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MASTERARBEIT

„Towards a Consolidated Approach: Overcoming Cognitive Biases in Medical Decision-Making"

Integrating Cognitive Training for Enhancing Executive Functions into Bias-Specific De-Biasing Techniques for Reducing Cognitive Errors in Diagnosis

Verfasserin

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1. Introduction

It has long been known that human decision-making deviates from normative rational benchmarks; humans tend to err and to make mistakes in their chains of reasoning. The *Homo economics* as an omniscient being was used as standard measurement in economics as well as for explaining the process of generally making choices, but is now outdated (Gigerenzer, 2001a); many diverse fields such as behavioral economics or psychology have shown that concepts like bounded rationality that acknowledge the cognitive restrictions of the brain are better applicable for understanding human decision-making (Gigerenzer, 2008).

Decision-making plays an important role in a plethora of fields in daily life; in principle, nearly all aspects of human behavior are tightly connected to it. From simple decisions like setting the alarm clock in the morning over deciding how to drive to work until far-reaching choices such as selecting a spouse or investing large amounts of money, humans make choices and are thus inherently faced with the cognitive limitations on making optimal or rational decisions – cognitive errors can potentially interfere in all situations. In the majority of these cases, the errors are acceptable and outperform overly detailed computational processes of weighing and comparing possible decision-making paths. However, this is not always the case; especially in the field of medical decision-making, cognitive biases can have fatal effects. According to the WHO, improved diagnosis could lead to "reducing annual mortality by up to 625,000 lives" (Keeler et al., 2006) for people suffering from tuberculosis. Beside this, cognitive errors also lead to financial and judicial problems; Graber, Gordon, and Franklin (2002) point out that "…diagnostic errors are the second largest cause of adverse events…[and] the second leading cause for malpractice suits against hospitals" (Graber, Gordon, & Franklin, 2002, p. 981), just to name a few examples.

A substantial amount of the mistakes made in the process of diagnosis are assumingly caused by cognitive errors in thinking and making decisions, and recent research has shown that techniques for preventing such errors exist. Nevertheless, cognitive biases are not easily prevented: They have co-evolved with the development of the human brain and serve fast and cost-effective decision-making where little time and energy have to be invested for reaching a satisficing solution. As such, they are strongly embedded in human behavior and hard to overcome; cognitive biases often operate on the unconscious level of cognition and are thus often difficult to identify. Modern approaches aim at not only detecting and describing these biases, but also at generating effective strategies for reducing their detrimental effects, i.e., at developing de-biasing techniques. Although progress have been made in this endeavor – an increasing number of studies documents the advancing accomplishments in reaching more rational and less biased decisions (Milkman, Chugh, & Bazerman, 2009) – much effort and research are still needed.

These biases or cognitive dispositions to respond can be described according to their underlying psychological mechanisms, which contribute to human decision-making behavior. The main clusters of these mechanisms are attention, the utilization of (working) memory, inhibition of responses and the inability to shift between different sets of rules, and overconfident reliance on one's own knowledge. A close investigation of the relation between cognitive errors in thinking and these aspects will be presented for a selected collection of biases that are especially important in diagnosing in the first main part of this thesis after giving a broad overview over the discussed topics. Further, the techniques for overcoming cognitive biases will be outlined; again, the prevalent psychological mechanisms that are at play during de-biasing will be outlined. They are similar to the structures involved in the original performance of cognitive biases and aim at tackling the defective processes. However, they are unfortunately still not exhaustively powerful to truly overcome the detrimental effects of the cognitive errors. Therefore, it is necessary to broaden the focus and to investigate cognitive processes in other fields. Executive functions as functions that comprise of higher-order cognitive processes such as for example attention, working memory, and cognitive flexibility have been shown to be a successful candidate for this endeavor. Following from this, the second key part of this thesis will thus be devoted to outlining relevant executive functions in the context of medical diagnosing in relation to cognitive biases. A special focus will be laid on the psychological processes that are shared by the cognitive biases themselves, the according de-biasing techniques, and the related executive functions. Due to this overlapping commonalities, it is assumed that an increase in controlling executive functions can have correlated effects on influencing cognitive biases; the main line of reasoning suggests that better controlled executive functions lead to greater success in alleviating the adverse effects of cognitive errors on rational decision-making when combined with bias-specific de-biasing techniques.

In order to overcome some of the main problems attached to enhancing cognitive abilities by training programs – non-adherence to training schedules or overly complicated routines – it is important to carefully select the training modus. An online and computer-based training program for enhancing cognitive abilities that has addressed these problems already exist: The program *Lumosity* was developed by the Lumos Labs Inc. (San Francisco, CA) and targets executive functions by remodeling neuroscientific tests into user-friendly applications. Such cognitive training could be implemented into the educational and regular routine of clinicians in correspondence with specific briefings on how to overcome biases. However, this is only a preliminary suggestion that needs further research and investigation in order to constitute a presentable recommendation.

And last but not least, the core of this thesis is rationality: It is the underlying and leading concept of not only my research that has led me through various fields of cognitive science, but also the concept that defines the expectations that I have for the standard of decision-making in general and medical decision-making in detail. Without setting the ground by explaining the development, various forms, and current understanding of rationality, it would seem prejudiced to expect clinical decision-making to be rational in the normative sense that I apply in the course of this thesis. It is my personal interest to clarify this aspect before going into detailed investigations of cognitive biases, medical decision-making, and executive functions in order to provide the reader with a coherent and conclusive explanation of my line of thoughts. In my regard, this is of special importance as this thesis does not postulate any hypotheses or presents any empirical data; it is solely grounded on literature investigations and my personal thinking that led me to propose this novel link between executive functions and cognitive biases. As such, further research will be necessarily needed for testing this innovative idea in order to prove both its flaws and correct insights. This aspect will be addressed at the end of this work.

2. Background information

2.0 Rationality as the leading concept

Aiming at understanding human decision-making as it is at the core of this work inevitably leads to the point where one judges the optimality of the achieved outcomes; at the beginning, every situation comprises of various – often countless – possibilities that could in theory be chosen. However, humans and other animals have the ability to decide for exactly *one* alternative out of the many existent ones. This selected option then governs many following steps that each again comprises of different possibilities that often exclude each other. Such processes of deciding for one option and simultaneously excluding all other available paths happen all the time and in nearly every situation; decisions do not only happen consciously such as when deciding what to buy for dinner or where to go for holidays, but also unconsciously many times during the day. We decide where to look when sitting in the tube going to work and we also choose to stop at a certain point when waiting in front of a red light.

As already said, humans have the ability to decide for one option over the other, but they also possess the capability of assessing these decision according to pre-defined standards. How these criteria are expressed is again a choice that has been taken before applying them. One possibility is to focus on the *rationality* of a decision and to compare the achieved outcome against a normative standard that has been set up *a priori*. This is the approach that I adopt in the course of this work: Rationality will be the guiding standard against which decisions and judgments are evaluated. As such it is necessary to explain why this is the case by explicating the development of the concept *per se* as well as its current understandings. The aim is to clarify *why* cognitive dispositions to respond have to be overcome at all as it is argued for in this thesis; it follows from these considerations and implies that if one takes on the standpoint to assess human decision-making ability as satisficing and not having the intention to reach for a rational standard, this goal of overcoming cognitive errors would not be necessary.

Thus, I will briefly outline a short history of the term rationality and some conflicting models of it as well as the notion that I apply in this paper and my other scientific projects. I do not dare to claim that this brief outline presents a complete history of the term rationality or the existing positions nowadays as such a detailed overview easily fills whole books and certainly would go far beyond the scope of this thesis.

2.0.1 History of the term rationality from the ancient times until Descartes

According to Rutgers (1999), the roots of rationality can be found in Greek philosophy where it can be traced from the term *logos* that was used by the Greeks to refer to a cosmic principle related to the structure of the universe and human thought and activity. This original term *logos* was then adopted by the Romans and transformed into the term *ratio*, which finally became the English term *rationality*. The meaning of rationality changed at the beginning of the sixteenth century (Rutgers, 1999). Whereas it had previously been a theistic association with the divine, rationality was now only about the human faculty of reason. Rutgers understanding is in accordance with the work of Bacon (1561-1626) and Descartes (1596-1650), but he added that the philosophical tradition of rationalism was the logical conclusion of this concept. At this time, the existing concept of rationality was detached from its earlier theistic and moral interpretation, and thus seen to be value-free.

2.0.2 Development of rationality in concordance with utility

In 1781, the philosopher Jeremy Bentham (1748-1832) put forward the concept of *utility* as the property in every item by which it possesses or aims at producing positive features like pleasure, happiness, advantage, or benefit as well as negative components like pain, mischief, or unhappiness. After Bentham proposed this concept, rationality became associated with it and took on the indicator of value. The modernist era changed the understanding of rationality again: From an idea having metaphysical and cosmic connotations and which implied an objective morality it was transformed to a concept that did not have these connotations and that had a relative morality associated with it. As such, rationality was detached from several notions that it had had before: Instead of the objective morality contemplations of the Greeks and the divinity-aspect of both the Romans and the medievalist, it became associated with relative morality. In this sense, *good* is defined as advantage for a certain party under consideration despite any objective advantage. The following example clarifies this shift: If a murder is the most advantageous action for a party, then it is the most rational action, and objective moral rules to the contrary should be abandoned.

In 1814, the mathematician Pierre-Simon Laplace (1749-1827) explained rationality by creating a fictional and well-known creature that embodied it: The Laplacean Demon. Laplace created a thought experiment in which he described a super-intelligence or demon that knew everything about past and present and thus could deduce the future with certainty. This demonic super-intelligence represents the original ideal of rationality: An omniscient and omnipotent being that is capable of optimization. Up to the present days, this had been the guiding metaphor of thoughts about rationality (Gigerenzer, 2008). Further disputes about rationality can be understood as being concerned with which of these concepts - omniscient, omnipotent, optimizing - are useful, be it as a way to model what happens or as an ideal by which it should be measured what happens.

In 1947, John von Neumann and Oskar Morgenstern mathematically formalized Bentham's idea of utility into axioms of rationality according to which any agent satisfying them can be described as if it had a utility function. They proved that an agent is *Von Neumann & Morgenstern* - (VNM-) rational if and only if there exists a real-valued function u defined by the possible outcomes so that every preference of the agent is characterized by maximizing the expected value of u. Here, u stands for the agent's VNM-utility. That means that if people's preferences follow these axioms then they behave as if they maximize utility in a way that is as if they were unboundedly rational agents (Von Neumann & Morgenstern, 1947).

2.0.3 Homo Economicus – acceptance and critique

The idea that humans act in accordance with axioms for maximizing the expected utility of their outcomes led to the development of the *Homo Economicus*. The idea is that such an agent always behaves according to the (normatively) best choice by always choosing the actions that help achieving its goals as measured by their utility. This means that the *Homo Economicus* always acts in a way that maximizes its utility function. This understanding is described as subjective utility theory.

At the same time of the appearance of this approach, psychologists became interested in utility theory due to the already mentioned publication by Von Neumann and Morgenstern (Von Neumann & Morgenstern, 1947) that also inspired the field of game theory (Baron, 2000).

In 1953, the economist Maurice Allais argued that Expected Utility Theory fails as a descriptive model of decision-making (Allais, 1953) and around this time, two competing theories of how to model agents where developed: First, Simon developed the concept of Bounded Rationality, which was a reaction against the perfectly rational utility-maximizing *Homo Economicus* in 1955 (Gigerenzer, 2008). Second, John F. Muth developed the Rational Expectations Hypothesis in the 1960ies. According to the Rational Expectations Principle, an agent should evaluate each possible course of action by multiplying the desirability of any achievable end-world state times the probability it believes this will be achieved given a course of action and beliefs about the current world state (Baron, 2000). This approach kept the *Homo Economicus* alive by being the core metaphor of game theory, social choice theory, and decision theory where the *Homo Economicus* was used as a standard concept (Oppenheimer, 2008).

Allais (1953) was the first but not last scholar to question the normative aspect of the Expected Utility Theory. In fact, since 1953, there is a gap between scholars that accept Expected Utility Theory as normative standard and those that do not do so. Those that accept this approach as normative also entail the existence of irrational decision-making, which they analyze trough descriptive models. They further aim at prescribing ways to cut those shortcomings and to become more rational. On the other hand, the scholars and researchers who do not accept the Expected Utility Theory argue that insufficient descriptive models lead to a poor understanding of what rationality is and that better descriptive models are needed for achieving to an improved normative understanding of it. This gap has been referred to as the "rationality wars" (Samuels, Stich, & Bishop, 2012) .

2.0.4 Two examples for current positions of rationality

Two programs challenge these agonistic positions in modern days: the Heuristics and Biases program, and the Study of Heuristics exist. Also, there exist two further subdivisions: first, Unbounded Rationality, and second, the Optimization under Constraints - approach. These two built as-if theories and do not aim at psychological realism, but at predicting behavior.

The influence of the previously introduced Laplacean Demon is undeniable in all conceptions of rationality except for the Study of Heuristics approach as this is the only theory without context-independent norms. The theories of Unbounded Rationality, Optimization under Constraints, and Heuristics and Biases all accept such a norm. The main difference between these approaches to rationality is whether they accept omniscience, optimization, and omnipotence in actual behavior, as an ideal that should be reached, or not at all. The influence of Simon's work (1955) is also explicitly present: The theory of Optimization under Constraints, Heuristics and Biases, and the Study of Heuristics all claim to be the followers of Simon's approach of Bounded Rationality (Gigerenzer, 2008).

2.0.4.1 The Heuristics and Biases *program*

The Heuristics and Biases program does not assume that human behavior conforms to the norms of rationality – the axioms of rationality that describe humans as utility-maximizing agents. It still posits these norms, but focuses on the unveiling of situations in which humans fail to attend to these norms (Kahneman & Tversky, 1996; Gilovich, Griffin, & Kahneman, 2002).

The approach is normative in the sense that it accepts these norms as a measure of rationality. According to it, humans use cognitive rules of thumb – so-called heuristics - for making decisions; these heuristics sometimes fail and then they are instantiated as (cognitive) biases (Tversky & Kahneman, 1974). The search for instances of these failures – which makes the program descriptive – are motivated by the assumption that the failures of a mechanism are the best way to understand how the system works when it does not fail. That is, when the output of a mechanism is correct, then the mechanism itself is a black box and the processes generating the output are not accessible. However, every time the mechanism fails, glimpses into its inner processes are possible. Accordingly, this approach allows for measuring rationality: It suggests that humans are more rational the more they comply with the norms of rationality. In greater detail, the Heuristics and Biases program allows measuring rationality by using the already addressed *Homo Economicus* as a standard, with both number and severity of biases being criteria of deviance from it. Clearly, it does not claim that humans are *Homi Economici*, but that this theoretical concept is useful as an abstract benchmark. Based on this, the Heuristics and Biases approach also makes prescriptive recommendations on how best to conform to the norms of rationality.

Cognitive biases are described via a prescriptive internalist-view: There is a pre-set standard of optimal decisions that are rated as most rational. If an agent fails to meet this standard by choosing sub-optimal options, it falls prey to a bias or differently spoken, it commits a cognitive error. As there exists an internal standard for optimally rational decisions, the agent needs to change its behavior until it approximates or even complies with this benchmark. Such changes are achieved via de-biasing, i.e., the application of specifically developed techniques for avoiding the bias and for being able to decide more rationally than before (Tversky & Kahneman, 1974).

2.0.4.2 The Science of Heuristics *program*

The Science of Heuristics program mainly focuses on the relationship between environment and mind (Gigerenzer, 2001b) and is mainly a descriptive program. This approach has two key concepts: The adaptive toolbox and the concept of ecological rationality (Gigerenzer, 2001). The adaptive toolbox can be understood as a descriptive theory comprising of two aspects: a heuristic is fast if it can solve a problem in little time and frugal if it can solve it with little information. Also, it states that heuristics can find good solutions independent of whether an optimal solution exists or not (Gigerenzer, 2008). Ecological rationality refers to the already mentioned connection between mind and environment.

The Science of Heuristics approach raises numerous questions regarding heuristics such as "In which environment does a given heuristic work? In what environment does it fail? How did the heuristics coevolve with other cognitive abilities?" According to this program, heuristics exploit structures of environments and rationality cannot be measured in a logical (context-independent) manner, but only in an ecological way. Further, a heuristic is neither good or bad nor rational or irrational *per se*, but can be only rated relatively to a certain form of environment as some environments can exploit the heuristic while others cannot do this. More specifically, this means that the goal is to determine the environmental structures in which a given heuristic is successful or not. This refers to the match between mind and environment, be it physical or social (Gigerenzer, 2008).

Here, the study of rationality should be descriptive by assessing in which environment a particular heuristic works, and prescriptive in an externalist sense. That is, it aims at answering the question of “How can an environment be modified so that a particular heuristic works in it?”

The compelling aspect of this approach is the clear acceptance of human mistakes as heuristics are seen as only failing in *some* environments, but being sufficiently satisfactory in many others. However, the main focus lies on investigating the set-up of these environmental structures rather than on human behavior and possible changes. Thus, in the context of this thesis, the main focus will lie on the Heuristics and Biases program that formulates strategies for overcoming cognitive biases and that aims at reducing the mistakes made by committing cognitive errors. This is especially important in the context of clinical decision-making: The individual clinician needs to apply techniques for overcoming a particular cognitive bias in a specific situation while operating in an environment that poses different demands simultaneously on different clinicians. For example, in one and the same hospital, i.e., environment, emergency clinicians work next to specialized ambulances that only accept patients with pre-registered appointments. The idea to develop an environment where such distinct workflows can be practiced is compelling, though unrealistic at the moment.

2.1 Decision-making

In the previous section I presented various concepts of rationality, their historical development, and how two of the current main two research programs – the Heuristics and Biases program, and Science of Heuristics program – conceptualize rationality. In the current section I will similarly proceed with giving a brief overview over the field of judgment and decision-making, as this is the second corner stone of this thesis before focusing on the underlying neuroscientific processes that govern human decision-making.

2.1.1 Normative, descriptive, and prescriptive approaches to decision-making

The field of judgment and decision-making is concerned with three interrelated forms of research: normative, descriptive and prescriptive research (Fischhoff, 2010). Normative analyses are concerned with identifying the best possible courses of action given a decision-maker's values (Baron, 2000). Descriptive studies examine actual behavior, which is subsequently compared to pre-set normative standards. Prescriptive research suggests behavioral interventions aiming at bridging the gap between the normative ideal and the descriptively actually acted out behavior.

A further distinction in the field of decision-making is often drawn between riskless choices and risky choices as well as between choices that have certain outcomes and those that have uncertain outcomes (Baron, 2000).

The term *judgment* is also an interesting aspect: It refers to assessments about the external world that occur in various situations. For example, one judges whether or not to take an option and by doing so, different values of desirability are assigned to each option (Baron, 2000). The notion of judgment also includes decisions in the sense of judgments about what action should be done and not only about their inherent value (Baron, 2005). Decision-making specifically refers to the process of taking a possible action (LeBoeuf & Shafir, 2005) with the degenerate case being the "lack" of a decision, i.e., the decision to take no action.

Systematic regularities in how people make decisions have been uncovered by psychological research; this has brought forward the possibility of creating descriptive models for decision-making behavior. In the field of decision-making, a decision is conceptualized as having the following three parts (Hastie, 2001):

(a) Choice options (the courses of action that are at disposal)
(b) Beliefs about the world
(c) Desires that evaluate the outcome of the chosen option

From this it follows that a good decision is selected according to the available resources in a way that the decision-makers goals are achieved (Hastie, 2001). Summing this up, judging refers to the evaluation of possibilities of action whereas decision-making is taking a possibility of action.

2.1.2 Decision-making from a neuroscientific point of view

Deliberations about the process of making and subsequently acting out a decision represent a crucial step in various disciplines; not only psychology and philosophy, but also the field of cognitive neuroscience is interested in understanding these complex cognitive processes (Bohanec et al., 2009). The importance of this endeavor can especially be seen in the clinical area: Neurological disorders that are connected with affected decision-making abilities such as Parkinson's disease can be better understood (and treated) when the fundamental processes are known (Lee, 2013). Several possibilities for investigating the neuroscience of decision-making are available: Clinical studies of patients with various brain damages or diseases, EEG-studies, or functional imaging methods such as fMRI or SPECT can be used for this purpose (Bohanec et al., 2009).

From a purely materialistic point of view, decision-making is a brain process that relies on the interplay between various structures; the following passage will give a short overview over the involved parts of the brain and their interaction that is necessary for making and acting out a decision because knowledge about the anatomical and neurological aspects represents an inevitable foundation. There also exists a relation to the so-called dual-system theory when looking at two different forms of decisions that can be described: on the one hand, decisions can require long and conscious deliberations and on the other hand, they can rely on fast and subconscious brain processes (Bohanec et al., 2009). According to Bohanec et al., 2009, the former can be described as follows: “complex, slower, reflexive cognitive-social processes with elements of self-awareness, evolutionary younger, dependent on frontal lobe, limited with working memory capacity”, whereas the latter is identified as “simple, fast, perceptive-motor process in sensory-motor parts ob [*sic!*] the brain, non dependent of prefrontal lobe” (Bohanec et al., 2009, p. 43).

Decision-making in general depends on deep subcortical structures such as the basal ganglia, the thalamus, and the frontal cortex as well as superficial cortical structures (Lee, 2013); circular connections between these areas are responsible for cognitive phenomena such as alertness, wakefulness, and decision-making (Bohanec et al., 2009). Five circuits form the basis for the interplay between decision-making behavior and the brain: They are called “cortico-subcortico-frontal pathways” (Bohanec et al., 2009, p. 42) and are responsible for processing incoming limbic, motoric, or cognitive information. They work according to the same operational procedure: Information is transferred from different parts of the frontal cortex to the basal ganglia, from which it is further transmitted to the nuclei of the thalamus and finally to the frontal cortex (Bohanec et al., 2009). The following overview is adapted from Bohanec et al. (2009) and presents the main brain areas involved in the decision-making process:

1. Midbrain (mesencephalon): Substantia nigra, ventral tegmental area, mesolimbic pathway, and mesocortical pathway
2. Basal ganglia: Ventral stratium (nucleus accumbens) and dorsal stratium
3. Limbic system: Cingulate gyrus, hippocampus, septum, amygdala
4. Prefrontal cortex: Ventromedial and orbitofrontal prefrontal cortex, dorsolateral prefrontal cortex (Bohanec et al., p. 42)

Beside the aforementioned anatomical circuits and the outlined brain areas, dopamine plays an important role in decision-making as the main biochemical neurotransmitter related to reward. Reward is a crucial motivator for judging various possible outcomes of a situation by assigning a weight to the expected outcome (Sanfey, 2007). The higher the reward expectation is, the more valuable the according option is perceived during the decision-making process. This connection has its root in the evolutionary development of life: Options that lead to enhanced survival – one of the driving forces of evolution – are linked with a greater activation of dopamine, which in turn elicits feelings of reward (Bohanec et al., 2009). The neurobiological structures involved in the activation of dopamine are linked to the parts of the brain that are central for decision-making via the limbic-cortico-subcortico-frontal loop (Bohanec et al., 2009).

However, not only reward is tightly linked to decision-making, but also the concept of theory of mind with its according brain structure plays an important role (Lee, 2013). Theory of mind describes the cognitive ability to impute mental states, goals, intentions, and beliefs to other beings (Gallese & Goldman, 1998) and involves the dorsomedial prefrontal cortex and the superior temporal sulcus (Lee, 2013). Especially in the context of social decision-making, it is crucial to include this aspect in a general overview over decision-making; clinical decision-making with its numerous patient-clinician and clinician-clinician encounters clearly falls into the category of social decision-making.

Further, the connection between decision-making and emotional processes can be established via the amygdala, which is connected to the experience of emotions and plays a central role in the Somatic Marker Hypothesis (Damasio, 1991). Emerging neuroscientific evidence suggests that sound and rational decision-making depends on prior accurate emotional processing. The somatic marker hypothesis by Damasio (1991) provides a systems-level neuroanatomical and cognitive framework for decision-making and its influence by emotions. The key idea is that decision-making is a process that is influenced by marker signals that arise in bioregulatory processes, including those that are expressed in emotions and feelings. This influence can occur at multiple levels of operations: Both on a conscious and on a non-conscious level. These elicited somatic markers mark the outcomes of complex and uncertain situations as either good or bad based on previous experiences. By doing so, the decision space between multiple possible outcomes is significantly reduced and fewer options are taken into consideration. Besides the insula, somatosensory cortices, and the basal ganglia, neuroscientific evidence points to the ventromedial prefrontal cortex (VMPFC) as the brain area that is mainly involved in this process. Empirical support for Damasio’s approach is mainly gained through the performance of patients with brain lesions in the VMPFC-area in the Iowa Gambling Task (IGT); the subjects preferred short-term gains (with the disadvantage of long-term losses) over short-term losses (with the advantage of long-term gains) and thus acted irrationally with regards to a normative standard as they did not aim for maximizing their gains. The somatic marker signal pointing to the better decision (accepting short-term losses, but profiting from long-term gains) are anticipatory skin conductance responses, which were missing in the brain lesion patients in the original experiment (Damasio, 1991).

The briefly addressed relations between decision-making and other important cognitive phenomena such as emotions illustrate how concatenated the phenomenon of making a decision is with other areas; however, the underlying neural structures that are outlined above and the various connections to other functional brain areas are yet not fully understood (Lee, 2013). Further research is needed to elucidate this and to shed further light on the neurobiological foundations of decision-making; this process will foster the endeavor of better controlling suboptimal decisions in order to increase rational outcomes.

2.2 Biases in decision – making

Cognitive Psychology has long been interested in investigating human decision-making especially in the circumstances when it fails and leads to suboptimal outcomes (Liu, Tzeng, Hung, Tseng, & Juan, 2012; Hilbert, 2012). Biases or mental heuristics have been extracted as being crucially causal for the humans' limited ability to reach rational decisions and thus highlighting their bounded rationality (see part 2.0 on rationality and its prevalent current understandings). According to Chao et al. (2012), such rules of thumbs for thinking and responding to the demands of increasingly complex environments are among the main causes for far-reaching mistakes in decision-making in various fields. Without solely focusing on the neuroscientific processes causing these biases, it can be said that dispositions to respond to information presented by the environment are prevalently distributed in ecological settings where humans operate and decide in a social context; may this be a medical environment, a business company, or a family. As such, the environmental aspect is the common denominator that elicits cognitive biases and leads to non-optimal decision-making. Here, a bridge to ecological rationality can be build: Human thinking is closely related to its surrounding environment and should not be seen as a (completely) separate entity (see part *2.0.3.2* The Science of Heuristics *program*).

Beside ecological limitations that lead rational decision-making astray, there is another group of causes that should be mentioned as causal perpetrator: Evolutionary constraints add to humans' bounded rationality (Johnson, Blumstein, Fowler, & Haselton, 2013). Evolutionary limitations to human thinking are embodied by the way how brain structures have evolved over time and encompass the aspect that older and previously useful brain constructions still exist while not being perfectly adapted to the current environment. In detail, this refers to "limits on efficiency, speed, evolvability, and the adaptive landscape" (Johnson et al., 2013, p. 446) of human brains. While ecological effects can be influenced to some extent in order to alleviate the detrimental effects of cognitive biases by changing their set-up in a way that accommodates the brains' needs, man cannot manipulate evolutionary limitations. Humans have to accept the sub-optimal set-up of the brain and need to develop strategies for ameliorating the efficiency of dealing with this fact. As such, it is important to first understand the default strategies of the brain on how to respond to varying environments and the subsequent processing steps that finally lead to a particular decision. The following section will provide an overview over the concept of cognitive biases as the major cause for the addresses non-rational decision-making abilities of humans; before reviewing existing techniques for overcoming biases and proposing new ways of de-biasing, it is necessary to first lay the ground by defining cognitive biases *per se*.

2.2.1 Cognitive biases

Contrary to what is expected by utility theory or classical probability theory, humans do not decide rationally (Hilbert, 2012). However, there are regularities that can be found in humans' decision-making processes: They are systemically irrational, or – as Ariel (2008) puts it – "predictably irrational". As such, the mistakes in reacting to evidence entering the sensory system can be classified and described as cognitive biases that are ubiquitously found. Hilbert defines cognitive biases as the behavior of "how humans systematically deviate from what is normatively expected from their decisions" (Hilbert, 2012, p. 211). He further designates these cognitive dispositions to respond as inherently possessing both positive as well as negative aspects; on the one hand, they allow human decision-making to be predictable and thus controllable to some extent, but on the other hand, they lead to far-reaching and often fatal errors. The first characteristic is presented as follows: When put in situation *X* with having *Y* possibilities to decide, the majority of subjects will decide for option *B*, even though option *A* would have been the rational choice from the probabilistic point of view. Even though are large number of these biases are already known, it is expected that there still exist many that are yet unknown (Hilbert, 2012). Therefore, and because of the addressed inherent risky nature of cognitive biases, their second aspect cannot be highlighted enough: Cognitive biases can lead to foreseeable errors with potentially fatal or even lethal consequences. Further, cognitive biases are similar in all humans as they operate on the brain; they are thus linked to its systematic processing of incoming information that is in general the same for every human being (Hilbert, 2012). As already known, the brain has been developed over thousands of years and hence it stills contains older and younger parts. Following from this, it is not optimally adapted to the current environment we live in and it is thus biologically limited. Whether a cognitive bias operate on something distinct from the brain – the "mind" – or solely on brain mechanisms is deliberatively left out in this thesis as the monism / dualism debate would go far beyond the scope of this work and demands their own discussion.

Beside the shared neural basis that all humans have in common, another aspect adds to the occurrence of cognitive biases: Mental heuristics that operate as short cuts for complex cognitive operations serve for reducing the cognitive effort needed to reach a decision (Hilbert, 2012). As such, they contribute to the effect that decisions are often based on “representative cases instead of the specific one” (Hilbert, 2012, p. 212) when evaluating information about possible solution paths. This usage of representative cases is defined as the representative heuristic and can be commonly found in various situations (Kruglanski & Gigerenzer, 2011). Another common heuristic is the availability heuristic that is related to the ease of cognitive retrieval of certain instances; the first type of an alternative of a category that comes to mind is assessed as the most common one and as such as more important than any other possible alternate (Kruglanski & Gigerenzer, 2011). Without going into the depth of describing the great variety of cognitive biases, it is important to point to the underlying mechanisms that contribute to their instantiation; beside morality, emotions, and social influences, noise in the information processing can be mentioned (Hilbert, 2012). In this context, *noise* refers to the suboptimal manipulation of information that leads to its distortion. Here, the link to the biological set-up of the brain becomes relevant again because the brain has not developed for achieving perfectly rational or optimal solutions, but instead it aims at securing fitness and reproduction in a certain environment. The resulting disordered design is thus responsible for the propagative mechanism of cognitive biases and heuristics (Hilbert, 2012). In general, the human sensory system consists of millions of single input and output points that are connected to each other in various forms; the consequential connections can thus be distorted in nearly infinite ways. However, an underlying aspect that plays a role in almost all biases that operate on this system is memory: For reaching any kind of decision, a certain amount of memory is inevitable (Hilbert, 2012).

At the moment, precise models for how cognitive biases are instantiated in the brain according to their underlying neural mechanisms are not known; further research is needed to elucidate the brain areas activated in their experience. This will further give rise to a better understanding of how to prevent biases and reduce their detrimental effects.

2.3 Executive functions

The term *executive function* is used as an umbrella term covering core cognitive abilities such as working memory, planning, attention and attentional control, set shifting, verbal fluency, and many others (Chan, Shum, Toulopoulou, & Chen, 2008). Listing all cognitive functions described by this concept would lead to conceptual difficulties as the term *per se* is loosely defined and it is the center of current debates to define what concrete cognitive aspects should be specified as belonging to it.

2.3.1 Development and difficulties of defining executive functions

A first description of the term *executive function* was given by Baddeley and Hitch in 1974 (Jurado & Rosselli, 2007); they described this 'central executive' as conceptualizing ""how" behavior is expressed" (Jurado & Rosselli, 2007, p. 213). As the term shows, this refers to high-level cognitive abilities that are mediated by the frontal lobes. Indeed, the first knowledge about executive functions was derived by patients with damage of the pre-frontal lobes (Jurado & Rosselli, 2007). However, an increasing body of research could show that not only the frontal lobes are responsible for the different properties that are referred to as executive functions, but the importance of other brain regions are also increasingly stressed: For example, the subcortical and posterior cortices influence the "integration (or association) of information and the regulation of emotion, thought, and action" (Jurado & Rosselli, 2007, p. 226), which can be grouped to the many other functions comprising the umbrella term executive functions.

Further, there is yet no full mechanistic understanding of the different parts coined as executive functions as well as the according neural underpinnings. As already mentioned above, the concept of executive functions can be seen as an umbrella term, whereas there also exists an understanding of it as being a higher order function that controls those cognitive capabilities (Braver, Cole, & Yarkoni, 2010). The following table (**Table 1**) illustrates this dominating ambiguity concerning this term by listing the main definitions for the phrase *executive function*.

Table 1. Different Definitions of Executive Control

Author	**Concepts and/or components of Executive functions**
Lezak (1983)	Volition, planning, purposive action, effective performance
Baddeley & Hitch (1974)	Central executive, phonological loop, visualspatial sketchpad
Norman & Shallice (1986)	Supervisory attentional system
Lafleche & Albert (1995)	Concurrent manipulation of information: cognitive flexibility, concept formation, cue-directed behavior
Borkowsky & Burke (1996)	Task analysis, strategy control, strategy monitoring
Anderson et al. (2001b)	Attentional control, cognitive flexibility, goal setting
Delis et al. (2001)	Flexibility of thinking, inhibition, problem-solving, impulse control, concept formation, abstract thinking, creativity
Hobson & Leeds (2001)	Planning, initiation, preservation and alteration of goal-directed behavior
Piguet et al. (2002)	Concept formation, reasoning, cognitive flexibility
Elliot (2003)	Solving novel problems, modifying behavior in light of new information, generating strategies, sequencing complex actions
Banich (2004)	Purposeful and coordinated organization of behavior, reflection and analysis of the success of the strategies employed

Executive functions do not develop homogenously; their unfolding and decline differ from each other. For example, attentional control – comprising of "attention, sustained attention and response inhibition (Jurado & Rosselli, 2007, p. 221) – develops relatively early in childhood. By the age of 12 months, children are able to succeed in Piaget’s A-not-B-task, which is only possible by having developed response inhibition. On the contrary, verbal fluency for example is among the latest executive functions that are fully developed (Jurado & Rosselli, 2007). Furthermore, executive functions do not only unfold with different pace, but they change over lifetime and finally also decline again. This aspect is especially important with respect to the difference between the cognitive abilities of novice clinicians and experts in the field of medical decision-making; their executive control mechanisms are not static, but change over time and can be actively influenced (Kesler et al., 2013).

2.3.2 Measurement of executive functions

There seems to be a consensus on the debate on how to measure executive control in recent years; the individual differences approach is taken to be the favored approach in this regard (Miyake et al., 2000; Del Missier et al., 2010). However, there are still some problems in the measurement of executive control, where some stem from the heterogeneous nature of this function. The most significant difficulty researchers face in measuring executive control is the task-impurity problem; this means that the tasks to measuring executive control by nature use some other processes and noise coming from those non-executive control processes also occurs within the executive control task.

The solution that is prevalently used against this measurement problem is the usage of a latent-variable approach. This refers to choosing several tasks that capture the same target (i.e. executive control) in such a way that the applied tasks have very little non-executive control variables in common. Thereby, the irrelevant parts can be eliminated by taking what is common across those tasks, ignoring the common variables, and thus reaching “purer” variables as a measure of executive functions (Miyake et al., 2012).

Keeping all these points in mind – especially the ambiguous definition of the term *per se* and the problems measuring the cognitive abilities described or controlled by it – I will focus on only a selected amount of executive functions in this thesis. These cognitive abilities will be *inter alia* planning, rule detection, or memory and have been chosen due to their assumed close link to the emergence of the cognitive biases investigated in this work.

The process of measuring executive functions is especially relevant for this thesis as I claim that improving executive functions via cognitive training has a positive influence on the efficacy of bias-specific de-biasing strategies. In order to enhance any ability, it is necessary that it can be defined and measured in the first place so that differences between its manifestations are possible to be detected. As already mentioned above, the concept of executive control *per se* is ambiguous and following from this, its measurement also presents a problem. However, as it was decided for this thesis to understand executive functions in as an umbrella term for a plethora of high-level cognitive abilities such as attention, set shifting, rule detection, and response inhibition – only to name some –, the measurements for executive function as a higher positioned entity controlling these abilities can be let aside for now.

There exist some standard tests for analyzing executive functions; the following table (**Table 2**) presents an overview and is adapted by Jurado & Rosselli (2007, p. 219). The described tests have been selected as they are covered by the cognitive trained that will be presented in further detail in section 2.4 and their assumed connection and relevance for the cognitive biases displayed in the process of diagnosis.

Table 2. Selected Tests for Executive Functions

Name of test	Reference	Short description of test	Tested executive function
COWAT	Benton and Hamsher (1989)	Words beginning with a specific letter combination have to be produced	Response generation Inhibition
Stroop	Stroop (1935)	Words denoting a color are written in a different color than they describe; subjects have to read the name of the word while ignoring its color	Inhibition
WCST	Berg (1948)	Participants have to sort cards according to unknown rules that can change over time without warning	Set shifting Set maintenance Inhibition Rule detection Concept formation Mental flexibility Working memory
Flanker Paradigm	(McDermott, Pérez-Edgar,&Fox, 2007)	Participants have to declare the orientation of an object in the middle surrounded by other objects (the flanking distractors) showing wither the same or different orientations	Selective attention Inhibition

2.3.3 The neuroscientific background of executive functions

Given the indistinct nature of the concept of executive functions, it is relatively hard to pin down specific brain areas involved in their processing. Further, there is no clear consent on the exact involved neural underpinnings. However, it is a common praxis to focus on three major groups of executive control especially when researching the neuroscientific background. These three functions are *updating*, *shifting*, and *inhibition* and can be defined as follows: *Updating* refers to the "constant monitoring and rapid addition/deletion of working memory contents" (Friedman et al., 2008, p.9), *shifting* is described as "switching flexibly between tasks or mental sets" (Friedman et al., 2008, p.9), and inhibition means the "deliberate overriding of dominant or prepotent responses" (Friedman et al., 2008, p.9). The underlying neural mechanisms and involved structures can be described via the so-called "prefrontal-cortex basal-ganglia working-memory (PBWM) model" (Friedman et al., 2008, p. 13) developed by O'Reilly and colleagues (Friedman et al., 2008). The name reveals the involved brain structures that are primarily involved in the execution of executive functions. The operational functioning of the PBWM-model can be described as follows:

> *"The prefrontal cortex layer can actively maintain relevant information through persistent activation and recurrent connectivity. Because it can bias lower-level activity through its connection to posterior-cortex layers, which do not have the same active maintenance mechanisms, it is particularly suited to maintaining goals and using these goals to bias ongoing processing. Information is flexibly gated into the pre-frontal cortex layer through the basal-ganglia layers, which learn what information is relevant through dopaminergic reward-learning mechanisms*." (Friedman et al., 2008, p. 13)

The role of the dopaminergic reward system has also been addressed in the context of decision-making (see *2.1.2 The neuroscientific background of decision-making*). This shared neurobiological mechanism adds to the proposed connection between executive functions and decision-making biases that is presented in the context of this thesis.

Beside the PBWM-model, there is a plethora of other models that have been suggested for explaining the underlying neurobiological structures of executive functions. According to Chan et al. (2008), there are at least six other models that are at use. First, there exists Luria's theory, which divides the brain into three functional units responsible for the execution of executive functions (Chan et al., 2008). Here, the first unit comprises of the brain stem that is in charge of "regulating and maintaining arousal of the cortex" (Chan et al., 2008, p.202), whereas the second functional unit is a linked compound of the temporal, parietal, and occipital lobes responsible for "encoding, processing, and [the] storage of information" (Chan et al., 2008, p. 202). It is further suggested that the anterior region of the brain – the frontal lobes – presents the third unit, which controls the “programming, regulating, and verifying [of] human behavior” (Chan et al., 2008, p. 202). Finally, the third unit is the prefrontal cortex that is supposed to represent a higher-order control structure for regulating “mental activity and behavior” (Chan et al., 2008, p. 202).

Second, another theory presented by Chan et al. (2008) is the Supervisory Attentional System (SAS), which is a further developed version of Luria’s theory and describes two distinct systems that are in control of the executive functions. The first system is thought to be responsible for “routine and overlearned behavior” (Chan et al., 2008, p. 203) and their prioritization. Following from this, the second system controls “non-routine and novel tasks” (Chan et al., 2008, p. 203). The frontal lobe is considered to play a major role in the execution of executive control.

Third, Stuss and Benson’s tripartite model is another variant for structuring executive functions and the according brain areas (Chan et al., 2008). Here, three interacting systems are identified rather than only two, as it is the case for the SAS – model. The first system is called ARAS, which stands for anterior reticular activating system, the second system is the diffuse thalamic projection system, and the third unit comprises of the fronto-thalamic gate (Chan et al., 2008, p. 205). The ARAS and the diffuse thalamic projection system “are responsible for maintaining an individual’s alertness” (Chan et al., 2008, p. 205) whereas the fronto-thalamic gate system is in charge of the executive attentional control. In contrary to some of the previously described models (e.g. the SAS), exact neural structures for attentional control are suggested (Chan et al., 2008). In detail, the following division is proposed: “sustaining (right frontal), concentrating (cingulate area), sharing (cingulate and orbitofrontal areas), suppressing (dorsolateral prefrontal cortex), switching (dorsolateral prefrontal and medial frontal areas), preparing (dorsolateral prefrontal cortex), and goal setting (left dorsolateral prefrontal cortex)” (Chan et al., 2008, p.205).

The fourth model – Dunclan’s goal-neglect theory (Chan et al., 2008) – mainly refers to goal-setting respectively goal-neglecting and will thus be not discussed in further detail as this only represents a subordinate aspect of the whole concept of executive functions.

A similar case is the fifth model that is primarily focused on working memory; the Goldman-Rakic’s working memory model suggests that subparts of the prefrontal cortex are each in control of different aspects of working memory. This divided mechanism is based on “two reciprocal pathways (viz., inhibition and excitation) that connect to the posterior brain” (Chan et al., 2008, p. 207). Even though this model only provides a structural explanation for one part of executive functions, it is worth mentioning as the addressed two pathways are suggested to be commanded via neurotransmitters and especially the dopaminergic pathway (Chan et al., 2008). As such, the importance of linking executive functions with the reward system as already mentioned above is further highlighted.

Finally, Damasio’s somatic marker hypothesis is also mentioned by Chan et al. (2008) as providing a reasonable explanation for executive functioning. This theory has already been described in passage *2.1.2 Decision-making from a neuroscientific point of view* where it was linked to the decision-making and the involved neural structures. In the context of executive functions, its role for social behavior and emotions, which are sometimes covered as “hot” components of executive functions (Chan et al., 2008). Similar to the influence of emotions on decision-making, the prefrontal cortex plays a major role in relation to regulating emotional behavior. Further, Damasio proposes a link between the ventromedial cortex and the subcortical areas (Chan et al., 2008).

These models do not present an exhaustive list of all the existing suggestions for defining executive functions and their neural structures; however, this overview gives an outline over the ongoing debate in the current literature and the according difficulties of precisely extracting the underlying causal brain structures. Following from this indecisiveness, it becomes even more striking how hard it is to measure and even influence single aspects of executive functions. Despite these unresolved problems, the cognitive training program that will be described in the subsequent section has been shown during a sufficient amount of studies to be able to reliably influence executive functions. It can thus be used as an exemplary program for the proposed connection between executive functions and cognitive biases.

2.4 Cognitive training

Cognitive training is defined as "behavioral method for treating cognitive deficits [, which] can result in significant improvements in a number of cognitive skills, including EF" (Kesler et al., 2013, p. 299), whereas EF stands for executive functions. It can be linked to the underlying human ability to learn new skills and to constantly adapt to new environments. This capacity is outstanding in the animal kingdom and a major contributor to our species' success. It encompasses specific and general ways of learning; specific learning refers to directly training one skill, whereas generalized methods attempt to tackle skills that are a necessary requirement for other the performance of other abilities (Green & Bavelier, 2008).

This broad distinction can also be applied to the field of cognition; cognitive skills can be either trained very specifically or on a broader level. Only focusing on improving one individual aspect of cognition such as shared attention or verbal fluency results in the benefit of being able directly influencing the target ability, but with the drawback of not being able to generalize to effort to other fields. Thus, aiming at operating on a higher level via targeting different cognitive abilities at the same time is supposed to have the benefit of weighing the input effort with the achieved output benefits of improved cognitive skills. Such a generalized approach can result in slightly reduced effects due to the distributed nature of the cognitive skills and the natural loss of efficacy when different aspects are trained more or less simultaneously. However, it intuitively is a preferable approach over only focusing on a single cognitive ability in a closed setting while trying to block out the other aspects because in the real-world environment, the human brain needs to operate on many levels and is forced to run different cognitive 'programs' at the same time. To illustrate this point, let us imagine a clinician in an everyday working setting: While unconsciously keeping track of his direct environment and the different parameters defining his ecosystem, he needs to focus on the patient he is confronted with at the moment. This also poses several responsibilities on him: He needs to filter the relevant cues out of the patient's narrative for formulating a first preliminary hypothesis while engaging in the conversation so that the patient feels comfortable enough to share his problems with him. Also, he needs to stay on top of managing the time that he has at this disposal as well as the selecting the appropriate tests for confirming or disconfirming any hypothesis for diagnosing the patient's problem.

As it can be seen from this very elementary and by far not exhaustive example, the real world demands the usage of different (cognitive) abilities at the same time. Thus, I will focus on cognitive training for improving executive functions that raise the claim of pursuing a holistic approach rather than selectively focusing on one cognitive skill in an enclosed setting.

2.4.1 Importance of cognitive training

Cognitive training can be broadly divided into two main applications: First, reducing decline of an already existing level of ability and second, improving the status quo. I will first briefly discuss the first aspect as this was the starting point for increased research in this area and laid the ground for transfer the insights gained here to the second addressed usage.

Cognitive decline is a phenomenon that is known to affect the elderly population; abilities such as working memory, reasoning, and speed-of-processing decline over time and lead to a decreased quality of life (Rebok et al., 2014). Recent research has shown that cognitive training for reducing this normal degeneration has a high utility as it significantly can decelerate this process in certain areas (Rebok et al., 2014). According to Rebok et al. (2014), not all cognitive abilities can be influenced to the same extent: Training for speed and reasoning caused less declined cognitive abilities even 10 years after the training, whereas training for memory could not yield the same effect (Rebok et al., 2014).

However, such deterioration of cognitive skills can also be observed in other groups of the population such as cancer patients; studies have shown that women surviving breast cancer exhibit difficulties with cognitive abilities that manifest in long term deficits (Kesler et al., 2013). The life quality of such women is reduced and imposes a further burden on them because daily life activities such as independently pursuing a profession might become impossible. These effects are especially observed in patients that were treated with chemotherapy and they affect declined executive functions such as "working memory, cognitive flexibility, multitasking, planning, and attention" (Kesler et al., 2013, p. 299). Recent studies have shown that a home-based, computerized cognitive training program can be successfully used for improving some of these deficits: "cognitive flexibility, verbal fluency, and processing speed" (Kesler et al., 2013, p. 299) could be enhanced the most, whereas verbal memory could be only slightly ameliorated. Other executive functions that were influenced by the cognitive training program were “planning, organizing, and task monitoring” (Kesler et al., 2013, p. 299), even though this could not statistically be shown and the results only rely on individual feedback.

Without going too much into detail at this point with regard to the cognitive training program *per se*, it can be pointed out that cognitive training programs have been shown to have the potential of significantly effecting a number of executive functions. Moreover, it has been shown in this passage that there exists a real-world relevance of such training techniques: Both the elderly as well as certain patient groups require such external programs for maintaining respectively restoring their thinking and problem-solving skills.

2.4.2 Requirements for cognitive training

Cognitive training often comprises of a consortium of tasks that each tackle distinct cognitive abilities; each training session consists of a selected collection of these exercises. There exist ambiguous opinions about the number of tasks and both the length and the frequency of the sessions in order to achieve the maximum improvement; according to Kesler et al. (2013), there are no clear scientific judgments on the critically necessary benchmark for these parameters. Training regimes for this so-called “brain training” (Owen et al., 2010, p. 1) often differ considerably in various studies, which could explain inconsistent results; for example, the effects of engaging in a six-weeks cognitive training program with three sessions per week that lasted at least 10 minutes led to no significant improvement in executive functions such as attention, memory, and visuospatial processing (Owen et al., 2010). On the contrary, a 12 weeks program with four sessions per week that each consisted of five tasks significantly increased the performance in “cognitive flexibility, verbal fluency, and processing speed” (Kesler et al., 2013, p. 299). Both studies rated the changed performance in the tested cognitive abilities right after the completion of the training cycle, but there also exists evidence for long-term effects of cognitive training. Rebok et al. (2014) designed a study that tested for possible effects of such ‘brain training’ ten years after the actual intervention with only two booster sessions after 11 and 35 months. The target group of participants was the elderly population with a mean age of 73.6 and compiled over 2,800 subjects (Rebok et al., 2014). The investigated executive functions were memory, reasoning, and speed of processing. In general, the findings show that the cognitive training in combination with the two booster sessions caused less decline in all executive functions, whereas reasoning and speed of processing could also be improved (Rebok et al., 2014).

This brief overview demonstrates that cognitive training for executive functions can be successfully used for both increasing existing levels of cognitive performance as well as decelerate normal ageing processes. Even though requirements for optimal training regimes for different target groups such as the elderly or after-treatment patients are not known yet, these results show the promising direction of further investigation research in this area.

2.4.3 Transfer of training effects and further difficulties

A major hurdle of computerized training programs for enhancing executive functions is the gap between the applied standardized tasks and real world behavior; even if the exercises mimic real settings to a high extent, it cannot be ensured for now that the targeted abilities are used in the same way in real world environments (Kesler et al., 2013). As the main goal of such 'brain training' is positively influencing the performance of executive functions in the real life as much as possible, this aspect cannot be underestimated; adequate transfer of the achieved effects in the course of the program has to be further researched in order to ensure this endeavor. Further, innovative strategies for implementing the exercises into the daily routine should be investigated as practical difficulties such as time management or motivational decline diminish the attainable improvements and can influence the potential transfer effects (Rebok et al., 2014). As an example, Kesler et al. (2013) suggest combining computerized training with workbook explanations of how to translate cognitive training tasks into real world behavior; by doing so, subjects are urged to actively engage in the transfer process and to further enhance their executive functions.

The need for developing innovative solutions for integrating cognitive training into the daily life in combination with defining the optimal training requirements are crucial for ensuring a maximal success rate for transferring the achieved effects to the daily life.

2.4.4 Neuroscientific effects of cognitive training

Cognitive training and the according changes on the underlying neural structures has been mainly researched in the context of cognitive decline over the life span of healthy humans (Cabeza, Nyberg, & Park, 2005). Here, processing and productions deficits are the main researched factors; the former refers to the decreased ability to process incoming information, whereas the latter describes the decreased ability to produce correct output based on incoming data (Cabeza et al., 2005). Cognitive training aims at reducing this decrease of cognitive functions over time and especially targets the prefrontal cortex area. As there are biological limitations of influencing the normal cognitive decline, cognitive training cannot reverse this effect completely. However, it has been found that directed training on the specific capabilities such as verbal fluency or working memory can significantly decelerate this process; the influence of specific training sessions can also be observed in the according brain regions (Cabeza et al., 2005). For example, mnemonic techniques for enhancing memory capacities in older people leads to "increased activity in posterior occipitoparietal brain regions" (Cabeza, et al., 2005, p. 317) compared to a control group that did not receive the training. Thus, for each executive function that is trained via specific training techniques, the according neural structures have to be investigated with appropriate neuroimaging techniques for identifying any changes that could be traced back to the exercises.

2.4.5 The training program Lumosity

The importance of cognitive training as well as the several difficulties attached to developing a program that succeeds in overcoming them has been outlined in the previous passages. Especially the need for building an innovative program that is feasible to get integrated into the daily routine has been pointed out. This aspect plays a crucial role in the context of making a diagnosis in the routine of clinicians: cognitive abilities get constrained by factors such as uncertainty and severe time limitations.

A computerized cognitive training program that appears to meet the addressed requirements has been developed by the Lumos Labs Inc. (San Francisco, CA) and is called *Lumosity*. It comprises of a series of exercises that aim at increasing cognitive abilities such as visual attention, verbal fluency, working memory, and others (Hardy

& Scanlon, 2009). It consists of web-based exercises that are constructed on the basis of research results in neuroscience. By adapting existing research paradigms into appealing games, the Lumos Labs Inc. does not only aim at supporting people of very diverse populations all over the world to increase their brain activity, but also at investigating the impact of such programs on the human brain by gathering anonymous data of its users. According to the website www.lumosity.com, 50 million users play the Lumosity program and the Lumos Lab has thus the biggest existing database of cognitive performance at the time of writing this thesis (state: May 2014).

This cognitive training program tackles five core areas of cognitive functions: "processing speed, attention, memory, flexibility, and problem solving" (Hardy & Scanlon, 2009). These abilities are also subsumed under executive functions; *Lumosity* is an appropriate program for the purpose of this thesis, which aims at investigating ways of increasing cognitive performance of executive functions.

An important aspect is the user-friendly interface in combination with the minimal time effort needed for accomplishing a complete session; the free version consists of three games, where each game lasts for around one minute, and the paid version comprises of five of such games. This set-up facilitates adherence to a daily training routine and its implementation into daily life procedures.

Ongoing research in various fields make use of the program *Lumosity* for investigating cognition in general, but also the development and decline of cognitive abilities over time as well as diminished performance in executive functions due to anti-cancer treatment (Kesler et al., 2013).

2.4.5.1 The scientific background of Lumosity

As already mentioned above, neuroscientific research has primarily influenced the web-based software tools of the Lumosity Lab Inc. product *Lumosity*. Since the main focus of this work is on executive functions, the correspondence between some of the *Lumosity* games to existing tests for executive functions will be outlined in this passage without claiming to present an exhaustive overview. The single games are based on tests that are regularly used in the course of scientific research; the main difference is the way they are presented, i.e., the gamification aspect. This approach ensures the transmission of already proven techniques for increasing executive

functions from the lab to the broader population and further guarantees the comparability of collected data with scientific findings (Hardy & Scanlon, 2009).
The first game that is related to improving executive functions is called “By the Rules”. It challenges the user to detect a “hidden rule in a dynamic card game” (Hardy & Scanlon, 2009, p.11) where he has to designate whether each card follows the rule or not. By doing so, he should detect the underlying pattern. The model for this game is the Wisconsin Card Sorting (WCST) test that is used for testing “abstract reasoning, concept formation, and response strategies to changing contextual contingencies” (Nyhus & Barceló, 2009, p.437) and that has a long tradition for being used to assess prefrontal lobe lesions. In its usual form, the WCST demands that a participant has to decide whether a response card belongs to one out of four keycards while receiving feedback by a examiner whether his choice for sorting each card is correct or not. Through this process the participant can identify the underlying hidden rule (Nyhus & Barceló, 2009). The adaption of this classic test is the Lumosity-game “By the rules”, which aims at improving “mental flexibility and working memory” (Hardy & Scanlon, 2009, p.11) by challenging the player with increasingly more complex rule systems.

Another game that is adapted from research applications is called “Lost in Migration” and mimics the Flanker paradigm. This paradigm is used for assessing “selective attention and associated self-regulatory processes” (McDermott et al., 2007, p.62) by testing the ability to focus on a key stimuli while disregarding surrounding and interfering stimuli. In the classical version, the orientation of an arrow in the middle of a cluster of arrows had to be designated; its orientation sometimes differed from the surrounding arrows, which requires selective attention to the predominant stimulus while simultaneously blocking the adjacent stimuli. This is further related to the underlying ability of processing incoming stimuli and translating this information to correct responses; developmental differences can be found and it is also known that this cognitive capacity changes over life (McDermott et al., 2007). Accordingly, younger children are less able to selectively focus on the target stimuli and to filter irrelevant information than older children or adults; such changing abilities suggest the possibility to get actively influenced by appropriate training techniques. Following from this, the Lumosity-game “Lost in Migration” was developed; it mimics the original set-up by using birds that are shaped like arrows. Specifically, the player has to designate the orientation of the bird located in the center of the flock while the whole group of birds appears on different places on the screen. As in the original Flanker paradigm, the addressed executive functions in this game are selective attention and the ability to suppress reporting the orientation of the majority of the perceived objects.

A third game that is mentioned in the course of this introductory overview of the scientific basics of Lumosity is the so-called “Color Match”; it is an adapted version of the Stroop-task (Hardy & Scanlon, 2009). Developed by Stroop in 1935, this test is used for examining “the neural basis of conflict processing” (Chen, Bailey, Tiernan, & West, 2011, p.129) by measuring the response time for congruent and incongruent trials. For congruent trials, participants are confronted with color words where the word itself is in the same color as it stands for, whereas the color word differs from the color for incongruent trials (Chen et al., 2011). The response time for processing this information is generally slower for incongruent trials suggesting that competing stimuli are processes (i.e., the color and the semantic meaning of the word itself) (Chen et al., 2011). This experimental set-up was used for developing the Lumosity game “Color Match” and aims at increasing participants’ ability to regulate competing levels of information processing.

This section has intended to only give a preliminary overview over the computerized training program and some of its games; it is of course thinkable to apply other programs or training schedules for enhancing executive functions.

3. Medical decision-making and de-biasing

3.1 Medical decision-making: Problems with irrationality

Decision-making in general is often directed by uncertainty as well as unknown probabilities of the various possible outcomes as already described above (Tsalatsanis, Hozo, Vickers, & Djulbegovic, 2010). Humans' ability to optimally operate in such complex environments in order to reach rational and prime solutions has been found to be bounded; this links back to the formerly described concept of bounded rationality (Kruglanski & Gigerenzer, 2011).

The clinical environment presents a special form of complex environments due to its high density of decisions made under limited time resources (Bornstein & Emler, 2001). The need to manage many patients in a short time leads to frequent mistakes in the clinical setting (Klein, 2005).

In the medical process, reaching a diagnosis is the first step. Making a diagnosis can be described as "updating opinion [*sic!*] with imperfect information (the clinical evidence)" (Elstein & Schwarz, 2002, p. 730). Understanding diagnosis as a process of revising an opinion, it is necessary to include as much information about the environment as required (Elstein & Schwarz, 2002). In order to do so, evidence has first to be gathered and then interpreted (Klein, 2005). The pre-test probability for testing certain hypotheses regarding the correct diagnosis is mainly unknown and the symptoms guiding the decision for a diagnosis are often unclear. However, they present the main clinical evidence that is available and which form the basis for a set of preliminary hypotheses formed by the clinician. In this context, cognitive biases and heuristics interfere with the doctors' ability to reach rational and correct decisions (Bornstein & Emler, 2001). These cognitive dispositions to respond are not specific to the medical domain or the process of making a diagnosis, but they have especially detrimental effects here; they alleviate gathering and using evidence leading to a diagnosis as well as all the subsequent steps that are based on these decisions (Bornstein & Emler, 2001). It has to be pointed out that a common belief is that doctors, as highly trained experts, are immune against these mistakes of thinking; unfortunately, this is not the case. On the contrary, it can be that they are even more prone to fall prey to cognitive biases due to their susceptibility to the overconfidence bias under specific circumstances that will be further explained subsequently (Klein, 2005). However, it is very important to point out the difference between novice and expert clinicians; whereas the former group is less self-confident and able to define its hypothesis based on a limited amount of cues, the latter is in some cases proficiently experienced to do so. Describing the difference in decision-making between experts and novices is a field of study in itself, though it is appropriate to briefly exemplify this aspect here, as making diagnoses is relevant for both groups. The ability to base a diagnosis on only a very limited set of cues as it is possible for vey well trained and highly experienced clinicians further depends on the sort of disease and the clarity of its symptoms. A brief example will illustrate this aspect: Imagine a patient suffering from Parkinson's disease, but only exhibiting very weak symptoms when first contacting a doctor. Parkinson's disease is characterized by a number of very distinctive features that clearly sets it apart from other diseases. For example, the gait of patients as well as their ability to react to barriers in their environment is specific; "akinesia, rigidity, tremor, and postural instability" (Sammer, Reuter, Hullmann, Kaps, & Vaitl, 2006, p.115) are the main characteristics for Parkinson's disease. Whereas a young and inexperienced clinician needs to fully examine the patient in order to verify or undermine any initial hypothesis, the expert clinician is able to interpret even the very weak symptoms at an early stage of Parkinson's disease. Thus, he can form his assumption significantly earlier than the novice can do that; subsequently, he has more time for applying conforming (as well as disproving) tests in order to test his initial hypothesis about the presence of this disease.

This phenomenon – the difference between novice and expert clinicians – is assumed to develop over time when doctors gain more experience. Even though this does not exclude them from falling prey to a cognitive bias or to applying an over-usage of heuristics, but it leads to a different sort of decision-making processes. The intuitive aspect of *knowing* (or confidently assuming) the cause for the symptoms is not based on irrational behavior and overly hasty interpreting cues in the environment, but on an embedded and vast body of knowledge as well as experience that the clinician could accumulate over time.

The challenge at hand is to differentiate between the experienced and often valid "quick and dirty" decision-making of experts and heuristics or cognitive biases that these experts naturally also experience. Novice clinicians are expected to commit cognitive errors of thinking on a more regular basis, which allows to easier identifying them because the patterns responsible for eliciting these irrationalities are more obvious to classify, whereas this is not the case for expert decision-makers. In the case of experts, the environment is expected to play a less important role and the occurring biases and heuristics are grounded in deeper cognitive processes. Without investigating this and other differences in decision-making of distinct groups, it should be pointed out that such dissimilarities exist and lead to separate decision-making processes where some of them seem to be irrational as they happen based on very few cues, all involved parties are potentially at risk to fall prey to a cognitive bias or heuristic.

In general, there are three forms of mistakes that can be committed by clinicians with respect to reaching a final diagnosis: These three categories are the so-called "no-fault errors" (Graber, Gordon, & Franklin, 2002, p. 981), the "system errors" (Graber, et al., 2002, p. 981), and the "cognitive errors" (Graber, et al., 2002, p. 981). The first cluster describes mistakes that cannot be omitted "when the disease is silent, presents atypically, or mimics something more common" (Graber, et al., 2002, p. 981). Even though the number of these mistakes is expected to decline as medicine and the technological possibilities evolve, they cannot be completely erased (Graber et al., 2002).

The second form of mistakes is the group of system errors that are caused by the "latent imperfections" (Graber et al., 2002, p. 981) of the medical system. This refers to the aforementioned problems of limited time resources and the limited amount of tests that are available for confirming a hypothesis.

The third cluster of mistakes is presented by the cognitive errors, which describe the "misdiagnosis from faulty data collection or interpretation, flawed reasoning, or incomplete knowledge" (Graber et al., 2002, p. 981). They are based on the set-up of the human brain as it has evolved over time; the human capacities to process information are limited and even further challenged in the complex environment of medical decision-making. Whereas the first group of mistakes cannot be erased, the second and the third group are possible to improve. System errors have to be decreased by improving the status quo of the current clinical system, but this is not the focus of this thesis, which investigates the attempts to reduce cognitive errors. According to Graber et al. (2002), "opportunities […] for improving the cognitive aspect of diagnosis" (Graber et al., 2002, p. 981) exist; they will be further elucidated and critically evaluated in the following passage.

3.2 Prevalent cognitive biases in diagnosis

The process of medical decision-making is inflicted by a variety of cognitive biases, which can lead to suboptimal outcomes in all involved parts: Gathering evidence, interpreting it, deciding for a diagnosis, prescribing treatment, and supervising the according treatment schedule are potentially affected. The underlying cognitive irrationalities leading to errors made in these fields are not specific to medical decision-making, but are defining features of humans' reasoning capabilities. However, as already mentioned earlier, the negative effects of suboptimal decisions can have especially severe consequences in the medical context. There are a great number of cognitive biases that have been described as interfering in the clinical decision-making processes; Croskerry (2002) developed a "Catalogue of Failed Heuristics, Biases, and Cognitive Dispositions to Respond (CDRs) with Descriptors, Consequences, and Strategies to Avoid Them" (Croskerry, 2002, p.1187) that lists the known heuristics and biases interfering in the medical decision-making process and according strategies for overcoming them. Here, diagnosis, treatment-decisions, and other parts of the process are taken together. In this thesis, a special focus is laid on diagnosis and as such, I extracted the prevalent cognitive biases that have the potentially highest negative influence on the clinicians' ability to reach a rational and optimal solution. The following selection is based on several factors; first, an extensive literature research enabled me to competently have an overview over the more prevalent biases and the less often experienced ones according to the reports given by the clinicians involved in the studies. Second, conversations with a practicing clinical expert further grounded this selection. However, it has to be stated that this collection might be biased through my personal experiences and interests; as such, it is not intended to present a final and general list of the most important biases in the diagnosis-process.

The criteria for choosing the following biases are their presumably often-occurring presence in diagnosing, their potential of eliciting strong effects (i.e., leading to significantly worse decisions as when they are not present), and the existence of suggestions for de-biasing them. The latter aspect is of special importance: At the moment, the existing de-biasing techniques are flawed in many aspects (Croskerry, 2002). First, they are very generally formulated and as such hardly "specific" to a single bias. Second, they are very vague as they include commands such as “They [*the clinicians, remark by the author*] should avoid having their clinical decision making influenced by demanding behavior of patients and relatives” (Croskerry, 2002, p. 1187). However, it will be further elucidated that even these imprecise commands address the involved cognitive abilities activated while experiencing cognitive biases and that the de-biasing techniques themselves also operate with these cognitive processes. This crucial connection will be further discussed in section *3.3.3 Shared cognitive requirements between cognitive biases and de-biasing techniques*.

The selected prevalent cognitive biases and heuristics in the diagnosis process are the following: Confirmation bias, availability heuristic, overconfidence bias, gambler’s fallacy, search satisficing, and premature closure. Each bias will be described in detail with the according de-biasing techniques that are known at the moment.

The *confirmation bias* describes humans’ tendency to look for conforming rather than disconfirming evidence of an initial hypothesis (Schwind & Buder, 2012). Further, it refers to people’s predisposition of failing “to take dissenting information into account” (Schwind & Buder, 2012, p. 2280) when presented with it. Thus, it is not only an actively unconscious avoidance of seeking disconfirming data, but also an – again – active, but unconscious rejection of such information when it is available. The biased process of selecting information is directed towards the primary preferences of the seeker and hinders him from adopting a critical and innovative position opposed to what he already believed or expected before the searching process had started (Schwind & Buder, 2012). As such, it is sometimes also referred to as *Positive Hypothesis Testing* (Kayhan, 2013), which captures the rejection of negative evidence for a personal prior hypothesis that is of special interest for diagnosis. The following example should further elucidate the nature of this bias: Imagine a doctor presented with a patient who suffers from headache and starts describing the pain. The patient might start with describing the circumstances of the onset as well as the duration and the locus of the headache. It has to be noted that this is one of the major complaints that doctors are presented with and it can often be a secondary cause of a primary disease (Bailey, 1958). Here, the challenge is to apply the correct routine for identifying the real cause; headache can be caused by a plethora of factors, including intracranial tumors, lesions of the cranial nerves, or lesions of the cranial or intercranial arteries (Bailey, 1958). Given the often blurred and imprecise descriptions given by the patient, the clinician has to rely on his test battery for detecting the correct source causing the pain. He will most probably form an initial hypothesis based on the patients' report, his investigation, and his clinical expertise and experience. However, if the origin of the headache is not absolutely clear, he has to apply certain tests in order to search out the correct diagnosis. Here, the confirmation bias is present when he only uses tests confirming the main hypothesis that he has formed; other tests that might disconfirm his initial assumption are left out.

Another cognitive error to respond that can be found in the field of diagnosis and that is often related to the confirmation bias is the so-called *availability heuristic*; it describes humans' tendency to recall recent or salient easier than rare or atypical events (Bornstein & Emler, 2001). Further, events are also rated as being more frequent when they come readily to mind; as such, the rule of thumb 'most available = most relevant' applies. Thinking back of the doctor presented with the patient suffering from headache, the availability heuristic could be instantiated as follows: The clinician has already seen a couple of patients at the concerning day who all suffered from headache; he has applied specific tests and followed his routine for identifying the underlying causes, which could possibly be similar or even exactly the same for a number of these patients. For each additional patient that he is seeing suffering from a certain type of headache, he will become more likely to diagnose the same origin of the pain as for the previous patients. In combination with the confirmation bias, which leads him to prefer the tests confirming his initial hypothesis, the clinician will be less likely to take different diagnoses into consideration. Further, he will also be more likely to estimate the probability of future patients suffering from exactly the same cause as higher, which is often a significant overestimation and as such very inaccurate (Bornstein & Emler, 2001). Bornstein & Emler (2001) investigated this effect in doctors regarding the probability that a blood sample was infected by bacteremia or not and the availability heuristic led to an increase of this estimation to 41% to 99%, whereas the real rate was only 12%.

This wrong estimation of the probability of an event is also an inherent aspect of the *overconfidence bias*, which often affects experts. They tend to be overly confident regarding their own judgment, especially when little evidence or feedback is available (Armstrong, 1984). Even though clinical decision-making differs between novice-clinicians and expert-clinicians as already discussed above (Croskerry, 2002), this aspect should be disregarded for the moment in the context of this thesis; the effect of overconfidence is supposed to be not restricted to highly experienced clinicians, but also to affect novices to some extent as they start carrying out their profession as highly educated ‘novice-experts’. The overconfidence bias does not only lead to a higher estimation of one’s own expertise, but also to investing an insufficient amount of effort into gathering and synthesizing data for confirming (or disconfirming) a hypothesis (Croskerry, 2002). On the contrary, decisions are made based on incomplete data sets and intuition that is believed to present one’s own experienced expertise. According to Croskerry (2002), this is a “dangerous personal trait in medicine” (Croskerry, 2002, p. 1193) and it is also closely tied to expecting a positive outcome when the personal involvement in the decision-making procedure is regarded as especially important. In combination with the aforementioned availability heuristic, the negative effects of the overconfidence bias can be further increased (Croskerry, 2002). In the example with the patient suffering from headache such a accumulation of biases occupies an increasing potential of receiving the wrong diagnosis; thinking about the multiple reasons that can cause headache, it should be expected that it is not possible to always find the correct diagnosis given the biased and flawed circumstances. In the case that a brain tumor is the origin of the pain, even a delayed diagnosis instead of a wrong one leads to severe dangers for the patient.

In relation to coming to the wrong conclusion when searching for a diagnosis, the *Gambler’s fallacy* also plays an important role: It describes the effect of integrating pre-test probabilities in the *a priori* assessment of the probability of a diagnosis by irrationally assuming that the likelihood for a distinct event is influenced by previous events (Croskerry, 2002). In detail, this violates the independency of distinct diagnoses; the occurrence of a certain disease in one patient is theoretically independent from the diagnoses relevant for subsequent patients. Thus, each patient should be objectively assessed without integrating prior cases into the assessment procedure. The name for this bias has its origins in the classic fallacy that humans experience when tossing a coin: Gamblers expect the change of a sequence of coin tosses according to a certain pattern. If a coin comes up heads five times in a row, it is expected that the 6th time it will come up tails because it *has to be tails now* (Croskerry, 2002). Even though each coin toss is perfectly independent from the previous ones, they are perceived as being related to each other and as such, the human mind expects a coherent pattern in how the coin comes up. In the context of medical decision-making, this fallacy can cause problems with deciding for the correct diagnosis. With the patient suffering from headache, it could be that five patients before him also came with headache to the doctor and they all were diagnosed with the same cause. The clinician might be compelled now to form a different initial hypothesis about the origin of the current patient's pain, as *this row of causes for headaches cannot continue* according to the Gambler's fallacy. However, it is possible that all patients' headaches are caused by the same problem.

The formerly described availability heuristic seems to stand in contrast to the Gambler's fallacy: Whereas the former leads to an increase of assuming the same cause behind distinct events due to their prevalence in experience, the latter leads to a decrease of the probability of the same event as change is expected to occur according to an underlying pattern. Therefore, these biases can be understood as presenting extreme cases of a continuum leading to irrational and wrong diagnoses that are detrimental for the patient in any case.

The last two biases that were selected for this thesis are closely related to each other as both refer to an insufficient amount of time devoted to gather evidence. The first one is called *search-satisficing* or *keyhole viewing* (Croskerry, 2002). This bias describes the stop of a search as soon as *anything* has been found; this tendency is justified in daily life situations where it is normally known what is searched for (e.g., a set of keys) and as soon as the item is found, there is no need to prolong the search. However, in medical decision-making, it is often not exactly known what is looked for and how it could look like; only visible symptoms can be observed at the beginning, but how their origins are constituted is often hard to determine. Further, there could be several diseases at play that all need to get diagnosed. If the search is called of too soon, it might be the case that not all diseases are detected or that important factors are left out, as they would require a continuation of the search. According to Croskerry (2002), one of the main reasons for this bias is that it is satisfactory to find something and in combination with being aware of the complicated ecological features of the clinical context (i.e., for example the severe time and resource constraints), this positive feelings leads to the seemingly rational decision to end the search.

Search satisficing is further related to *premature closure*, which describes clinicians' tendency to accept an initial hypothesis only based on an insufficient amount of evidence (Croskerry, 2002). As they normally tend to formulate several hypotheses before deciding for a single diagnosis, clinicians have to collect data supporting their assumptions; if this gathering of data is finished too soon (as *something* has been found; see *search satisficing*), important aspects of the origin of a disease are probably overlooked or – in the worst case – complete diseases are not detected. This behavior may reflect the need for completion that is – similar to search satisficing – related to a positive feeling, but also to some "laziness of though" (Croskerry, 2002, p. 1195).

3.3 Bias specific de-biasing techniques

De-biasing refers to the endeavor of decreasing the detrimental effects of cognitive biases by applying structured techniques that have been specifically adapted to each cognitive bias (Almashat, Ayotte, Edelstein, & Margrett, 2008). The goal is to develop these techniques in a way that they are applicable to varying situations where the bias arises without being too general in their nature. Unfortunately, the de-biasing techniques that are known at the moment are generally very broadly and vaguely defined; they lack the specificity that is necessary for significantly changing the behavior that is related to a cognitive bias. They only remain specific enough to be able to get identified with a certain set of biases, but not specific enough to account for one single bias and its necessary changes. The underlying assumption of de-biasing is that there exists a normative standard of rational decisions; as mentioned in the first part of the thesis, there are diverging positions to this standpoint. Whereas Gigerenzer (2008) posits that heuristics and cognitive biases are useful in uncertain environments where they led to as rational decisions as possible because they are ecologically adapted to the environment, other researchers such as Kahnemann (1986) apply a different approach. He describes cognitive biases are systematic errors of thinking that deter humans from reaching optimal and rational decisions, which would in theory be possible (Tversky & Kahneman, 1986). As already mentioned in the chapter explaining the concept of rationality, I agree with Kahnemann regarding the theoretical normativity of decisions; even if there exists more than one rational outcome of a decision process, the important aspect is that there *is* at least one such optimal outcome. Without deciding whether humans possess the abilities to *always* reach this result – which would be a very bold assumption and should thus be taken aside – there exists at least the ambition to do so in as many situations as possible. Further, there are certain fields where reaching *a* rational decision is more urgent than in others. Clearly, the field of medical decision-making should be placed in this cluster: Suboptimal medical decisions leading to errors in diagnosis or treatment are highly costly and can have fatal effects (Keeler et al., 2006).

As already mentioned above, the techniques available at the moment are not optimal and can be criticized on various levels; after giving an overview over the proposed techniques for overcoming the six cognitive biases respectively heuristics that are relevant for this thesis, a detailed critique will be presented. Based on this elaboration and the description of the used underlying cognitive abilities that are necessary for both experiencing a cognitive bias as well as for de-biasing it, it will be argued for the importance of integrating training of executive functions into the process of de-biasing.

3.3.1 Specific de-biasing techniques

The first cognitive bias that has been discussed in the course of this thesis regarding its relevance for making a diagnosis is the *confirmation bias*. The suggested technique according to Croskerry (2002) is to "mentally monitor" (Croskerry, 2002, p. 1189) the process of creating and testing for different hypothesis at the beginning of the diagnosis process while avoiding to only select confirming diagnostic tests. Further, it should be paid attention to the value of disconfirming evidence, which is described as "may be worth ten pieces of confirming evidence" (Croskerry, 2002, p. 1189). This asymmetrical weighing of disconfirming evidence over confirming data is highly questionable and presents a bias in itself; medical tests are not disconfirming or confirming *per se*, but only in respect to the specific medical problem they are used for; as such, one test can be confirming for one disease and disconfirming for a different disease. Another de-biasing suggestion for the confirmation bias is the application of checklists for ensuring that differing hypotheses are treated equally. However, little information about a detailed description or procedural implementation of such checklists are given (Croskerry, 2002, p. 1189).

Similar suggestions are given for overcoming the *availability heuristic*; here, a main focus is laid on physicians' effort to being "aware of the tendency to pay too much attention to the most readily information" (Croskerry, 2002, p. 1187) without giving sufficient suggestions how this goal could be achieved. Further, special emphasis should be laid on gathering "objective information" (Croskerry, 2002, p.

1187) that should then be assessed “systematically” (Croskerry, 2002, p. 1187). Given the demanding environmental circumstances of the medical context and the already high standard of a clinicians’ education that presumably integrates a systematic line of action, such advice is assumed to be of limited use.

The systematic sampling of information is also recommended for alleviating the *overconfidence bias*. In accordance with asking questions such as “How much is really known?” (Croskerry, 2002, p. 1193), effort should be directed towards enhancing one’s attention of the information already sampled through various tests, the systematic fashion of this data gathering procedure, and whether they hereby gained evidence confirms or disconfirms the initial hypothesis. How this effort could be realized in the real-life setting is generally not further exemplified (Croskerry, 2002, p. 1193). Further, it can be seen that even at this general level, an overlap between the overconfidence bias and the confirmation bias is present; both are challenged with the problem of deciding whether enough confirming or disconfirming evidence has been sampled through applying different medical tests. That these tests also carry the risk of leading to wrong results is not even mentioned in this context; no medical test is absolutely certain, but considering this aspect would go beyond the scope of this thesis.

The next cognitive disposition to respond that has been previously discussed is the so-called *Gambler’s fallacy*. As it refers to the intuitive feeling of an expected (though not rationally explicable) feeling of change that accompanies unusual sequences of similar events, one suggested de-biasing technique is that “physicians should remind themselves of the laws of probability” (Croskerry, 2002, p. 1190). Additionally, it is recommended to “restart” (Croskerry, 2002, p. 1190) the search for the correct diagnosis with each patient – a self-explanatory step in each medical diagnosis process. Again, it can be pointed out here that simply suggesting to remind oneself about a certain detail of the world such as the laws of probability is most probably not correlated with a high success rate; *if* clinicians could do that, they would already know about the bias and the according rules of probability and would have already reminded themselves about them. However, as cognitive biases are supposed to often operate on an unconscious level, a simple reminder on basic mathematical rules is not expected to diminish the intuitive feeling of irrationally expected change.

It is similarly difficult to overcome the heuristic of *search satisficing*; the intuitive feeling of success when *something* has been found is hard to overcome with rational deliberations promoting the prolongation of the search process if it is not obvious that further diseases are present. The suggested technique for solving this problem at least to some extent is to ask oneself questions such "Is there anything else to be found?" (Croskerry, 2002, p. 1196). A further suggestion is to define search domains before closing the search procedure, but this seems impossible to generally implement into the daily practice of clinicians, which is already characterized by very limited time resources. Moreover, it is not clear how simply asking such questions could lead to a less-biased behavior; it intuitively appears to be more successful to increase the attention of the clinician for detecting clues of further diseases. As it was mentioned before, it is expected that highly trained people such as clinicians are used to ask such systematic questions anyways and thus, if this would be sufficient for overcoming a bias, it would probably not even arise. However, as the bias is present, it is expected that this proposed technique is too weak for significantly diminishing the detrimental effects of stopping the search too early.

Similar problems occur in relation to the heuristic of *premature closure*. It is very difficult to determine when a search has been exhaustive enough to be finished or when additionally data should be acquired, because *if* the clinician was aware of the need for prolonging the search for the correct hypothesis, he would continue with the process until he reaches the point of saturation and the bias would not occur. However, this point of saturation could again also be premature and is not necessarily the final point of the search. The de-biasing technique that is proposed for alleviating this effect is very vague: "Physicians should keep an open mind about the diagnostic possibilities" (Croskerry, 2002, p. 1195), whereas it is not described how this state of open mindedness could be achieved. Further, it is proposed to be aware of the fact that once a diagnosis is reached, it is not inherently the final conclusion (Croskerry, 2002, p. 1195). However, as no hypothesis can ever be fully verified, this advice could be generalized to many varying fields of science and is as such not specified for medical diagnosis.

As this brief overview over the de-biasing techniques for six common cognitive dispositions to respond shows, there are many open points that can be criticized, which will be done in the following section.

3.3.2 Critique of current de-biasing techniques

As already briefly mentioned before, there are several points of critique that can be mentioned regarding the current de-biasing techniques.

First, they are often formulated in a very general format so that they could be applied to de-bias more than one cognitive bias or heuristic. For example, mental monitoring of the situation is suggested to help overcoming the confirmation bias (Croskerry, 2002, p. 1189), but it is also thinkable that this improves performance under the influence of the availability heuristic where frequent events are rated as more relevant as they are more salient than rare events. Following from this, such a technique can be hardly described as *bias-specific* as it is not restricted to a single cognitive disposition to respond. On the contrary, it would probably be more useful to identify clusters of biases and attribute common rules for overcoming them according to the underlying and necessary cognitive requirements.

Second, de-biasing techniques as they exist at the moment are too vaguely defined as they could be labeled ‘bias-specific techniques’; advices such as “Physicians should keep an open mind about the diagnostic possibilities” (Croskerry, 2002, p. 1195) for avoiding premature closure is hardly tangible and lacks detailed descriptions of how this endeavor should be achieved. It is important to point out that the default case is assumed to be that clinicians aim at working with an open mind while trying to seek for hints that the current decision for a diagnosis could be optimized; otherwise, their qualification and expertise should be regarded as dubious. Even though it is clear that a demanding environment such as the clinical world does not allow perfect decision-making due to the severe limitations of time and resources as well as the omnipresent uncertainty, it can be expected that clinicians already try to keep their minds as open as they can. Similar comparisons can be made with many other de-biasing advices; reminding oneself about the underlying rules of probability (used for avoiding the Gambler’s fallacy), asking oneself questions whether further diseases could be found or not (suggested in order to avoid the heuristic of search satisficing), or advising to restart the whole diagnosis procedure with each patient (in order to avoid the availability heuristic) address procedures that are inherently assumed to be used during the diagnosis process. Further, the question must be raised whether plainly requesting to *raise one’s awareness* can have any effect: How exactly should this be done? What are techniques for raising awareness? How can they be implemented into the daily routine of clinical decision-making? These and similar questions are left open, but they are crucially important for truly overcoming cognitive biases under the assumption that the desired effect of alleviating the negative effects of cognitive dispositions to respond can be successfully tackled by addressing cognitive abilities like awareness.

Third, it is left unanswered why these advices should be successful. It is for example not defined why mental monitoring will significantly improve the ability to cope with the confirmation bias or why asking oneself questions is the appropriate way for avoiding search satisficing. It is necessary to investigate the underlying cognitive abilities used by cognitive biases as well as the according cognitive abilities engaged during the de-biasing procedures; they have to overlap in order to address the same underlying neural components. Thus, the de-biasing techniques are predicted to be able to influence the emergence of cognitive biases and will thus lead to decreased interferences with rational decision-making.

A preliminary overview over the assumingly involved cognitive requirements for cognitive biases as well as the according de-biasing techniques will be given in the next passage.

3.3.3 Shared cognitive requirements between cognitive biases and de-biasing techniques

The following table (**Table 3**) presents an overview over the assumed cognitive requirements that are shared between cognitive dispositions to respond and the according de-biasing techniques. It is important to notice that this is only a primary and preliminary comparison that do not lay claim to completeness respectively empirical evidence; further research will be necessary to determine the correctness of these assumptions. Especially the field of neuroscience will adopt an important role here; identifying the involved brain areas that are activated during exhibiting a cognitive bias and also during the application of the de-biasing techniques will add evidence to their proposed connection.

The addressed cognitive abilities that are presented in **Table 3** were identified trough thorough investigation of the nature of the according cognitive dispositions to respond and the related de-biasing techniques that were advised by Croskerry (2002); it should be noted that this is a subjective analysis, which naturally bears the risk of being biased. However, as these are theoretical deliberations, it is justified to propose this first suggestion.

Table 3. Shared cognitive requirements between cognitive dispositions to respond and the according de-biasing techniques. CB = Cognitive Disposition to Respond. DBT = De-Biasing Technique (De-Biasing Techniques according to Croskerry (2002)).

Cognitive Ability	CDR / DBT
Attention	CB, AH, OB, SS, PC
Planning	CB, SS, PC
Memory	AH, OB, GF
Feeling of confidence	CB, PC, AV, GF
Inhibition	GF, AV,OB
Rule detection	GF

CB = Confirmation bias; DBT: Mentally monitoring one's approach, being open minded
AH = Availability heuristic; DBT: Being aware of tendencies, systematically gathering information
OB = Overconfidence bias; DBT: Being reflective, testing knowledge
GF = Gambler's fallacy; DBT: Reminding oneself of the laws of probability, being open minded
SS = Search satisficing; DBT: Paying closer attention to the right place for searching
PC = Premature closure; DBT: Keep an open mind, being more open for more testing

The main cognitive abilities that could be identified are attention, planning, memory, the ability to feel overconfident, inhibition, and rule detection. These capabilities are supposed to be the underlying factors at play during the exposure to cognitive biases and heuristics.

Attention is one of the main cognitive requirements that is supposed to be activated during the majority of cognitive biases and the according de-biasing techniques; reduced attention interferes with the ability to apply rules of probability, to detect further clues for a disease, to pay enough attention to colleagues' opinion when developing a diagnosis, or to understand that further evidence need to get gathered before the search for the correct decision can be finished. Unfortunately, attention is highly challenged in the clinical environment as this is characterized *inter alia* by "stress, fatigue, distractions, and excessive workload" (Graber et al., 2002). Therefore, it is hardly surprising that cognitive biases reducing attention can be often found in this context and they are assumed to be especially strong because the overall level of attention is already reduced compared to normal daily life. Thus, the importance of directly training attention via cognitive training is not only relevant for overcoming cognitive biases, but also for improving non-biased decision-making abilities in clinicians.

Planning is defined as “the ability to identify and organize the steps and elements needed to achieve a goal” (Jurado & Rosselli, 2007, p. 221) and is thus connected to the ability to pay attention to the important aspects of the environment. In the context of medical decision-making, one of these goals is to reach a correct diagnosis on which subsequent steps are based on; for example, the choice of treatment as well the amount of patient-clinician interaction depend on the diagnosis. This overall goal of reaching the correct diagnosis can be further divided into smaller goals: Several hypothesis have to be formed and coordinated according to the symptoms presented by the patient, fitting tests for confirming or disconfirming these hypotheses have to be selected and carried out, the hereby resulting data need to get interpreted, and it has to be decided and planned whether further tests are necessary. As it can be seen here, the ability to correctly plan all these sub goals is crucially important for achieving a rational and correct diagnosis. However, this ability is supposed to be reduced when primarily relying on cognitive dispositions to respond because rational planning is substituted by heuristics and biases. In combination with a decreased ability to pay attention to relevant clues and factors in the environment, the capacity to reach the final goal – the correct decision – is further aggravated.

It is additionally intuitive to expect that memory plays a decisive factor in this process; the ability to recall the correct disease based on the presented symptoms as well as other factors such as age or general health constitution about the patient is necessary. Moreover, previous cases and diagnoses are held in memory and they influence subsequent decisions: The availability heuristic and the Gambler’s fallacy are classic examples for this. Even though diagnoses for different patients constitute distinct events that are not related to each other, they are often perceived on a continuum where the a priori probability for a disease is influenced by the preceding diagnoses, as they are hold in memory.

Further, the feeling of confidence arises when long education and a high social status attribute expert-status to the practicing clinician; overconfidence is supposed to elicit positive feelings of making the right decisions and thus, these decisions are not further questioned. The reward system is activated during the experience of overconfidence (Peterson, 2005), which refers to the activation of dopamine in the brain. This connection leads to positive emotional experiences and a reduced incentive for change; thus, little effort is made for further searching causes for a disease or for investing more time and effort in additional tests. Even though this problem is directly described as a specific bias, the feeling of overconfidence can also be suspected to interfere in situations when other biases or heuristics are applied; for example, the need for prolonging the search for the cause of a disease or questioning one's own intuition are also decreased when experiencing confidence. When being exposed to the availability heuristic or the Gambler's fallacy, overconfidence in one's own judgment may increase the negative effect of theses biases.

Moreover, the lack of inhibition further aggravates the effects of biases: Intuitive judgments or feelings of 'uncanny' sequences of patients with similar diagnoses, as it is the case for the Gambler's fallacy, needed to be overcome if the according biases are effectively decreased. Similarly, the feeling of knowing the answer due to the experience of overconfidence would be necessary to get inhibited as well as the diagnosed origins of previous patients' diseases. Ideally, each patient is perceived as a distinct unit and independent from environmental factors; in this case, there would be little need to inhibit interfering intuitions or influences from previous cases. Unfortunately, as this is not the case, inhibition is supposed to be necessary in medical decision-making and especially during the process of diagnosis. Here, the influence from preceding patients is at the highest level as well as the uncertainty regarding the current patient and his disease.

Finally, rule detection was mentioned as crucial cognitive ability that is important for both the experience as well as the de-biasing of cognitive dispositions to respond. It requires attentional control for detecting underlying rules and the according sorting criterion that characterizes any given rules (Kalashnikova & Mattock, 2014). The Wisconsin Card Sorting Test (WCST) is the classic version for deciding whether people are able to detect such underlying rules based on their prefrontal cortical function (Merriam, Thase, Haas, Keshavan, & Sweeney, 1999). Here, cards have to be sorted according to unknown rules that have to be detected during the sorting process. This ability to operate on formerly unknown principles in an uncertain environment is important in the clinical context; even though diseases have been able to get structured and described in a formalized way, there are still many unknown factors existent. In real life, diseases and their causes are hardly presented in a workbook-fashion and further, not all diseases are already known. Thus, it is necessary to detect the ‘rules’ underlying a specific disease during the process of investigating it and producing a diagnosis for it. This also applies to the detection to the rules of probability that is necessary in order to avoid the Gambler’s fallacy; these rules do not only have to be understood and hold in memory, but they also need to get actively detected when they are violated in real life as it is the case when experiencing this cognitive bias.

These previously described cognitive requirements play a role and get activated not only during the experience of cognitive dispositions to respond, but also during the attempt to overcome them; when looking at the so-called bias specific de-biasing procedures – that are effectively too vaguely defined for successfully fulfilling their purpose – one detects the same requirements. This intuitively makes sense, as they have to address the same brain areas and cognitive abilities that they aim to influence. For example, attention is mentioned in the de-biasing procedure for overcoming premature closure; clinicians are encouraged to “keep an open mind” (Croskerry, 2002, p. 1195) in order to think of further possibilities to search for causes. Similarly, the de-biasing procedure for search satisficing includes the advice to pay attention for whether the clinician searches at the right place for the cause of a disease. Here, planning also plays an important role: As already mentioned above, each search path has to be planned before it can get implemented and using this as a de-bias procedure requires an increasingly enhanced ability to do so. Being more open for formerly unknown places to search for the cause of a disease as it is advised for overcoming premature closure involves a structured plan of the already searched locations and the reminding loci. Naturally, the ability to hold this information in memory is crucial; this is also the case for overcoming the availability heuristic where it is recommended to systematically look for further information in order to decide whether a diagnosis is influenced by the previous diagnoses or not. As much as holding information in memory and paying attention to it is important, it is also significant to inhibit information and automatic reactions; being aware of tendencies that might occur in the clinical practice and inhibiting an intuitive reaction to them by only taking them as correct hints for diagnosing requires the ability to inhibit automatic responses. The availability heuristic is not for nothing one of the supposedly main influential cognitive dispositions to respond (Klein, 2005): It is hard to overcome and one of the cognitive requirements for weakening its effect is to inhibit the intuitive feeling of knowing the diagnosis by only relying on what is most salient in memory and the field of attention. Further, the underlying rule that frequent events are rated as more relevant has to be set aside, whereas in other cases such unconscious rules have to be made conscious in order to alleviating the detrimental effects of cognitive biases. For example, the ability to detect and apply the laws of probability is crucially necessary for overcoming the Gambler's fallacy. The corresponding technique advises clinicians to remind themselves about these rules and to aim at detecting them in their environment when presented with patients. Even though this is a sound advise in theory, it is not explicated or described in detail *how* clinicians should approach this endeavor. Unfortunately, this is often the case with the techniques recommend as de-biasing procedures.

Even though any elicitation of the feeling of confidence or overconfidence is not directly suggested as being a de-biasing technique, it is nevertheless an important connection between cognitive dispositions to respond and the according techniques for overcoming them. It is expected to lead to an increased feeling of reward when rational decisions are achieved; the rational outcome of the search process should be the correct diagnosis and this naturally is predicted to activate the reward system of the clinician.

4. Executive functions and cognitive biases

Executive functions have been described in detail in section 2.3, where their development, measurement and neuroscientific background was outlined. They encompass cognitive abilities such as planning, memory, attention, reasoning, and verbal fluency (Jurado & Rosselli, 2007). However, the concept is still under discussion: It is debated whether it comprises of a central executive function that controls higher order cognitive abilities (Braver et al., 2010) or of distinct units as described above (Jurado & Rosselli, 2007). At the moment, there is no clear decision possible, but I ground my work on the second understanding; the neuroscientific evidence that is available further speaks in favor of this. Namely, it is feasible to spot distinct brain areas involved in the separate cognitive abilities that are covered under the term executive functions. This has been outlined in greater detail in section *2.3.3 The neuroscientific background of executive functions.*

The cognitive requirements that were mentioned for the experience and the de-biasing procedures of cognitive errors to respond in the medical context overlap with executive functions as understood in this thesis. They include attention, planning, memory, the feeling of confidence, inhibition, and rule detection. These components have been described in section *3.3.3 Shared cognitive requirements between cognitive biases and de- biasing techniques* in order to define the shared underlying components involved in these two processes.

Combining these requirements with executive functions shows that overlaps can be found here: Attention, planning, memory, inhibition, and rule detection are also taken to be part of the group of executive functions (Jurado & Rosselli, 2007). It intuitively makes sense to expect that if the same cognitive abilities are described as being involved in the experience and overcoming of cognitive dispositions to respond *and* the cluster of executive functions, that they are most probably the same. Complying with Occam's razor, it is assumed that one and the same cognitive system is at play in the fields of executive functions and cognitive biases that are regarded as being separated from each other. To my knowledge, it has not been suggested before to connect them with each other. Further, it has not been considered whether influencing one of these parts will result in a change of the other aspect.

In the following sections, I will argue for the following approach: Enhancing the ability to control executive functions such as attention or verbal fluency will lead to an increased ability to overcome cognitive bias by applying the bias-specific techniques that are known at the moment and which are flawed. This enhancement of executive functions should be applied with a cognitive training program; an available online and computerized training program has been outlined in the previous sections *2.4.5 The training program Lumosity* and *2.4.5.1 The scientific background of Lumosity* and serves as an example for a possible application of the approach adopted in this thesis.

As already outlined in previous sections, executive functions are a fundamentally important aspect of humans' cognitive abilities because they comprise of the capabilities that are an inherent part of daily functioning. It would not possible to function properly in the demanding ecosystem which is our habitat without the ability to plan sequences of next actions, memorize what we already know about the world in general and a certain situation specifically, or pay attention to salient features of a specific condition. All these functions develop over time and decline with age (Jurado & Rosselli, 2007), but as already presented in section *2.4 Cognitive training*, it is possible to influence this natural lifecycle (Kesler et al., 2013).

Without repeating what has already been said, it should be clear by known how executive functions are understood in this thesis and that this understanding shows clear overlaps with the aforementioned cognitive dispositions to respond. The special focus on making a diagnosis in the medical context also requires a narrower focus on this aspect with regard to executive functions. Further, executive functions are often experienced unconsciously, though they have to get consciously trained in order to get influenced. They present the fundament on which cognitive biases and heuristics operate; leaving them out of the focus when dealing with these errors of thinking leads to a major blind spot. Similar to a successful sportsman who trains all of muscles and not only the ones that he specifically needs for his discipline, the fundament for the de-biasing techniques has to be taken into consideration: Executive functions are the basis for cognitive dispositions to respond.

The available neuroscientific evidence is also expected to point into this direction: Similar or even the same neural areas are supposed to be employed by some executive functions and cognitive biases. As research in linking the experience of cognitive biases and heuristics to according brain areas in order to identify the neural components is still at the beginning and not much is known at the moment, these approaches stay theoretical for the time being. Nevertheless, it is assumed that areas like the prefrontal cortex are involved in cognitive biases such as the so-called search satisficing bias where the search for further data is prematurely stopped and no subsequent steps planned. Similarly, the prefrontal cortex plays an important role for the executive function of planning (Miyake & Friedman, 2012). A detailed outline over the prevalent theories aiming at explaining the neural basis of executive functions has been given in section *2.3.3 The neuroscientific background of executive functions*.

Under the assumption that the neural basis of executive functions and cognitive dispositions to respond are the same or at least shared, it becomes further understandable why it is advised to bridge these two concepts rather than investigating them as a separate and distinct areas when focusing on overcoming cognitive biases and heuristics.

5. Linking the pieces together: Towards an integrated approach

As outlined in the previous sections, medical decision-making and especially the process of finding the correct diagnosis are challenged by numerous factors: The highly complex environment and cognitive errors cumulate and lead to an aggravated decision-making ability. Cognitive dispositions to respond are an inherent part of humans' evolutionary set-up skill set, and as such they also interfere with these processes. Unfortunately, they are very likely to directly contribute to high costs in the clinical settings; impairing clinicians' ability to reach a rational decision in diagnosis entails suboptimal, if not fatal, consequences in the subsequent steps of the medical process of diagnosing and treating diseases. This does not only entails suboptimal healing-circumstances for patients, but *inter alia* also financial complications as pointed out by Kesler et al. (2013): "in 2010, the direct cost of cancer on society due to illness-related loss of productivity was 20.9 billion" (Kesler et al., 2013, p.305).

The need for overcoming cognitive biases and heuristics is thus understandable; however, the current approaches for this endeavor are not sufficient enough. Therefore, novel methods have to be developed in order to reach the goal of rational decision-making in the medical context. Given the mutual cognitive abilities that are necessary for executing executive functions and cognitive dispositions to respond, the proposal of this thesis is to suggest a combination of these theoretically distinct fields. Executive functions such as planning or memory are understood as the main fundament on which cognitive biases and heuristics operate. This means that executive functions are inherently involved in the exertion of cognitive errors in the sense that they are employed by the according brain areas, but not as functionally effective as when working under circumstances where no cognitive biases or heuristics are active. Consequently, it is expected that enhancing the executive capabilities via specific cognitive training will lead to an increased ability to control cognitive dispositions to respond. Specifically, it is suggested to apply already proven training programs in combination with the present-day bias specific de-biasing techniques; by doing so, it is expected to decrease the flaws of these techniques that are mainly caused by their imprecise and vague commands that make them hardly applicable to the daily life routines.

Further, there is also a suggestion for the specific cognitive training program that could be used for increasing cognitive control: The Lumosity program that has been developed by neuroscientists in San Francisco presents a user-friendly computerized solution for integrating this training in the clinical routine. It addresses the problems and difficulties that are generally associated with cognitive training by using a novel gamification-approach. Classic tests for executive functions are transformed into engaging and short games that correspond to the needs of operating in complex environments such as the medical world. Here, the human-machine-interface is user-friendly, which leads to a greater compliance to the training program. Further, it flexibly adapts to the user's needs and developments and is thus able to present the right level of complexity to the user.

As this thesis aims at opening a new way for overcoming biases in the medical context, it suggests a novel connection between cognitive enhancement of executive functions and bias-specific de-biasing techniques. It is important to note that the neuroscientific commonalities between these two fields are not yet fully understood, though there are neural components such as the area of the prefrontal cortex that are shared by them. Further research will be needed to clarify which parts of the brain are only used for either the executive functions or the he cognitive dispositions to respond, or both.

In this section, an introductory outline will be given for how the proposed integrating of the executive training into the bias-specific de-biasing could be realized. First, it is necessary to identify the exact cognitive requirements that play a role in the cognitive bias that should be eliminated. In this thesis, a subjective selection of six biases and heuristics has been chosen for demonstrating this step. A close examination of the behavior when experiencing any bias is necessary; further, the environmental factors have to be taken into consideration. In the clinical world, this involves constraints of time and resources such as medical tests in combination with long working hours and highly critical decision situations; finding the right diagnosis is especially connected with a high level of responsibility as all the subsequent medical decisions are based on this step.

The required cognitive abilities are expected to encompass aspects such as memory, attention, and planning. They are supposed to be necessary in the majority of cognitive biases and heuristics experienced in the medical decision-making context, as these are the main constraints for reaching a rational decision in this environment. Parallel to this step it is required to identify the specific executive functions that are anticipated to be employed in the situation; this can be done again by closely examining the factors defining the environment and deducing the cognitive capabilities needed in this context.

Based on these two steps – identifying the cognitive requirements employed by the biases and heuristics and the executive functions that are at play – the according training schedule has to be developed. It requires knowledge about the possibilities of influencing the executive functions with consolidated tests; there is a compact amount of data based on numerous studies available for this endeavor. The training program Lumosity is based on established studies and employs paradigms such as the Flanker paradigm (McDermott et al., 2007) for specific cognitive training exercises. This paradigm is used for testing selective attention in combination with self-regulatory processes, which are two crucially necessary abilities in the medical decision-making context (McDermott et al., 2007).

When the cognitive errors impairing the decision-making ability and the according executive functions as well as the underlying shared cognitive requirements are identified, a personalized training schedule can be developed. The agenda for enhancing executive functions could also be held general so that a broad range of executive functions is trained; however, in combination with specific de-biasing techniques, it is suggested that a particular focus is laid on the specific components necessary for overcoming the cognitive dispositions to respond that are at play. Beside this aspect, the bias-specific de-biasing techniques have to be extracted and implemented in the daily routine of clinicians; this can involve further developed feedback loops with colleagues (as it is recommended for the overconfidence bias) or behavioral changes that each clinician has to train on his own (for example, enhancing the ability to identify violations of the common rules of probability as it is recommended for overcoming the Gambler's fallacy).

The combination of these two streams of training – the computerized cognitive training for executive functions and the implementation of already known de-biasing techniques – is the first and mainly important step towards a consolidated approach for successfully overcoming cognitive dispositions to respond in the clinical context. At the moment, this approach requires an individualized coordination of cognitive training exercises in combination with de-biasing techniques. However, it is expected that once the effectiveness of this methodology has been proven, standardized training programs will be developed.

Regardless of whether the approach of combining executive functions with de-biasing cognitive errors of thinking is adopted on an individual or a general level, it is anticipated that either of them will lead to a demonstrable improvement of overcoming cognitive biases. As a consequence, fewer mistakes in finding the right diagnosis are expected to occur. Based on this, the number of people dying from a wrong treatment or an undetected disease is further anticipated to decrease.

The aim of this work has been to argue for a novel way for achieving this goal; as it is only a preliminary suggestion for a training schedule, there are a number of open questions and possible restraints that have to be addressed. This will be done in the following final chapter.

6. Discussion and outline for further research

As it was already outlined in the previous section and present as a guiding line throughout this thesis, this work operates on a theoretical level and does not claim to produce any hypotheses ready for testability. On the contrary, it deliberatively leaves room open for exploring the suggested connection between executive functions and cognitive biases, as this is a novel association that should not be restricted at this very beginning. Even though a specific computer program for enhancing executive functions was presented, this should only be understood a possibility for realizing the approach suggested here; other formats like intense and blocked training units that do not have to be integrated in the daily life of clinicians are also conceivable.

The key statement of this work is that the training of executive functions – both on a general as well as on a specific level – affects the experience and controllability of cognitive dispositions to respond. These dispositions can be cognitive biases in the strict sense where they take on the following structure: “When confronted with evidence of type X, a judge will consistently chose *[sic!]* alternative B instead of the expected alternative A” (Hilbert, 2012, p. 211). Further, the addressed cognitive dispositions to respond can also refer to heuristics, which are generally defined as rules of thumb for thinking and for dealing with complex situations where a detailed evaluation would require extended time and effort for coming to a conclusion.

The proposed connection of executive functions can be discussed and challenged. In this work, it is supposed that this link exists based on the shared psychological mechanisms that are activated both during the experience of cognitive errors of thinking and the operation of executive functions. This can be for example the need for (selective) attention or the usage of memory activity as well as planning or extracting different sets of rules. However, it is conceivable that this does not necessarily requires shared neural components respectively and the ability from one component to influence the other element. They could both operate with the same cognitive requirements, but are completely separate from each other. If this is the case, training effects from executive functions could not be transferred to the de-biasing procedure of cognitive biases. The specific enhancement of executive functions as it is suggested in this work would only influence the ability to control executive functions as such, but the ability to overcome cognitive biases would not be improved at all. This has to be tested in empirical research studies; one group of participant is advised to apply cognitive training for executive functions, while the control group does not receive any training. After the completion of a significant amount of cognitive training for the experimental group, both groups are presented with situations where cognitive biases are very likely to occur. Their performance will be measured and according to the approach proposed in this thesis, it is expected that the experimental group scores better on avoiding cognitive errors.

However, as the anticipated link between executive functions and cognitive dispositions to respond is further expanded on the application of bias-specific de-biasing techniques, it is further necessary to test this effect. This would again require an experimental group that receives cognitive training for a substantial amount of time and a control group that does not receive any training. In a next step, both groups are advised to learn techniques for overcoming cognitive biases before they are confronted with the bias-eliciting situations. Again, it is expected that the experimental group is better in applying the de-biasing techniques than the control group. Comparing these two suggested experiments with each other, I assume a difference in degree of overcoming the cognitive dispositions to respond: Measured against a normative standard of rationality as it is assumed to exist in the real world and argued for in the beginning of this thesis, the group receiving cognitive training for executive functions and bias-specific de-biasing techniques act more rationally than the group only receiving cognitive training and is thus able to avoid the specific cognitive errors that are generally elicited in the investigated situations. Following this logic, the third-best group would be the second control group that only received bias-specific instructions, but no cognitive training. The group performing the worst would be the first experimental group that neither received cognitive training nor bias-specific instructions. The rationality of a decision in the medical context is given by its correspondence to the real cause or disease that leads to a specific disease or malfunction. Therefore, there is a clear normative demand here: The proposed diagnosis of the clinician can be either wrong or right, and the real origin is either found or dismissed. As already mentioned several times in this thesis, it is crucially important that the cause of a disease is found and correctly identified because all the subsequent steps in the medical process depend on this first part.

Here, further research could shed light on interesting aspects that are related to this work: How is the ability to make diagnoses affected by cognitive dispositions to respond in different groups of clinicians? This refers to the differentiation between expert and novel clinicians as addressed in this thesis; it is expected that their ability to come to conclusions is different because a growing body of knowledge and expertise is only accumulated during actual working and cannot be taught in class to the novel clinicians.

Another aspect that could not have been proven in this thesis with empirical data is the neuroscience behind executive functions and cognitive errors in thinking. Empirical studies are necessary to further shed light on the neural components that are activated and causally relevant for the experience of executive functions and cognitive dispositions to respond. This is especially necessary for the later group; very little to almost no research has been done in this field so far. Being able to identify the brain parts activated during the experience of cognitive biases and heuristics would not only add to the existing body of knowledge that exists for these phenomena, but could further add evidence to the approach argued for in this thesis. The shared cognitive requirements that have been addressed previously are for now only based on subjective observations and assessments; their neuroscientific overlapping would present a crucial step in demonstrating their existence in an enhanced objective manner.

Based on this brief outline, it is clear that there are a number of open questions regarding the true existence of the assumed connection between two fields that have been considered separately for a long time. Further research is especially needed on the empirical level for establishing the neuroscientific link between these fields as well as on the level of testing the ability to reach more rational outcomes when relying on this novel approach.

It would have gone beyond the constraints of this work to aim for testing this, but further research will hopefully shed light on it and will show whether the here-proposed connection – partly or completely - exists or not.

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Abstract – English

This thesis is located at the intersection of executive functions and cognitive errors in thinking in the field of medical decision-making. It proposes a novel connection between these two fields based on shared neural and psychological components. The underlying and leading concept of this thesis is rationality because a normative approach with regard to diagnoses is adopted. Thus, a short introduction about the development and current understandings of rationality introduces this work in order to lay the ground for the subsequent passages.

Executive functions are understood as an umbrella term for various cognitive functions such as planning, memory, attention, set shifting, and rule detection. The various definitions of this concept as well as the development, the measurement, and the neural correlates of executive functions are discussed.

Cognitive biases and heuristics are understood as deviations from rational thinking and as leading causes for detrimental and non-rational decisions when searching for a diagnosis. These errors in thinking are especially costly in the field of medical decision-making, as incorrect and irrational decisions cannot only lead to delays in finding the right diagnosis, but also to financial and judicial problems as well as to fatal outcomes for the patient. The current methods for overcoming cognitive dispositions to respond are limited in their success rate and too vaguely defined. Therefore, the leading trigger for this work was the aim to (theoretically) develop and argue for an improved method for decreasing the detrimental effects of cognitive errors in thinking.

The main argument is that enhancing executive functions with cognitive training leads to an improved ability to overcome cognitive biases and heuristics. This is assumed because the cognitive requirements that are employed when using bias-specific de-biasing techniques resemble the executive functions, i.e., attention, planning, or set-shifting, are similar to the cognitive functions that are active during the experience of cognitive dispositions to respond and the according de-biasing techniques. The overlap between these fields has led to the idea that training effects from enhancing the controllability of executive functions via a specific training program can be transferred to the field of overcoming biases. A specific training program is presented in the course of this thesis, but it is pointed out that this is not an exclusive solution; the most important aspect is that the problems with cognitive

training – e.g., adherence to the program and integration in the medical context – are successfully addressed and diminished as much as possible.

Finally, as this is a theoretical thesis that does not pose any hypotheses, there are a number of open questions remaining, which are addressed in the final chapter. It is especially important to invest further research in the investigation of the neural components of cognitive biases and heuristics; there is little to nothing known about the brain parts that are active during the experience or the process of overcoming cognitive dispositions to respond. It is supposed that these areas will overlap with the ones responsible for executive functions, and proving this assumption would support the approach of this thesis. In general, further research will be necessary to empirically investigate the claims posited in this thesis.

Abstract – German

Diese Masterarbeit ist am Schnittpunkt der Forschungsgebiete der Exekutivfunktionen und der kognitiven Verzerrungen angesiedelt und beschränkt sich auf das Gebiet der medizinischen Entscheidungsfindung.
Eine neue Verbindung zwischen den Bereichen der Exekutivfunktionen und der kognitiven Verzerrungen auf Grundlage gemeinsamer neuronaler und kognitionspsychologischer Komponenten wird vorgeschlagen. Das dieser Arbeit zugrunde liegende und richtungsweisende Konzept ist Rationalität und ein normativer Ansatz im Hinblick auf die Diagnoseerstellung wird angenommen. Die Einführung zu dieser Masterarbeit stellt daher eine Übersicht über die Entwicklung und das aktuelle Verständnis von Rationalität dar und konstituiert somit die Grundlage für die im Kernpunkt stehenden Argumentationen.

Exekutive Funktionen werden als Oberbegriff für verschiedene kognitive Fähigkeiten wie Planungsfertigkeit, Gedächtnis und Aufmerksamkeit verstanden. Verschiedene Definitionen dieses Konzeptes sowie deren Entwicklung, potentielle Messbarkeit und neuronale Korrelate werden diskutiert. Kognitiven Verzerrungen und Heuristiken werden als Abweichungen vom rationalen Denken und als Hauptursachen für suboptimale und nicht-rationale Entscheidungen im Diagnoseprozess definiert. Diese Fehler im Denken sind besonders nachteilig im Bereich der medizinischen Entscheidungsfindung, da irrationale Entscheidungen nicht nur zu zeitliche Verzögerungen bei Stellung der korrekten Diagnose sondern auch zu finanziellen und juristischen Probleme führen können. Fatalen Folgen für den Patienten sind mögliche Folgen. Die aktuellen Methoden zur Überwindung dieser kognitiven Dispositionen sind in ihrer Erfolgsrate begrenzt und vage definiert.

Basierend auf dieser Faktenlage ist der Anstoß für diese Masterarbeit das Ziel, ein verbessertes Verfahren zur Verringerung der nachteiligen Auswirkungen der kognitive Fehler im Denken in der Theorie vorzuschlagen. Das hierbei angeführte Hauptargument ist, dass die Verbesserung der Kontrollierbarkeit der Exekutivfunktionen durch kognitives Training erhöhte Fähigkeiten in der Verminderung der kognitiven Verzerrungen und Heuristiken nach sich zieht. Dieser Ansatz basiert auf der Grundannahme, dass die kognitiven Fähigkeiten, die bei der Verwendung von verzerrungsspezifischen Vermeidungstechniken aktiviert werden, den Exekutivfunktionen ähneln. Das bedeutet, dass Exekutivfunktionen wie

Aufmerksamkeit und Planung neuronale und kognitionspsychologische Gemeinsamkeiten mit den kognitiven Fähigkeiten zur Vermeidung von kognitiven Irrationalitäten aufweisen. Diese angenommene Überschneidung führt zu der Idee, dass Trainingseffekte zur verbesserten Kontrollierbarkeit von Exekutivfunktionen auf die Fähigkeit, kognitive Verzerrungen und Heuristiken zu überwinden, übertragen werden können.

Ein spezielles Trainingsprogramm für Exekutivfunktionen ist im Rahmen dieser Arbeit vorgestellt, jedoch wird darauf hingewiesen, dass dies nicht ein exklusiver Vorschlag ist.

Da diese Masterarbeit nicht durch empirische Forschung entwickelt wurde, gibt es eine Reihe von offenen Fragen. Diese werden im letzten Kapitel angesprochen. Es wird besonders auf die Wichtigkeit hingewiesen, weitere Forschung bezüglich der neuronalen Komponenten der bei kognitiven Verzerrungen und Heuristiken involvierten Gehirnareale zu betreiben. Das Wissen über die Bereiche des menschlichen Gehirns, die bei der Aktivierung der kognitiven Irrationalitäten sowie deren Überwindung beteiligt sind, ist unzureichend. In dieser Arbeit wird angenommen, dass diese Bereiche mit den für die Exekutivfunktionen zuständigen Gehirnarealen zumindest in Teilen übereinstimmen und weiterführende Forschung im Bereich der Neurowissenschaft ist daher unumgänglich.

Curriculum vitae **Theresa Schachner**

Education

since Oct 2012 **Master Studies in Cognitive Science** — **Vienna, Austria**

Joint Program by University of Vienna, Medical University of Vienna and the Austrian Research Institute for Artificial Intelligence, conducted in English language

Ljubljana, Slovenia

- ► Weighted grade point average: 1.08 (on a scale from 1: excellent – 5: failed)
- ► Academic performance ranking among top 1%
- ► Specialization in Rationality, Decision Making and Behavioral Economics
- ► Master Thesis on Cognitive Biases and Executive Functions of the brain in Medical Decision Making
- ► Erasmus Scholarship Awarded for a 10-month research exchange

Apr 2012 – June 2012 **Kensington and Chelsea College (KCC)** — **London, UK**

- ► Psychology, English for Speakers of Foreign Language (ESOL) Level 2

Oct 2009 – June 2012 **Bachelor Studies in Scandinavian Studies – University of Vienna** — **Vienna, Austria**

- ► Weighted grade point average: 1.89 (on a scale from 1: excellent – 5: failed)
- ► Academic performance ranking among top 5%
- ► Specialization in Old Norse and Cultural Studies of the Nordic Region
- ► Bachelor Theses in Cultural Studies and Literature Studies

Oct 2008 – Oct 2012 **Bachelor Studies in Equine Science** — **Vienna, Austria**

Joint program conducted by Veterinarian University of Vienna and University of Natural Resources and Life Sciences Vienna

- ► Weighted grade point average: 1.71 (on a scale from 1: excellent – 5: failed)
- ► Academic performance ranking among top 5%
- ► Specialization in Medicine and Economy
- ► Bachelor Thesis in Ethology

Sept 2000 – June 2008 **Gymnasium Sacré-Coeur** *(High School)* — **Vienna, Austria**

A levels (Austrian Matura) completed with distinction

Work experience

starting Oct 2014 **KPMG** — **Vienna, Austria**

Management Consulting

- ► Mutually agreed internship in the Management Consulting department

since Mar 2014 **Giordano-Bruno-Foundation Austria** — **Vienna, Austria**

Member of the Board

- ► Operative planning of internal and external projects in the Austrian subsidiary of the international think-tank

since Mar 2012 **LessWrong Vienna** *(International Association focused on Rationality)* — **Vienna, Austria**

Co-Founder

- ► Strategic and operational planning of internal and external projects such as national and international scientifically oriented meetings
- ► Scientific research in the fields of Rationality and Decision-Making

since Mar 2012 **Insight Institute Vienna** *(Start-Up Institute focused on Rationality)* — **Vienna, Austria**

Co-Founder

- ► Planning and execution of internal and external development
- ► Development and implementation of applications aiming at increasing human rationality
- ► Organization of a local conference focused on Rationality

Mar 2011– May 2011 **Tax Consultant Office Nagy** — **Vienna, Austria**

Data Bank Management
- ► Administration of publications
- ► Continuous supervision of internal data bank

Aug 2010 – Oct 2010 **Saenautasel Farming** **Saenautasel, Iceland**

Marketing Development
- ► Development of marketing strategies for the increasing flow of tourists in the eastern part of Iceland

July 2011 – Oct 2011 **National Breeding station for Icelandic horses in Austria** **Marchegg, Austria**

Sports Management
- ► Assistant to the CEO
- ► Developing national training plans for world championship-ranking sports horses

Sept 2009 **National Stud Farm Neustadt/Dosse** **Brandenburg, Germany**

Strategic Supervision
- ► Weekly coordination of training plans for world championship-ranking sports horses
- ► Responsible for supervision of the show jumping section in the main stud farm

since Mar 2009 **Austrian Society for Transactional Analysis – ÖGTA** **Vienna, Austria**
- ► Assistant to the Members of the Board
- ► Organization and execution of national and international conferences

Academic work

June 2014 International Conference for Cognitive Science in Krakow, Poland:
- ► Research area: Cognitive Biases and Executive Functions of the brain in Medical Decision Making
- ► Accepted to present scientific research as a 20-minutes talk
- ► Publication in the Conference Proceedings

June 2013 International Conference for Cognitive Science in Budapest, Hungary:
- ► Research area: Cognitive Biases and Framing in Medical Decision Making
- ► Accepted to present scientific research at the poster session
- ► Publication in the Conference Proceedings

Leadership roles

since June 2014 **Member of the executive board – icons consulting by students**
- ► Responsible for the Viennese subsidiary of Austria's largest Junior Enterprise with 30 active members
- ► Establishment of cooperation with international consulting companies (e.g. BCG, Strategy&)
- ► External contact person for new projects and the establishment of collaborations
- ► Final responsibility for internal activities in the division of Human Resources, Sales, and the Board of Advisors

Oct 2011 – July 2012 **Student representative for Scandinavian Studies**
- ► Responsible for contact between students and teaching staff
- ► Representing the students of Scandinavian Studies in the official representation of university students (ÖH)
- ► Planning and execution of events of the Institute of Scandinavian studies

Language skills

German – native
English – business fluent (TOEFL iBt 112 points)
French – advanced
Icelandic – advanced
Norwegian – advanced

IT skills

MS Office (Word, Excel, PowerPoint), Python, SPSS, MatLab

Awards

2014
- ► e-fellows.net scholarship
- ► Full scholarship for excellent academic performance at the Philosophy department of University of Vienn
- ► careerloft.net scholarship

2013
- ► Scholarship for the European Forum Alpbach (consecutively awarded in 2014)

2007
- ► 1st in regional round of the Austrian Chemistry School Competition

2005
- ► 2nd in regional round of the Austrian Chemistry School Competition (consecutively awarded in 2006 and 2008)

Memberships

since 2014
- ► Uni Management Club Vienna

since 2013
- ► Academic Forum for Foreign Policy - AFA
- ► Austrian Start ups

Corporate Events

Participated in company workshops on a selective application basis
- ► McKinsey & Company (Alpbach) – Circular Economy workshop
- ► KPMG (Vienna) – Supply Chain optimization

Interests

- ► Horse riding: Show jumping and dressage – regional vice champion in dressage
- ► Piano – private education for 8 years
- ► Ice dancing – private education for 8 years
- ► Art history – special focus on Gothic style and iconography at University of Vienna

Theresa Schachner