of a general-purpose, functionally undifferentiated central executive … highly implausible." (Allport 1993, 202)[8]

[8] Dennett writes: "The frontal lobes of the cortex … are known to be involved in long-term control, and the scheduling and sequencing of behavior. … So it is tempting to install the Boss in the frontal lobes, and several models make moves in this direction. … [A]nyone who goes hunting for the frontal display screen where the Boss keeps track of the projects he is controlling is on a wild goose chase." (Dennett 1994, 275) Also: "Since

Allport was right to point out that no one exclusive brain location exhibits neural activity during processes that involve the central executive system. While more recent work in cognitive neuroscience supports this part of Allport's verdict, neuroscience now also suggests that there is *some* anatomical unity underlying the central executive system's functioning.

Since Patricia Goldman-Rakic's pioneering work, executive control had been firmly linked to the prefrontal cortex. (Goldman-Rakic 1987; Buchsbaum & D'Esposito 2008, 245ff.) In the late 1980s technological advances in positron emission tomography coincided with the development of cognitive subtraction techniques. These techniques made it possible to associate variations of activity in specific brain regions with the execution of specific tasks.[9]

Positron emission tomography has fairly low temporal resolution (30 – 40 sec). On its basis alone, we cannot distinguish brain areas underlying different components of the central executive that are active within a single task phase. We cannot distinguish which areas of the prefrontal cortex underlie, say, the maintenance of a stimulus configuration in memory or the subsequent recognition that this configuration is present in a display. With the introduction of event related functional magnetic resonance imaging in the late 90s, this obstacle could be overcome. Functional magnetic resonance imaging allowed mapping executive functions to activity in the prefrontal cortex with a temporal resolution of 2 to 4 sec.

Evolutionary speculation suggests that the prefrontal cortex evolved to enable goal-directed behavior. The prefrontal cortex enables the use of sensory information about the environment *for* goal-directed behavior, such as the maintenance of an image of a visual search's target. Parts of the brain different from the prefrontal cortex process the relevant sensory information. The prefrontal cortex accordingly should serve to modulate neural activity occurring elsewhere in the brain. (Gazzaley & D'Esposito 2006, 5) Sensory and motor representations, for example, are predominantly processed on the basis of neural activity in the unimodal association regions. Functional magnetic resonance imaging reveals co-activation of these regions along with prefrontal cortex, for instance, during goal-directed motor action.

---

there is no single organizational summit to the brain … In an arena of opponent processes … the 'top' is distributed, not localized." (Dennett 2005, 133) And: "It is … the accessibility [of specialized brain modules] to each other (and not to some imagined higher Executive or Central Ego) that could in principle explain the dramatic increases in cognitive competence that we associate with consciousness: the availability to deliberate reflection, the non-automaticity, in short, the open-mindedness that permits a conscious agent to consider anything in its purview in any way it chooses." (Dennett 2005, 136)

[9] For any set of hypothesized cognitive operations, one had to find a task involving all of them, and several tasks involving only subsets. Researchers reasoned that brain areas active during tasks engaging *all* cognitive operations in the set, but not in tasks engaging all cognitive operations but *one*, realize this one cognitive operation at the level of the brain.

For the prefrontal cortex to control activity in remote brain regions, it must be *connected* to these regions. Temporal imaging alone does not provide evidence for the interconnection and interaction of different brain regions. Only the development of multivariate methods for analyzing neuroimaging data have, during the 2000s, allowed the specification of neural networks that underlie the prefrontal cortex's modulation of neural activity.[10] Complex cognitive processes are not confined to specific brain regions functioning in isolation. Rather, they emerge from intricate neural connections between different parts of the brain.

Functional magnetic resonance imaging and positron emission tomography together allow a fairly precise specification of neural networks active during the performance of executive functions. They do not in and of themselves show that prefrontal-cortex activities are *control* processes. But already in the mid-2000s, neuroscientists gathered evidence for this stronger claim. Gazzaley and D'Esposito, for example, asked individuals to actively observe a display with the goal to memorize items in it. (Gazzaley & D'Esposito 2007, 198ff. & 205/6) They found that when individuals pursued the goal of observing a display, activity in the prefrontal cortex and the relevant regions of the association cortex increased against a baseline of activity during passive viewing. The prefrontal cortex presumably enables individuals' goal-directed cognitive processes. These findings suggest that the prefrontal cortex controls modulations of neural activity in the association cortex. Other evidence for prefrontal-cortex control comes from disrupting prefrontal-cortex afferents and recording activity in distant brain regions while the subject is engaged in a control task. There have been several such studies in humans and animals. They show that the prefrontal cortex controls enhancement and suppression of neural activity in other areas. Cooling the prefrontal cortex in cats, for example, results in increased responses to sensory stimulation, suggesting the lack of inhibitory control by the prefrontal cortex. Cooling the prefrontal cortex in monkeys leads to diminution of neural activity in the inferotemporal cortex, associated with poorer performance in recalling items from working memory. In humans, combined lesion and event-related potential studies provide evidence that the prefrontal cortex enhances activity in the visual association cortex for the processing of visually attended stimuli. (Cf. Funahashi 2007, 228/9) More advanced neuroscientific paradigms and methods – involving, for instance, combinations of repetitive and single pulse transcranial magnetic stimulation – have since provided additional support for

[10] Multivariate approaches evaluate covariance of activation across brain regions. Cf. Miller & D'Esposito 2005, 537; Gazzaley & D'Esposito 2006, 11.

these claims. (Cf. e.g. Reis et al. 2007; Neubert et al. 2010; Munakata et al. 2011; Duque et al. 2012; Duque et al. 2013; for general overviews, see Fuster 2015; Passingham & Wise 2012; cf. also Gottlieb 2007 & 2014; Clark et al. 2014)

Allport was right to point out that activity of the central executive system causes activation of many different areas in the brain. Allport was likely wrong to suggest that, therefore, no part of the brain implements the executive system. More recent neuroscientific theorizing can accommodate and explain the fact that neural activity implementing executive functions spreads over many different parts of the brain. We should update Allport's verdict in light of more recent methods and data. Central executive control is likely implemented through the prefrontal cortex's modulation of neural activity in domain specific neural networks.

Stinson, in her 2009 article, denies that more recent evidence from neuroscience supports this conclusion by pointing out that "the patterns of connections found to exist between [the relevant brain-regions are] put forward as necessary properties of an attentional control system, not sufficient ones." Stinson continues: "Identifying the only part of the brain that has a necessary property of an executive controller would only warrant the conclusion that this area is an executive controller *if we had some prior reason for believing that there exists an executive controller somewhere in the brain*." (Stinson 2009, 149; my emphasis) But we *do* have independent, 'prior reason' from behavioral studies for positing executive functions. I present some of the relevant evidence in the next section. The neuroscientific argument should now be understood abductively. Given the behavioral studies, neuroscientific research makes it plausible that prefrontal cortex (partly) implements these functions. Stinson does not undermine this abductive argument. (Cf. Clark 2009.)[11]

There is now evidence for some unity in areas of the brain that realize the central executive system.[12] [13] I conclude that the first premise of the objector's argument, according to

[11] Stinson confines her discussion to evidence about the prefrontal cortex' connectedness and its being the unique area in the brain that has this property. She does not mention the other evidence discussed in the main text..

Stinson writes that the "psychological phenomenon of executive control may be difficult to deny, but *it does not follow* from this that a part of the brain is the controller." (Stinson 2009, 149; my emphasis) I agree. But the neuroscientific evidence *does* make the implementation of executive functioning by prefrontal cortex plausible. Stinson then apparently concludes, from her claim that empirical evidence is not sufficient to identify the prefrontal cortex as a controller, that "we have instead reason to believe that there is not an executive controller in the brain." (Ibid. 149) As far as I can see, no support is provided for this further step.

[12] In a later article, Allport seems to implicitly recognize the availability of this reply to his early argument. (Allport 2011, 39ff.)

[13] The first assumption might be supported by claiming that cognitive processes are connectionist or parallel-

which empirical evidence shows that no part of the brain realizes the central executive system, is likely false.

2.2 Neuroscientific and Psychological Explanation

The second premise of the objector's argument is the claim that a coherent, principled account of a central executive system requires identifying it with a narrowly circumscribed, precisely identifiable region or fully specified mechanism in the brain.

What support might there be for such a requirement? According to Allport's 1993 critique of then current research on the executive system, the second premise was assumed to be true by all relevant theories of the central executive system. (Allport 1993, 187) The premise was part of the classical computational picture of the mind. According to this picture, information processing is to be thought of in analogy with a computer. Input analyzers process sensory input in parallel fashion. Then a linearly ordered, uni-directional sequence of further processing ensues. Executive processing is high-resource processing with limited capacity, beginning at some particular processing stage. An analogue of a central processing unit in a computer achieves central executive processing. This physically separate processor in the brain thus realizes the central executive system. But even adherents of a computational picture of the mind no longer take the analogy between brains and computers this literally.

How might the executive system be distinguished from other systems, if not as a narrowly circumscribed, precisely identifiable region or fully specified mechanism in the brain? The preceding sketch of the executive system's implementation in the brain may hint at a neuroscientific answer to this question. The prefrontal cortex may turn out to be the primary source of executive control in the brain.

The objector might concede these points but insist that *only* explanation in terms of a fully specified neural mechanism is *genuine* explanation. She might reason that until we have a full specification of a neural mechanism for central executive control of cognitive processes,

---

distributed brain processes. According to this position, cognitive processes emerge from the activity of entire neural networks. No part of a neural network is privileged as the control system for other parts of the network. (Dennett 1994; Dennett 2005) But even the earliest connectionist models acknowledged hierarchical levels of processing. (Rumelhart et al. 1986, 59). Dennett provides no reason for thinking that his more radical 'global' version of a parallel-distributed architecture is the right version. Connectionism as a general model of neural activity is consistent with the existence of a hierarchical structure of systems. (Stokes & Duncan 2014). Some of the more sophisticated computational models of the executive system are indeed connectionist models (O'Reilly 2006). [redacted] we have no genuine explanations in terms of the central executive system. Her second premise hence stands.

But reflection on psychological method does not support the view that only explanation in terms of fully specified brain mechanisms is valid explanation. Psychological explanation appears to some extent independent of explanations in terms of neural mechanism. Large parts of psychology continue to generate powerful theory on the basis of behavioral studies and computational modeling. Neither behavioral studies nor computational modeling need appeal to structures of the brain. Our understanding of how psychological theory correlates with activity in the brain is often poor. There is at this point no positive reason to think that all psychological explanations will ultimately be reduced to explanations in terms of brain mechanisms. If we take actual explanatory practice in psychology at face value, then we have reason to be skeptical of this objector's claims about *genuine* explanation.[14]

Even if the preceding sketch of the executive system's implementation in the brain should turn out to be false, there are alternative ways of distinguishing an executive system from other psychological systems. Behavioral data support the identification of distinct modes of functioning – the executive functions.[15] Earlier I illustrated these modes of functioning. I elaborate on the study of these modes of functioning in the next section. Identification of such modes of functioning helps systematize and explain distinctive sets of behavioral data. Postulating a psychological system such as the executive system yields generalizations and predictions that explain the behavioral data. Such successful explanations in psychology provide evidence for the existence of the entities that the explanations are in terms of.[16] Such successful explanations in psychology do not depend on whether they can be reduced to explanations in terms of brain activity.

Vision science may serve as an analogy. Much of the success in vision science is due to behavioral studies and computational modeling. While there are attempts to integrate behavioral and computational studies in vision science with brain studies, the latter are less advanced than the former, especially for later stages of visual processing. Integration of the

---

[14] The *locus classicus* for these claims in psychology is Marr 1982.

[15] Computational modeling provides a further way of specifying a psychological system or competency without relying on neuroscience.

[16] Psychologists are clear on this point. See for example Anderson 2008, 6: "Executive function is a psychological construct, but the concomitant neural systems (i.e. prefrontal cortex and related systems) provide important information about specific processes and the integration of these functions." Baddeley insists that his model is "principally a functional model that would exist and be useful even if there proved to be no simple mapping on to underlying neuro-anatomy." (Baddeley 1996, 6)

different fields succeeds mostly for very low-level vision. Our understanding of higher-level visual functions, such as the processing of objects or object-categories, often relies on behavioral and computational research. Nevertheless, vision science provides genuine, powerful explanations. We are committed to the existence of the competencies and systems that these explanations are in terms of. We can thus legitimately expect genuine explanation in psychology that is not given in terms of neural mechanisms. We can expect that psychological competencies and systems can be individuated on the basis of such psychological explanations. (Cf. Palmer, S. 1999, chapters 5ff.)

According to some conceptions of explanation in psychology, psychological (or cognitive) models are always rough, incomplete sketches that, when completed, will yield full specifications of neural mechanisms. According to Piccinini and Craver, for instance, all "functional analyses are sketches of mechanisms [that will turn] into a full-blown mechanistic explanation" in terms of neural processes once the sketches have been completed. (Piccinini & Craver 2011, 283) Even on these mechanistic conceptions, however, an incomplete sketch of a mechanism can be explanatory. And, as I explained earlier, cognitive neuroscience appears to provide at least the very rough outlines of the neural mechanisms underlying cognitive models of executive functioning. So even a commitment to strict mechanistic explanation in psychology need not conflict with my claim that appeals to executive functioning, given the present state of psychology and neuroscience, can be explanatory. (See also Machamer et al. 2000; Craver 2007; Bechtel 2008)

And it is far from obvious that we should commit to the eventual specification of a neural mechanism for *each* case in which we make explanatory appeal to a psychological (or cognitive) model in psychology. Not only does current psychology continue to produce explanations in absence of such specifications. Also, convincing arguments have been made in favor of psychological explanation that does not require the eventual specification of an underlying neural mechanism. Daniel Weiskopf, for instance, recently argued that "cognitive models, [that is,] componentially organized, causally structured, semantically interpretable models of systems that are capable of producing or instantiating psychological capacities" can underlie psychological explanation absent any appeal to neurobiological facts in these models' characterization. (Weiskopf 2011, 24) Such models, and explanations in terms of them, crucially, "can be confirmed or disconfirmed independent of neurobiological evidence." (*Ibid.*, 38) As I will illustrate in the next section, explanations in terms of executive functioning meet this demand. (See also Burge 2010c; Aizawa & Gillett 2011; Weiskopf 2016, forthcoming; Stinson 2016)

So the claim that a coherent, principled account of a central executive system requires identifying a narrowly circumscribed, precisely identifiable region and fully specifying a mechanism in the brain is implausible. The first line of objection against appeals to the central executive system fails.

3 The Objection from Explanation

The second objection consists in the claim that no genuine psychological explanations derive from appeals to the central executive system. Some objectors more specifically claim that a behaviorally or functionally characterized executive system is, or would have to be, an over-endowed homunculus. The executive system is an over-endowed homunculus in so far as it is equipped with those of the individual's capacities that the system is supposed to help explain. Thus writes Allport: "The concept of a central executive has yet to be elaborated in a way that avoids the homunculus problem, namely, the problem of practically unconstrained explanatory powers. As a consequence, the idea has yet – to my knowledge – to generate specific, hypothesis-generating research." (Allport 1993, 200/1)[17]

Again, I believe that more recent research on executive functioning allays these worries. In the first sub-section, I illustrate some ways in which research on the executive system is explanatory, including ways in which the research has made progress, yielded testable hypotheses, and new explanations. This research offers principled constraints on appeals executive functions. The constraints in turn allow the generation, confirmation, and falsification of hypotheses about a wide range of processes involving executive functioning. Such constraints are often taken to be hallmarks of genuine explanations. (Cf. e.g. Craver 2007; Weiskopf 2011, 2016) In the next sub-section I discuss the more specific charge that the executive system in its current state is an over-endowed homunculus. I argue that there is no reason to think that explanation in terms of executive functioning is explanation in terms of those capacities of individuals that we are striving to explain.

[17] See also also Dennett 1994, chapter 5. Monsell & Driver write: "The homunculus has continued to parade about in broad daylight, its powers largely intact and indeed dignified by even grander titles – not merely the "executive" but the "central executive" or the "supervisory attention system"." (Monsell & Driver 2000, 3)

3.1 The Psychology of the Central Executive System

For several decades, the executive system served almost exclusively as a placeholder for a number of aspects of mind that needed explanation. (Anderson et al. 2008; Anderson 2008; Miyake & Shah 1999; Conway et al. 2007) Broadbent's early computational theory of the mind postulated a central processor that selects information through a bottleneck for privileged processing. Others, like Kahneman, thought of the executive system as a limited, all-purpose processing resource. Yet others conceived of the executive system in terms of the difference between automatic and deliberate processes. While postulating a central executive system, these theories did not provide accounts of *how* the system contributed to psychological processing. (Broadbent 1958; Kahneman 1973; Shiffrin & Schneider 1977; Norman & Shallice 1986)

An important step forward was Baddeley's 1986 conceptualization of the central executive system as the principal part of the working memory system. (Baddeley 1986, 1996, 2007 & 2012) He distinguished the central executive *qua* allocator of resources from working memory as a system of memory stores. The model in its outline is now widely accepted, even though its details have been debated. While Baddeley's work inspired a great number of researchers to investigate his model, they obtained widely diverging results.[18]

For decades, research on the executive system had relied mainly on individual difference studies.[19] By the late 1990s, more sophisticated structural equation modeling methods were widely used in other sciences, for instance, evolutionary biology.

Psychologists first introduced exploratory factor analyses to study the executive system. Factor analyses take covariation of observed factors as data. Sophisticated statistical methods extract underlying unobserved, or latent, factors from observed covariations. Covariations between observed data, for example arithmetical and verbal skills, may indicate the influence of an underlying latent factor, for example some specific executive function. Exploratory factor analyses register all statistically relevant covariations in a data set. They account for an in-principle unlimited number of covariations. These analyses hence yield a potentially unlimited number of supposed latent factors. Often, only few of these latent factors

[18] See the criticism especially in Miyake & Shah 1999 and Miyake et al. 2000, 53 & 78.

[19] Individual difference studies typically picked fairly complex tests for studying executive function. They correlated individuals' performance on different such tests. A consistent result from these studies was that the inter-correlations among different tasks were low and often statistically not significant. These results were mistakenly used to argue that the executive system is highly fractionated. Cf. Rabbitt 1997.

correspond to actual causal factors that underlie the observations. Exploratory factor analyses provided poor guidance for specifying which executive functions influenced individuals' performance on specific tasks. (Thompson 2004)

Miyake et al. 2000 addressed this obstacle by introducing confirmatory factor analysis to the study of executive functions. Confirmatory factor analysis starts from an initial hypothesis about the relevant latent factors. It tests this hypothesis against the covariational data. A measure of fit is used to determine whether a hypothesis is a good one. If the initial hypothesis is a good one, confirmatory factor analysis tries to determine which observed covariations are due to actual causal factors underlying the observations.

The study by Miyake et al. illustrates one way of constraining explanatory appeals to executive functioning. Miyake et al. used the new statistical method to identify and characterize the set of basic executive functions introduced earlier – the functions of *Switching*, *Inhibition*, and *Maintenance*. For each of these three target executive functions, they specified three tasks. Performance on these tasks relied on carrying out the respective executive function as exclusively as possible. Take *Inhibition*, for example. Miyake et al. identified the Antisaccade task, an object identification task, and the Stroop task as plausibly engaging the executive system's inhibitory function. Miyake et al. measured individuals' performance on each of these tasks. They determined a value for the involvement of the target executive function in those tasks. High correlation of this factor between the three tasks constituted evidence that the targeted inhibitory executive function was involved in all three tasks.

Miyake et al.'s results confirmed that the specific tasks they proposed for investigating *Switching*, *Inhibition*, and *Maintenance* plausibly do engage them fairly exclusively. They had identified basic executive functions and paradigms for their study. They had done so in a principled way, by relying on their use of new statistical methods. Reapplying the same methods to their analyses for the three different executive functions, Miyake et al. showed that the three proposed basic executive functions are clearly distinguishable. Performance on the tasks varies sufficiently to think that the tested executive functions are independent factors.[20]

This new approach to the study of the central executive system subsequently yielded further results. Friedman et al., for instance, used Miyake et al.'s methods to further investigate Inhibition. (Friedman & Miyake 2004; Friedman et al. 2008; Miyake & Friedman 2012) What

[20] Miyake et al. 2000, 72. A similar result was obtained for a set of executive functions supposedly controlling visuo-spatial working memory. Cf. Miyake et al. 2001.

had been treated as a single competency turned out to be a family of related competencies. *Prepotent Response Inhibition* consists in the exercise of an ability to suppress dominant, automatic, or prepotent responses. *Resistance to Distractor Interference* is the exercise of an ability to resist or resolve interference from information concurrently available, but irrelevant to the task at hand. Both types of inhibitory competency must be distinguished from *Resistance to Prior Information* or exercise of the ability to resist intrusions from information that was previously relevant to a task, but has since become irrelevant. Friedman et al. showed that individuals' performance on tasks that engaged *Resistance to Prior Information* was unrelated to their performance on tasks engaging *Prepotent Response Inhibition* and *Resistance to Distractor Interference.* These latter two inhibitory competencies, however, turned out to be closely connected. Friedman et al. concluded that these latter two inhibitory competencies, but not *Resistance to Prior Information*, should be grouped as the inhibitory executive function. (Friedman & Miyake 2004, 102; Friedman et al. 2008, 23) This result disconfirmed prior claims to the effect that one and the same inhibitory competency underlies all three types of executive function. (Kane et al. 2001)

Research flowing from the Miyake et al. study illustrates one way of constraining explanatory appeals to executive functioning. Other ways include appeals to behavioral characteristics such as times courses, error rates and profiles, or capacity limits. (cf. e.g. Baddeley 2007; Reynolds et al. 2006)

The second line of objection claims that no genuine psychological explanation comes from appealing to the central executive system. The preceding summary of some recent results about the executive system suggests that this claim is false.

Miyake et al. provide evidence for three independent basic executive functions. Friedman et al. suggest that we should distinguish between two basic types of inhibition. Both studies provide evidence that a fairly clearly circumscribed set of tasks serves to investigate these different executive functions. They offer principled statistical methods for their investigation. The studies thus contribute to our understanding of a psychological system that helps explain individuals' cognitive activity – the central executive system.

Aspects of individuals' cognitive activity are explained *in terms of* the executive functions that have thus each been independently characterized. Their characteristics provide grounds for predictions and generalizations about a wide range of individuals' cognitive activities. Characteristic time courses for switching from one mental set to another may, for example, explain individuals' characteristic mistakes in simultaneously performing a multiplication and a random letter generation task. Characteristic capacity limits for working memory storage may explain interference between a visual search and a mental imagery task. So the studies not only constitute progress in understanding the executive system. They thereby generate new and better explanations of individuals' performance on specific cognitive tasks.

Explanatory progress, as illustrated by the Miyake et al. and Friedman et al. studies, extends beyond carving out basic executive functions and paradigms for their investigation. A more sharply circumscribed set of executive functions and paradigms for their investigation makes it possible to test hypotheses about the interaction of these executive functions with other cognitive competencies. Having such a set of executive functions and paradigms allows neuroscientists to attempt more precise mappings of central executive control to activity in brain areas. Having a set of executive functions drives investigations of the central executive system's relation to intelligence, its role in infant development, ageing, and motivation. A close look at the psychology of the executive system shows that this science yields a wide variety and increasing number of predictions, explanations, and regimented paradigms for testing them.[21]

The Miyake et al. and the Friedman et al. studies illustrate a way of providing a basis for, and regimenting, research on the executive system. They offer principled statistical methods for studying individual executive functions. They discover behavioral facts that characterize exercises of executive functions. They generate new hypotheses about basic executive functions by applying the new statistical methods and respecting the newly discovered behavioral facts (as much as already available background knowledge about executive functioning). These methods and facts impose constraints on the confirmation and falsification of novel hypotheses about executive functioning. The studies not merely devise paradigms for investigating these basic executive functions. The studies also generate hypotheses about the interrelation of the basic executive functions, as much as their interaction with other psychological competencies. And again, the studies offer ways of

[21] For research on the relation between executive system and the brain, cf. Munakata et al. 2011. 453 ff.; Munakata et al. 2012. On the connection between the executive system and more complex tasks, see Miyake et al. 2000. On the connection between the executive system and development, learning, or general intelligence, see Munakata et al. 2012; Anderson et al. 2008; Anderson 2008; Miyake & Shah 1999; Conway et al. 2007; Zaitchik et al. 2014. On the executive system and the will or self-control, see Inzlicht & Schmeichel 2012; Kurzban et al. 2013. For attempts to computationally model executive functions, e.g. O'Reilly 2006. [redacted]

confirming or falsifying such hypotheses. So the studies exhibit marks of genuine explanation and explanatory progress.[22]

Progress in psychology often takes the form of breaking down complex information-processing problems into smaller, more tractable ones. Again, the analogy with vision science helps. Vision science attempts to explain how the visual system generates a representation of the distal physical environment from the registration of physical intensities on the retina. Progress, initially, consisted in understanding that this process has several stages. Each stage involves component processes, such as image-based processing, surface-based processing, object-based processing, and so on. Identifying the component processes allowed researchers to propose computational models for the information-transformations achieved by the component processes. Identifying the component processes allowed researchers to integrate data from behavioral studies with knowledge about the neural realization of these more tractable processes. Vision scientists were thus able to model in great detail, for example, how the visual system generates surface-representations from representations of edges. These mathematical models became more sophisticated and more widely integrated with research on other phenomena such as visual attention and motor action. Each step of this development constituted explanatory progress. (Cummins 1975; Palmer 1999; Frisby & Stone 2010)

Research on the central executive system has not yet reached a stage of fully successful mathematical modeling. Findings about correlations of executive functions and the brain are somewhat preliminary. It seems, nevertheless, that executive research has advanced from the initial stage to a stage where more tractable problems are better understood. While research on the executive system may not have the status of a mature science, like vision science, its advances do constitute genuine explanatory progress. Findings involving the executive system form part of our best understanding of individuals' cognitive activity. We should acknowledge that appeals to the executive system do genuine explanatory work. The objection according to which appeals to the central executive system do not yield genuine explanations can be rejected.

3.2 Homunculus-Charges

[22] For a general discussion of constraints on explanation in terms of cognitive models, see e.g. Weiskopf 2011 & forthcoming.

Sometimes objectors support the claim that the central executive system is explanatorily worthless by claiming more specifically that this system is endowed with abilities making it a homunculus. Dennett, for instance, cautions: "We haven't really solved the problem … until [the] Executive is itself broken down into subcomponents that are themselves clearly just unconscious underlaborers who work … without supervision." (Dennett 1978, 124; also Dennett 2005, 137) According to this worry, the executive system has the very abilities of the individual that the system is supposed to help explain. In this sub-section I suggest that the homunculus-charge, too, rests on a misunderstanding of the science. I then argue that even if a version of the homunculus-charge were accurate, it would not discredit the executive system's explanatory value.

In psychology, a primary explanatory purpose of the executive system is to help explain individuals' abilities to carry out certain cognitive processes. (Baddeley 2007) Examples of such cognitive processes are instances of deductive or inductive reasoning, mathematical calculations, problem solving, and the like. Carrying out such cognitive processes requires the individual to exercise her abilities to reason, calculate, and solve problems. The executive system does not have abilities to reason, calculate, or solve problems. Rather, it functions to control these cognitive processes.

Indeed, the relevant cognitive processes typically involve the exercise of many different psychological competencies. Remember the example of adding the numbers 123,145 and 224,187. Adding these numbers requires some competency with integers. It requires some competency to add. To add the numbers, the numbers must be maintained in working memory. The executive system must inhibit irrelevant memories of yesterday's lunch. Only some of the competencies activated in this example are executive functions. Competencies other than the executive functions are involved in the exercise of these cognitive activities. So the executive system *could not* exercise the individuals' ability to add.

A more promising version of the homunculus-charge insists that exercises of executive functions themselves are exercises of individuals' competencies. According to this version of the objection, *individuals* switch between task sets, encode information into working memory, maintain information in working memory for concurrent tasks, and inhibit irrelevant information and prepotent responses from interfering with the ongoing cognitive process.

To assess this claim, it will be helpful to reflect on the role of the central executive in psychological explanations. The central executive system is just one of the many sub-systems involved in the individual's execution of cognitive tasks. Psychological sub-systems are components of an individual's psychology. These components must be distinguished from the individual herself.

The digestive system is one of the individual's sub-systems. Her stomach and intestines digest the food she eats. We can say that the individual is having difficulties digesting her food. But on reflection, we firmly distinguish between the digesting of the food by her stomach – a process that occurs *inside* the individual – and processes that we attribute to the individual *herself*. We equally distinguish individuals' *psychological* sub-systems from individuals themselves. The visual perceptual system is one of human individuals' psychological sub-systems. Transformations in the visual system are events inside the individual in the same sense as the digestion of food. The computation of lightness from luminance contours is not an event that we attribute to the individual herself.

Processes of individuals' sub-systems have marks that indicate that they are activities *inside*, not *of*, the individual. First, the individual does not make transformations in the early visual system occur. Second, such events are not accessible to consciousness. (Burge 2010, 369ff.) Processes bearing one of these three marks tend to not be events at the level of the whole individual, although the marks are not obviously sufficient for a process to occur at the sub-individual level alone. While our intuitive grip on the distinction is firm, it is difficult to draw it sharply. Understanding the distinction is complicated by the fact that sometimes, states and events are *both* attributable to the individual and her sub-system. The visual perception of the palm tree, for instance, is both a state of the individual and her visual system.

The addition of 123,145 and 224,187 occurs at the level of the whole individual. No sub-system of the individual adds numbers. Appeals to activity by the executive system helps *explain* this individual-level event. Many of the executive system's activities do not seem to be the individual's activities. The individual adds the numbers. The individual does not always *also* encode 123,145 and 224,187 into working memory. She does not always update working memory with a 2 when she carries the 1. She does not also maintain the memories of these numbers in working memory. The individual plausibly does not always activate a competency for adding integers from long-term memory. She does not always engage in the activity of suppressing irrelevant memories. Nor does she inhibit orienting attention to distractors, in many cases. *Those* activities are exercises of executive functions by the central executive system. It seems plausible that often they are events *exclusively* at the level of this sub-system, not at the level of the individual. Empirical research tends to support rejecting the stronger version of the homunculus-charge.[23]

Of course, states in working memory are often attributable to the individual. Individuals recall information from memory. Similarly, individuals may suppress a tendency to engage in the wrong kind of activity. Individuals may shift goals and hence switch from one cognitive activity to another. Such states and events are then attributable to the individual herself, not merely her sub-system. Just as in the case of vision, these states and events seem to be attributable to *both* individual and sub-system. It is an important and difficult question when and why states and events of the executive system are the individual's. I do not have a principled answer to this question.

The important point in the present context is that, again as in the case of vision, many states and events of the executive system seem not to be the individual's. They are occurrences *merely* at the level of the sub-system. So they are inaccurately described as activities of a homunculus or a theoretical construct endowed with (even some of the) capacities of the whole individual.

It is even more important to realize that even if the considerations in the preceding paragraphs turned out to be mistaken, explanations in terms of the executive system would not be without value. For suppose that the objector is right when she claims that exercises of executive functions are events at the level of the whole individual. Executive functions are, in this scenario, individuals' competencies to control cognitive activity. The central executive system would consist in a set of individual-competencies. It would have turned out, perhaps surprisingly, that individuals not merely add numbers. Individuals also switch from one task to the next, maintain numbers to be added, and activate an adding-competence from long-term memory. The psychologist would now rightly ask the same questions she asked before: Which are the executive functions? Which executive functions are the basic ones? How do they impact the exercise of basic cognitive activities such as adding? How do basic executive functions interact to explain individuals' performance on more complex tasks? How can research on individuals' control functions be integrated with other research in psychology and

[23] There is some evidence that neither exercises of executive functions, nor the states upon which executive functions operate, must be accessible to consciousness. (see Fockert & Bremner 2011; Lavie & Dalton 2014; and also Soto et al. 2011; Soto & Silvanto 2014) For an overview of empirical research on unconscious exercises of executive functions, see Ansorge 2014. The empirical distinction between conscious and unconscious states and events is a matter of ongoing debate. (Cf. Phillips 2016; Block 2016; Block & Phillips 2016) The evidence must be treated as preliminary and with extreme caution.

neuroscience? While psychology's answers to these questions purport to concern the activity of one of the individual's systems – not the individuals' own competencies – they would be genuine answers even if they concerned the activity of the individual herself. The entire suite of new hypotheses and explanations sketched in the last sub-section would have to be reformulated in terms of individuals' competencies. But new hypotheses and explanations they would be nevertheless. Generating them would constitute genuine explanatory progress.

The individual's adding could be explained in part on the basis of her exercising cognitive control functions such as maintenance and inhibition. Such explanations would be more detailed, more specific, and differentiated than explanations merely in terms of a generic capacity to add. An explanation of the individual's failure to add correctly while maintaining a sequence of letters in memory and being exposed to loud music would not stop with stating these facts. The explanation would point out how maintaining the letters takes up some of the individuals' resources for controlling cognitive activity. It would point out how under these circumstances, fewer resources are available for suppressing interfering stimuli. It would explain that because of these facts, the noise distracted the individual from her addition. Such an explanation would improve on common-sense psychological explanations not by explaining the individual's activities in terms of one of her systems– the central executive system. Rather, it would constitute explanatory progress by differentiating and providing a more detailed account of the individual's operations. This more detailed, more specific, and differentiated explanation would be superior to the common-sense explanation.

I conclude that we should reject the accusation that the central executive system does not figure in genuine psychological explanations. Claims to the effect that the executive system is an over-endowed homunculus are unconvincing. They do not justify the accusation that appeals to the central executive system lack genuine explanatory value.

4 Executive functioning, action, and thought

In what ways might philosophical theorizing benefit from reflection on the science of executive functioning? Let me, very briefly, sketch two ways. One way might be to exploit connections between executive functioning and goal-directed action. Psychology explains paradigm exercises of human agency by appeal to executive functioning. When humans actively shift visual attention, reach for a target, or solve a problem, they switch mental set from prior to current activity. In doing so their executive system holds active a mental set, and a representation of their goal, in working memory. The system top-down biases psychological processing in other sub-systems. This bias activates processes that contribute to fulfilling the current set. The bias inhibits interfering psychological processing. In explaining paradigm instances of goal-directed action, psychology appeals to executive switching, maintenance, and inhibition. (Fuster 2015; Stokes & Duncan 2014)[24] This observation suggests that executive functioning might help realize a capacity to act, at least in humans. We might even attempt to appeal to executive functioning to deepen our understanding of what it *is* (for such animals) to act. (Cf. Buehler 2014; Watzl 2017)

Another way might be to exploit connections between executive functioning and problem-solving in humans. One central type of goal-directed agency that psychology explains by appealing to executive functioning is problem-solving. Psychology has, over the last two decades, consistently found correlations between individuals' problem-solving capacity and their performance at executive tasks. (Zelazo et al. 1997)[25] A similar correlation has been found between executive functioning and measures of general intelligence. (Arffa 2007) Problem-solving and intelligence probably crucially involve flexibly allocating mental resources, as much as flexibly adopting (and switching) problem-solving strategies. Such flexible allocation, at least in humans, seems to be achieved by executive functioning. To the extent that problem-solving and intelligence mark human *thinking*, it might be argued that executive functioning helps realize it. Appeals to executive functioning might help explain what is distinctive about human problem-solving. Or we might even attempt to appeal to executive functioning to better understand thought in general.

Engagement with the science of executive functioning thus offers new avenues for philosophical research on either of these two topics. I hope that the sketch in the last two paragraphs at least suggests that these avenues merit exploration. I conjectured that these (and other) avenues have not been taken so far, in part, because research on the central executive system has been dismissed early on, both in psychology and philosophy, as not genuine. While we should appreciate that research on the central executive system is at a relatively early stage, I have argued there is no reason to dismiss the notion of a central executive system and

---

[24] Several connections have been made between executive functioning and willpower. (e.g. Kurzban 2013; Inzlicht & Schmeichel 2012)

[25] Executive functioning has also been discussed in connection with the distinction between two reasoning systems. (Cf. Stanovich et al. 2000 and Stanovich 2010)

explanations in its terms as not genuine. My aim in the present paper was to lay the groundwork for a more fruitful philosophical engagement with the science of executive functioning.

Literature:

Aizawa, K. & Gillett, C. 2011. "The Autonomy of Psychology in the Age of Neuroscience." In P. Illari, F. Russo, J. Williamson (eds.), *Causality in the Sciences*, Newy York: Oxford University Press.

Allport, A. 1993. "Attention and Control: have we been asking the wrong questions? A Critical Review of Twenty-five Years." In D. E. Meyers & S. M. Kornblum (eds.), *Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience* (pp. 183-216). Cambridge, MA: MIT Press.

Allport, A. 2011. "Attention and Integration." In C. Mole, D. Smithies & W. Wu (eds.), *Attention. Philosophical and Psychological Essays (pp. 24-59)*, Oxford: Oxford University Press.

Alvarez, G. & Cavanagh, P. 2004. "The Capacity of Visual Short-Term Memory is Set Both by Visual Information Load and by Number of Objects." *Psychological Science* 15(2): 106-111

Anderson, R. Jacobs & P. Anderson 2008 (eds.), *Executive Functions and the Frontal Lobes. A Lifespan Perspective. (pp. 3-22),* New York: Taylor & Francis.

Anderson, P. 2008. "Towards a Developmental Model of Executive Function." In V. Anderson, R. Jacobs & P. Anderson (eds.), *Executive Functions and the Frontal Lobes. A Lifespan Perspective. (pp. 3-22),* New York: Taylor & Francis.

Ardila, A. 2016. "Is 'self-consciousness' equivalent to 'executive function'?" *Psychology & Neuroscience* 9(2): 215-220

Arffa, S. 2007. "The relationship of intelligence to executive function and non-executive function measures in a sample of average, above average, and gifted youth." *Archives of Clinical Psychology* 22(8): 969-978

Baddeley, A. D. 1986. *Working Memory*. New York: Oxford University Press.

Baddeley, A. D. 1996. "Exploring the Central Executive." *Quarterly Journal of Experimental Psychology* 49: 5-28

Baddeley, A. D. 2007. *Working Memory, Thought, and Action*. Oxford: Oxford University Press.

Baddeley, A. D. 2012. "Working Memory: Theories, Models, and Controversies." *Annu. Rev. Psychol.* 63:1-29

Bechtel, W. 2008. *Mental Mechanisms: Philosophical Perspectives on Cognitive Neuroscience*. London: Routledge.

Block, N. 1993. "Review of Daniel Dennett, *Consciousness Explained*." In N. Block, *Consciousness, Function, and Representation (pp. 129-140)*, Cambridge, MA: MIT Press.

Block, N. 1994. "What is Dennett's Theory a Theory of?" In N. Block, *Consciousness, Function, and Representation (pp. 141-158)*, Cambridge, MA: MIT Press.

Block, N. 1995. "On a Confusion about a Function of Consciousness." In N. Block, *Consciousness, Function, and Representation (pp. 159-214)*, Cambridge, MA: MIT Press.

Block, N. 2013. "Seeing and Windows of Integration." *Thought: A Journal of Philosophy* 1(3): DOI: 10.1002/tht62

Block, N. 2015. "The Puzzle of Perceptual Precision." In J. Windt & T. Metzinger (eds.), *MIND Anniversary Collection*, Cambridge, MA: MIT

Block, N. 2016. "The Anna Karenina Principle and Skepticism about Unconscious Perception." Philosophy and Phenomenological Research 93(2)

Block, N. [MS]. "There is a joint in nature between cognition and perception even though cognitive penetration is rife and there is no modularity of mind."

Block, N. & Phillips, I. 2016. "Unconscious Seeing." In B. Nanay (ed.), *Current Controversies in Philosophy of Perception*, London: Routledge

Brady, T., Konkle, T., Alvarez, G. & Oliva, A. 2008. "Visual Long-Term Memory has a Massive Storage Capacity for Object Details." *Proceedings of the National Academy of Sciences* 105: 14325-14329

Brady, T., Konkle, T. & Alvarez, G. 2011. "A Review of Visual Memory Capacity: Beyond Individual Items and Toward Structured Representations." *Journal of Vision* 11: 1-34

Broadbent, D. 1958. *Perception and Communication*. London: Pergamon Press.

Buchsbaum, B. & D'Esposito, M. 2008. "Short Term and Working Memory Systems." In H, Eichenbaum (ed.), *Memory Systems Vol. 3, Learning and Memory: A Comprehensive Reference, 4 Vols. (J. Byrne (ed.))* (pp. 237-260), Oxford: Elsevier.

Buehler, D. 2014. *Psychological Agency – Guidance of Visual Attention*. UCLA Dissertation.

Burge, T. 2010. *Origins of Objectivity*. Oxford: Oxford University Press.

Burge, T. 2010a. "Origins of Perception." *Disputatio* 4(29): 1-38

Burge, T. 2010b. "Steps Towards Origins of Propositional Thought." *Disputatio* 4(29): 39-67

Burge, T. 2010c. "Modest Dualism." In T. Burge (2013), *Cognition Through Understanding. Self-Knowledge, Interlocution, Reasoning, Reflection. Philosophical Essays Vol. 3 (pp. 471-488)*. Oxford: Oxford University Press

Butterfill, S. & Sinigaglia, C. 2012. "Intention and Motor Representation in Purposive Action." *Philosophy and Phenomenological Research* 88(1): 119-145

Carey, S. 2009. *The Origin of Concepts*. Oxford: Oxford University Press.

Carruthers, P. 2015. *The Centered Mind. What the Science of Working Memory Shows Us about the Nature of Human Thought*. Oxford: OUP

Clark, A. 2009. "On Executive Attention." *Association for the Study of Consciousness*. http://www.theassc.org/files/assc/2586.pdf

Clark, K., Noudoost, B., Schafer, R. & Moore, T. 2014. "Neural Mechanisms of Attentional Control: Frontal Cortex." In A. Nobre & S. Kastner (eds.), *The Oxford Handbook of Attention (pp. 375-398)*, Oxford: Oxford University Press.

Conway, A., Jarrold, C., Kane, M., Miyake, A., & Towse, J. (eds.) 2007. *Variation in Working Memory*. Oxford: Oxford University Press.

Cowan, N. 2005. *Working Memory Capacity*. New York: Psychology Press.

Cowan, N. 1995. *Attention and Memory: An Integrated Framework*. Oxford Psychology Series #26. New York: Oxford University Press.

Craver, C. 2007. *Explaining the Brain. Mechanisms and the Mosaic Unity of Neuroscience*. New York: Oxford University Press.

Dennett, D. 1978. *Brainstorms: Philosophical Essays on Mind and Psychology*. Montgomery, VT: Bradford Books.

Dennett, D. 1994. *Consciousness Explained*. Boston: Little, Brown & Co.

Dennett, D. 2005. *Sweet Dreams: Philosophical Obstacles to a Science of Consciousness (Jean Nicod Lectures)*. Cambridge, MA: MIT Press.

Duque, J., Labrua, L. Verset, S., Olivier, E. & Ivry, R. 2012. "Dissociating the Role of Prefrontal and Premotor Cortices in Controlling Inhibitory Mechanisms during Motor Preparation." *Journal of Neuroscience* 32: 806-816

Duque, J., Olivier, E. & Rushworth, M. 2013. "Top-down Inhibitory Control Exerted by the Media Frontal Cortex during Action Selection under Conflict." *Journal of Cognitive Neuroscience* 25(10): 1634-1648

Firestone, C. & Scholl, B. 2016. "Cognition does not Affect Perception: Evaluating the Evidence for 'Top-Down' Effects." *Behavioral and Brain Sciences* 39: 1-77

Fockert, J. & Bremner, A. 2011. "Release of Inattentional Blindness by High Working Memory Load: Elucidating the Relationship between Working Memory and Selective Attention." *Cognition* 121: 400-408

Friedman, N. & Miyake, A. 2004. "The Relations among Inhibition and Interference Control Functions: A Latent-Variable Analysis." *Journal of Experimental Psychology: General* 133(1): 101-135

Friedman, N., Miyake, A., Corley, R. Young, S. Defries, J. & Hewitt, J. 2006. "Not all executive functions are related to intelligence." *Psychological science* 17: 172-9

Fodor, J. 1983. *The Modularity of Mind*. MIT Press.

Fodor, J. 2001. *The Mind Doesn't Work That Way. The Scope and Limits of Computational Psychology*. Cambridge, MA: MIT Press

Fodor, J. & Pylyshyn, Z. 1988. "Connectionism and Cognitive Architecture." In S.Pinker & J. Mehler (eds.) *Connections and Symbols*. Cambridge, MA: MIT Press

Fougnie, D. 2009. "The Relationship between Attention and Working Memory." In N. B. Johansen (ed.), *New Research on Short-Term Memory* (pp. 1- 45), New York: Nova Science Publishers.

Frisby, J. & Stone, J. 2010. *Seeing*. Cambridge, MA: MIT Press.

Funahashi, S. 2007. "The General-Purpose Working Memory System and Functions of the Dorsolateral Prefrontal Cortex." In N. Osaka, R. Logie & M. D'Esposito (eds.), *The Cognitive Neuroscience of Working Memory,* (pp. 213-230), Oxford: Oxford University Press.

Fuster, J. 2015. *The prefrontal cortex*. New York: Academic Press.

Garson, J. 2010. "Connectionism." *The Stanford Encyclopedia of Philosophy* (Winter 2012 Edition), E. Zalta (ed.), URL = <http://plato.stanford.edu/archives/win2012/entries/connectionism/>.

Gazzaley, A. & D'Esposito, M. 2006. "Unifying the Prefrontal Cortex: Executive Control, Neural Networks, and Top-Down Modulation." In B. Miller & J. Cummings (eds.), *The Human Frontal Lobes. Functions and Disorders.* (pp. 187-207) New York: Guilford Press.

Gazzaley, A. & D'Esposito, M. 2007. "Top-Down Modulation in Visual Working Memory." In N. Osaka, R. Logie & M. D'Esposito (eds.), *The Cognitive Neuroscience of Working Memory,* (pp. 197-212), Oxford: Oxford University Press.

Goldman-Rakic, P. 1987. "Circuitry of Primate Prefrontal Cortex and Regulation of Behavior by Representational Memory." In F. Plum (ed.), *Handbook of Phyiology – The Nervous System, Vol. 5* (pp. 373-417), Bethesda, MD: American Physiological Society.

Gottlieb, J. 2007. "From Thought to Action: The Parietal Cortex as a Bridge between Perception, Action, and Cognition." *Neuron* 53: 9-16

Gottlieb, J. 2014. "Neural Mechanisms of Attentional Control: Parietal Cortex." In A. Nobre & S. Kastner (eds.), *The Oxford Handbook of Attention (pp. 346-374)*, Oxford: Oxford University Press.

Horgan, T. 1997. "Connectionism and the Philosophical Foundations of Cognitive Science." *Metaphilosophy* 28(1/2): 1-30

Inzlicht, M. & Schmeichel, B. 2012. "What is Ego Depletion? Toward a Mechanistic Revision of the Resource Model of Self-Control." *Perspectives on Psychological Science* 7(5): 450-465.

Jurado, M. & Roselli, M. 2007. "The Elusive Nature of Executive Functions: A Review of our Current Understanding." *Neuropsychological Review* 17: 213-233

Kahneman, D. 1973. *Attention and Effort*. Englewood Cliffs, NJ: Prentice Hall.

Kane, M., Bleckley, M., Conway, A. & Engle, R. 2001. "A Controlled-Attention View of Working Memory Capacity." *Journal of Experimental Psychology: General* 130: 169-183

Kurzban, R., Duckworth, A., Kable, J. & Myers, J. 2013. "An Opportunity Cost Model of Subjective Effort and Task Performance." *Behavioral and Brain Sciences* 36(6): 661-726

Lavie, N. & Dalton, P. 2014. "Load Theory of Attention and Cognitive Control." In A. Nobre & S. Kastner (eds.), *The Oxford Handbook of Attention (pp. 56-75)*, Oxford: Oxford University Press.

Machamer, E., Darden, L. & Craver, C. 2000. "Thinking about Mechanisms." *Philosophy of Science* 67(1): 1-25

Marr, D. 1982. *Vision*. New York: Freeman.

Miller, E. & Cohen, J. 2001. "An Integrative Theory of Prefrontal Cortex Function." *Annual Review of Neuroscience* 24: 167-202

Miller, B. & D'Esposito, M. 2005. "Searching for "the Top" in Top-Down Control." *Neuron* 48: 535-538

Miyake, A. & Shah, P. (eds.) 1999. *Models of Working Memory. Mechanisms of Active Maintenance and Executive Control.* New York: Cambridge University Press.

Miyake, A. & Friedman, N. 2012. "The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions." *Current Directions in Psychological Science* 21(1): 8-14

Miyake, A., Friedman, N., Emerson, M., Witzki, A., Howerter, A. & Wager, T. 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

Miyake, A., Friedman, N., Rettinger, D., Shah, P. & Hegarty, M. 2001. "How are Visuospatial Working Memory, Executive Functioning, and Spatial Abilities Related? A Latent-Variable Analysis." *Journal of Experimental Psychology* 130(4): 621-640.

Monsell, S. & Driver, J. 2000. "Banishing the Control Homunculus." In S. Monsell & J. Driver (eds.), *Control of Cognitive Processes: Attention and Performance XVIII* (pp. 3-32), Cambridge, MA: MIT Press.

Mole, C. 2010. *Attention as Cognitive Unison: An Essay in Philosophical Psychology*. Oxford: Oxford University Press.

Munakata, Y., Herd, S., Chatham, C., Depue, B., Banich, M. & O'Reilly, R. 2011. "A Unified Framework for Inhibitory Control." *Trends in Cognitive Sciences* 15(10): 453-459

Munakata, Y., Snyder, H. & Chatham, C. 2012. "Developing Cognitive Control: Three Key Transitions." *Current Directions in the Psychological Sciences* 21(2): 71-77

Neubert, F., Mars, R., Buch, E., Olivier, E. & Rushworth, M. 2010. "Cortical and Subcortical Interactions during Action Reprogramming and their Related White Matter Pathways." *Proceedings of the National Academy of Sciences, USA* 107: 13240-13245

Norman, D., & Shallice, T. 1986. "Attention to action: Willed and Automatic Control of Behavior." In R. J. Davidson, G. E. Schwartz, & D. Shapiro, (Eds.), *Consciousness and Self-regulation: Advances in Research, Vol. IV (pp. 1-18)*. New York: Plenum Press.

O'Reilly, R. 2006. "Biologically Based Computational Models of High-Level Cognition." *Science* 314: 91-94

Palmer, S. 1999. *Vision science*. Cambridge: MIT Press

Passingham, R. & Wise, S. 2012. *The neurobiology of the prefrontal cortex*. Oxford: OUP

Piccinini, G. & Craver, C. 2011. "Integrating Psychology and Neuroscience: Functional Analyses as Mechanism Sketches." *Synthese* 183(3): 283-311

Phillips, I. 2016. "Consciousness and Criterion: On Block's Case for Unconscious Perception." *Philosophy and Phenomenological Research* 93(2)

Pockett, S. 2002. "On Subjective Back-Referral and how long it takes to become Conscious of a Stimulus: A Reinterpretation of Libet's Data." *Consciousness and Cognition* 11(2): 144-161

Rabbitt, P. (ed.) 1997. *Methodology of Frontal and Executive Function*. Hove, UK: Psychology Press

Rabbitt, P. 1997a. "Introduction: Methodologies and Models in the Study of Executive Function." In P. Rabbitt (ed.) 1997. *Methodology of Frontal and Executive Function (pp. 1-38)*. Hove, UK: Psychology Press

Reis, J. et al. 2007. "Contribution of Transcranial Magnetic Stimulation to the Understanding of Cortical Mechanisms involved in Motor Control." *Journal of Physiology* 586: 325-351

Reynolds, J., Braver, T., Brown, J. & Van der Stigchel, S. 2006. "Computational and neural mechanisms of task switching." *Neurocomputing* 69: 1332-36

Richland, L. & Burchinal, M. 2013. "Early executive function predicts reasoning development." *Psychological science* 24(1)

Rumelhart, D., Hinton, G. & McClelland, J. 1986. "A framework for Parallel Distributed Processing." In Rumelhart, D., McClelland, J., & the PDP research group. *Parallel distributed processing: Explorations in the microstructure of cognition. Volume I.* Cambridge, MA: MIT Press.

Shea, N. 2015. "Distinguishing Top-Down from Bottom-Up Effects." In Biggs, Matthen & Stokes (eds.), *Perception and its Modalities*, Oxford: OUP.

Shiffrin, R. & Schneider, W. 1977. "Controlled and Automatic Information Processing: II. Perception, Learning, Automatic Attending, and a General Theory." *Psychological Review* 84: 127-190

Soto, D., Mäntylä, T. & Silvanto, J. 2011. "Working Memory Without Consciousness." *Current Biology* 21(22): 912-913

Squire, L. 2004. "Memory Systems of the Brain: A Brief History and Current Perspective." *Neurobiology of Leaning and Memory* 82: 171-177

Stanovich, K. 2010. *Rationality and the Reflective Mind.* Oxford: Oxford University Press.

Stanovich, K. & West, R. 2000. "Individual Differences in Reasoning: Implications for the Rationality Debate?" *Behavioral and Brain Sciences* 23: 645-726

Stinson, C. 2009. "Searching for the Source of Executive Attention." *Psyche* 15: 137-154

Stinson, C. 2016. "Mechanisms in Psychology: Ripping Nature at its Seams." *Synthese* 193: 1585-1614

Stokes, M. & Duncan, J. 2014. "Dynamic brain states for preparatory attention and working memory." In K. Nobre & S. Kastner (eds.), *The Oxford Handbook of Attention*, Oxford: OUP

Thompson, B. 2004. *Exploratory and Confirmatory Factor Analysis. Understanding Concepts and Applications*. Washington, DC: APA

Watzl, S. 2017. *Structuring Mind: The Nature of Attention and How it Shapes Consciousness*. Oxford: Oxford University Press.

Weiskopf, D. 2011. "Models and Mechanisms in Psychological Explanation." *Synthese* 183(3): 313-338

Weiskopf, D. 2016. "Integrative Modeling and the Role of Neural Constraints." *Philosophy of Science* 83(5): 674:685

Weiskopf, D. [forthcoming]. "The Explanatory Autonomy of Cognitive Models." In M. Kaplan (ed.), *Integrating Psychology and Neuroscience: Prospects and Problems*, Oxford: Oxford University Press.

Wu, W. 2014. *Attention*. New York: Routledge.

Zaitchik, D., Iqbal, Y. & Carey, S. 2014. "The Effect of Executive Function on Biological Reasoning in Young Children: An Individual Differences Study." *Child Development* 85(1): 160-175

Zelazo, P., Carter, A., Reznick, S. & Frye, E. 1997. "Early development of executive function: a problem-solving framework." Review of general psychology 1(2): 198-226