**MASTER THESIS**

# AUTONOMY THROUGH TECHNOLOGY

## ENGAGING EXECUTIVE FUNCTIONS IN ADHD WITH AN EXTENDED MIND APPROACH

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# Table of Contents

# Chapter 1: Introduction

The treatment of ADHD has become increasingly well-researched in recent years. Knowledge on effectivity of both pharmaceutical and behavioral therapies is increasing. However, they are limited in many ways, and access to such treatments remains a dependent on a person's social, structural and political environment. Due to the widespread nature of technology, it is worthwhile to consider this as potential source of accessible aid. In this thesis, I will argue that Executive Function (EF) is a core mechanism for human autonomy. In those with EF deficits, as is the case in ADHD, their deficits infringe on the development of personal autonomy. This thesis explores what is necessary to stimulate autonomy through cognitive technology, by focusing on cognitive enabling technologies in the treatment of executive function (EF) deficit in adult attention deficit hyperactivity disorder (ADHD).

**Relevance**: The true prevalence of ADHD is unclear, as research often comes up with different numbers depending on method and diagnostic criteria. Executive Function (EF) deficits are a historically overlooked part of ADHD that is receiving more attention recently, and are clearly impaired in not just ADHD but many disorders and under certain conditions in 'neurotypical' people as well, making this research highly generalizable with further work. The proposed technology would answer a clear and present need for these people, and it would be hard to overestimate how many people would benefit.

**Research Questions** & **Methodology:** This thesis aims to examine the current epistemic knowledge of the topic, place it in the context of philosophical theories, societal influence and scientific practice, and analyze this knowledge, in order to understand how to apply it in practice. I adopt constructivist[1] epistemological assumptions underlying methodological frameworks. That is to say that understanding humans is not possible through reductionist methods, but rather through recognizing that science is value-laden and needs to be understood in its cultural, historical and technological context. Because EF is a notion recognized in many fields, epistemic diversity is ensured by incorporating academic knowledge from philosophical, psychological, neuroscientific, biological, evolutionary, archeological and anthropological research.

Part I encorporates exploratory literature research on what we know about EF, followed by phenomenological analysis and interpretation. Chapter 2 will examine social epistemology among experts, to give us an idea what EF is and how exactly it is impaired in ADHD. By examining the historical evolution of the concept and the process of synthesis and consensus will produce more useful knowledge than picking one of the many definitions of EF at 'random'. Chapter 3 assumes the reader has basic understanding of philosophy of mind, specifically extended mind theory. It analyzes the context in which we should be understanding EF by examining the paradigm under which most of this knowledge was created, and how we may address its limits.

[1] as opposed to positivist

Part II will take this knowledge and examine how to affect it through technology. Recently, research has been published which re-interprets existing phenomena through extended mind theory, and have found explanatory power in aspects that were previously contested. Having argued for an extended mind framework, chapter 4 focuses on re-interpretation in light of EMT to bring readily available theoretical knowledge into practical application as relevant to the topic, and strengthening evidence for an extended mind view in the process. Chapter 5 This part will combine evidence from previous research with argumentation to form specific technology recommendations.

**Main contribution**: This will serve to expand on existing literature on treatment of ADHD by answering the need for additional strategies with suggestions for a long-term reliable technology.

**Layout**: Part I is dedicated to reviewing literature, first of executive functions, and second of our current understanding of mind. Chapter 2 is based on a multidisciplinary review including psychological, neurophysiological and evolutionary literature, with attention to the influence of scientific practice on the progress and development of the field. By examining what EF is and how to understand it in the context of scientific progress, it will become apparent that EF is a crucial component in human self-regulation in both thought and action. Goal-directed behavior as an agent of free will, cannot arise without properly developed EF. As such, those with EF deficits due to mental illness or other circumstances are less able to sustain action over time, as is required for goal-directed behavior in general and for the creation of self-reliance specifically. This lack of ability to develop self-sufficiency has several negative consequences for both the individual and their environment. This shows, I argue, that in order to see long term gains there is a need for ADHD treatment to account for EFd. To show that in studying EF as a component of mind, it must be considered extended, as the identified operational definition by Barkley (2012a) does. By examining EF in the light of EMT, a picture starts to form that argues that technology is a viable enabling option.

Part II is dedicated to finding out what such a technology might need to look like. Chapter 4 examines what we know about EF and goal-directed behavior, so as to produce a concise outline of strategies for candidate technologies to employ. Chapter 5 integrates the gathered information and examine them and offers evidence for recommendations for bringing the found principles for candidate technologies into a technological design.

# Part I: Theoretical Background

## Chapter 2: Condensed Review of Executive Function Literature

Though executive function (EF) is a widely recognized and long-researched topic of interest, there is little true consensus over that *exactly* it is. When recognizing the subtle differences in definitions by various researchers, the overall picture of EF becomes vague at best. The first goal of this chapter is therefore to present a clear and concise overview of what may be considered to be EF, and why. This will be approached by examining social epistemic discourse[2] in academia in practice. By examining social epistemic attitudes, institutions, trust, attitudes and diversity, and the processes of coming to consensus, a narrative will form that shows the current academic understanding of the topic as well as how to place this in context. Attention will also be paid to the use of technology in this process and how this influenced practice. It will be argued that for the purposes of this thesis, the operational definition of EF and model for understanding can be drawn from the work of Russel A. Barkley (2012a). Secondly, this chapter investigates what the inherent consequences are for those who have EF deficits, like those with ADHD. It will be argued that EF deficits interfere in goal-directed behavior across settings and into most every aspect of life. This corrupts the neurological basis for personal autonomy, and affects the formation of self and ability to act consciously. ADHD should more explicitly account for EF deficits if treatment is to be effective as a general rule, but particularly when one wishes to increase autonomy and increase treatment effectivity in the long term.

### 2.1 Identifying Executive Functions

Executive functions (EF) are generally understood to be a set of cognitive processes that drive the cognitive control over behavior, specifically in regards to goal-attainment and the processes involved in this. What does this mean, precisely?

#### An Incredibly Short History of Executive Function

Finding its origins in research into the functions of the frontal lobe and the prefrontal cortex (PFC), the term ‘Executive Function’ was introduced to refer to the neurophysiological functions of the prefrontal and premotor regions of the brain (Barkley, 2012a). Noted scientists in the field “observed that damaging the prefrontal lobes resulted in a disintegration of goal-directed behavior, which they say as the principal function of the PFC” (Barkley, 2012a, p. 14). Thus, the study into goal-directed behavior began.

[2] Research into social epistemology in practice often suggests that single authors do not always know, but the collective distributed group seems to have a pretty good grasp.

"Although the concept of EF was first defined in the 1970s, the concept of a control mechanism was discussed as far back as the 1840s." (Goldstein et al., 2014, p. 3). Those familiar with the case of Phineas Gage in 1840, know that this man suffered a large iron rod straight through the left Frontal Lobe and lived[3]. The consequent changes to his behavior and character have made for a fascinating case study even into the modern era. Among other changes, Phineas appeared to be disinhibited and hyperactive, and showed a lack of initiative or drive. This lack of drive in behavior indicated this area of the brain had some function in controlling goal-directed behavior. Since then, much of EF conceptualization has been driven by studies on individuals with frontal lobe lesions. Such individuals were often reported to become disorganized in their actions and strategies in normal everyday conditions. With this apparent disruption of goal-directed behavior, discussion became centralized to (what would later come to be known as) EFs as the function of the PFC. As theory mounted and mechanisms became clearer, common acceptance of EF as an established theory grew in scientific community. By the 1950s scientific consensus slowly emerged for the idea that a cognitive control system is housed in the PFC (Goldstein et al., 2014). How exactly this cognitive control system works and what it does were now a subject of interest.

The initial source of the investigations into the term *Executive Functions* is widely attributed. Those who wish to trace its origins will likely encounter the works of Alexander Luria (1966), Alan Baddeley[4] (1986) and more (sidebars 1 and 2). "At the time, Luria proposed the existence of a system in charge of intentionality, the formulation of goals, the plans of action subordinate to the goals, the identification of goal-appropriate cognitive routines, the sequential access to these routines, the temporally ordered transition from one routine to another, and the editorial evaluation of the outcome of our actions." (Baars & Gage, 2010, p. 405). All in all, different sources attribute different origins for the concept of EF. Clearly, as the progress of many scientific concepts goes, it was not the product of a lone genius but a cumulative collaboration of scientists building on each other's work. This may have contributed to the lack of single coherent definition, but rather a collection of overlapping definitions that is seen reflected in works within and across domains.

As research into the field progressed, the exact processes identified to be involved became more varied and more complex. EF is now known to also be involved in emotional, social, economic, and moral domains among others (Barkley, 2012a). "Executive functions (EFs) make possible mentally playing with ideas; taking the time to think before acting; meeting novel, unanticipated challenges; resisting temptations; and staying focused." (Diamond, 2013, p. 135). The story being told here is one of discovery into what makes a person act toward their goals, and how exactly the brain (specifically the PFC) is involved. What has been found is that EFs allow us to rise above our automatic reactions to the environment and to direct our attention toward goal-attainment. To act in a way that is human.

[3] "Phineas Gage offers perhaps one of the most fascinating case studies associated with EF. In 1840, as a railroad construction foreman, Phineas was pierced with a large iron rod through his frontal lobe. This accident destroyed a majority of his left temporal lobe. Phineas survived and after a period of recovery changes in Phineas' behavior and personality became apparent. Phineas was described as "disinhibited" or "hyperactive". Which suggested a lack of inhibitions often found in those with damage to the pre-frontal cortex." (Goldstein et al., 2014, p. 3).

[4] Another source of "the term comes from Alan Baddeley's (1986) influential model of working memory in which there are separate short-term storage systems for verbal and visual information and a central executive that operates on the contents in storage" (Smith & Kosslyn, 2013, p. 281).

| | |
|---|---|
| 1953 – | D. Broadbent describes difference between automatic and controlled processes. |
| 1975 – | M. Posner introduces 'cognitive control' as an executive branch of the attentional system that focusses |
| 1977 – | Shifrin and Schneider suggest the idea of 'selective attention' |
| 1986 – | Baddeley proposes that a 'central executive' allows for the manipulation of short-term memory, as a mechanism of the Working Memory system. |
| 1988 – | T. Shallice suggests attention is regulated by a supervisory system which can override automatic responses in favor of scheduling behavior. |

*SIDEBAR 1: Sample **of historically significant findings in EF research.** From: Goldstein et al., 2014.*

| | |
|---|---|
| Information-Processing Theory of EF | (Borkowski & Burke, 1996) |
| Theory of Cross-Temporal Organization | (Fuster, 1989) |
| Theory of Goal Neglect | (Duncan, 1986) |
| Behavioral Theory of EF as Rule-Governed Behavioral | (Hayes, 1996) |
| Hierarchical Model of EF | (Stuss & Benson, 1986) |

*SIDEBAR 2: Some **historical theories of EF**.*

## Definitional Problems and Scientific Consensus

EF is controversial, only in the sense that discussions don't seem to have crystalized into a single clear and distinct definition despite controlled experimentation and professional argumentation. When there is non-consensus among the experts, social epistemology and hot cognition[5] become more prominent alongside supposed cold cognitive logic (Solomon, 2014). Therefore it is important to understand the prominent challenges facing EF research and the surrounding scientific narrative.

### *Defining EF Turns Out to be Pretty Hard*

There is a problem in the origin of the term EF. As has been shown, EF was historically viewed as the principal function of the PFC. However, Barkley (2012a) argues that "the origin of these processes in the PFC as a basis for defining EF is a nonstarter" (Barkley, 2012a, p. 174). He points out that using this as a definitional criteria is problematic, as it has created a circularity of reasoning on the topic[6]. By defining EFs as 'the function of the PFC' while defining the function of the PFC as 'EFs', neither are truly defined. This conflates our understanding of both as an object of study. As such, care must be taken in the discourse surrounding it to ensure the object of study is in fact one and the same object and not an ambiguous collection of similar or related constructs. The scientific fields that concern themselves with EFs have their own jargon surrounding the term that uses the same term to refer to what is essentially the same concept across fields, but show a difference in specific theoretical and mechanical knowledge of the concept. Underlying theory of mind, for instance, is a base understanding of how the mind works. The underlying theory of mind shows nuances between some scientific fields and gaping differences between others. If left unadressed, this conflates understanding of EF in the discourse between all the fields that concern themselves with it. Chapter 3 goes further into the current state of the field in theory of mind.

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[5] Cognition influenced by emotion and other non-logical biases.

[6] "The term "EF" came out of these earlier efforts to understand the neuropsychological functions mediated by the prefrontal or premotor regions of the brain. This history has led to a conflating of the term "EF" with the functions of the PFC and vice versa." (Barkley, 2012a, p. 1) (EF→ fPFC, fPFC → EF)

Consensus on the totality of EF and of which mechanisms specifically make it up differ per field, underlying theory of mind and even per author. If this part of our brain does *something* (employ EFs) in order to achieve *something* (goal-directed behavior), then *how* does it do so? In the attempts by various authors to define EF in their research, we find a discussion fairly decided on the general function of EFs as self-regulation in service of goal-attainment. Where authors disagree is often about which mental or neurological processes to include and which to exclude, and how they fit together. Over the years the amount of definitional interpretations of EF have increased and diversified to include various concepts including, but not limited to, *abstract thinking, anticipation, attentional control, behavioral regulation, cognitive flexibility, -estimation, and -inhibition, critical faculty, emotional regulation, goal-directed action, goal selection, impulse control, inhibitory control, initiation of action, interference control, mental flexibility, monitoring, motivation, motor-control, perception, planning, problem-solving, prospective memory, rule-adoption, rule-acquisition, self-awareness, self-directed action, self-regulation, sensory-motor action, sequencing, social maturity, switching, utilization of feedback, volition, and working memory*. "Executive function (EF) has come to be an umbrella term used for a diversity of hypothesized cognitive processes, … carried out by prefrontal areas of the frontal lobes." (Goldstein et al., 2014, p. 3). There is as of yet little true consensus in making a clear distinction between which mental faculties belong under the term 'executive' and which ones do not. This lack of specificity presents problems for researchers. Many authors present notions of EF seem to be irrevocably tied to other cognitive processes, most prominent among which are inhibition, working memory, planning, and mental flexibility and problem solving. While these processes have all shown a connection to EF in previous studies, they do not encompass what is necessary for self-regulation by themselves. "Some [authors] also limited the definition of EF to simply that of sustaining problem solving toward goals. Problem solving is only one type or component of EF according to various earlier model and not its sole or essential nature." (Barkley, 2012a, p. 174). It is when these cognitive processes are equated with EF to the exclusion of others, that researchers lose sight of the whole. The neurophysiological mechanisms of EF are not yet clear. The interactionary nature of mental processes with not just each other, but also the external environment, mean that this is a puzzle that will not soon be completely solved. Therefore, we must do the best we can with the most reliable information that we have.

In his book on Executive Functions, Barkley (2012a) argues that many of the current operational definitions of EF used in research are less of a solid set of clearly demarcated constructs (based on 'hard' scientific evidence) and more an almost arbitrary choice from among the many related constructs, usually based on popularity and expert opinion. Barkley (2012a) argues that consensus of opinion is not sufficient evidence for its truth, and thus "does nothing to advance the clarity or operationalizing of a definition of a scientific construct such as EF."[7] (p.8). And indeed, "Consensus is not truth, it is merely agreement." (Solomon, 2014, p. 253) So how can we know EF from among the mountain of research that has been done on it? What can we accept as an operational definition of EF? The constructs mentioned in this section are all pieces of the puzzle to keep in mind as we further uncover what EF really is. All pieces that seem to fit together in a way that allows a human to act towards goals in accordance with their will as determined by the self.

[7] For example: Eslinger collected (1996) 33 terms considered to be EF, based on the participation of 10 experts on EF at a conference. "The greatest agreement (endorsed by 40% or more of the participants) existed for the following six components of EF: self-regulation, sequencing of behavior, flexibility, response inhibition, planning, and organization of behavior" (Barkley, 2012a, p. 8) , which were then the 6 terms proposed as definitional for EF.

*The Trouble in Measuring EFs*

Some authors have chosen to attempt definitional clarity through the tests designed to quantify EF. This has several problems. For one, defining something by the technologies made to quantify them inevitably leads back to construction criteria and use. Tests might prove prominent simply because they went with what was easiest to construct. Focus on the most easily measurable concepts of EF to the exclusion of the more difficult leads to huge gaps in knowledge and an incomplete picture of the whole. Tests might prove prominent because they are most popular or most widely accessible. There have been many cases where the spread of a technology has been dominated by a specific artefact for reasons other than its quality. There are several instances of this reflected in practice.

Cognitivist models of EF, for instance, have excluded the study of emotion in relation to EF for a long time despite historical evidence of a correlation between the two. Some authors speculate that this is because of the dominant cognitivist computer-metaphor of the mind, as computers having no emotions to interact with processes, and thus scientists did not pursue it. Others have argued that emotions have long been too difficult to reliably measure, leading to a lack of psychometric testability and a gross underrepresentation in research. This is the exclusion of a construct because scientists lack the tools to measure it. The omission of emotion from models of EF despite evidence is not plausible.

Best, Miller and Jones (2009)' definition of EF identified 15 components of contemporary EF research through meta-analysis, and chose 4 of the most frequently published to present as the central constructs of EF: (1) inhibition, (2) working memory, (3) shifting, and (4) planning (including problem solving). As Barkley (2012a) points out, the choice for the 4 most popular constructs to define EF to the exclusion of the other 11 (of the 15 identified) is not the result of solid scientific argumentation, but a "psychometric popularity contest". This implies that there is hot cognition at play, the authors having reached synthesis by omission of evidence.

What of the artefacts themselves? "Over the past 40 years occasional voices have been raised warning that neuropsychological tests of EF were problematic. The tests were unlikely to be capturing much of what is considered to be the essence of EF or its important features as humans use it in their daily life or to be adversely affected by injuries to the PFC[8]" (Barkley, 2012a, p. 9). Barkley makes many arguments as to the fallibility of EF tests: they (1) do not assess self-regulation directly, (2) miss cross-temporal aspects of EF due to the nature of test-taking in short time intervals, (3) ignore social purposes for which it evolved, and (4) fail to recognize significance of reciprocity, cooperation, mutualism and culture (Barkley, 2012a). They also often only test one tiny fraction of the totality of EF. Executive Function tests are made to test specific cognitive functions, such as working memory or attentional abilities. This does not show the extent of EF deficits as a whole, nor does it accurately represent the effects on a person's life. The impact of EF deficits on real life scenarios are not shown by the average EF test. After all, "a patient with damaged frontal lobes retains, at least to a certain degree, the ability to exercise most cognitive skills in isolation (Luria, 1966). Basic abilities such as reading, writing, simple computations, verbal expression, and movements may remain largely unimpaired. Deceptively, the patient will perform well on the psychological tests measuring these functions in isolation. However, any synthetic activity requiring the coordination of many cognitive skills into a coherent, goal-directed process will become severely impaired." (Baars & Gage, 2010, p. 414). Does this mean all EF tests are useless? No. Psychometric tests cannot capture EF in its totality,

[8] Barkley, 2001; Dimond, 1980; Dodrill, 1997; Lezak, 2004; Rabbitt, 1997; Shallice & Burgess, 1991.

but it can offer insight into its constituent processes. This simply calls for careful examination of psychometric tests with attention to what exactly they measure. After all, the previously described lack of solid operational clarity gives rise to the following problem: "If the term is not defined operationally, then anything goes; any measure or test can be declared to be executive in nature by mere assertion." (Barkley, 2012a, p. 190)

We must remember that EF tests are constructs in use, and as such subject to its surrounding architecture. Measures of EF are products of a process, and not a golden standard of objectivity. Concepts of EF are limited by both hot cognition in the scientific process and by technology constraints. Therefore, EFs cannot reliably be defined by the artefacts made to assess them.

## Operational Definition

The concept of EF has shown to be closely tied to the human behavior of planning for and acting towards goal-attainment. There is strong neuroscientific and psychological evidence that acting towards goals is a complex process of both conscious and unconscious mechanisms. In order to contribute to the clarity of discourse surrounding EF, we will show weighed epistemic trust[9] in the expertise of academic authorities (as subject to peer review). Barkley (2012a) provides an extended view[10] of EFs in a way that accounts for scientific consensus[11], while remaining critical of the history these definitions have undergone and how this has shaped current discourse. This definition also accounts for EF's neurological substrates, developmental nature, and their interaction with their social and cultural environment[12]. In doing so, Barkley shapes a picture of an acting individual[13], not a passive automaton. Therefore, for the purposes of this thesis we will define Executive Functions as follows:

> "EF is the use of self-directed actions so as to choose goals and to select, enact, and sustain actions across the time toward these goals, usually in the context of others, often relying on social and cultural means for the maximization of one's longer-term welfare as the person defines that to be". (Barkley, 2012a, p. 174).

With this definition of EF, Barkley notes that a mature EF system is a highly interrelated collection of functions working together to bring about complex behavior. Specifically, eight developmental capacities arise out of a working EF system (Barkley, 2012a).

[9] Like any piece of scientific progress, the model will likely be changed in time with progress. Only the future will reveal the accuracy of current knowledge. For now, however, it is recent and up to date with scientific progress while being cognizant of the past, it is supported by evidence, and was constructed by a psychiatric authority on executive function and adult attention deficit hyperactivity disorder. This is enough to show epistemic trust.

[10] See Chapter 3

[11] "I will accept my starting point for defining EF the most commonly agreed upon feature of it as noted in the survey of neuropsychologists by Eslinger (1996) – EF is self-regulation." (Barkley, 2012a, p. 34).

[12] "to start with a given set of mental functions compromising EF and look outward as to how they impact the individual's behavior, daily functioning, social relations, cooperative ventures, economic transactions, and even moral, legal, occupational, child-rearing, and community activities."(Barkley, 2012a, p. 36).

[13] "The computer metaphor of EF possessing a central executive or ghost in the machine will be abandoned here in favor of an acting self that ponders choices, makes decisions, and enacts those decisions over extensive periods of time and large social networks." (Barkley, 2012a, p. 35)

(1) The individual has a grasp on the **spatial** distance over which to contemplate goals and means, and purposefully rearrange their physical environment to assist goal-attainment.
(2) The individual has the **temporal** capacity to reflect on and take action to prepare for future events. A mature EF system will have a larger time-horizon than an undeveloped one[14].
(3) The individual has the capacity for "hot" appraisal of the contemplated future, giving personal valuation of the goal with emotion. This **motivational** capacity arises out of the previous two "cold" cognitive abilities, and allows the individual is able to act with time preference (e.g. willing to wait for delayed gratification).
(4) The individual has the capacity to **inhibit** prepotent response, and subordinate their immediate interests in favor of long-term goals.
(5) The individual has the capacity to consider **abstract** rules (law, moral codes, etc.) that need to be followed in service of goal-attainment, and act on this over simple self-directed rules (stop, go, etc.).
(6) The individual has the **behavioral-structural** capacity to handle behavioral complexity and hierarchical structuring of their own actions to attain a goal over time. This involves processing complex sets of actions that need to be planned, sequenced and performed.
(7) The individual has the **social** capacity to interact, reciprocate, and cooperate with others in service of goal-attainment.
(8) The individual has the **cultural** capacity to adopt scaffolding and categorize on available shared information.

These capacities will serve as target guidelines for what one wishes to achieve when developing EFs in someone with an EF deficit.

### *Model for considering the totality of EF in adult life – Review (Barkley, 2012a)*

In his attempt to build a theory of EF that can unite the various levels of symptoms and deficits, Barkley (2012a) also presents a model of "radiating influence of EF as used across long intervals of one's life" (figure 1). Since this thesis is primarily interested in adults, Barkley's definition has the added advantage that it means to evaluate the totality of adult life[15]. Barkley specifically considers EF as extended, and explains it as a series of interacting functionalities, accounting for self, others and the environment, and not limited solely to the body/brain. In doing so, Barkley has addressed several of the limitations of previous models, including a disparity between models of EF and deficits in patients with PFC disorders, a link between EF and social functioning, the importance of emotion and motivation in EF, recognizing the distinction between a computer and a brain[16], not recognizing a

[14] Contemplative ability goes from minutes to hours, to days, weeks, months and eventually years.
[15] "Adults pursue various goals, at varying distances across time and space, using various social means such as reciprocity, exchange, trade, cooperation, and mutualism as well as various cultural means (rules, laws, ethical principles, etc.) and products or interventions." (Barkley, 2012a, p. 172)
[16] Refers to the use of the Computer Brain metaphor in most information-processing models of brain functioning.

‘central executive’ as a conscious actor, a place for the ‘self’, and accommodating for the bidirectional influence of EF and culture.

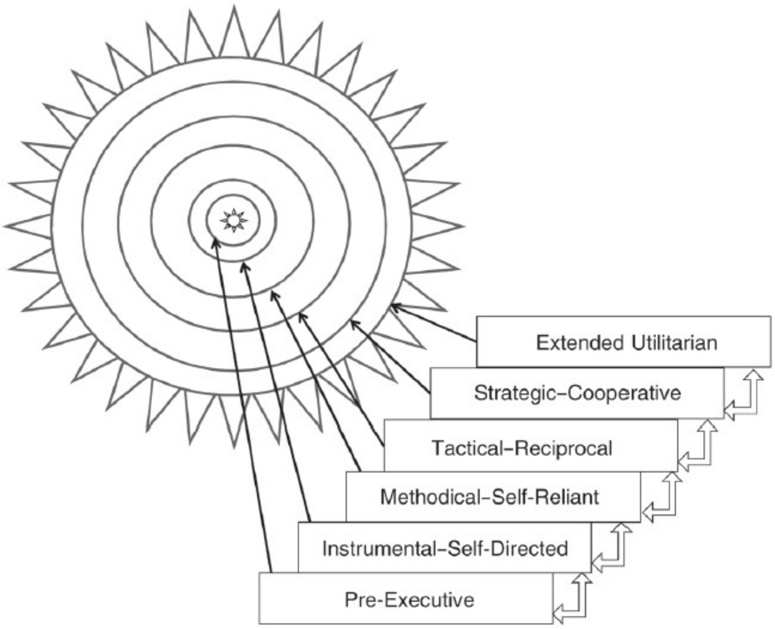


*Figure 1:* ***A model for considering the totality of EF in adult life****. “The concentric rings at the left indicate the outwardly radiating nature of the phenotype (…), as does the leftward-pointing arrow. The final sunburst edging of this diagram reflects the extended consequences or utility of employing EF across these levels and one’s lifetime. The stacked boxes at the right indicate the hierarchical arrangement of these six phenotypic levels and the ultimate utility (effects-at-a-distance) of using them. The bidirectional arrows to the right of each box are intended to convey the bidirectional flow of information between the levels. Information from the lower levels flows upward to the higher levels, while management of the lower levels may be exerted downward by the next higher level.” (Barkley, 2012a, p. 171).*

This model paints an evolutionary picture of how we got from a primitive reactive organism to a complex acting human. Level one is a product of pure biology and behaviorism, what the human would look like as a reactive automaton, before the development of ‘higher’ brain function. Levels 2-5 show behavioral mechanisms necessary for and used in EF. The extended level indicates that the realized EF system also allows for higher-level interaction with community and environment. Figure 1 is a hierarchical representation of the different ways in which EFs are involved at various levels. It is hierarchical in that ‘lower’ level functions are pre-requisite for the higher level ones. For instance, one must have operative (1) pre-executive functions to be able to (2) self-direct behavior. One must be able to be (3) methodical/self-reliant in order to allow for social symbiotic levels of behavior (4&5). One must have effective EFs, in order to extend them into the utilitarian zone (6). This hierarchy does not imply a static progression of personal ability, it displays a historical growth of function with interactivity and a bidirectional flow of information between levels. Nonetheless, it serves as an indication of natural progression of abilities if one wishes to be proficient at higher level EF. As such, this model will serve as a structuring guideline later in this thesis. Appendix A is a concise description of each level, as presented by Barkley (2012a). Each level lists its constituent parts, and shows the chain of structures and behaviors that build up EF.

## 2.2 Executive Function Deficits

The frontal lobes (FL) – the neurological basis of EFs – are rich in connections, and is thought to function as a ‘traffic hub’ for the central nervous system (CNS). This makes this magnificent structure incredibly important for human functioning. Unfortunately it also leaves the FL rather vulnerable. Damage anywhere in the brain may have ripple effects to the FL and vice versa. This leaves it with an exceptionally low ‘functional breakdown threshold’ (Baars & Gage, 2010). Previous studies show the impacts of EF-deficits on varied groups of people under varying conditions. Firstly, EFs are impaired in a wide range of mental disorders, including: addictions, ADHD, conduct disorder, depression, obsessive compulsive disorder, and schizophrenia (Diamond, 2013). While it may be tempting to simply assign EF deficits as a prevalent symptom of the mentally ill, research shows that *any* person's EFs can suffer decreased function under the corresponding, surprisingly common, circumstances. In comparison to other brain functions, "EFs and prefrontal cortex are the first to suffer and suffer disproportionately if you are stressed, sad, lonely, or not physically fit" (Diamond, 2013, p. 36). While there is no estimated prevalence for people with EF deficits, it would be hard to overstate how many people could belong to this group.

So, what does it look like when an individual has diminished EF capacity? In other words, what happens when the functional mechanism that guides goal-directed behavior and self-sufficiency is not doing what is it supposed to do? The study of disintegration of EF following brain damage has given researchers something to focus on for over a century. "Like Gage, patients with PFC damage studied in these early years demonstrated a lack of initiative or drive, a curtailing of their circle of interests, profound disturbances of goal-directed behavior, a loss of abstract or categorical behavior, and emotional changes, such as a proneness to irritation, emotional instability, and indifference toward their surroundings, often superimposed on depression[17]. … Just as likely was an adverse impact on moral conduct, independence and self-reliance, financial-economic self-support, effective occupational performance, and socially cooperative activities that all require the capacity for evaluating the longer-term consequences of one's actions as noted in the initial report on Gage[18]." (Barkley, 2012a, pp. 13–14) These symptoms of PFC damage are directly reflective of those with EF-deficits (EFd), which have shown to have an adverse effect on "… economic behavior (occupational functioning, financial management), transportation (driving), and community participation (politics and government)." (Barkley, 2012a, p. 184)

"Behaviourally, EF deficits may manifest as forgetfulness and difficulty in planning and co-ordinating everyday tasks such as getting ready for school." (Tarver et al., 2014, p. 765) When one has trouble planning everyday tasks, the impact of symptoms becomes very direct. All of this indicates that a person with EF deficits, whether mentally ill or not, will encounter more difficulty with that which you need to do in order to live a happy, healthy, 'successful' life, within their (socially constructed) climate. "All of these contractions will result in a loss of freedom or self-determination and the dynamic and flexible quality that higher levels of EF contributed to human adaptation to the environment." (Barkley, 2012a, p. 186) Specifically, Diamond (2013) summarizes impacts on mental- and physical health, quality of life, school readiness and -success, job success, marital harmony and public safety (table 1). All of which require the proper functioning of EFs and are negatively impacted if EFs are impaired. Perhaps the following quote from Luria (1966) describes life with an EF deficit best; "Syntheses underlying own actions, without which goal-directed, selective behavior is impossible." (p.224). "…besides the disturbance of initiative and the other aforementioned behavioral disturbances, almost all patients with a lesion of the frontal lobes have a marked loss of their 'critical faculty,' i.e., a disturbance of their ability to correctly evaluate their own behavior and the adequacy of their actions." (p.227).

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[17] (Fuster, 1997; Luria, 1966; Stuss & Benson, 1986)

[18] (Harlow, 1848)

| Aspect of Life | The ways in which EFs are relevant to that aspect of life | References |
|---|---|---|
| Mental Health | EFs are impaired in many mental disorders, including: | |
| | - Addictions | Baler & Volkow 2006 |
| | - Attention deficit hyperactivity disorder (ADHD) | Diamond 2005, Lui & Tannock 2007 |
| | - Conduct disorder | Fairchild et al. 2009 |
| | - Depression | Taylor-Travares et al. 2007 |
| | - Obsessive compulsive disorder (OCD) | Penadés et al. 2007 |
| | - Schizophrenia | Barch 2005 |
| Physical health | Poorer EFs are associated with obesity, overeating, substance abuse, and poor treatment adherence | Crescioni et al. 2011, Miller et al. 2011, Riggs et al. 2010 |
| Quality of life | People with better EFs enjoy a better quality of life | Brown & Landgraf 2010, Davis et al. 2010 |
| School readiness | EFs are more important for school readiness than are IQ or entry-level reading or math | Blair & Razza 2007, Morrison et al. 2010 |
| School success | EFs predict both math and reading competence throughout the school years. | Borella et al. 2010, Duncan et al. 2007, Gathercole et al. 2004 |
| Job success | Poor EFs lead to poor productivity and difficulty finding and keeping a job | Bailey 2007 |
| Marital harmony | A partner with poor EFs can be more difficult to get along with, less dependable, and/or more likely to act on impulse | Eakin et al. 2004 |
| Public safety | Poor EFs lead to social problems (including crime, reckless behavior, violence, and emotional outbursts) | Broidy et al. 2003, Denson et al. 2011 |

*Table 1: **Executive functions (EFs) are important to just about every aspect of life**. From: Diamond, 2013 (table 1).*

As evidenced above, (and noted in Barkley's model of outwardly radiating effects of EFs on various aspects of a person's life,) these mechanisms do not function in isolation inside the brain. There is constant interplay with the person's social environment and personal decision-making. The cultural scaffolding that societies and institutions provide are imperative to the success of the individual, as mediated by EFs. As such, even a society which promotes self-reliance in its citizens is benefited by promoting healthy EF in its citizens. After all, EFs are indispensable for creating self-reliance and independence from others (Barkley, 2012a). Without well-developed EF the affected individual is much more likely to become dependent on supportive government institutions, social contacts, or – in the absence of either – get into trouble with more symptom-related behavior (e.g. social parasitism or self-medication). A simple illustration of the many ways in which proper EF is crucial to the self-sufficiency of the individual can be seen in institutions of learning: "Because EFs are critical for academic achievement, a society that wants its students to excel needs to take seriously that the different parts of the human being are fundamentally interrelated. If emotional, social, or physical needs are ignored, those unmet needs will work against good EFs and hence against academic excellence." (Diamond, 2013, p. 36). Patriarchal policies in which students are told to achieve regardless of personal health and happiness[19] retard the development of EF, and thus help create the circumstances for failure. Specialists have argued that this justifies structural access to treatment as the duty of society, due to their role in shaping the policies and cultural circumstances in which the individual citizen is or is not

[19] Stress, sadness, loneliness and physical fitness are examples of the emotional, social and physical needs that have shown to influence the developing of EFs.

able to develop their EFs[20]. By aiding the individual to enable themselves, this radiates into behavior that is healthier for the individual and more beneficial to society.

## 2.3 EF deficits in ADHD

Those familiar with ADHD may have recognized many of the symptoms in the previous sections. In fact, in reading up on EFs there is quite often mention of ADHD specifically (Baars & Gage, 2010; Barkley, 2012a; Diamond, 2013; Smith & Kosslyn, 2013). The reason is simple – those with ADHD almost always have EF deficits. Attention Deficit Hyperactivity Disorder (ADHD) is classified as a neurodevelopmental disorder (American Psychiatric Association, 2013), meaning that a delay in the development of certain areas of the brain is the cause of neuropsychiatric problems and impaired functioning. In the last decade or so, more and more research identify EFs as developmentally lesser in those with ADHD than in neurotypicals. As will be shown in this section, there is both theory and empirical evidence that suggests ADHD and EF deficits are strongly related. Studies that indicate otherwise are often based on psychometric EF tests that, as discussed earlier, are inherently fallible. Impulsivity and other symptoms which are prominent in cases with PFC lesions as we have seen in the previous section are diagnostically definitional for ADHD. *Those who are not familiar with ADHD - See appendix A for a comprehensive overview of diagnostic criteria, prevalence, causes, and co-morbidities in ADHD.*

Adult ADHD is a real and complex disorder. ADHD individuals are shown to have great difficulty with sustaining attention, inhibiting reactions to task-irrelevant stimuli and resisting distractions. They often have trouble with socially appropriate behaviors, and have trouble acting appropriately and persistently toward long-term goals. Executive Function deficits have been revealed to have great neuro-mechanical influence in this (Barkley, 2012a). Common neuropsychological co-morbidities of ADHD include EF deficits, delay aversion, temporal processing deficits (Tarver et al., 2014). Individual research and meta-analytic reviews show consistent impairment of ADHD individuals on tasks that are meant to measure EFs (Willcutt et al., 2005). “EF deficits have featured prominently in neuropsychological models of ADHD and are in keeping with the structural abnormalities observed in the frontal regions of the brain” (Tarver et al., 2014, p. 765). To illustrate; Neuropsychological research suggests many underlying deficits including response inhibition, delay aversion, and EF deficits, which have been related to dysfunction of frontal–striatal–cerebellar circuits (Valera et al., 2010). Response inhibition, delay aversion and temporal processing in turn have been linked, or rather included in the complex neural interplay that is EF. “ADHD is a valid and significantly impairing neurodevelopmental syndrome characterized by executive dysfunction that has the potential to negatively impact most domains of adaptive functioning.” (Ramsay et al., 2014, p. 44) Figure 2 shows a concise summary of the mechanisms used by EF and impaired in ADHD, and clearly shows that EFs impaired in ADHD make it more than neurotypically difficult for the individual to (1) activate themselves in service of working towards a goal, (2) focus on task-relevant information[21], (3) sustaining their efforts toward a goal over longer periods of time, (4) self-regulating emotional reactivity to a socially acceptable level, (5)

[20] “Societies and cultural institutions can also be judged for the extent to which their policies and practices promote, retard, preclude, or snuff out the adaptive effects of the extended EF phenotype.” (Barkley, 2012a, p. 170)

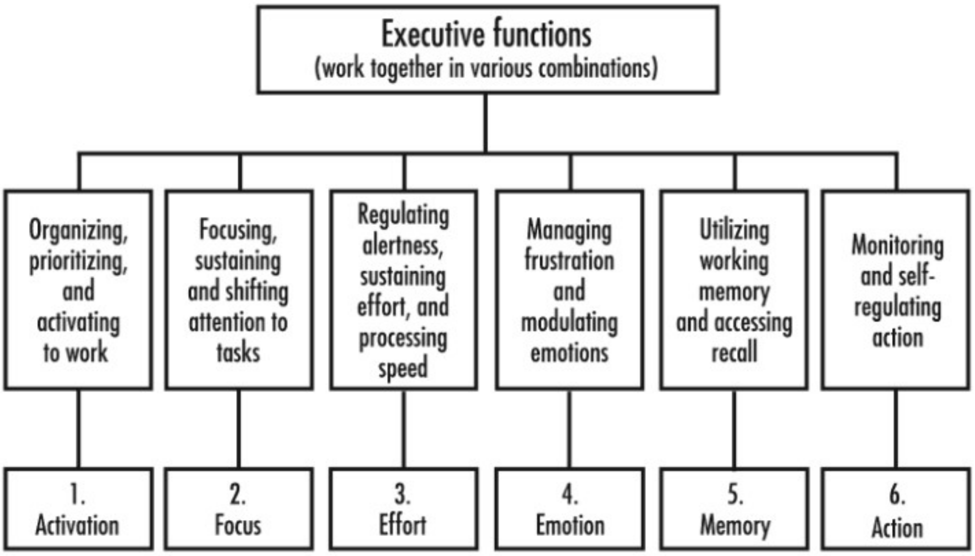
[21] Not only retaining attention to the exclusion of interfering stimuli, but also returning to the task once an interfering stimulus has inevitably been presented.

effectively utilizing their working memory[22], and (6) acting in accordance with own wishes and desires (such as acting toward goals). The result is that "there is virtually no area of adult life that is unaffected by ADHD" (Ramsay et al., 2014, p. 44). As such, anything constructed to target those with ADHD, must consider the role EFs play.

*Figure 2:*

***Executive Functions Impaired In Attention Deficit Disorder.***

*From: Brown, 2009 (figure 1-1)*




In comparing the EFs impaired in ADHD (figure 2) and the ways in which EFs are relevant to aspects of life (table 1), we start to see mechanisms emerge for how poor EFs interfere in the lives of those with ADHD. Furthermore, studies have shown that the ADHD person themselves often have a tendency to underestimate the extent of their impairment. Symptom severity is now known to be frequently underreported in those with ADHD (Sibley et al., 2016), likely due to EFs vital function in self-appraisal (Barkley, 2012a).

These symptoms also have an effect on social relationships. The high rate of divorce and marital problems in those with ADHD does not appear spontaneously. It is the result of structural behaviors that a person displays to other people. The behavior that manifests as a result of EF deficits is often not considered desirable by social groups. Social interaction in turn exudes influence on self-efficacy[23]. This can lead to giving up, procrastination, anxiety, feelings of incompetence and underachievement (Safren et al., 2017).

The amount of research done on EFs has advanced in previous years, and it's relation to ADHD has been well documented. As neurological research progresses it is increasingly difficult for practicing clinicians to stay up to date with new relevant findings (Tarver, Daley & Sayal, 2014), and EF-deficits appear to be insufficiently accounted for in the treatment process. As a result, patients are often being treated in a way that is out-of-date and potentially incompatible with their neurological functioning. Executive Function deficits are not just a side-effect of ADHD, they have shown to be involved in the neural mechanisms of ADHD and thus related at the very source to some of its core symptoms (hyperactivity /impulsivity and inattention). Though EF deficits do not appear to 'cause' ADHD, they have proven to be an important component of its complex neuropsychology (Willcutt et al., 2005).

[22] The amount of information that needs to be mentally manipulated through working memory is significantly less, with subsequent effects on memory transferal from WM to long-term memory systems.
[23] Summing up far too simplistically, self-efficacy relates to the ability to have confidence or belief in oneself. A higher self-efficacy corresponds to positive social function outcomes.

To sum up, most cases of ADHD come with an EF deficit. Having an EFd has been shown to interfere with the ability to act and perform as a conscious agent. To see any long-term gain in aid for those with ADHD, EFs must be accounted for.

## 2.4 Takeaway

This thesis will adhere to Barkley's definition of Executive Functions[24] and the corresponding model for understanding how EF deficits radiate throughout adult life.

The way in which EFs appear to work together indicates that damage to these crucial functions has radiating negative effects on the person on both an individual and a social level. Executive function deficits impaired in ADHD interact with or in some way impede activation, focus, effort, emotion, memory and action (Brown, 2009). Research has started into the ways that this radiates through a person's life, and has already shown several effects. Poorer EFs are associated with poorer physical health, quality of life, school readiness and –success, job success, marital harmony, and public safety (Diamond, 2013). This means the individual is affected across all settings; self, social and occupational. The society (and its culture, structures and institutions) in which an individual lives has also shown to impact those with lower EFs, showing structures in the environment can retard or promote EF in a person.

The next chapter will place our understanding of EF in context of theory of mind, and show its recent narrative. This will serve to further explain why it is important that Barkley's model is an extended view, and set up an examination of an EMT view of technological development to target technological interventions.

# Chapter 3: The Extension of Mind

How we think about the mind has evolved throughout the history of science and philosophy, and studies into the nature of mind and cognition are found as part of a large multidisciplinary field. Significant contributions have been made or influenced by fields including philosophy, anthropology, psychology, cognitive science, biology, neuroscience, computer science, and theories in mathematics. This chapter will serve to lay out the growing expansion of what we consider to be the mind in philosophical, psychological, anthropological and other literature. This chapter will illustrate progress in cognitive science by concisely reviewing the growing body of theories that argue that the mind is not simply the brain. Nor it is simply the brain as influenced by the body. Section 3.1 serves as a review of the state of the field in current philosophical questioning into how far the mind may extend outward. Section 3.2 outlines extended mind theory as compatible with EF, and section 3.3 discusses how to apply this theory for the purposes of this thesis.

This chapter will argue that technological devices are in the position to form and aid individual cognition simply by being used. To prevent misunderstandings, keep in mind that cognition is not the same as mind, it is considered a part of what gives rise to the mind – in this same way ADHD is not the same as an EFd, but EF deficits are part of what give rise to ADHD.

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[24] "EF is the use of self-directed actions so as to choose goals and to select, enact, and sustain actions across the time toward these goals, usually in the context of others, often relying on social and cultural means for the maximization of one's longer-term welfare as the person defines that to be". (Barkley, 2012a, p. 174).

## 3.1 Challenging Traditional Cognitive Science

Until recently the dominant paradigm in thinking about cognition was a fundamentally computational and representational approach. Cognitivism is the idea that "the mind is fundamentally computational in operation (i.e., like a digital computer) and that it processes units of information in the form of mental representations or symbols" (Osbeck, 2009, p. 16).

The inherent conclusion of the cognitivist approach is an attempt to study cognition through isolationist methods. By isolating the mind from its environment under specific experimental conditions, one could theoretically study a single cognitive process, thus identifying single puzzle pieces in order to put together the whole. The very notion that this is possible, is challenged in the idea of embedded and embodied cognition. One cannot study a single cognitive process independent of its environment if the very environment is part of cognitive processing. Even in our own investigations, one may note that cognitivist methods would be fatally flawed for the simple reason that EFs do not function in isolation in the brain. The very reason that psychometric tests do not accurately show EFs has been shown briefly in this thesis[25], and extensively by Barkley (Barkley, 2012a, pp. 9–13). And indeed, "Criticisms converge around the individualistic framework and dualist implications following from the study of mind in isolation, mechanistic accounts of intentionality, and shortcomings of the experimental protocols required for isolating cognitive mechanisms." (Osbeck, 2009, p. 16) There is no studying them in isolation because they do not function that way. So when researching EF a cognitivist approach is not ideal as a sole viewpoint.

Research into neurobiological bases of mental illness has started to show the same patterns. Fuchs (2009) is of the opinion that the currently prominent neurobiological paradigm produces a restricted perspective when researching mental illness, as it is subject to reductionism, reification and isolation. It is reductionist in that neurobiology reduces subjectivity of mental processes to a by-product of neuronal activity. This is a problem because the patient and their illness are treated as separate from the interconnections with their environment (Fuchs, 2009). Consequently, Fuchs argues for an "extended/ecological view of the mind and the brain", in which the Mind is a complex interplay between Brain, Body and Environment. This departure from cognitivist notions of mind is growing in both philosophical, psychological and other fields that make up the interdisciplinary study of mind, and is thus worth examining.

To illustrate the point, consider a known[26] philosophical puzzle: the Blind Man's Walking Stick. This classic puzzle questions the boundaries and nature of the limits between what can be considered the 'self' and what not. When a blind man navigates the world, he uses his walking stick to provide him with information about his environment. This tool he uses, some argue, has become critical to the way he perceives and interacts with the word. This has many implications depending on one's philosophical viewpoint. Post-Cognitivist philosophers, psychologists and neuroscientists view the mind as extended beyond only the brain, and have argued for its extension in many ways. The mind can be seen as embodied, embedded, situated, distributed, enactive or affective. *Those who are not familiar with theories of mind - See appendix C for a comprehensive overview of these terms.* Interestingly, these are not mutually exclusive. The mind can be extended in all these ways.

[25] section 2.1 – The trouble with measuring EFs

[26] e.g. Merleau-Ponty, 1962; Polanyi, 1962; Bateson, 1973; Malafouris, 2013; etc.

Conceptualizing the mind through a computer metaphor has been the state of the field for a long time, meaning much research and treatment implementation was based on this notion of cognition. In the past decade post-cognitivist notions have surged, and what is emerging is a view of the mind in which mind is historically, physically and individually tied in an interactionary relationship with things beyond the brain. In order to gain understanding of how these notions of cognition interact into a conception of mind that clearly breaks with traditional cognitivist approaches, the next section will examine the scientifically prominent theory of extended mind, and argue its relevance to our understanding of EF.

## 3.2 The Extended Mind

Extended Mind Theory (EMT) is a way of conceptualizing the human mind that does not abide by the barrier of the skin in order to determine what is 'inside' the mind and what is not. In their seminal work, Clark & Chalmers (1998) argue that the mind is embodied and embedded, as a distributed process that is influenced by the (social, cultural and technological) environment it interacts with. EMT is arguably also enactive in that it targets only the emergence of epistemic actions[27]. This is consistent with "an *active externalism*, based on the active role of the environment in driving cognitive processes" (Clark & Chalmers, 1998, p. 7). The idea Clark & Chalmers (1998) call the *extended mind*, formalizes the extension of cognitive processing into the environment. In a way, this unites the mentioned post-cognitivist notions into complimentary theories. The definition of Executive Function as chosen in the previous chapter reflects this extended notion of mind wonderfully. Executive Function as we understand it now does not revolve around a trail of isolated neurochemical actions, but is exactly that which moves beyond the pre-executive CNS into an understanding of self within the world. EF develops precisely through its interaction with the environment. EF represents the purposive mind. The self that acts towards goals to achieve them. The Instrumental - Self-directed level of EF is the creation of awareness of self in time, allowing purposive behavior. The Methodical - Self-reliant level entails active interaction with and alteration of the physical environment to suit one's purposes. Tactical - Reciprocal behavior incorporates others into their own purposive behavior. Strategic - Cooperative EFs allow social symbiotic behavior to give rise to structured tactics and strategies, using that which is of benefit. From the development of a sense of self within its environment, to the extended utilitarian level, the Executive mind shows it is embodied, embedded, distributed, enactive and affective. In sum, it is extended.

Initial counterarguments to EMT have been aimed at a lack of definitional clarity in when a process is thought to be cognitive, and when not. In response to this the *Parity Principle* was born. It states that "If, as we confront some task, a part of the world functions as a process which, were it not done in the head, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process" (Clark, 2010, p. 4). In other words, the parity principle is not interested in how the mind works mechanically, but rather how it functions. This too, is consistent with our definition of EF, since it does not describe neuromechanical chemistry so much as it does the functions that EF provide. Given our current explanatory power, the intricate and often unobservable intricacies of *how* it functions is secondary to *that* it functions. This generates explanatory power in itself. As studying the system offers far more than simply trying to identify the

[27] "*Epistemic actions* alter the world so as to aid and augment cognitive processes such as recognition and search. Merely *pragmatic actions*, by contrast, alter the world because some physical change is desirable for its own sake" (Clark & Chalmers, 1998, p. 8).

cogs. And the system shows to be extended. By relying on the mind as a system made up of not just the intracranial, but also that which extends it outward, human capacities like understanding and computation are increased to more than what the brain alone would be capable of. For instance, performing scientific research often represents a series of complex problems (e.g. calculations), during which the brain "acts as a mediating factor in a variety of complex and interrelated processes which continually loop between brain, body, and technological environment. And it is this larger system which solves the problem" (Clark, 2001, p. 132). The socio-technical environment an actor interacts with and the brain together form a system that is more than the sum of its parts. An interdependent, interactionary, dynamic system is revealed that fundamentally changes everything we do and indeed *are* as thinking, feeling and acting humans.

The emergence of EMT and the shift in philosophy, psychology, and many other fields, have gained enough support to have evoked a traditionalist response. Supporters of the representational view of mind hold that EMT is too radical, insufficiently sophisticated, and make an inaccurate appeal to functionalism (Osbeck, 2009). Adams & Aizawa (2001) argue that the proposition is too hasty since the generalizations made are too broad. They also hold to the existence of a "coupling–constitution fallacy", which indicates that something simply being part of a cognitive process does not mean that it is constitutive of one's cognitive processing. This is true. However, Clark and Chalmers argue that since external features play an ineliminable role in our cognitive process, they are just as causally relevant as internal features of the brain. Other authors have also argued that "features of an agent's physical, social, and cultural environment can do more than distribute cognitive processing: they may well partially constitute that agent's cognitive system." (Wilson & Foglia, 2017) So, not just a passive part of cognition, but a formative role in shaping the agent's cognition, mind and self. Central to the argument, is that this extends to the agent's technical environment. The evidence that technologies are not simply a tool-for-use but a formative part of our environment can be seen in evolutionary studies. Clark & Chalmers suggests that our own evolution may have been shaped partly by the technologies we use. And indeed, minds and brains, have shown to be subject to constant change and alteration throughout life, caused by ordinary engagement with culture practices and the material world (Malafouris, 2013). Recent findings suggest that, historically, the brain has evolved to complement external artefacts. "The brain, far from a hard-wired modular organ adapted to a specific ancestral lifestyle, emerges as a dynamic product of a co-evolutionary process that is still ongoing." (Malafouris, 2013, p. 42) This co-evolution spans across generations, and also plays out within the individual. Studies into transactive memory systems showed that in individuals who relied on technological aid in tasks like navigation or information search, the natural ability for accurate recall was reduced. However, due to the reliable presence of these artefactual resources the accuracy of the goal task actually increased, and corresponding neural structures were seen to be increased in the dynamic engagement (Risko & Gilbert, 2016). In other words, our memories are getting worse at remembering-by-themselves when we rely on technology, but adversely our own ability to make use of these technologies and with them achieve enhanced results has grown. Our 'hard-wired' human anatomy has shown to be adaptive with technology. So, "in one sense it can be argued that *things* are to human intelligence as the eye is to sight: constitutive and yet invisible" (Malafouris, 2013, p. 45). Technology and cultural environment are indeed constitutional for an agent's mind.

This all is consistent with notions of Extended Phenotype. Barkley (2012a) explicitly recognizes the effects of artifacts, shared artifacts and other organisms (and their structures, functions and behaviors), on physical and structural differences within and between species. This dynamic view of the extended phenotype stresses reciprocal influence, and as such is complementary to post-cognitivist accounts of mind. Dr. Russel Barkley's work implies that whether or not a treatment of EFd is sufficiently effective is largely dependent on either the environment itself, or its interaction with it. The same should be true for any Cognitive Assistive Technology.

## Conditions for cognitive extension

Technical devices take an active part in a person's cognition (e.g. supplying information, taking over part of the cognitive load of processing). By using 'external' artifacts we incorporate them into our cognitive process, so they are a part of it, and the mind is distributed across agent and cognitive device. Importantly, this is not unilaterally the case for all technology. EMT proposes that the mind *can* extend in a certain context. According to EMT, externalization through active extension requires the formation of what Clark & Chalmers (1998) refer to as a coupled system. A human organism, linked to an external entity in a two-way interaction, thereby bringing technology into the cognitive fold. If these criteria are met, then they may form a coupled system with the organic agent. If a durable coupling between technology and user is achieved, extended mind theorists argue, this results in the formation of a system with enhanced skills of the (coupled) individual. If this is so, then it could be possible to offset the parts of cognition that are deficient in EF with a technological aid. The core assumption here is that human action and behavior arises from an interaction of cognitive processes and their socio-technical environment. If this is so, then decreased cognitive function such as those in EF deficits may be offset by suitable socio-technical support. The main challenge is finding that which is suitable to target the specific functions that are deficient in users. Neuroscientists are slowly starting to make this possible through research into cognitive assistive technology. In this way, technology could provide what current treatment of ADHD are missing. After all, we have established a "need for future non-pharmacological interventions to be more specifically targeted for ADHD symptoms and its commonly associated functioning deficits in order to ensure the best long-term outcomes" (Tarver et al., 2014). So, if the technology and its user must be able to form a coupled system in a way that offsets the original deficits, then how is this done?

"The true cognitive processes are those that lie at the constant core of the system; anything else is an add-on extra." (Clark & Chalmers, 1998, p. 10) In other words, building a successful scaffolding will require the right context, not just any technology will do. "There is a special class of artifact (…) that are capable of engaging in 'symbiotic' relationships with the human body." (Brey, 2000, p. 1) To be included in this class, Clark offers a "rough-and-ready set of additional criteria to be met by non-biological candidates for inclusion into an individual's cognitive system" (Clark, 2010, pp. 6–7). Specifically, "(1) that the resource be reliably available and typically invoked, (2) that any information thus retrieved be more-or-less automatically endorsed. It should also not usually be subject to critical scrutiny (unlike the opinions of other people, for example). It should be deemed about as trustworthy as something retrieved clearly from biological memory. (3) that information contained in the resource should be easily accessible as and when required" (Clark, 2010, pp. 6–7). "Clark & Chalmers argue that what is central for external information to be constitutive of a cognitive state or process is a high degree of trust, reliance, and accessibility, and we must have endorsed it at some point in the past. These conditions are often referred to as 'trust and glue' " (Heersmink, 2017, p. 23). The *strength* of the coupling, as described in EMT, is dependent on portability and contingency of coupling, as it needs to be reliable and accessible across settings. Therefore, candidate systems must be reliably available, typically invoked, facilitate automatically endorsed information retrieval, not typically subject to critical scrutiny, trustworthy (to the extent a biological memory would be), easily accessible when required (Clark, 2010). Achieving unification into a cognitive system is dependent on kind and intensity of information, accessibility, durability of the coupling, trust of user in the scaffold (/technology), transparency-in-use, ease of interpretation, personalization, and amount of cognitive transformation (Heersmink, 2017). The candidate technology need not be infallible and permanently attached to the user, they need only be as reliable as the typical human brain[28].

## 3.3 Takeaway

All of these theories articulate that elements of our environment are not dead matter simply used by our living biology, but are in fact playing a role in shaping mind itself. What exactly our cognitive ecology[29] looks like remains uncertain. Regardless, the evidence for a concept of mind that is embodied, embedded, enactive and even extended is mounting. Prominence of the extended mind theory is rising, and it is proving a useful step in scientific progress. We may infer that whatever makes up the mind – our environment, in the broadest sense of the word, has proven to be a part of it.

This thesis shows that the research into treatment of EF deficits shows a technology-shaped hole in its outline. Access to such a technology for people with ADHD would be like giving the philosophical blind man a walking stick. Providing aid through re-imagining technology would offer those with ADHD a new and beneficial way of interacting with the world as a coupled system that accounts for their EF deficits. So what would one need to accomplish this? The next chapters will examine how to bring this knowledge into practice through technology.

[28] "These systems cannot be impugned simply on the basis of the danger of discrete damage, loss, or malfunction, or because of any occasional decoupling: the biological brain is in similar danger, and occasionally loses capacities temporarily in episodes of sleep, intoxication, and emotion. If the relevant capacities are generally there when they are required, this is coupling enough." (Clark & Chalmers, 1998, p. 10)

[29] (Hutchins, 2010) attempt to uncover connectivity, that is, "the web of mutual dependence among the elements of a cognitive ecosystem" (p.705)

# Part II: Offsetting EF deficits through technology

## Chapter 4: Strategies for offsetting an EF deficit.

In order to know how to offset an Executive Function deficit through technology, we need to know how to affect it. This section investigates requirements for candidate technologies which are inherent in those with EFd, the user.

In this chapter, we will examine what we know about EF and goal-directed behavior, in order to identify what a theoretical enabling technology would need to accommodate. In order to do so, we will begin by reviewing previous research into engaging with EFs and EF deficits. This is followed by theoretical reflection that is philosophical in nature and multi-disciplinary in content.

### 4.1 Known Executive Function Interventions

The following sections contain analysis of current knowledge about existing treatment and its limits, a description of principals for symptom accommodation for ADHD as an executive Disorder (Barkley, 2012a), and principles in relation to EF programs and interventions (Diamond, 2013). This will give us insight to better target EF deficits in our theoretical technological artefact.

#### Learning from general ADHD treatment guidelines

In most developed places, the ADHD individual currently has several options when they are first diagnosed with ADHD. One can either go untreated, seek behavioral therapy and/or medication.

Not being professionally treated is undesirable, as repeated studies have shown that negative social consequences like 'social function outcomes' (Harpin et al., 2016), substance abuse (Horner & Scheibe, 1997; Wilens et al., 2003) and criminality (Rasmussen & Levander, 2009) is significantly higher among people with ADHD than with control groups (Shaw et al., 2012). If left untreated, moral and emotional dysregulation interact with coping mechanisms (e.g. thrill seeking behavior, drug-abuse[30]), and lead to more negative social outcomes like contact with law-enforcement. This means that treatment is better than no treatment, because the consequences of going without treatment are detrimental to both the individual and the society they inhabit.

[30] (Arria et al., 2011; J. Biederman et al., 1995; Horner & Scheibe, 1997)

Stimulant medications[31] have shown to be effective in reducing symptom severity[32] in many adults, despite the lack of understanding as to exactly how and why it works. However, stimulant therapy does not normalize cognition in recipients, and its effects only last as long as the medication is taken (Toplak et al., 2008). In other words, there are no long-term gains. This short-term effectivity is one of many reasons why experts advocate a "need for future non-pharmacological interventions to be more specifically targeted for ADHD symptoms and its commonly associated functioning deficits in order to ensure the best long-term outcomes" (Tarver et al., 2014, p. 762).

Behavioral approaches[33] are "critical to support a transition from extrinsic rewards to internalized cognitive (self-regulated) habits" (Toplak et al., 2008, p. 805). Such treatments often include cognitive remediation training involving therapist-led (group) sessions, with strategy training (structured skill training programs) to improve motivation, concentration, listening, impulsivity, organization, anger management, and self-esteem (Toplak et al., 2008). Access to treatment is important. That said, behavioral treatment suffers the same problem as pharmaceutical intervention. Once the treatment ends, clients slip back into old ways, and no long term gains are seen (Toplak et al., 2008). Recent research evidence indicates that some forms of existing treatment not only lack benefit, but could perhaps be inducing harm (Safren et al., 2017). A clear incompatibility of behavioral treatments with EF deficits is an overreliance on psychoeducation and skills training. Due to EFd, skills training and psychoeducation only have minimal effects in the ability of the individual to apply what they have learned outside of treatment settings. People with ADHD are not known to have abnormalities in memory retrieval (Skodzik et al., 2017) so psychoeducation *is* sufficient to teach people with ADHD to know what to do. The problem is that due to the executive function deficits, this knowledge has no controlling value over the patient's actions (Barkley, 2012b1). One problem is that outside the training environment where they are not actively stimulated to act in accordance with the training, and the person is reliant on their own deficient executive function in order to execute these acquired skills. This is potentially the reason we see so little effectivity in training of ADHD individuals – the individual is being taught to rely on something that is dysfunctional in their neuroanatomy. No true autonomy has been created. "Overall, both medication and behavioral approaches have been demonstrated to be effective, but limitations exist suggesting the need to consider additional strategies and approaches" (Toplak et al., 2008, p. 803).

Additionally, ADHD treatment programs indicate...

- Presenting information to the client across multiple modalities enforces that information, increasing likelihood of effectivity.
- Treatment is a learning process. Natural buildup in this process is beneficial.
- One can account for the heterogenic nature of ADHD through customizability of treatment.

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[31] Cortese et al. (2018) estimated the comparative efficacy and tolerability of oral medications for ADHD in different age groups. They found that amphetamines show the best short-term results for treatment of ADHD adults. Long-term effects of these medications are yet to be fully understood and urgently require further study. (Cortese et al., 2018)

[32] There are several indications that childhood stimulant therapy reduces the risk of drug and alcohol use disorders later in life (Joseph Biederman et al., 1999; Wilens et al., 2003). Studies also indicate that treatment with stimulants in childhood actually increased social and psychological functioning in adulthood (Goksøyr & Nøttestad, 2008; Harpin et al., 2016).

[33] Evidence-based behavioral programs designed specifically for adults that have shown positive results in boosting medication effects include those by Solanto et al. (2008), Ramsey et al. (2014) and Safren et al. (2017). These treatments target main ADHD symptoms. For instance, the treatment program by Safren et al. (2017) focusses on four main goals; (1) psychoeducation, organizing and planning, (2) reducing distractibility, (3) adaptive thinking, and (4) procrastination and maintaining gains.

## Principles in Relation to EF Programs and Interventions (Diamond, 2013)

While this information was gathered in the service of treating children with ADHD, we may yet learn from it for adults. See Appendix D: "Excerpt from Diamond, 2013. Principles That Hold For EF Interventions"

There are several conclusions we can draw from Diamond's principles. First and foremost is that while EFs seem to be particularly vulnerable to cognitive aging (Best et al., 2009, p. 181), research also suggests EF can be trained at any age (Diamond, 2013, p. 21). For adults, this means that while older people will feel the effects of EF deficits more keenly, the *can* be improved through training. In order to attempt this, we must recognize the following. (1) The earlier the intervention the better, those who were diagnosed in adulthood will not have sought treatment for something they didn't know they had. Others may have been diagnosed in childhood, but not had the benefit of (sufficient) treatment. We cannot prevent already developed social disparities in academic achievement and health in adults, so we must expect and account for them where necessary. (2) EF training seems to transfer, meaning that training specific EF skills may benefit other EFs in some small way. EF gains from training in task switching, traditional martial arts, and possibly from reinforcement across settings. (3) In order to see results from EF training the individual needs to be constantly pushed, challenged, or otherwise encouraged to try what is just beyond their current limits. (4) In order to see results, repeated practice is key. (5) Using tools to improve EFs may be possible, but only if participants are constantly pushed.

## Symptom Accommodation for ADHD as an Executive Disorder (Barkley, 2012).

If we treat ADHD as an executive disorder there are several things that can be done to try and accommodate for symptoms. Barkley offers several accommodation guidelines to directly target several specific EF problems in ADHD individuals, and specifies that this should preferably always be done in combination with medication. Table 2 illustrates Barkley's specific recommendations.

Barkley adds that "For goal-directed behavior to arise, attention must be shifted away from the moment and external reality and turned toward the self and the mentally contemplated future for that self – the goal" (Barkley, 2012a, p. 82). Diamond (2013) states much the same, in that one can only engage EF by ceasing to rely on automatic processes. The critical roles of self-awareness and self-appraisal are mechanisms by which a person creates a sense of self to ultimately set goals. Consequently, self-awareness must be the first to arise in the development of EF (Barkley, 2012a). This is supported by evidence that "reinforced self-evaluation treatment, which involved explicit training in self-monitoring and evaluating one's performance with very salient skills and concepts, such as anger control, was superior to other treatments" (Toplak et al., 2008, p. 804). In other words, one must also take time to step away from this external reality and reflect. To do so we must engage with self-awareness and self-appraisal. When deficits interfere in the engagement with these goals, offset them by externalizing everything that EFs should be doing, but aren't.

| **"HOW CAN WE COMPENSATE FOR EF DEFICITS? BY REVERSE ENGINEERING THE EF SYSTEM."** Source: (Barkley, 2012b2, p. 35) | **WHAT DOES THIS MEAN?** Source: (Barkley, 2012b1) |
|---|---|
| "Externalize important information at key points of performance" | Make mental information physical (externalize information; use cues, signs, charts, reminders, to-do-lists). |
| "Externalize time and time periods related to tasks and important deadlines" | Use clocks, timers, counters, watch-minders. |
| "Break up lengthy tasks or ones spanning long periods of time into many small steps" | Do not involve delays, bring the person back into the now. |
| "Externalize sources of motivation" | Put the consequences in the now - continuous external motivation. |
| "Externalize mental problem-solving" | (make it manual, don't make them depend on defective working memory). |
| "Replenish the SR Resource Pool (Willpower)" | Take into account that engaging EF has been shown to be 'effortful', and have the user learn to manage their cognitive resources (through alternating between effort and rest). |
| "Practice incorporating the 5 strategies for emotional regulation in daily life activities" | |

*Table 2: Barkley's specific recommendations for offsetting an EF deficit. As presented in his 2012 Lecture at The 11th Timothy B. and Jane A. Burnett Seminar for Academic Achievement*

If we may draw any conclusions from previous studies into the treatment of ADHD and expert-opinion, they are the following. Due to the EF interference in time delay, support in the 'now' is crucial. On the short-term both medication and behavioral therapy are beneficial. Providing access to treatment for those with ADHD is crucial to their ability to learn to manage their symptoms. Thus, the "first step in providing help for an adult patient with ADHD is to conduct a comprehensive diagnostic assessment." (Ramsay et al., 2014, p. 45) However, providing only access is not good enough and additional strategies are needed if one is to stimulate true autonomy. Under conditions laid out in chapter 3, a cognitive enabling technology could offer this, not as a replacement for treatment but as a supplement that may allow the individual to become self-sufficient on the long-term where the effects of the former have shown to lag. Cognitive enabling technology could provide the consistent support across settings that an individual needs in order to see long-term results.

So, what would technological strategies need to consider in order form a long-term reliable intervention? The next section explores how to bring autonomy into practice by going into the discrepancy between knowing what to do and the difficulties in bringing this knowledge into practice and how we may be able to affect it.

## 4.2 Reflection assuming extended worldview

Those who have ever made new-year's resolutions will be acquainted with the idea that intentions do not have a straightforward causal relationship with actions. This discrepancy between intentions and behavior is well-documented in those with ADHD. As noted earlier, due to their EF deficits knowledge has no controlling value over behavior. In order to increase this control over behavior, and strengthen the relationship between action and intent, EFs *need* to be engaged. But in people whose EFs are naturally less able to do what they ought, how can one appeal to them? If the intent of the conscious actor does not offer enough stimulus to transform intent into action, then what? Are people with EF deficits doomed to a reactive existence? In this section, multi-disciplinary epistemic knowledge and philosophical theory will be related to what we know of how EF works. I will argue that specific difficulties in the neurological substrates of EF will offer specific strategies. By focusing on interpretation in light of EMT and philosophical theory, we will explicitly address that which is not inherently assumed in the cognitivist framework in which much of EF knowledge was created, like time, effort and emotion.

As Clark (2001) said, it is important not to confuse the cognitive with the conscious. "[N]ot every cognitive process, at least on standard usage, is a conscious process. It is widely accepted that all sorts of processes beyond the borders of consciousness play a crucial role in cognitive processing: in the retrieval of memories, linguistic processes, and skill acquisition, for example." (Clark & Chalmers, 1998, p. 10). Cognition is considered to be the product of diverse conscious *and* unconscious processes. It is well known that diverse nonconscious processes play a role in behavior. In fact, "several lines of research suggest that nonconscious goal pursuit is blessed with executive processes that promote effective goal pursuit. However, these processes seem to run below the threshold of consciousness." (Aarts, 2007, p. 69) EFs are unconscious mechanisms of acting toward what one wants on the long-term, rather than what is immediately in front of them. In this way, I regard EF as one of the mechanisms of autonomy, and by extension free will.

### *Conscious awareness of time*

Cognition in itself is said to have a strong temporal component. Temporal distance is a key aspect of a post-genomic view of behavioral biology[34], and temporal proximity plays a role specifically in goal-activation (Aarts, 2007). Barkley stresses the role of time in executive processes, stating that "an essential component in EF is that of time. It plays an important role in the contemplation of the future and especially in the appraisal or valuation assigned to means (working time) and ends (duration of serviceableness) and more generally to the total time between the decision to act and the attainment of the goal toward which it aims." (Barkley, 2012a, p. 94) Those with EF deficits are said to have what amounts to 'time-blindness', meaning they have trouble with both perceiving and accounting for the passage of time. For goal-directed behavior to arise, one must consistently act toward a goal in the now in order to attain it in the future. An inability to do this leads to problems both in the 'now' and 'in the future'. On a cognitive level, time-blindness is revealed to be far more harmful than it would appear. "The factor of time is inherent in human contemplation, valuation, choice, and actions toward goals. (…) Time, therefore, is essential to every act of reasoning that precedes and directs actions toward goals." (Barkley, 2012a, p. 93) And indeed, ADHD equates to an inability to enact goal-directed

[34] This view holds that our genotype is not confined to intracranial expression, rather, it is influenced by the agent's cultural environment (Malafouris, 2013). This includes everything from social structures to technological artifacts. The way a person lives, where they live, how they live, who they live with, what they live with, how they live with what they live with, (I could go on…), they all interact with our minds, yes. But not just ours, our descendants' as well, since "even gene expression can be influenced in very specific ways by environmental and experiential factors" (Malafouris, 2013, p. 42). Methods of investigation in this field include 'niche construction', which investigates systematic changes in the developmental niche humans have carved out for themselves in evolutionary progression (Malafouris, 2013).

behavior over time. If a successful technological intervention is to be mounted, it must consider temporality, and the time-blindness of its user. The distinction between proximal[35] and distal[36] time must be made.

For actions in temporal proximity, problems perceiving and accounting for the passage of time lead to symptoms including trouble estimating the length of tasks, often resulting in behaviors of planning to take far too long or far too short. This reflects in the average person with ADHD, who is always late to appointments, struggling against deadlines, and behaving in accordance with what they need or want 'now' thereby forgetting that which has no urgency (even if that might be more important). The neurodevelopmental delays that cause difficulties engaging EFs mean that these people are by default more likely to rely on automatic processes like habits and acting in a more response-based way to stimuli and their environment. As we have found, it is crucial to the engagement of EFs to manage the removal from these automatic responses. After all, living solely in a reactive manner limits a person's ability to choose to what is immediately in front of them. If one wants to affect the future, blindness to the future must be overcome. In this way, a person's ability to exercise their free will is compromised by deficient executive functioning.

For goals with temporal distance, this lack of ability to regularly stop and reflect means that the long-term goals the individual deems important do not transfer from that which must be done later, to that which must be done now. And when distant goals have no proximal cues to act, they are not acted on. Again, on a cognitive level this is more dangerous than it would seem, as it interrupts processes of review and anticipation, meaning that the individual does not learn to 'do better' next time. The present must be put on hold in order to contemplate that which is not 'now' but later, or one will never be able to adjust their own actions through hindsight and foresight (Barkley, 2012a). That is not to say that this makes them incapable of making conscious decisions, it simply means that if left without enabling aid, most will likely never learn to be as effective at forming goals nor executing them, as those with EFs operating at capacity. This enabling aid must recognize that goal pursuit is partially dependent on the very systems which are defective in an ADHD person's symptom profile, and that if one wants to increase their ability to exercise their will, one must increase their autonomy through the stimulation of EFs.

### *Consciously Affecting Goal Pursuit*

Studies have shown some effectivity with goal priming in engaging EFs (Aarts, 2007), so engaging in goal-setting activities will help to engage EFs. Specifically, rehearsal, inhibition, monitoring, feedback processing, and managing effort (accounting for the EF resource pool) (Aarts, 2007). These goal-setting activities require creating goals, and forming intentions to act on those goals. Normally, this would be followed by a structured planning procedure that is reduced in EF deficits. So can an artefact intervene on behalf of this deficit?

Aarts (2007) proposes that goal pursuit can emerge without conscious intent, and may be environmentally triggered, as guided by unconscious processes. Slors (2015) offers an interesting perspective on the relationship between intent and action in goal pursuit, by i.a. stressing the difference between triggering and structural causes. Triggering causes, he argues, are when a stimulus causes a trigger to produce an action ( X → Y ). A structuring causes on the other hand, is the cause (Z)

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[35] Now

[36] Later

that allows for the conditions in which a stimulus may present itself, in which case cause (X) may take effect and result in action (Y). In other words (Z) increases the likelihood that (X) will occur, hopefully triggering (Y). ( Z → X → Y ). This, Slors argues, suggests that consciously formed goals can be unconsciously triggered. If one were to construct a cause (Z) that could facilitate (X), we engage in what is essentially 'self-programming' (Slors, 2015), increasing conscious intentional agency. "The idea that distal intention formation is not a triggering but rather a structuring cause behind our actions explains why and in what sense conscious causation of action is delayed, indirect and dependent upon interplay with unconscious processes." (Slors, 2015, p. 15) This is problematic for those with EFd, who do not handle delay well when it comes engagement with goal-directed behavior over time. This would explain how EF deficits tear a hole right in the functional mechanism that transforms the distal into proximal. This process of situational anchoring[37] is subject to interference in EFd, and what is 'later' never becomes 'now', meaning the brain never tells the individual that it is time to engage in action. We see this reflected in Barkley's recommendation that for EF deficits, delay should be avoided at all costs. Fortunately, we may be able to trigger this process. "Conscious distal intention formation causes me to be disposed to be responsive to those triggers that set off the intentional anchoring process – be they external or internal" (Slors, 2015, p. 12). So a cognitive technology should offer external triggers to set off the anchoring process, and help the individual to stop reacting and start acting when the time is appropriate (at the point of performance).

The main considerations in unconscious goal pursuit are the formation of habits in service of automatizing goal enactment, and of course the functioning of one's EFs (Aarts, 2007). In the formation of habits, engaging in environmental shaping could function as a structuring cause and thus empower automatizing enactment by providing triggers to act in the environment. Assuming that users will first engage with our theoretical technology when their EFd are naturally at a lower hierarchical level (and thus prone to reactive behavior), and given that proximal intentions are inherently perceptual, this may suggest that those with EF deficits would be suitable for environmental shaping (section 5.1) for that which is proximal.

For distal goals, explicit engagement in goal–formation means stopping to reflect and engage in goal-setting activities, and is crucial to our theoretical artefact. "We might say that it causes us to be 'programmed' to be responsive in specific ways to specific stimuli in specific circumstances. Conscious intention formation is a form of self-programming." (Slors, 2015, p. 13) Specifying implementation intentions, making them explicit, yields stronger self-programming than mere goal intentions (Slors, 2015). Psychological research on cognitive pathways suggests that the further visualization of actually taking these implementation actions strengthens cognitive pathways and increases the chance of them successfully being carried out. In other words; the conscious action of sitting down to set a goal – taking the time to explicitly state what one would need to do to accomplish the goal, and then imagining actually doing it – will ease future goal-directed behavior, when it is time to perform.

### *Managing Effort*

Research findings suggest that "nonconscious goal pursuit requires mental resources and is effortful" (Aarts, 2007, p. 69). Consequently, actively engaging EFs is bound to deplete these resources, and require quite some effort. And indeed, research has proven EFs to be 'effortful' (Aarts, 2007; Barkley,

[37] "Distal, future-directed intentions are turned into proximal, present-directed intentions in a process that Pacherie calls "situational anchoring."" (Slors, 2015, p. 103)

2012ab; Diamond, 2013), that is, to employ them demands mental resources. In order to maintain self-control over a delayed period of time, we must manage this resource pool. This resource pool seems to act like a fuel tank. “Researchers have long proposed that EF/SR is based on a limited resource pool of effort or willpower that can be *depleted*, *replenished*, or *reduced* or even *boosted* in capacity by various factors (e.g., protracted use of SR, exposure to reward or to visually imagined delayed rewards, brain injury, physical exercise, respectively)[38].” (Barkley, 2012a, pp. 94–95)

It seems as though simply engaging with EFs depletes the resource pool. Some studies indicate that for ADHD individuals, trying too hard to engage EFs may actually end up decreasing performance. Since our ultimate goal is to activate EFs, thereby training them, we must avoid that which reduces the resource pool, and restrict that which depletes it to prevent over-exhaustion. How then, do we actively engage with EFs in a way that does not push us past this point? Since management over time involves delay, managing this resource pool will need to take into account EF deficits themselves. In order to effectively manage this, we must appeal to habits to enforce John to actually perform this management, or it will fail. Effective management should include restricting depletion of the self-regulation resource-pool, and promoting that which replenishes it. Additionally, we must avoid that which shrinks the pool, and either ignore or seek that which grows it. Having a low pool size correspondingly makes it more difficult to rely on and engage with EFs. Therefore seeking that which grows it is advisable.

What replenishes the resource pool? “Greater rewards and positive emotions, statements of self-efficacy & encouragement, 10 minute breaks between EF/SR tasks, 3+ minutes of relaxation or meditation, visualizing and talking about future rewards before and during SR demanding tasks, routine physical exercise. Also glucose ingestion” (Barkley, 2012b2, p. 37). Since glucose ‘powers’ the frontal lobe, making sure it is well fueled is a pre-requisite to engaging EFs. As such, managing glucose ingestion is advisable. The brain needs sugar to activate EFs. Don’t keep the ADHD brains away from sugar, instead feed it in small amounts on a regular basis.

What depletes the resource pool? Inhibition and self-restraint, self-management of time, self-organization & problem solving, emotional self-regulation, self-motivation, stress, alcohol, drug use and illness (Barkley, 2012b1). When the agent is inevitably called upon to exercise their EF in one of these cases, duration should be minimized and alternated with RP-replenishing tasks as mentioned above.

What grows or shrinks the resource pool? There is a robust bidirectional link between executive function and physical activity (Daly et al., 2015). The best way to expand your research pool is to engage in regular physical exercise (Barkley, 2012b1). Conversely, a lack of exercise or only engaging it on an irregular basis will shrink it, allowing less engagement of EF for shorter lengths of time. This indicates it is advisable for any person with EF deficits to be involved in a physical program. Further research is needed on other possible ways to affect the size of the SR-RP.

### *Emotion Regulation and Self-Motivation*

Adults with EF deficits are highly likely to also have altered motivational circuitry. The role of emotion and motivation of sustaining effort is crucial. Both EF deficits and ADHD symptomology directly interfere in the typical regulation of both these systems. Models of EF *not* based on traditional

[38] (Bauer & Baumeister, 2011)

computational/representational view of mind generally take emotion and motivation into account[39], because "[t]he supposedly 'cool' EF brain networks, such as working memory, planning, problem solving, and foresight, may provide for the 'what, where, and when' of goal-directed action, but it is the "hot" EF brain network [40] that provides the 'why' or basis for choosing to pursue that goal in the first place and the motivation that will be needed to get there." (Barkley, 2012a, p. 26) These extended notions of cognition all account for emotion and motivation as playing an important role in self-regulation. Self-motivation is necessary to ultimately achieve goals (Barkley, 2012a). Therefore it should be accounted for in attempts to offset EFs, through technological or otherwise.

For the user it would be beneficial to stimulate continued use, due to purpose and the high likelihood of abandonment that poor-treatment adherence among ADHD individuals implies. In a treatment that by its very nature will require constant pushing of effortful EF use, there is likely to be a high drop-out rate. Thus, easing successful adherence to the technology by making motivational appeals should increase success of the intended intervention. If one wished to offset an EF deficit and stimulate EF engagement, it would thus be beneficial to appeal to self-motivation to sustain effort. There are many current business- and gaming-strategies available to inspire how to keep users using a program. More importantly, one be aware that ethical choices are going to have to be made by the design team. The role EFs play in the development of the brain, mind and self, ensures that the act of designing such a technology – that by its very nature is intended to form a constituent part of the user's cognition – will have real and impacting consequences on the user as an individual. Through design-choices, it is inherent in the process. In order to intervene an appeal could be made to unconscious processes. Is the means compatible with the intended goal? If we must unconsciously affect motivation in order to increase likelihood of a 'desirable' behavior. What must be done with this? The *intended* consequence is greater autonomy, which would be positive for the user. But would we be infringing on current autonomy by applying to unconscious factors? This presents ethical dilemma of nudging. Everything we know about stimulating EFs as well as stimulating behavior indicates that the crucial factor is *choice*. It has to be *self*-reflection, *self*-directed action, *self*-motivation. The user has to choose their own subjective goals and whether to make appeals to their own unconscious mind. The user has to choose to *self*-program. Both from consequentialist and duty-based standpoint, there must be a choice. The actor has to want to act, but then acting is precisely the autonomy that is compromised in EFd. This is a problem. A solution may lie in customization, as the emphasis on the self requires the user be approached as a unique individual. Why? Human interaction with their surroundings is vital for the behavioral patterns the individual forms and adheres to. If one has a negative environment, negative experiences will continue to add up, where they can eventually be internalized and form beliefs about the self. With lowered self-efficacy, socially desirable functioning is even more likely to suffer. When viewing the individual in his or her entirety, rather than regarding 'the ADHD' in isolation, many more issues often have to be addressed over the course of treatment. Adult patients have lived with their symptoms for a long time, meaning they have developed habits, personal coping strategies, and experienced social degradation when they have inevitably and repeatedly struggled with their own behavior. This mountain of acquired experiences, beliefs, etc. means that patients often have to work on their symptoms in the context of the secondary consequences of those symptoms. Users should therefore be able to customize the technology to suit them as individuals.

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[39] "Fuster's theory of cross-temporal synthesis (1997), Damasio's (1994) somatic marker theory, Stuss and Benson's (1986) hierarchical model, and [Barkley's] hybrid model of EF (Barkley, 1997a, 1997b)." (Barkley, 2012a, p. 25).

[40] Castellanos et al., 2006; Nigg & Casey, 2005

Notably, it is likely not useful to make appeals to use satisfaction. Initial studies into the use of assistive technologies for ADHD indicate this may initially lead to lower satisfaction on some settings, due to the mediating effects of increased aspirations and awareness of limitations (Lindstedt & Umb-Carlsson, 2013). While not pleasant for the participant, this indicates a growth of self-awareness and is therefore congruent with the goal of increased autonomy through self-sufficiency. In order not to let dissatisfaction interfere with the further stimulation and development of EFs, motivational appeals must be made to sustain effort without depleting the SR-resource pool.

## 4.3 Takeaway

Diamond (2013) suggests that EFs can be trained through active engagement. Barkley (2012b1) suggests the externalization of everything EF should be doing, but isn't. This includes externalizing information, time, motivation and mental problem-solving, as well as avoiding delay in the mental schema by breaking up lengthy tasks or time into small steps that can be brought into the now. He also specifies an SR resource pool that must be effectively managed in order to prevent depletion.

Through analysis of theory I argue that it is important to make the distinction between what is distal and what is proximal. In the now, offsetting EF deficits requires a removal from automatic responses, making the individual stop and think "am I doing what I want to be doing". One important thing to make active time for is the user stopping to reflect, and engage in goal-setting activities for that which is distal. This self- and future-contemplation allows the individual to become self-aware and subsequently aware of their goals and the actions that they would need to take to achieve them. In order to achieve and sustain this effortful and long-term process, one must manage effort, emotion and self-motivation.

# Chapter 5: Externalizing an EF Deficit through Technology

The main problem has shown to include not just setting goals, but compensating for the defective circuitry that should allow the individual to bring them into action. In the previous chapter, we examined what we would need to consider in order to account for EFd. In this chapter, we will explore various ways of how this could be done through technology.

## 5.1 Environmental Shaping

Proximal intentions are inherently perceptual (Slors, 2015), meaning that 'right now' involves no actions of reflection. Thus in order to influence 'now', we must appeal to re-action. By presenting stimuli in a perceptual fashion, such as providing visual cues, neural pathways related to goal-directed behavior are activated. This is consistent with Barkley's (2012b1) suggestions for externalizing EFs, which suggests that presenting stimuli in proximity to the call for action, likelihood that the behavioral action will engage is increased. I argue that environmental shaping could be used to do this. By having a structured home environment where everything has a place, an individual can self-program by providing structured triggers for themselves with a calls-to-action[41]. Furthermore, Barkley's model of EF suggests that EFs that are severely underdeveloped (in lower hierarchical phases) are more likely to respond in a manner consistent with behaviorist theories. These 'automatic responses' decrease as EFs develop and self-regulation is increased through (i.a.) self-awareness. Shaping one's own physical environment is an active behavior that arises by the time the individual is at the Methodical – Self-reliant level of EF. Using this intentional shaping of one's environment should also prove useful for stimulating behavior that is consistent with one's own subjective goals. This would need to be done for many things dependent on the individual's needs. By changing the environment to provide a trigger, the individual is able to interact with the consequences of his deficits.

This sounds promising. There are many ways imaginable to externalize cognitive functions to some extent. Attention, memory, spatial and motor functions, could all be engaged through the use of many different artifacts, and adjusting them to one's environment. And this would likely be helpful, but there is problem. The dependence on visual cues has the downside of only working in that single altered setting, and nowhere else. There is no portability, so this system would not be reliably coupled when going outside the shaped environment. Since for many users the only environment that is available for reliable and consistent shaping, free from outside interference, is the home environment. Inside this environment the link is strong, provided one continues to actively continue shaping, but the user needs support across settings. The inherent conclusion is that environmental shaping will never be enough on its own to form a reliably coupled system.

Another problem is that the level of EF development has a pronounced effect on how useful environmental shaping can be. Only at the methodical – self-reliant level, third in the developmental hierarchy of interactionary development, would one naturally begin to actively reconfigure the environment. Using manipulations of the environment should be most beneficial to those who are naturally inclined to react to their environment in automatic ways – those with less developed EFs. Since ADHD interferes with EFs at all levels, we must assume that aid is needed even at the most undeveloped levels. Thus an EFd individual is even less able to engage in the behavior when it would provide the greatest benefit. Could, and should it then be shaped for them? Arguably it would help to kick-start some behaviors and make life easier on the individual, but it offers no long-term solutions. One's environment changes again and again to suit the passage of time in daily life and the natural changes that occur in the environment, as do the individual's subjective goals.

Current accessible technology is not advanced enough to shape and environment for an individual in the way they desire. It is possible to target individual's behavior rather than the environment, and build an enabling technological scaffolding that stimulates the formation of habits to ease unconscious initiation of behavior**.** Yet again due to the very deficit we are attempting to improve it will be hard to get those with ADHD to engage in shaping behavior such as forming habits, especially at lower levels of EF engagement.

Environmental shaping should not be discarded as useless, especially for those with undeveloped EFs. However its usefulness is very limited. Explicit shaping behavior appears to be able to offer aid in self-programming, but cannot offer a unified system for the user to completely rely upon. It can only offer support. Thus, it is not the final answer. What else is there to appeal to?

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[41] E.g. by moving something so that it is in an odd place. Due to attentional primacy of the non-normal, perceptual capacities will register this oddity, resulting in a trigger of the message mentally attached to the artifact.

## 5.2 Cognitive Offloading

Offsetting deficits by externalizing them onto something other than one's own brain, thus sharing the cognitive load and easing the stress on the individual is a known concept called cognitive offloading. It is possible to offload in many places, but we are interested in technology. Cognition can be said to be offloaded to an 'external' device when a human agent uses a technological agent (a cognitive technology) as a part of the cognitive process in order to improve upon this process in some way, lightening the cognitive burden placed on the human. Examples are pen and paper, a calculator, a digital agenda on a smartphone, processing software on a PC, et cetera. This recognition of the bi-directional nature of influence within the coupled system is complementary to EMT. The pen and paper, for example, are said to be used for offloading information, lightening the load on i.a. working memory, and enhancing accuracy of information retrieval. When interpreted in the light of EMT, this pen and paper can create a coupled cognitive system by forming it into a notebook one carries everywhere. As a cognitive system it is a source of knowledge at least as reliable as the biological human's own. However, the 'hardware limitations' that guide technological processing almost always far exceed the capacities of the human brain. (e.g. rote memory retrieval, computation) especially with computational technologies (e.g. cellphones). "In the online era, increasingly powerful cognitive technology is available for people to enhance their performance capacity and help them do what they formerly had to do in their heads. It is becoming possible to offload more and more cognitive processing onto cognitive technology, thereby both liberating and augmenting the performance power of the human brain." (Carr & Harnad, 2011, p. 33) Cognitive Offloading can therefore extend human performance capacity beyond our biological limits. But can we aid function in a network that is so complexly situated and interwoven with other cognitive functions, indeed with the very physiology that gives rise to the self? Given Diamond's (2013) assertions that EFs can be trained and this training is transferrable, the benefits of offloading specific EF processes could and should be shared by the whole system. If so, cognitive offloading will be able to enhance performance in those with EF deficits.

This is supported by research into cognitive technologies. "[I]ndividuals with impaired unaided cognitive ability may particularly benefit from cognitive offloading. The metacognitive model of cognitive offloading put forward in this article suggests that compensatory offloading strategies are most likely to be adopted in individuals with metacognitive awareness of their impairment. (…) Improving metacognitive insight in cases such as these could lead to more-appropriate compensatory offloading." (Risko & Gilbert, 2016, p. 685) This is consistent with Barkley's assertion that the first EF to arise is centered on self-awareness, as it is necessary for all following EF development. As does it affirm an approach following temporal succession of EF development along the lines of Barkley's hierarchical model. This is not to say that users would not benefit from offloading at all levels within the same device, but offering everything at once is not a way to exact meaningful change in those with EFd. By focusing first on the primary needs the user can go through a learning process with natural buildup of skills. By offering cognitive assistive technology the individual can offset their deficits by offloading them onto a reliable system, and by presenting it with focus on hierarchical succession the individual can train the system including biological function. In order to do this, we must see what is possible per level. So how would we offload functions of specific levels?

### Pre-executive level

Before EFs can arise at all, the pre-executive necessities must be met and functioning as they ought. This level concerns itself with automatic human activity, at a "primitive, unthinking, unreasoning, unself-regulating level of existence" (Barkley, 2012a, p. 78) that is only concerned with moment-to-moment survival. The functional intention is to offset deficits by making the individual aware of their environment and able to react to it. This requires a healthy central nervous system with routine primary neuropsychological functions, including basic human needs such as sleep, exercise and diet. Specifically for EFs this includes attention, alertness, visual-spatial performance, autonomic-emotional actions, memory, sensory-perceptual functions, language and motor abilities[42]. Of these functions "spatial, temporal, and motivational— are likely the most fundamental to the development of EF. They generate the capacity for a sense of the self, a sense of one's current state, and a conscious sense of the hypothetical future—an ability to imagine goals ever more distant in time and space and to contemplate the action plans needed to attain them." (Barkley, 2012a, p. 73) As we know these abilities are disturbed to some extent in ADHD, so how can these functions be offloaded in a way that would offset natural deficits?

CNS functions and behavior are not easily available for targeted intervention without relying on medical aid to offset the severity of the impairment. There are ongoing experiments with cognitive technologies such as transcranial stimulation which show potential. However we have an accessibility requirement. Other technologies make contact with treatment professionals available to the user. And indeed, the facilitation of access to local stakeholders such as diagnostic and treatment facilities is recommended for reasons already discussed. Note that accessibility to social institutions is heavily dependent on one's social and cultural environment and institutions – or political landscape.

Much research is still to be done on the interaction between technology and specific cognitive functions, but there exists a growing body of research on the cognitive assistive technology and specific impairments. During a 2012 review of publications on cognitive assistive technologies, the only research on specific mental functions related to the experience of self and time was into locational awareness[43], and all are dementia-centered, showing only limited effectiveness (Gillespie et al., 2012). In this review, it is apparent that research into locational and temporal awareness has focused on behaving in relation to awareness rather than the awareness itself. Research into cognitive technologies into functions this basic is little or absent[44]. A primary problem is the following: If one tries to offload primary mental functions like spatial temporal awareness, it must be offloaded onto a location where it is constantly and inseparably available to the user, and constantly sending information to the user in order for them to process it and use it to react. A cognitive assistive technology like a walking stick assists a single function in a single process. Until Clark's neural implant is invented, assisting all primary processes may not be possible with a single unified technology. Not to mention overkill. Spatial and temporal awareness, it appears, must stay in the environment it is meant to build awareness of. There are courses that promote teaching awareness of one's surroundings through meditation or mindfulness. A candidate can offer access to these, but not otherwise *directly* offload spatial and temporal awareness in a way that would be beneficial to the user.

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[42] Barkley, 2012a. Specific functions mentioned p.76

[43] (1) the use of GPS to locate the user, (2) giving the user context-dependent directions by using information in the environment, (3) guiding the user based on a pre-programmed internal map of their environment. (Gillespie et al., 2012)

[44] "We did not find any ATC which primarily assisted the psychomotor functions (b147), perceptual functions (b156), thought functions (b160), mental functions of language (b167), or mental function of sequencing complex movements (b176)." (Gillespie et al., 2012, p. 10)

Certain cognitive assistive technologies have shown good overall evidence of effectiveness in attentional functions[45] (Gillespie et al., 2012). Experiments by Fish et al. (2007) test the contribution of EF toward prospective memory in those with brain injuries, and found striking improvements in performance on days that participants were provided with intermittent support through content-free cues. They were able to do this by linking the cue phrase "STOP" to the participant pausing their current activity, and sending this message to the participant's phone 8 times throughout 5 random days[46]. To minimize retrospective memory-based failure, they had participants set and record goals. Technologies that attempt to improve prospective memory and awareness through time-management functions often employ aural or visual reminders to perform a task at a particular time. Fish et al.'s (2007) results show that cues do not need to contain a message to be useful to the participant. It appears as though simply giving the participant a cue to cease their automatic behavior, and engage conscious goal-directed behavior. The ability to stop and re-evaluate, that is less in those with EF deficits, is offloaded onto a technological device that will cue them to start this activity rather than staying in the chain of automatic responses to stimuli in their environment. A content-free cue that tells a user to STOP is recommended for candidate technologies.

Cognitive Offloading is said to increase informational accuracy, so beneficially offloading a part of one's memory is possible. But will only be able to form a coupled system if the information is accurate, helpful and trusted. Cognitive assistive technologies for memory functions include cameras and multimedia reminiscence devices (Gillespie et al., 2012). Crucially though, those with ADHD do not have problems with memory retrieval (Skodzik et al., 2017) and it is speculated among experts that the main interference in memory functions have more to do with attention-based failure to record and working memory deficits. Use of camera's as a source later recall could be used during active reflection by offering the user something to aid processes of hindsight and foresight, in the form of supplying imagery to either re-enforce already existing memories or offering a cue for reflection.

Motivational systems have a large body of research, not just in psychology and neuroscience but in business and marketing. There are many ways to influence motivational systems, many of them ethically dubious. "Nudging" may not be so much of a problem in marketing strategies like gamification, if the user is intent on *self*-programming their motivational systems. Specific cognitive assistive technology for motivation structures in cases with deficits or injuries are harder to find. But emotion and motivation go hand in hand. Emotional dysregulation in EFd usually takes form in the lack of ability to deal with the emotion once it has arisen. Typical self-regulatory strategies such as self-soothing and inhibiting immediate response are lacking. The environment in which an actor finds themselves can be shaped to be calming, and this may help to lower the base stress a person experiences at home, but this is not sufficient. It is in the nature of emotion that it is a response to something in the environment (social interaction, event, etc.), and this cannot be shaped. Research into cognitive assistive technologies on emotional processes seems to have focused on lowering anxiety[47]. Lowering general anxiety is arguably always beneficial for those who have problems with impulse control in a disorder that interferes with emotional functions, but it is not the core of the

[45] Focussing on a specific desired internal or external stimulus for a required period of time, without prematurele diversion of attention to irrelevant other stimuli.

[46] NB: these messages were not sent withing 1hr of a recorded target time of goal completion by the participant.

[47] Examples include use of personal stereos for managing the effects of hallucinations in those with schizophrenia, and biofeedback to reduce autonomic arousal with good evidence of reducing subjective anxiety in post-traumatic stress disorder and anxiety disorders (Gillespie et al., 2012).

problem in those with EF deficits. Lowering anxiety will not teach someone with ADHD to regulate their emotional outbursts once they have been triggered. For this, one needs self-awareness of their emotional states and both know and be able to employ the strategies to self soothe and inhibit an immediate response. Furthermore, one needs a reason to want to do this. These are all capacities developed in the next level of EF development.

## Instrumental – Self-directed level: Developing Self-awareness

This level marks the first executive (self-regulatory) functions. The intention is to create capacity for self-awareness, self-modification, and regulation over time. This is achieved through self-monitoring (to allow hindsight) and reflection (to allow foresight) (Barkley, 2012a). The target goal for this level is to engage the actor in 6 self-directed actions. These are, as mentioned by Barkley (2012b2, p. 63) (1) "Self-directed attention – self-awareness", (2) "Self-restraint (inhibition)", (3) "Self-directed sensory-motor action (nonverbal working memory; imagination[48])", (4) "Self-directed private speech (verbal working memory; verbal thought)", (5) "Self-directed appraisal (emotion – motivation)", (6) "Self-directed play (innovation, problem solving)" .

Psychoeducation is a crucial part of development of self-awareness, yet EFs must be developed enough to use this information and bring it into the realm of action. Since individuals with severely undeveloped EFs are stuck at a more automatic and responsive behavior, there is little stable agential autonomy for any treatment to rely upon. Psychoeducation should be all but useless for bringing about conscious behavior in the early stages of EF development. However, it could make the individual more willing and responsive to use of operant conditioning strategies, to start the process of self-programming. It may therefore be beneficial to offer types of information in line with development, and offering education to stimulate certain behaviors per level. This means a focus on self-awareness at the instrumental – self-directed level.

By their very nature, self-directed actions cannot be offloaded. If, in a coupled system, the technological entity undertakes these 'self'-directed actions over itself and the biological agent, then this will not create the desired effects. Attention of technological entity will not create self-awareness in the biological entity. Inhibition of technological entity will not create restraint in the biological entity. Appraisal will not affect motivation, play will not increase problem solving, and so on. The functions themselves cannot be offloaded. However, if the cue to start the agent engaging in these behaviors can be offloaded, then that would help towards initiation of the behavior. Triggering behavior has already been at length. The anticipated constraint here is the engagement of the user. Since there is little agential autonomy to rely on at these early stages, we cannot *assume* that merely cueing these behaviors will be enough. To assist those with natural deficits, assisting the process itself will be beneficial. "It is difficult to imagine a device which mediates thought[49] processes without primarily assisting attention, planning or memory. However, if one assumes a close relationship between thought and language (Vygotsky & Luria, 1994), then it might be possible to have a system which monitors verbal output and provides feedback to, for example, slow down, keep on track, or prompt general problem solving." (Gillespie et al., 2012, p. 10). Gillespie's theoretical device could be taken as inspiration for an artefact that can do this for all the mentioned self-directed actions. Users would need to use a think-aloud method in specified reflective times, or use writing to structure their

[48] Self-directed sensory activity – re-seeing, re-hearing, re-smelling, re-feeling to create the capacity for imaginary construction. This Behavioral reenactment allows for practice and rehearsal, helping the agent to prepare for possible future events and how to react to them.
[49] Thought functions refer to the pace, form, and content of thought. (Gillespie et al., 2012, p. 10)

thoughts. To trigger self-awareness functions specifically, cognitive assistive technologies can focus on prompting acts of self-monitoring, reflective contemplation, or goal-reflection. In order for this to work, exercises would need to be made to guide the user in these processes, or can be taken from cognitive behavioral therapies.

## Methodical – Self-reliant: Developing Independence

This level marks the rise of overt observable activities (behavior) as distinct from private mental and self-directed events, as well as self-organization of the environment. The intention is to facilitate daily adaptive functioning and growing independence. This includes self-care, self-defense against others and reconfiguring the physical environment. The goals for this level are (1) Use of methods to attain near-term goals, (2) Self-management across time, (3) Self-organization and problem solving, (4) Self-restraint, (5) Self-motivation, (6) Self-regulation of emotions, (7) Social independence and social self-defense. Note that developing EFs requires constant hard work and training. One cannot offload a person's willingness to engage in these, and to stay motivated to stay at it, without essentially infringing on their free will. However, one can teach and stimulate a person to apply themselves when they have chosen to act.

Externalization does not only occur with objects, it can also occur with fellow humans. "Cognition is not only distributed but collaborative" (Carr & Harnad, 2011). Using another person as a tool to stabilize some of one's own mental faculties is common in cases with little pressure. For instance, going to a trusted other for advice, is effectively offloading part of their working memory into a conversation with this other, organizing relevant thoughts on the topic by verbalizing them and having other sound off on them. The same as one would organize their thoughts using pen and paper. Morally, this is normal human behavior and considered socially engaged. However, when a person becomes truly dependent on another, this is counterproductive to the creation of autonomy within the individual. Parasitism is what happens when too many of a person's core abilities are offloaded onto another to the detriment of this other. The capacity for social-parasitism and –predation rise in this level, and should be guarded against. This balance of interaction with others will become more important in later levels. Barkley's hierarchical model of EFs focuses on social relationships in distinct ways on each level after the creation of self-reliance. For now, it is important to build independence from others. Not distance, but independence.

Moëll, Hollberg, Nasri, Lindefors & Kaldo (2015) report on tools that adults with ADHD found useful identified "tools that give support for organization, structure and scheduling and coordination of activities" as the most desirable. Lindstedt & Umb-Carlsson (2013) reflect well-known problems in ADHD, and indeed EF, literature in that frequency of support for their participants indeed centered around planning and organizing everyday activities. Reflecting this necessity, assistive technology should offer support in carrying out daily routines, economic self-sufficiency, undertaking a single task, and looking after one's health (Lindstedt & Umb-Carlsson, 2013). Making these daily actions (customizable and) explicit will help the individual actually engage in them to create routines. Also identified as necessities in this study were cooperation with authorities, and informing and educating staff or personnel in housing and workplaces. These may not be necessary for all users, but having been identified, these should also be areas of attention. Consider the constraint that these are all time-consuming.

Research into cognitive assistive technologies for time-management functions engages with prospective memory and start-stop behavior at specific times. Examples include aural and visual reminders to perform a task at a certain time, like voice recorders with timer functions, messaging to personal devices, reminders and scheduling software. Experimentation showed strong overall evidence for these techniques, but mixed results (Gillespie et al., 2012). Research into cognitive assistive technology for daily routines shows several examples of successful designs. There is some research on assistive technology in the employment domain, but this is most all about either intellectual disabilities (which ADHD is not) or coping with amnesia. Table 3 show examples of cognitive technologies that are relevant for a candidate assistive EF technology. These could serve as inspiration for adaptation into something usable for users with EF deficits.

Extended Mind theorists like to illustrate their theories with computing devices, because they are especially easy to couple with. Technologies with capabilities for offloading (e.g. smartphones, tablets, laptops, PCs, etc.) have become thoroughly entrenched in the everyday lives of those who use them, which is an ever growing population all over the world. As such, these technologies have a larger spread of easy accessibility. Many of them also meet the portability criterion, which is a strong endorsement. As such, this gives them a recommendation for candidacy.

Once the capabilities in this level have been established, the individual will arguably have created autonomy through becoming self-reliant. However, since EFs are interactionary across developmental levels, it would offer additional benefit to look beyond and see if there is ability to be gained by offsetting deficits at later levels.

| | | *Device* |
|---|---|---|
| *Target function* | Daily routines | VICAID aids the user by providing them with pictorial instruction designed to help users correctly complete their tasks, as well as reminders to do them and automatic feedback to a caretaker if the device decides the user is having trouble. |
| *Target user* | severe developmental disabilities | |
| *Source* | (Furniss et al., 2001) | |
| *Target function* | Daily routines | COACH makes use of artificial intelligence to guide elderly users through daily living activities, through audio and/or audio-video prompts. In this system, a camera captures visual data (e.g. position of the users hands) to gain feedback on task progress (e.g. washing hands), and then selects an appropriate auditory prompt. |
| *Target user* | dementia | |
| *Source* | (Mihailidis et al., 2008) | |
| *Target function* | Daily routines | Neuropage is a reminder messaging system. First published in 1994 as a pager system, it has developed along with our current technological landscape. During its development and scientific evaluation, it showed to be more effective than simple cueing. Examples of reminders such technologies offer are medication reminders, orientation, everyday activities, appointments, social events, family responsibilities, finances[50]. |
| *Target user* | memory and planning impairments | |
| *Source* | (Hersh & Treadgold, 1994) | |
| *Target function* | Daily routines | ISAAC is a small, individualized, wearable, software system that assists users in performing daily routines through the use of i.e. checklists. |
| *Target user* | Deficits, disabilities or brain injuries | |
| *Source* | (Gorman et al., 2003) | |
| *Target function* | Self-care | GUIDE[51] uses an interactive auditory-verbal interface to simulate normal conversation with its user, in order to simulate naturalistic instruction with verbal prompts and questions. This helps those with difficulties performing complex behavioral sequences. |
| *Target user* | Cognitive impairments | |
| *Source* | (O'Neill et al., 2010; O'Neill & Gillespie, 2008) | |

*Table 3: **Examples of published cognitive assistive technology**.*

## Social Symbiotic levels

"It is via EF/SR that individuals engage in this process of evaluating ends and means and the subjective use-value of these for their own welfare. … This means there is a large measure of unpredictability to the choices and actions of others; each individual must take this variability into account in living among and dealing with other people." (Barkley, 2012a, p. 62) It is in these levels that the capacities to engage in social behaviors is seen. Both levels deal with the use of tactics and methods for goal-attainment over some period of time, as well as developing beneficial social behavior.

[50] (n.d.). Retrieved May 19, 2020, from http://www.ozc.nhs.uk/Neuropage.asp
[51] General User Interface for Disorders of Execution (GUIDE)

**Tactical – Reciprocal:**
**Developing Human Social Exchange**

This level gives rise to the inclusion of others in one's life and goals. Social symbiotic behaviors like turn taking, reciprocity, promise keeping, trading, social skills, and etiquette become more important. The intention is to facilitate self-organizing of social arrangements involving symbiotic reciprocal exchanges with others. The target goal for this level is to set up the basis for human social exchange. This involves bringing about (1) Use of tactics – nested sets of methods – to attain midterm goals, (2) Daily social exchange (sharing, turn-taking, reciprocity, etc.), (3) Group living (lower proportion of individual dispersal), (4) Beginning of economic behavior (trading), (5) Social independence (using others to attain goals).

**Strategic – Cooperative:**
**Expanding Human Cooperation**

This level gives rise to a higher order social engagement with a cooperative/unity approach, which allows for goal-attainment that would be impossible for the individual. The intention is to allow the individual to become competent in the use of social arrangements for cooperative ventures with others and social arrangements for mutualistic communities. The target behavior for this level includes (1) Use of strategies – nested sets of tactics – to achieve longer-term goals, (2) Arrangements of social cooperatives with division of labor, (3) Acting in unison to achieve common ends and shared benefits.

People with ADHD are not known to have abnormalities in memory retrieval (Skodzik et al., 2017), so psychoeducation is sufficient to teach people with ADHD to know what to do. "Education can be usefully portrayed as the construction of this type of cognitive and social scaffolding via the active training involved in pedagogy. This training is not merely the passive display of cultural information to the child recipient. It is active training in its content, meaning, and use. And it is the active pursuit of such training by the recipient as well. … Availability of and training in the cultural knowledge base is an essential part of this developmental dimension" (Barkley, 2012a, p. 73). This suggests inherent necessity of some form of psychoeducation to be incorporated in our candidate device. Basic underlying needs for social exchange such as emotion-regulation have by this level already been addressed. Here the use of tactics and social exchange skills, lie at the basis for what deficits need to be offset. However, social exchange is difficult to anticipate and highly subjective. Taking the same approach as when attempting to form routines, the user may benefit from being explicitly guided through (examples of) tactics. However, considering that the socially constructed narrative is a maze of accurate and inaccurate information, myths and opinion pieces, access to information that will help, not harm, is key. The user can be taught to be self-sufficient in exploring and evaluating the value of information, or they can trust in expert advice. In considering appropriate offload sites, I would like to note the following. "In reality, learning is distributed between the medium, the learner and the context[52]. There is nothing inherent in the Internet that guarantees learning. However, in a specific context involving learning activities, such as research, collaboration, self-expression, and reflection, the Internet offers multiple affordances, so numerous that it may be a mistake for us to treat it as a medium. It is really an infrastructure which brings together media, tools, people, places and information, expanding the range of human capabilities." (Ryder & Wilson, 1996, pp. 646–647) This makes the internet an ideal environment for facilitating psychoeducation. Entirely offloading direct

[52] (Jonassen, Campbell & Davidson,1994)

exchange with people in one's environment with others is not only immensely difficult, it is unhealthy and counterproductive for the development of the individual. However, in addition to being a hotbed of information the internet is famously able to offload direct communication trough online media. Therefore an online environment offers a versatility messaging environment to practice some tactics.

An affordance of the internet that has grown in the recent decennia is the ease, accessibility and popularity of online contact. Not only does most everyone communicate digitally to some extent, but the popularity of social platforms has a destigmatizing effect on online media as a form of communication. This offers an opportunity for psychosocial support. Online platforms can help to connect and empower minorities, as illustrated by the recent feminist movement in Iran that centered on sharing pictures and videos to protest a law that prohibited women from dancing or showing their hair in public. Online platforms can offer a forum to connect individuals with overlapping interests, like we see in Reddit communities. Additionally, technological growth has ensured that proximity to a location is not a constraint for most. After all, facilitating accessibility to the internet and all it provides is a multi-billion dollar industry.

A constraint in this is taking care of the accessibility criterion. Worldviews being based on environments, people often think that in our modern society everybody has access to the internet and modern devices, but this is not the case. Not only developing nations struggle with lack of access, but populations within advanced developed nations such as the elderly, cognitively impaired and (digitally) illiterate. This concept is further articulated in the term "Digital Divide", which disproportionately affects the 'vulnerable' population. The internet and the devices that offer access to it are complex, and use is difficult for those who are not used to handling them. Sometimes the user must learn to use the technology, which is never a good sign. We must consider not only the availability of and access to the technological artefact, but ability to use it as well. However 'digital literacy' is rising, especially in younger generations, meaning that it would be useful for specific target audiences, such as the digitally literate in developed countries.

If a technology wished to offset deficits at these levels, more research is to be done on how EF deficits interfere in human social interaction and how to offset them with cognitive technology.

### Extended Utilitarian (or Principled – Mutualistic)

This level is what matured EFs can engage in, and gives us the capacity to interact with our social ecology and engage in social arrangements for mutualistic communities. This includes (1) Use of principles – nested sets of strategies – to achieve long-term goals, (2) Pursuit of long-term self-interests by putting others' long-term self-interests ahead of one's own near-term and midterm self-interests, (3) Preference for larger delayed over smaller immediate consequences. And is the evolutionary origin of colonies, cities, city-states, states, and countries. As it is not EF itself nor is it necessary to engage in it, but rather extended executive function, this no longer falls inside the scope of this thesis and we have come to a natural conclusion.

## 5.3 Takeaway

Environmental Shaping can *support* the interruption of automatic behavior in service of goal-directed behavior.

Cognitive Offloading strategies for candidate devices to target specific cognitive functions per developmental level:

Pre-Executive Level

- It is desirable that our candidate device should aim to provide access to diagnostic centers, and aid health-behavior.
- There is evidence that attentional functions benefit from content-free cueing.
- There is evidence that memory functions benefit from cameras and multimedia reminiscence devices.
- Consider appealing to spatial, temporal, and motivational functions. More research is needed on cognitive assistive technology that effects these functions. Other examples of appealing to awareness of these functions include meditation and mindfulness programs.
- Most evidence for technologies on motivational systems is for lowering anxiety. More research is needed on how to assist emotional dysregulation in EFd. Areas of focus should include inhibition of immediate response, emotion regulation, self-soothing and self-redirection of attention.

Instrumental – Self-Directed

- Psychoeducation plays a strange role in all this, as it is an important aspect of creating self-awareness and yet it does not show great effect in those with EFd. They *know*, but they cannot necessarily therefore also *do*. It is advised to offer and adjust psychoeducation to focus on the relevant information along with the succession up Barkley's hierarchical levels.
- Self-directed actions cannot be directly offloaded and still have the desired effect of stimulating EF engagement. But an artefact may cue the beginning of the six specified self-directed actions at certain times. In order to increase ease of use and offload part of the deficiency the user may be guided through the processes of self-monitoring, reflective contemplation, or goal-reflection.
- The relationship between thought and language makes language devices appealing.

Methodical – Self-Reliant

- It is important to approach the user as an actor, and recognize subjective-use-value of goals.
- Guard against social-parasitism and –predation
- Candidate technologies should offer explicit support in carrying out daily routines, economic self-sufficiency, undertaking a single task, and looking after one's health. (Possibly: cooperation with authorities, and informing and educating staff or personnel in housing and workplaces)
- Table 3 offers examples of other assistive technologies targeting daily routines and self-care.
- Modern computing devices offer many capabilities and should definitely be considered in candidacy. However, keep in mind that complex technology is not available to everyone (due to problems with access or understanding complexity.)

Social – Symbiotic (Tactical – Reciprocal & Strategic – Cooperative)

- The internet offers an ideal environment for facilitating psychoeducation.
- Accessibility and ability to handle technological complexity varies per population. Using devices with access to the internet offer an excellent platform, for those who have access to them.
- More research is to be done on how to offset EF deficits in social interaction.

# Part IV: Concluding Remarks

## Chapter 6: Conclusion

Executive Function research has a rich epistemological history. The overall field is fairly certain of what EFs are and what they include, but there is still much disagreement about the specifics. What is clear is that EF and goal-directed behavior are tied at the core. EF = SR, and self-regulation is the behavioral basis of EF.

> "EF is the use of self-directed actions so as to choose goals and to select, enact, and sustain actions across the time toward these goals, usually in the context of others, often relying on social and cultural means for the maximization of one's longer-term welfare as the person defines that to be". (Barkley, 2012a, p. 174).

Barkley's model offers explanations for what constitutes EF. It ranges from requirement of neurophysiological substrates, to the several levels of EF and how they give rise to self-regulation, and takes into account the radiating nature of these functions into not just a person's life but how they interact with social arrangements and communities. Viewing EF-engagement as our drive to cease automatic response, set goals and act toward them, it could be argued that EF is one of the mechanisms of both free will and autonomy, it drives self-reliance and separates behavior from automatic responses to immediate external stimuli. To engage EFs, is to stimulate autonomy.

Extended Mind theory is complimentary with embodied, embedded, distributed, enactive notions of mind. The identified operational definition and model of executive function is also complementary with these notions. This creates a strong bond that will allow for examining and interpreting the use of artifacts in EFd, and presents an opportunity for research into enabling treatment through technological means. In this, it is important to note that not simply any technology will do if the aim is to offset cognitive deficits such as EFd. Only in a coupled system, I argue, does the mind truly rely on a symbiotic technology enough to allow for any long-term, meaningful interaction between technology and biology that would benefit the user as more than a tool-for-use.

Awareness of how specific technologies assist the brain in specific ways will lead to understanding of which candidate technologies are suitable. Cognitive offloading can enhance human performance and offset cognitive deficits. Due to the changeable nature of the human brain, it is not possible to offload EF in its entirety, but it is possible to assist specific processes to offset specific deficiencies. Barkley's (2012a) model of EF offers specific target behaviors and capacities that correspond with each executive level, offering us an understanding of which functions are more basic and require priority. Using a technology to offer support by offloading deficits would be beneficial to the independence and growth potential of the individual. Offloading specific cognitive functions in a way that stimulates personal autonomy is key. Even when offloading deficiencies, research shows the actor will need to train and push themselves in order to further develop their own EFs. Those that can be offloaded to offset deficits strengthen the newly formed coupled system. Appendix E offers a concise overview of core recommendations identified in this thesis.

## Limitations

These principles are targeted to ADHD individuals, but due to the heavy focus on EFd it is highly generalizable to EFds in general. This makes these findings useful for technological design processes for those with other mental disorders (addictions, conduct disorder, depression, obsessive compulsive disorder, schizophrenia) that also present with EF deficits. But all people have EFs, and anyone's EFs can suffer quite easily. In this way, it could be generalized to benefit the overall population.

This research has not concerned itself with the ethical debate of a technology that is meant to form a part of the self. Due to the impact on the person, the technology has a high moral status and should be ethically investigated. A lot more is to be said, especially now in times when our newly expanding computational technology is showing to have a lot of effect on how we behave as individuals and as a society, and the social, cultural and economic values we hold all around the world. The scaffolding a societies offer can have a promoting or retarding effect on the EF engagement of its citizens. If EF engagement is truly a mechanism for autonomic behavior, as this thesis suggests, then how exactly society decides to engage with it is an active choice whether it receives attention or not. The consequences of structural choices have their effects on EF whether this is intended or not. Promoting EF in citizens is beneficial for the health and independent capabilities of the populace and is therefore generally advised. However, a full ethical investigation is still required.

In attempting to engage with a phenomenon in understanding, both epistemic and non-epistemic factors should be considered. This thesis focusses mostly on academic accounts of knowledge, as full examination of social epistemic attitudes among non-experts unfortunately fell outside the scope of this thesis. Such attitudes influence the uptake of treatment and technology and reveal collective patient knowledge. Where this thesis focusses mainly on scientific theory, much is to be gained by examining the surrounding social belief systems including ideology, culture, ethics and values, and guard for testimonial injustice. Further research and/or development is advised to take a participatory approach.

Much research is yet to be done on how exactly certain cognitive functions interact with assistive technology, and how this affects the user. Areas of interest should include what grows or shrinks the EF resource pool, and how else to affect it. Technology is able to take over some of the cognitive burden of processing when used correctly, but it would be beneficial to the biological entity to train innate capacities to increase overall personal ability, even as part of a coupled system.

People suffer from this, and they don't have to. I am convinced that EF deficits are both the source and solution to many problematic symptoms in ADHD, especially in that deficits cause personal impairments across settings and that if individuals are aided in development of EFs then they will be more aware and able to act in their own interest on the long term. They will have more autonomy capacities. My hope is that this thesis will serve as a jumping off point for some technology design that will help those with ADHD with their EF deficits.

# Reference Section

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## Abbreviations Index

| | |
|---|---|
| ADHD | Attention Deficit Hyperactivity Disorder |
| CNS | Central Nervous System |
| EF | Executive Function |
| EFd | Executive Function Deficit |
| EMT | Extended Mind Theory |
| FL | Frontal Lobes |
| PFC | Pre-frontal Cortex |
| SR | Self-regulation |

# Bibliography

Aarts, H. (2007). Health and goal-directed behavior: The nonconscious regulation and motivation of goals and their pursuit. *Health Psychology Review*, *1*(1), 53–82. https://doi.org/10.1080/17437190701485852

Adams, F., & Aizawa, K. (2001). The bounds of cognition. *Philosophical Psychology*, *14*(1), 43–64. https://doi.org/10.1080/09515080120033571

Arria, A. M., Garnier-Dykstra, L. M., Caldeira, K. M., Vincent, K. B., O'Grady, K. E., & Wish, E. D. (2011). Persistent Nonmedical Use of Prescription Stimulants Among College Students: Possible Association With ADHD Symptoms. *Journal of Attention Disorders*, *15*(5), 347–356. https://doi.org/10.1177/1087054710367621

Association, A. P., & others. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Baars, B. J., & Gage, N. M. (2010). *Cognition, brain, and consciousness: Introduction to cognitive neuroscience*. Academic Press.

Barkley, R. A. (2012a). *Executive Functions: What They Are, How They Work, and Why They Evolved*. Guilford Press.

Barkley, R.A. (2012b1). *2012 Burnett Lecture Part 2 ADHD, Self-Regulation and Executive Functioning Theory* [Lecture]. The 11th Timothy B. and Jane A. Burnett Seminar for Academic Achievement, The University of North Carolina at Chapel Hill. https://www.youtube.com/watch?v=QZpF2_IelWo&t=10s

Barkley, R.A. (2012b2). *ADHD, Self-Regulation, and Executive Functioning: Theory and Implications for Management*. https://learningcenter.unc.edu/services/ldadhd-services/burnett-seminars/dr-russell-barkley/

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review*, *29*(3), 180–200. https://doi.org/10.1016/j.dr.2009.05.002

Biederman, J., Wilens, T., Mick, E., Milberger, S., Spencer, T. J., & Faraone, S. V. (1995). Psychoactive substance use disorders in adults with attention deficit hyperactivity disorder (ADHD): Effects of ADHD and psychiatric comorbidity. *The American Journal of Psychiatry*, *152*(11), 1652–1658. https://doi.org/10.1176/ajp.152.11.1652

Biederman, Joseph, Wilens, T., Mick, E., Spencer, T., & Faraone, S. V. (1999). Pharmacotherapy of Attention-deficit/Hyperactivity Disorder Reduces Risk for Substance Use Disorder. *Pediatrics*, *104*(2), e20–e20. https://doi.org/10.1542/peds.104.2.e20

Borkowski, J. G., & Burke, J. E. (1996). Theories, models, and measurements of executive functioning: An information processing perspective. In *Attention, memory, and executive function* (pp. 235–261). Paul H Brookes Publishing Co.

Brey, Philip A.E. (2000). Technology and Embodiment in Ihde and Merleay-Ponty. In *Metaphysics, Epistemology and Technology (Research in Philosophy and Technology, vol.19)* (pp. 45–58). Elsevier/JAI Press. http://research.utwente.nl/en/publications/technology-and-embodiment-in-ihde-and-merleayponty(bcf6af21-9f59-4b32-b343-65d0592aa3c1).html

Brown, T. E. (2009). *ADHD Comorbidities: Handbook for ADHD Complications in Children and Adults*. American Psychiatric Pub.

Carr, L., & Harnad, S. (2011). Offloading Cognition onto the Web. *IEEE Intelligent Systems*, *26*(1), 33–39. https://doi.org/10.1109/MIS.2011.19

Clark, A. (2001). Reasons, Robots and the Extended Mind. *Mind & Language*, *16*(2), 121–145. https://doi.org/10.1111/1468-0017.00162

Clark, A. (2010). Memento's Revenge: The Extended Mind, Extended. In R. Menary (Ed.), *The Extended Mind* (pp. 43–66). The MIT Press. https://doi.org/10.7551/mitpress/9780262014038.003.0003

Clark, A., & Chalmers, D. (1998). The Extended Mind. *Analysis*, *58*(1), 7–19. https://doi.org/10.1111/1467-8284.00096

Cortese, S., Adamo, N., Del Giovane, C., Mohr-Jensen, C., Hayes, A. J., Carucci, S., Atkinson, L. Z., Tessari, L., Banaschewski, T., Coghill, D., Hollis, C., Simonoff, E., Zuddas, A., Barbui, C., Purgato, M., Steinhausen, H.-C., Shokraneh, F., Xia, J., & Cipriani, A. (2018). Comparative efficacy and tolerability of medications for attention-deficit hyperactivity disorder in children, adolescents, and adults: A systematic review and network meta-analysis. *The Lancet. Psychiatry*, *5*(9), 727–738. https://doi.org/10.1016/S2215-0366(18)30269-4

Daly, M., McMinn, D., & Allan, J. L. (2015). A bidirectional relationship between physical activity and executive function in older adults. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.01044

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Duncan, J. (1986). Disorganisation of behaviour after frontal lobe damage. *Cognitive Neuropsychology*, *3*(3), 271–290. https://doi.org/10.1080/02643298608253360

Fish, J., Evans, J. J., Nimmo, M., Martin, E., Kersel, D., Bateman, A., Wilson, B. A., & Manly, T. (2007). Rehabilitation of executive dysfunction following brain injury: “Content-free” cueing improves everyday prospective memory performance. *Neuropsychologia*, *45*(6), 1318–1330. https://doi.org/10.1016/j.neuropsychologia.2006.09.015

Fuchs, T. (2009). Embodied cognitive neuroscience and its consequences for psychiatry. *Poiesis & Praxis*, *6*(3), 219–233. https://doi.org/10.1007/s10202-008-0068-9

Furniss, F., Lancioni, G., Rocha, N., Cunha, B., Seedhouse, P., Morato, P., & O’Reilly, M. F. (2001). VICAID: Development and evaluation of a palmtop-based job aid for workers with severe developmental disabilities. *British Journal of Educational Technology*, *32*(3), 277–287. https://doi.org/10.1111/1467-8535.00198

Fuster, J. M. (1989). *The prefrontal cortex*. Raven.

Gillespie, A., Best, C., & O'Neill, B. (2012). Cognitive Function and Assistive Technology for Cognition: A Systematic Review. *Journal of the International Neuropsychological Society*, *18*(1), 1–19. https://doi.org/10.1017/S1355617711001548

Goksøyr, P. K., & Nøttestad, J. A. (2008). The burden of untreated ADHD among adults: The role of stimulant medication. *Addictive Behaviors*, *33*(2), 342–346. https://doi.org/10.1016/j.addbeh.2007.09.008

Goldstein, S., Naglieri, J. A., Princiotta, D., & Otero, T. M. (2014). Introduction: A History of Executive Functioning as a Theoretical and Clinical Construct. In S. Goldstein & J. A. Naglieri (Eds.), *Handbook of Executive Functioning* (pp. 3–12). Springer New York. https://doi.org/10.1007/978-1-4614-8106-5_1

Gorman, P., Dayle, R., Hood, C.-A., & Rumrell, L. (2003). Effectiveness of the ISAAC cognitive prosthetic system for improving rehabilitation outcomes with neurofunctional impairment. *NeuroRehabilitation*, *18*(1), 57–67. https://doi.org/10.3233/NRE-2003-18107

Harpin, V., Mazzone, L., Raynaud, J. P., Kahle, J., & Hodgkins, P. (2016). Long-Term Outcomes of ADHD: A Systematic Review of Self-Esteem and Social Function. *Journal of Attention Disorders*, *20*(4), 295–305. https://doi.org/10.1177/1087054713486516

Heersmink, R. (2017). Extended mind and cognitive enhancement: Moral aspects of cognitive artifacts. *Phenomenology and the Cognitive Sciences*, *16*(1), 17–32. https://doi.org/10.1007/s11097-015-9448-5

Hersh, N. A., & Treadgold, L. G. (1994). NeuroPage: The Rehabilitation of Memory Dysfunction by Prosthetic Memory and Cueing. *NeuroRehabilitation*, *4*(3), 187–197. https://doi.org/10.3233/NRE-1994-4309

Horner, B. R., & Scheibe, K. E. (1997). Prevalence and Implications of Attention-Deficit Hyperactivity Disorder Among Adolescents in Treatment for Substance Abuse. *Journal of the American Academy of Child & Adolescent Psychiatry*, *36*(1), 30–36. https://doi.org/10.1097/00004583-199701000-00014

Hutchins, E. (2010). Cognitive Ecology. *Topics in Cognitive Science*, *2*(4), 705–715. https://doi.org/10.1111/j.1756-8765.2010.01089.x

Lindstedt, H., & Umb-Carlsson, Õ. (2013). Cognitive assistive technology and professional support in everyday life for adults with ADHD. *Disability and Rehabilitation: Assistive Technology*, *8*(5), 402–408. https://doi.org/10.3109/17483107.2013.769120

Malafouris, L. (2013). *How Things Shape the Mind*. MIT Press.

Mihailidis, A., Boger, J. N., Craig, T., & Hoey, J. (2008). The COACH prompting system to assist older adults with dementia through handwashing: An efficacy study. *BMC Geriatrics*, *8*(1), 28. https://doi.org/10.1186/1471-2318-8-28

O'Neill, B., & Gillespie, A. (2008). Simulating naturalistic instruction: The case for a voice mediated interface for assistive technology for cognition. *Journal of Assistive Technologies*, *2*(2), 22–31.

O'Neill, B., Moran, K., & Gillespie, A. (2010). Scaffolding rehabilitation behaviour using a voice-mediated assistive technology for cognition. *Neuropsychological Rehabilitation*, *20*(4), 509–527. https://doi.org/10.1080/09602010903519652

Osbeck, L. M. (2009). Transformations in cognitive science: Implications and issues posed. *Journal of Theoretical and Philosophical Psychology*, *29*(1), 16–33. https://doi.org/10.1037/a0015454

Ramsay, J. R., Rostain, A. L., & Rostain, A. L. (2014). *Cognitive Behavioral Therapy for Adult ADHD: An Integrative Psychosocial and Medical Approach*. Routledge. https://doi.org/10.4324/9780203375488

Rasmussen, K., & Levander, S. (2009). Untreated ADHD in Adults: Are There Sex Differences in Symptoms, Comorbidity, and Impairment? *Journal of Attention Disorders*, *12*(4), 353–360. https://doi.org/10.1177/1087054708314621

Risko, E. F., & Gilbert, S. J. (2016). Cognitive Offloading. *Trends in Cognitive Sciences*, *20*(9), 676–688. https://doi.org/10.1016/j.tics.2016.07.002

Ryder, M., & Wilson, B. (1996). *Affordances and Constraints of the Internet for Learning and Instruction*. https://eric.ed.gov/?id=ED397833

Safren, S. A., Sprich, S. E., Perlman, C. A., & Otto, M. W. (2017). *Mastering Your Adult ADHD: A Cognitive-Behavioral Treatment Program, Therapist Guide*. Oxford University Press.

Shaw, M., Hodgkins, P., Caci, H., Young, S., Kahle, J., Woods, A. G., & Arnold, L. E. (2012). A systematic review and analysis of long-term outcomes in attention deficit hyperactivity disorder: Effects of treatment and non-treatment. *BMC Medicine*, *10*(1), 99. https://doi.org/10.1186/1741-7015-10-99

Sibley, M. H., Mitchell, J. T., & Becker, S. P. (2016). Method of adult diagnosis influences estimated persistence of childhood ADHD: A systematic review of longitudinal studies. *The Lancet Psychiatry*, *3*(12), 1157–1165. https://doi.org/10.1016/S2215-0366(16)30190-0

Skodzik, T., Holling, H., & Pedersen, A. (2017). Long-Term Memory Performance in Adult ADHD. *Journal of Attention Disorders*, *21*(4), 267–283. https://doi.org/10.1177/1087054713510561

Slors, M. (2015). Conscious intending as self-programming. *Philosophical Psychology*, *28*(1), 94–113. https://doi.org/10.1080/09515089.2013.803922

Smith, E. E., & Kosslyn, S. M. (2013). *Cognitive psychology: Pearson new international edition: mind and brain*. Pearson Higher Ed.

Solomon, M. (2014). Social Epistemology in Practice. *Philosophy of Social Science: A New Introduction*, 249.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes.* Raven Press.

Tarver, J., Daley, D., & Sayal, K. (2014). Attention-deficit hyperactivity disorder (ADHD): An updated review of the essential facts. *Child: Care, Health and Development*, *40*(6), 762–774. https://doi.org/10.1111/cch.12139

Thelen, E., Schöner, G., Scheier, C., & Smith, L. B. (2001). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences*, *24*(1), 1–34. https://doi.org/10.1017/S0140525X01003910

Thomas, R., Sanders, S., Doust, J., Beller, E., & Glasziou, P. (2015). Prevalence of Attention-Deficit/Hyperactivity Disorder: A Systematic Review and Meta-analysis. *Pediatrics*, *135*(4), e994–e1001. https://doi.org/10.1542/peds.2014-3482

Toplak, M. E., Connors, L., Shuster, J., Knezevic, B., & Parks, S. (2008). Review of cognitive, cognitive-behavioral, and neural-based interventions for Attention-Deficit/Hyperactivity Disorder (ADHD). *Clinical Psychology Review*, *28*(5), 801–823. https://doi.org/10.1016/j.cpr.2007.10.008

Valera, E. M., Spencer, R. M. C., Zeffiro, T. A., Makris, N., Spencer, T. J., Faraone, S. V., Biederman, J., & Seidman, L. J. (2010). Neural Substrates of Impaired Sensorimotor Timing in Adult Attention-Deficit/Hyperactivity Disorder. *Biological Psychiatry*, *68*(4), 359–367. https://doi.org/10.1016/j.biopsych.2010.05.012

Ward, D., & Stapleton, M. (2012). Es are good: Cognition as enacted, embodied, embedded, affective and extended. In F. Paglieri (Ed.), *Advances in Consciousness Research* (Vol. 86, pp. 89–104). John Benjamins Publishing Company. https://doi.org/10.1075/aicr.86.06war

Wilens, T. E., Faraone, S. V., Biederman, J., & Gunawardene, S. (2003). Does Stimulant Therapy of Attention-Deficit/Hyperactivity Disorder Beget Later Substance Abuse? A Meta-analytic Review of the Literature. *Pediatrics*, *111*(1), 179–185. https://doi.org/10.1542/peds.111.1.179

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the Executive Function Theory of Attention-Deficit/Hyperactivity Disorder: A Meta-Analytic Review. *Biological Psychiatry*, *57*(11), 1336–1346. https://doi.org/10.1016/j.biopsych.2005.02.006

Wilson, R. A., & Foglia, L. (2017). Embodied Cognition. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2017). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2017/entries/embodied-cognition/

# Appendices



## Appendix A: Description of Barkley (2012a) model of EF throughout adult life.

What follows is a concise summary of each level as presented by Barkley (2012a, pp. 63–68). Each level lists its constituent parts, and shows the chain of structures and behaviors that build up EF.

[1] **Pre-Executive**
This first level shows an early human with only CNS functions and automatic behavior as guided by operant conditioning. This level is necessary for EFs to arise.

- Central Nervous System functions. ("Routine primary neuropsychological functions, for example, attention, memory, spatial and motor functions, primary emotions and motivations")
- Behavior. ("Automatic activity; operant conditioning")

*"CNS relevant genes*
*–> CNS poteins & enzymes –> CNS structures –> CNS functions*
*–> overt behavior" (automatic activity) (p.64)*

[2] **Instrumental – Self-directed**
Internalized mental processes give rise to basic self-regulation, by creating a capacity for self-awareness, self-modification, and self-regulation over time. Self-monitoring of ongoing and largely automatic activities allows for hindsight (mentally re-experienced for further analysis, if mistake detected) which allow for foresight. It creates a conscious mental life for the individual. "A self-directing, purposive primate with a sense of future has arisen." (p.92)

- "Self-directed attention (self-awareness)
- Self-restraint (inhibition)
- Self-directed sensory-motor actions (nonverbal working memory; imagination)
- Self-directed private speech (verbal working memory; verbal thought)
- Self-directed appraisal (emotion – motivation)
- Self-directed play (innovation, problem solving)" (p.63)

*–> "Self-Regulatory EFs" ('covert self-directed actions') (p.65)*

[3] **Methodical – Self-reliant**

Here we have the rise of executive behavior as distinct from executive cognition[53]. The first overt goal-directed behavior is coupled with self-directed actions, which allows for daily adaptive functioning: self-care (often growing independence) and self-defense against others. Part of this overt self-regulatory behavior includes the reconfigurations of the physical environment.

- “Use of methods to attain near-term goals
- Self-management across time
- Self-organization and problem solving
- Self-restraint
- Self-motivation
- Self-regulation of emotions
- Social independence, social predation or parasitism, and social self-defense” (p.63)

*“–> overt self-regulatory behavior (executive adaptive behavior)*
*–> self-organization of environmental arrangements (products, artifacts)” (p.65)*

[4] **Tactical – Reciprocal**

Social symbiotic behaviors are now possible; others now become means for attaining goals that are mutually beneficial. This involves a set of methods that use subgoals to achieve higher-order, longer term goals. It is the basis of Human Social exchange[54].

- “Use of tactics – nested sets of methods – to attain midterm goals
- Daily social exchange (sharing, turn-taking, reciprocity, etc.)
- Group living (lower proportion of individual dispersal)
- Beginning of economic behavior (trading)
- Social independence (using others to attain goals)” (p.63)

*“–> self-organizing of social arrangements involving symbiotic reciprocal exchanges with others” (p.66)*

[53] "Executive cognition comprises the private mental and self-directed events subjective to the individual, while executive behavior includes the overt and observable activities being driven by those mental representations (executive cognition)." (p.65)

[54] E.g: turn taking, reciprocity, promise keeping. Trading. Social skills, etiquette. Basis for legal contracts.

[5] **Strategic – Cooperative**

Social symbiotic behaviors allow for higher order social engagement including strategic behaviors. One can now employ methods[55] (tactics and strategies) as well as use their large social networks to allow for goal-attainment over considerable distance in time. More so than simple reciprocity, this cooperative/unity approach allows for goal-attainment that would be impossible for the individual. Human coordinated group activities include cooperative ventures, division of labor, formation of communities & governments.

- "Use of strategies – nested sets of tactics – to achieve longer-term goals
- Arrangements of social cooperatives with division of labor
- Acting in unison to achieve common ends and shared benefits
- Origin of larger settlements (further decrease in individual dispersal)" (p.63)

*"–> social arrangements for cooperative ventures with others*
*–> social arrangements for mutualistic communities" (p.67)*

[6] **Extended Utilitarian (or Principled – Mutualistic)**

The use of EFs can be seen to interact with our Social ecology. In this level we see the use of principled behavior[56], and a sense of community where people include striving for the long-term self-interests of mutualistic others.

- "Use of principles – nested sets of strategies – to achieve long-term goals
- Pursuit of long-term self-interests by putting others' long-term self-interests ahead of one's own near-term and midterm self-interests
- Preference for larger delayed over smaller immediate consequences
- Origin of colonies, cities, city-states, states, and countries" (p.63)

*"–> social arrangements for mutualistic communities" (p.67)*

[55] "methods are nested under tactics that are nested under strategies that can eventually attain goals at a considerable distance in time." (p.66)

[56] "A principle is a set or sets of strategies that are being employed to achieve the longest range, most complex, and most abstract forms of human goal-seeking." (p.67)

## Appendix B: Concise review of ADHD

Attention Deficit Hyperactivity Disorder is characterized by inattention, hyperactivity and impulsivity as core diagnostic symptoms, but are intimately related with a host of other symptoms like emotional-regulation, poor functioning across multiple settings, poor motor-coordination, and comorbid disorders. The cause of ADHD has shown to likely be a complex interplay of biological and environmental risk factors, including a strong genetic component, diet, familial environment, and early deprivation/neglect. "ADHD is a heterogeneous disorder; aetiological factors, clinical presentation and response to treatment are likely to vary greatly between individuals." (Tarver et al., 2014, p. 769) This complex and diverse list of symptoms, causes and co-morbidities clearly shows that ADHD cannot be seen as a single isolated dysfunction. Instead, it must be viewed as a complex web of interacting factors (neurophysiological and environmental) and explored in treatment on the individual level.

### *Diagnostic criteria for ADHD (APA, 2013)*

The DSM-5 characterizes ADHD as: "A persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development, as characterized by (1) Inattention and/or (2) Hyperactivity and impulsivity" (American Psychiatric Association, 2013, p.59). Symptoms must be inconsistent with typical developmental level, and onset has to have occurred prior to the age of 12. Symptoms must be persistent, and have negative impacts directly on social and academic or occupational activity, with inattentive or hyperactive-impulsive behavior occurring across more than one setting (e.g. at home, school or work, in social situations, or other). As a result, there should be clear evidence of reduced quality of functioning in these settings. Symptoms must not be the result of lack of understanding or oppositional behavior, nor be able to be explained as the result of another mental disorder. Notably, the DSM distinguishes between three subtypes of ADHD, namely (1) predominantly hyperactive/impulsive type, (2) predominantly inattentive type and (3) combined type. It can also be classified as mild, moderate or severe.

### *Prevalence*

There is much discussion about the true prevalence of ADHD, as different studies often come up with different numbers, and estimations differ across countries and different versions of the DSM[57] as time progresses. In 2007 a meta-analysis of literature showed the worldwide prevalence of Attention Deficit Hyperactivity Disorder (ADHD) to be 5,29% (Polancyk, De Lima, Horta, Biederman & Rohde, 2007). In 2015 a meta-analysis of literature showed this to then be 7,2% (Thomas et al., 2015). In recent years there has been a surge of ADHD diagnoses being made. As a result the social narrative surrounding ADHD in the lay public often includes discussions around the fear of over-diagnosis and overtreatment with medication, especially in children. This is not the result of scientific non-consensus, but rather an interplay of arguments by interested parties obscuring and muddying the narrative[58]. Fear not. In Neuropsychological research, the connection between ADHD and the frontal lobes has been well established. Due to the neurophysiology of the frontal lobes it is arguably only natural that the

[57] Diagnostic criteria for ADHD update with each version, meaning someone who *just* met the criteria in one version might *just* not meet them in another.
[58] Like the current social debate with climate change – the science is pretty much in, but somehow we're still talking about it.

prevalence of ADHD is high. This is because “frontal lobes are particularly vulnerable in a very broad range of disorders, hence the very high rate of frontal lobe dysfunction. The way the diagnosis of AD(H)D is commonly made, it refers to any condition characterized by mild dysfunction of the frontal lobes and related pathways in the absence of any other, comparably severe dysfunction. Given the high rate of frontal lobe dysfunction due to a variety of causes, the prevalence of genuine AD(H)D should be expected to be very high.” (Baars & Gage, 2010, p. 416) Note here that the neurophysiological structures said to be at the root of ADHD symptomology overlap with those in EF deficits.

### *Causes*

The exact causes of ADHD are as of yet unknown. However, there has been much research into potential risk factors. The current understanding of the etiology of ADHD points to both biological and environmental factors.

It is clear through neuroimaging techniques that there are a number of morphological abnormalities in the neural anatomy of individuals with ADHD[59]. Therefore, ADHD is “likely to be the result of complex structural abnormalities involving a number of brain regions and connecting circuitry” (Tarver et al., 2014, p. 763). Genetic factors include a hereditability probability of 0.7, making it incredibly heritable while no single genetic factor has been found (Tarver et al., 2014).

Environmental factors have shown to include diet[60], familial environment/parenting[61], and early deprivation/neglect[62] (Tarver et al., 2014). There are also *gene-environment interactions* and *gene-environment correlations* to be considered. A possible example of this is the increase in risk of ADHD in children with parents who engage in pre-natal smoking[63].

### *Co-morbidities*

In the interest of a more complete picture, common co-morbidities will be mentioned as well. These are symptoms that are not included in the diagnostic criteria, but very often manifest in ADHD individuals to some degree or another. The degree of co-morbidity can depend on many things. Some co-morbidities manifest only in some cases, others in almost all.

Common comorbid features of ADHD include emotional dysfunction[64], poor social and peer functioning[65] and poor academic functioning (Tarver et al., 2014). It also often comes with poor motor-coordination, resulting in clumsiness and higher rate of injuries (Tarver et al., 2014). ADHD also

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[59] These include “reduced grey matter in regions forming part of frontostriatal circuits”, “atypical white matter volume in numerous neural tracts”, cortical thinning, possibly along with delayed cortical development. (Tarver et al., 2014, p. 763).

[60] The is correlational (not causational) evidence for nutritional definiencies (e.g. fatty acids, zinc and iron) as having an effect on symptom severity in ADHD. (Tarver et al., 2014)

[61] Adverse familial environments and parenting practices are often observed in families with ADHD members. “It is most likely that the relationship between parenting and child behaviour is bi-directional” (Tarver et al., 2014, p. 764). Due to high heritability, it is often likely one of the parents themselves may also have ADHD.

[62] There is strong evidence “implicating severe early neglect as a risk factor for later ADHD type symptoms” (Tarver et al., 2014, p. 764).

[63] Increased risk of ADHD in the child when the mother or father smokes curing pregnancy. (Tarver et al., 2014)

[64] Low levels of emotional control and high amount of negative emotions.

[65] Possibly due to aggressive and intrusive behavior in ADHD hyperactive subtype, or poor memory of interactions in ADHD inattentive subtype.

sometimes presents along with other diagnosable disorders, such as disruptive behavioral disorders[66], mood and anxiety disorders[67] with comorbid internalization symptoms, tic disorders[68], and substance abuse (Tarver et al., 2014).

*ADHD in adulthood*

Individuals with ADHD are affected by their disorder across their lifespan. While it affects both children and adults, some children do 'grow out of it', catch up in their development, and are either mostly symptom free or have severely reduced impairment some time into their adulthood. The remaining majority[69,70,71] of individuals diagnosed with ADHD will present impairing symptoms for the rest of their lives. Additionally, "research suggests that the DSM might not capture the full breadth of ADHD in adulthood because its symptoms were developed for children, leading to false negatives" (Sibley et al., 2016, p. 1162). It is therefore the intention of this thesis to focus primarily on those who show persistent ADHD symptomology into adulthood. Research into ADHD treatment, as will be later discussed, shows that a major problem for ADHD individuals is the longevity of the effects. The goal of treatment is to make these individuals self-sufficient, but often the effects only last temporarily after treatment has ended, meaning that those with ADHD often end up back in treatment. This is consistent with EF research with shows that those with EF deficits have problems with time and delays. It could be, that when treatment is finished, deficits due to the disorder are free to grow without the external stimulation of a therapist or medication, which leads the individual back to lower levels of EF and their corresponding behaviors.

[66] For example: oppositional defiant disorder (ODD) and conduct disorder (CD).
[67] For example: major depressive disorder, dysthymia, bipolar disorder or separation anxiety, generalized anxiety disorder or panic disorder.
[68] Touretty Sybdrome (TS).
[69] Longitudal studies on symptom persistence into adulthood differ enormously. A meta-analysis in 2016 did not present a specific number, but did reason it to likely be above 44% (Sibley et al., 2016). This is based on analysis of diagnostic methodology and symptom severity, but noted that this estimate was based largely on self-reported symptom severity. ADHD patients are known to severely underreport their symptoms, so it is likely that the true prevalence of ADHD from childhood into adulthood is higher than 44%.
[70] "It is apparent that symptoms persist into adulthood for well over half of children diagnosed with ADHD, but this may very well be an underestimation" (Ramsay et al., 2014, p. 44)
[71] Also to be considered are diagnoses first made in adulthood. "Diagnoses first given in adulthood do not necessarily reflect cases of adult onset with no childhood history. In many cases, a newly presenting adult might have a history of sub-clinical symptoms that only become noticeable when environmental demands or risk factors increase later in life" (Sibley et al., 2016, p. 1163).

## Appendix C: Brief explanation of post-cognitive approaches

Extended approaches include notions that the mind and cognition are embodied, embedded, situated, distributed, enactive, and/or affective.

### *Embodiment Thesis*

"Cognition is embodied – our cognitive properties and performances can crucially depend on facts about our embodiment[72]" (Ward & Stapleton, 2012, p. 89). Embodied cognitive science examines the extent to which the body, not just the brain, is involved in the rise of cognition and the mind. "[E]mbodied cognitive science aims to understand the full range of perceptual, cognitive, and motor capacities we possess, cognition *in the broad sense*, as capacities that are dependent upon features of the physical body." (Wilson & Foglia, 2017). In understanding the mind and cognition, the body should not be seen as peripheral as there is a dependency of cognition on the body. Evidence for this is found into such studies as those that investigate mental effects of chronic illness. Those with long term disorders of the body often experience mental distress such as comorbid depression. But even when the body is not malfunctioning, the body is involved in mental processing. There are many examples of this in psychological and somatization studies. For instance; decision making processes are altered when a person experiences stress on the bladder. Or, more relatable is the mood changes most experience when they get hungry. Theorists in this field argue that the body (beyond just the brain) make up a part of mind and cognition. "Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing." (Wilson & Foglia, 2017) Adding credibility to this viewpoint are studies into the mechanisms of embodied cognition are already reporting supporting findings (Thelen et al., 2001). Embodiment suggests that the philosophical blind man's mind is not intracranial, it includes his body. His case, then, would be considered an embodiment technology[73], meaning he has incorporated his cane into his body-schema.

### *Embedded / Situated*

In order to argue that cognition is more then only embodied, please consider the following. There are groups of blind and visually impaired individuals experimenting with, training in and using a rudimentary form of human echo location. This form involves using sounds (either from the

[72] (Haugeland 1998; Clark 1997; Gallagher 2000)

[73] "To sum up, an embodiment technology is a technology that is incorporated into one's body schema, which implies that it becomes part of one's bodily space (Merleau-Ponty's 'space of situation'). It then becomes an integral part of one's repertoire of motor or perceptual skills, and serves as a medium through which motor or perceptual skills, and functions, or both, are expressed. Perceptual functions that are mediated are either visual, aural or tactile functions. Motor functions that are mediated are either navigational functions or interactive functions (or both). As an artifact becomes incorporated into one's repertoire of skills, it often, though not invariably, enhances these skills. That is, it often extends the 'potentialities' of the body schema, and consequently what the body, as mediated by the artifact it incorporates, is able to affect or perceive in its environment. An exception is constituted by objects that merely serve to enlarge the bulk of the body, and complicate navigational tasks without enhancing one's potential, or even serve as a limitation." (Brey, Philip A.E., 2000, p. 11)

environment, or produced by the actor) to mediate the way they interact with the material environment. Users have reported being able to form a mental picture of their environment in this way. This representation was not so much visual as affective. The result is that the user can 'hear' a whole collection of information about the environment around them in the same way those with unimpaired vision get information from our eyes. The exact information and how we use it may be different, but the function is the same. This form of echo location is making active use of the material environment to increase perception, without even being in physical contact with it. Boundaries of mind beyond the body indeed. Does this mean that the environment as a whole is incorporated into the body schema? Is the environment itself a cognitive artifact? Or, is the environment simply a tool for use in this specific context? Post-genomic evolutionary biology shows that cultural environment plays a shaping role in our neural physiology and mental function. While the notion of embodiment focuses on inclusion of the body inside the skin, "embedded cognition, by contrast, draws on the view that cognition deeply depends on the natural and social environment" (Wilson & Foglia, 2017). Cognition, proponents argue, is shaped by the social and cultural contexts in which it occurs. "Cognition is embedded – our cognitive properties and performances can crucially depend on facts about our relationship to the surrounding environment"[74] (Ward & Stapleton, 2012, p. 89). Relatedly, "Situated cognition theory is a set of approaches to human cognition that underlines the importance of our embodied interactions with the social-technological environment." (Heersmink, 2017, p. 21) The mind is more than its cognitive processes and neural activity, it has moved beyond the body, as cognition is considered tangled with the agent's environment.

### *Distributed*

The idea of a 'Distributed Mind' proposes that cognition is distributed across individuals, artefacts, and tools in the environment. Studies mostly focus on social and cultural interaction to display that cognition is not limited even to the individual, but is distributed across individuals. For instance, in "transactive memory systems, knowledge is distributed across two or more individuals such that the system as a whole knows more than any one individual" (Risko & Gilbert, 2016, p. 69).

### *Enactive*

"Cognition is enactive – that is, dependent on aspects of the activity of the cognizing organism"[75] (Ward & Stapleton, 2012, p. 89). Based on arguments that one's world is not 'a pre-specified external realm', rather it is a 'relational domain' where autonomous agency and coupling with the environment shape this domain. This field triggers studies into i.a. perception and adaptive interaction. For example, Noë's sensimotor theory, in which "perceptual experience depends upon a grasp of how what we can do affects what we can see"(Ward & Stapleton, 2012, p. 92). Proponents' main message holds that the activity of the cognizing agent has a crucial role in the constitution of the sensible world, and is essential to cognition.

[74] (Haugeland 1998; Clark 1997; Hurley 1998)
[75] (Varela, Thompson & Rosch 1991; Hurley 1998; Noë 2004; Thompson 2007)

*Affective*

"The relations we have presented between cognition, perception, agency, embodiment, embeddedness and affect have been essential because we have sketched and endorsed a specific enactivist view of the co-dependence of perception, agency and cognition from which the essential dependence of cognition upon embodiment, embeddedness and affect have followed." (Ward & Stapleton, 2012, p. 100). "[C]ognition is affective[76] – that is, intimately dependent upon the value of the object of cognition to the cognizer." (Ward & Stapleton, 2012, p. 90)

[76] (Colombetti 2007; Ratcliffe 2009)

## Appendix D: Principles that hold for EF interventions

| **Excerpt from Diamond, A. (2013). Executive functions. Annual review of psychology, 64, 135-168.** |
| --- |
| A few principles hold regardless of the EF program or intervention:[77]<br><br>1. The children most behind on EFs (including disadvantaged children) benefit the most from any EF intervention or program (Flook et al. 2010, Karbach & Kray 2009, Lakes & Hoyt 2004). Hence, early EF training might level the playing field by reducing social disparities in EFs, thus heading off social disparities in academic achievement and health (O'Shaughnessy et al. 2003).<br><br>2. EF training appears to transfer, but transfer from computerized WM or reasoning training has been narrow (e.g., computer training on spatial WM transfers to other measures of spatial WM but not to visual WM or other EF subcomponents; Bergman Nutley et al. 2011). EF gains from training in task switching (Karbach & Kray 2009), traditional martial arts (Lakes & Hoyt 2004) and school curricula (Raver et al. 2011, Riggs et al. 2006) have been wider, perhaps because the programs address EFs more globally. For example, training task switching (which arguably requires all three core EFs) transferred not only to an untrained taskswitching task, but also to inhibition (Stroop interference), verbal and nonverbal WM, and reasoning (Karbach & Kray 2009).<br><br>3. EF demands need to be continually incrementally increased or few gains are seen (Bergman Nutley et al. 2011, Holmes et al. 2009, Klingberg et al. 2005). There may be two reasons for that. (a) If difficulty doesn't increase, the activity becomes boring and people lose interest. (...) (b) You need to keep pushing yourself to do better or you stop improving. Similarly, Ericsson et al. (2009) emphasize that the practice that leads to expertise at anything consists of trying to master what is just beyond your current level of competence and comfort.<br><br>4. Repeated practice is key. Whether EF gains are seen depends on the amount of time spent doggedly working on those skills, pushing oneself to improve (Klingberg et al. 2005). School curricula shown to improve EFs train and challenge EFs throughout the day, embedding that in all activities, not only in a module (which may also have the benefit of varying the content and kind of EF practice; Diamond et al. 2007, Lillard & Else-Quest 2006, Riggs et al. 2006).<br><br>5. The largest differences between intervention groups and controls are consistently found on the most demanding EF tasks and task conditions. It is often only in pushing the limits of children's EF skills that group differences emerge (Davis et al. 2011, Diamond et al. 2007, Manjunath & Telles 2001). For example, in their first year of data collection, Farran & Wilson (2011) found no EF benefits from Tools of the Mind, but their assessment tasks were plagued by ceiling and floor effects. |

[77] *Operates under the assumption that*: "There is general agreement that there are three core EFs (e.g., Lehto et al. 2003, Miyake et al. 2000): inhibition [inhibitory control, including self-control (behavioral inhibition) and interference control (selective attention and cognitive inhibition)], working memory (WM), and cognitive flexibility (also called set shifting, mental flexibility, or mental set shifting and closely linked to creativity). From these, higher-order EFs are built such as reasoning, problem solving, and planning (Collins & Koechlin 2012, Lunt et al. 2012)." (Diamond, 2013, p.1-2)

## Appendix E: Overview of recommendations and conclusions

**Conditions for cognitive extension / Core system requirements**

First, it must be based on Active externalism (connected to the here-and-now). Second, the overall technology must by definition be able for form a coupled system, aiming for strength and durability of coupling. To stimulate coupling, candidate technology must consider:

- Reliably availability
  - Easily accessible
  - Portable
- Typically invoked
  - Ease of accessibility
  - Not typically subject to scrutiny
  - Stimulate use
- Facilitation of automatically endorsed information retrieval
- Trustworthiness
  - Trust in provided information
  - Trust in scaffold
  - Transparency-in-use
- Ease of interpretation
  - Visualization eases cognition by offloading information
- Personalization
- Amount of cognitive transformation

**In consideration of support for ADHD treatment and strengthening it effects**:

- Provide information on or facilitate access to treatment professionals.
  - Pharmacological treatment (affects neurophysiological problems)
  - Behavioral treatment (facilitates internalization)
- Attempt to include social environment, while guarding for social parasitism or predation.
- Limit reliance on psychoeducation and skills training. We can teach them to know, but they will not do, because their neural circuitry interferes with their ability to do the things they are taught. Instead, help the user implement what they have been taught.
- Offer support in carrying out daily routines, economic self-sufficiency, undertaking a single task, and looking after one's health.
- Take cues from existing behavioral treatments as outlined in this thesis.

**Specific ways to stimulate EFs**:

- Stop reacting, and actively reflect
  - rehearsal,
  - inhibition,
  - monitoring,
  - feedback processing,
  - managing effort (accounting for the EF resource pool)
- Engage in goal-setting activities
  - Specify implementation intentions
  - Make them explicit
  - Visualize doing them (rehearsal)

- Manage mental resource-pool to stave off negative effects of effortful EF-engagement. (e.g. exhaustion)
    - Managing glucose ingestion. (Provide 'fuel' for EFs that need help in doing what they ought to be.) This need not be more complicated than reminding users to have a snack or sip a soda during EF-tasks.
    - Restrict depletion (inhibition and self-restraint, self-management of time, self-organization & problem solving, emotional self-regulation, self-motivation, stress, alcohol, drug use and illness)
    - Promote replenishing ("greater rewards and positive emotions, statements of self-efficacy & encouragement, 10 minute breaks between EF/SR tasks, 3+ minutes of relaxation or meditation, visualizing and talking about future rewards before and during demanding tasks, routine physical exercise [and] glucose ingestion" (Barkley, R.A., 2012b2, p. 37).)
    - Affect the size of the RP through regular physical exercise.

**Specific technology and strategy recommendations for engaging EFs**:

- Offer high degrees of customization would benefit benefits the high subjectivity of goals and actions needed for EF engagement. This also the high degree of variability in symptoms and circumstance between ADHD individuals.
- It is important to address both distal and proximal time, since those with EFd have trouble with both. Using cues, prompts or triggers is effective for affecting goal pursuit in those with EFd.
    - In the proximal 'now', use cues to stop reactive automatic behavior and reflect on task necessity.
    - For the distal future, goal-reflecting activities are beneficial. Actually doing these, must be made proximal in order for the user to engage in them.
- It would be beneficial to help ease sustained effort. However, bringing this into practice introduces ethical judgements. This discussion should not be forgotten when making design choices.
- Appeal to motivational systems - Emotion and Motivation should definitely be considered in a design that wishes to promote the development of EFs.
    - Stimulation of emotional regulation benefits behaviors that will make the implementation of EFs easier.

**Environmental Shaping** can support the interruption of automatic behavior in service of goal-directed behavior.

**Cognitive Offloading**:

1: pre-executive level

- It is desirable that our candidate device should aim to provide access to diagnostic centers, and aid health-behavior.
- There is evidence that attentional functions benefit from content-free cueing.
- There is evidence that memory functions benefit from cameras and multimedia reminiscence devices.
- Consider appealing to spatial, temporal, and motivational functions. More research is needed on cognitive assistive technology that effects these functions. Other examples of appealing to awareness of these functions include meditation and mindfulness programs.
- Most evidence for technologies on motivational systems is for lowering anxiety. More research is needed on how to assist emotional dysregulation in EFd. Areas of focus should include inhibition of immediate response, emotion regulation, self-soothing and self-redirection of attention.

2: instrumental – self-directed

- Psychoeducation plays a strange role in all this, as it is an important aspect of creating self-awareness and yet it does not show great effect in those with EFd. They *know*, but they cannot necessarily therefore also *do*. It is advised to offer and adjust psychoeducation to focus on the relevant information along with the succession up Barkley's hierarchical levels.
- Self-directed actions cannot be directly offloaded and still have the desired effect of stimulating EF engagement. But an artefact may cue the beginning of the six specified self-directed actions at certain times. In order to increase ease of use and offload part of the deficiency the user may be guided through the processes of self-monitoring, reflective contemplation, or goal-reflection.
- The relationship between thought and language makes language devices appealing.

3: methodical – self-reliant

- It is important to approach the user as an actor, and recognize subjective-use-value of goals.
- Guard against social-parasitism and –predation
- Candidate technologies should offer explicit support in carrying out daily routines, economic self-sufficiency, undertaking a single task, and looking after one's health. (Possibly: cooperation with authorities, and informing and educating staff or personnel in housing and workplaces)
- Table 3 offers examples of other assistive technologies targeting daily routines and self-care.
- Modern computing devices offer many capabilities and should definitely be considered in candidacy. However, keep in mind that complex technology is not available to everyone (due to problems with access or understanding complexity.)

4, 5: social – symbiotic (tactical – reciprocal & Strategic – Cooperative)

- The internet offers an ideal environment for facilitating psychoeducation.
- Accessibility and ability to handle technological complexity varies per population. Using devices with access to the internet offer an excellent platform, for those who have access to them.
- More research is to be done on how to offset EF deficits in social interaction.