WHERE EXPECTATION MEETS ATTENTION

THE DYNAMIC INTERPLAY BETWEEN OPTIMISM BIAS AND ATTENTION BIAS

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Urheberrechtlicher Hinweis

“We don’t see things the way they are.

We see them the way *we* are.”

Talmud

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Chapter 1

General Introduction

Introduction

op·ti·mism (/ˈɒptɪmɪz(ə)m/) *noun* **1.** Hopefulness and confidence about the future or the success of something (Oxford English Dictionary, 2018)

We have numerous symbolic expressions to describe the term *optimism* in the English language. May it be the “light at the end of the tunnel” that keeps us moving through the darkness, the “door that opens when another one closes” providing us an unexpected path to reach our goals, the “glass that is half full instead of half empty” reminding us to change perspectives from time to time, or the “rose-colored glasses” putting our world into a favorable light. Optimism comes in many different forms. We encounter the power of optimism in political success stories, such as the one of Barack Obama, who spread his optimistic “Yes, we can” attitude before winning the United States presidential election in 2008. We marvel at exceptional careers formed through optimism as shown by Joanne K. Rowling, who would have never become a best-selling novelist if she had not been optimistic enough to resend her famous Harry Potter manuscript to another publisher after it had already been rejected twelve times. We all enjoy the optimistic spirit conveyed by certain music (such as Monty Python’s “Always look on the bright side of life”) and we tell our children stories about the colorful world one can discover with an optimistic outlook (e.g., the boundless world of Pippi Longstocking who may be the greatest optimist of our time). Optimism is all around us and it plays an essential role in many aspects of our everyday life.

And then there is reality, which is not always so bright and rose-colored. We listen to the news telling us about another terror attack in the Middle East; we see pictures of people crossing the sea in nutshells that do not deserve the name boat to flee the war; we pass by an accident on the highway and glimpse at ambulances rushing to a hospital. How do we stay optimistic in such a world? How can we see the good things in our future while so many bad things surround us as well? How do we process the information around us to keep an optimistic outlook on our future? The present thesis will bring us one step further to answering these intriguing questions. Its purpose is to investigate how optimistic expectancies change the way we see our present environment (i.e., the reality around us) and how (selectively) attending to certain parts of our environment, in turn, changes what we expect from our future. These relations between future expectancies and the way we process the here and now are examined with the help of multiple experimental methods to uncover an in-depth view on specific mechanisms that may underlie the powerful and persistent phenomenon of optimism.

A brief overview on optimism bias and attention bias

The many different examples described so far show that optimism is often defined quite vaguely. Apart from positive expectancies about the future (the light at the end of the tunnel) such vague definitions may, for instance, also include the way people interpret situations in the present (the glass being half full). Furthermore, optimism is sometimes defined as a stable personality trait (e.g., she is an optimist, he is a pessimist) or as a more transient and situation-specific state of mind (e.g., I am optimistic that I will submit my thesis on time; Hecht, 2013). In the present work, optimism is defined narrower and only includes expectancies about specific positive future situations. This narrow definition allows to attribute any research findings to a precise and most common characteristic of optimism and reduces potential confounds that may result from a more multifaceted definition. Examples for such expectancies about specific positive future situations include expecting to gain money in the future or expecting to get a good job after graduation.

In the 1980s, seminal research by Neil Weinstein revealed for the first time that such positive future expectancies are often biased, meaning that most people are unrealistically optimistic about their future. Specifically, when asked to compare expectancies about their own future with expectancies about other people's future, most people indicate that they will experience more positive events and less negative events than others will. However, this belief cannot hold true for all people (everybody cannot have a better future than everybody else), thus revealing a systematic cognitive bias called unrealistic comparative optimism (Weinstein, 1980). After this seminal discovery, optimism bias has been extensively investigated. Such investigations revealed that the same systematic bias emerges when people´s future expectancies are compared with base-rates obtained from epidemiological data (i.e., unrealistic absolute optimism). For instance, people greatly underestimate their personal risk of getting a divorce even though popular statistics show that more or less every second marriage is divorced in the Western World – ironically enough this is even true for divorce lawyers (Sharot, 2011).

By now, different neurocognitive mechanisms that likely underlie and maintain such overly optimistic future expectancies have been investigated. For instance, a specific cognitive process has been suggested to contribute to the formation and maintenance of optimism bias: People selectively update (i.e., adapt) their future expectancies after receiving positive (desirable) feedback but not after receiving negative (undesirable) feedback (Sharot, Korn, & Dolan, 2011). This updating asymmetry can maintain optimism bias over time because negative information is not integrated into the formation of new future expectancies. Furthermore, investigations of the neural processes underlying optimism bias have revealed that the bias can be enhanced through neuromodulation (e.g., by administering L-Dopa which enhances the dopaminergic function in the brain; Sharot, Guitart-Masip, Korn, Chowdhury, & Dolan, 2012a). In addition, the updating asymmetry that strengthens optimism bias can be altered by disrupting the function of important brain areas involved in optimism bias (i.e., through neuro stimulation of the left inferior frontal gyrus; Sharot et al., 2012b).

Notably, optimism bias about the future is not only shown by people who would generally be described as optimists but more or less by everyone (i.e., optimism bias and the personality trait optimism describe conceptually distinct phenomena; Shepperd, Waters, Weinstein, & Klein, 2015). According to statistics, the bias is shown by about 80% of the population, making it a very general and pervasive cognitive phenomenon (Sharot, 2011). However, optimism bias is not shown by a specific group of people, namely people who suffer from depression. Instead of having overly optimistic expectancies about the future, patients with depression have realistic or even overly pessimistic expectancies about the future (Strunk, Lopez, & DeRubeis, 2006). Furthermore, instead of asymmetric expectancy updating and associated neural mechanisms maintaining optimism bias in healthy people, patients with depression show symmetric expectancy updating following both positive and negative feedback and altered underlying neural responses (Garrett et al., 2014; Korn, Sharot, Walter, Heekeren, & Dolan, 2014).

Similar to this optimism bias, another positive cognitive bias is seen in healthy people but not in patients with depression, namely positive attention bias (Joormann & Gotlib, 2007). Whereas healthy people preferably pay attention to positive (compared to neutral) information in their environment (Pool, Brosch, Delplanque, & Sander, 2016a), patients with depression preferably pay attention to negative (compared to neutral) information (e.g., sad faces; Gotlib, Krasnoperova, Yue, & Joormann, 2004). Thus, optimism bias and positive attention bias are both related to mental health, whereas pessimism bias and negative attention bias are both related to depression. To illustrate these similarities, the most important research findings on optimism and attention bias were embedded into a model of behavior that serves as a basis for the present thesis (see Figure 1.1).

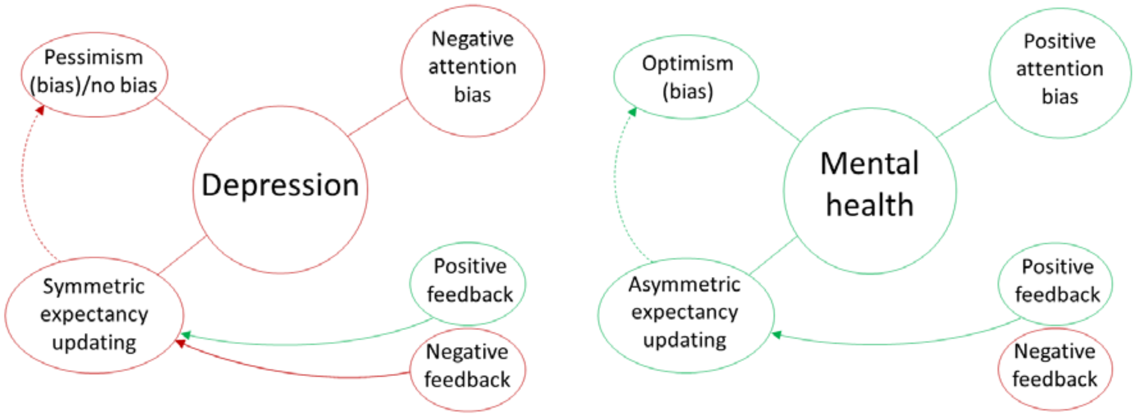

Figure 1.1. Cognitive biases in future expectancies and attention displayed by patients with depression (left) and healthy people (right). *Whereas patients with depression show no expectancy bias (or even a pessimism bias), healthy people show an optimism bias about their future. Similarly, patients with depression preferably attend to negative information in their environment, whereas healthy people preferably attend to positive information. Finally, patients with depression update their expectancies in both an optimistic and a pessimistic direction following positive and negative feedback, whereas healthy people update their expectancies selectively into an optimistic direction following positive feedback but not into a pessimistic direction following negative feedback. This asymmetric expectancy updating has been suggested to maintain optimism bias in healthy people, whereas symmetric expectancy updating may contribute to the absence of optimism bias in patients with depression.*

Starting points for an integrative perspective on optimism bias and attention bias

As described above, optimism bias and positive attention bias have very similar implications for mental health (Joormann & Gotlib, 2007; Sharot, 2011). In addition, the two biases are associated with activity in largely overlapping brain areas (e.g., the anterior cingulate cortex; Blair et al., 2013; Hickey, Chelazzi, & Theeuwes, 2010; Sharot, Riccardi, Raio, & Phelps, 2007), indicating that they may interact. Furthermore, recent theories (i.e., the combined cognitive biases hypothesis) suggest that cognitive biases usually interact and mutually enforce each other (Hirsch, Clark, & Mathews, 2006). Even though this combined cognitive biases hypothesis has largely stimulated research on negative cognitive bias interactions (e.g., in depression; Everaert, Koster, & Derakshan, 2012), positive cognitive biases have mostly been investigated separately. It is currently unclear how optimism bias and attention bias interact or mutually inforce each other and which neural mechanisms may support such links. To date, very little research has focused on the interaction between the two phenomena and the few studies that did examine such interactions have several shortcomings (Peters, Vieler, & Lautenbacher, 2015). For instance, prior empirical studies revealed that optimism is associated with an attention bias to positive and away from negative information (Isaacowitz, 2005; Luo & Isaacowitz, 2007; Segerstrom, 2001).

However, these studies investigated the personality trait optimism instead of optimism bias. Moreover, they only used correlational methods that cannot uncover causal relations between optimism and attention processes and they did not examine the neural mechanisms underlying optimism-attention interactions. Thus, the current state of research on optimism bias and positive attention bias has significant gaps and raises specific important questions:

1. How do optimism bias and positive attention bias resemble each other with respect to motivating factors, underlying brain mechanisms, and beneficial consequences?
2. How do optimistic expectancies causally influence attention deployment?
3. Which neural mechanisms support such causal influences of optimistic expectancies on attention?
4. How does selective attention causally influence optimism bias?

These intriguing questions will be answered in the present thesis (chapters 2-5). Thereby, the present thesis will for the first time reveal how different positivity biases interact and how such mutually enforcing biases shape healthy information processing. For instance, interacting positive cognitive biases may prevent the development of mental disorders and can reveal specific cognitive mechanisms that should be targeted by future interventions aimed to protect mental health.

Outline of the present thesis

Based on the above described starting points, the present thesis will examine the neurocognitive mechanisms underlying causal relations between optimism bias and attention bias. Chapter 2 provides an overview on prior literature that examined the two biases separately to uncover similarities in motivating factors, underlying neural processes, and beneficial consequences of optimism bias and attention bias. Furthermore, an integrative perspective combining these two separate lines of research is developed by emphasizing possible optimism-attention interactions and neurocognitive communication paths. This theoretical framework serves as a basis for the empirical studies on causal links between optimism and attention reported in chapters 3-5 and provides specific hypotheses that will be investigated in the current thesis.

In chapter 3, causal influences of optimistic and pessimistic expectancies on attention deployment are examined. Therefore, optimistic and pessimistic expectancies about future gains and losses were experimentally induced and their causal influence on subsequent attention to stimuli signaling reward (i.e., gains) and punishment (i.e., losses) was tested with reaction time measures and eye tracking (to examine both initial orientation of attention and maintenance of attention). In addition, the neural mechanisms underlying such causal influence of optimistic expectancies on attention deployment are investigated in chapter 4. Therefore, participants performed the same attention task in a magnetic resonance imaging (MRI) scanner. Here, the influence of optimistic and pessimistic expectancies on attention deployment and activity in large-scale neural networks such as the salience network and the executive control network was examined.

Furthermore, chapter 5 focuses on the opposite direction of influence, namely causal influences of attention processes on optimism. Participants either performed a two-week attention training during which they actively directed attention to positive social information or a neutral control training. To reveal specific causal effects of the positive attention training on optimism, participants completed questionnaires on optimism bias and state optimism before they started the training, after one week of training, and after two weeks of training.

Together, these empirical investigations can shed light on how optimism and attention bias interact and which neural mechanisms support such dynamic optimism-attention interactions. This in-depth view on specific mechanisms underlying the powerful and persistent phenomenon of optimism can ameliorate our understanding of healthy information processing and reveal crucial implications for the prevention of mental health and the treatment of psychopathology.

Chapter 2

The Link Between Optimism Bias and Attention Bias: A Neurocognitive Perspective

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Abstract

Both optimism bias and reward-related attention bias have crucial implications for well-being and mental health. Yet, the extent to which the two biases interact remains unclear because, to date, they have mostly been discussed in isolation. Examining interactions between the two biases can lead to new directions in neurocognitive research by revealing their underlying cognitive and neurophysiological mechanisms. In the present article, we suggest that optimism bias and reward-related attention bias mutually enforce each other and recruit a common underlying neural network. Key components of this network include specific activations in the anterior and posterior cingulate cortex with connections to the amygdala. We further postulate that biased memory processes influence the interplay of optimism and reward-related attention bias. Studying such causal relations between cognitive biases reveals important information not only about normal functioning and adaptive neural pathways in maintaining mental health, but also about the development and maintenance of psychological diseases, thereby contributing to the effectiveness of treatment.

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1 Introduction

Being able to adequately predict future events is crucial in everyday life, especially when planning behavior and making decisions (Damasio, 1994). Humans, however, tend to overestimate the likelihood of future positive events and underestimate the likelihood of future negative events (Sharot et al., 2011; Weinstein, 1980). This phenomenon, named optimism bias, describes a positivity bias in expectancies about the future and has cognitive (forming beliefs about the future, imagining and judging future events, estimating probabilities), motivational (maintaining favorable self-perception, denying threat), and affective origins (mood, hope; Armor & Taylor, 1998). Moreover, it entails a behavioral component (initiating goal-directed behavior, persistent pursuit of goals).

Optimism bias has been studied extensively in recent years because of its implications in everyday life (e.g., goal persistence, positive affect; Armor & Taylor, 1998; Shepperd et al., 2015) and in the clinical domain (e.g., better physical health, lowered depression rates; Garrett et al., 2014; Hevey, McGee, & Horgan, 2014; Korn et al., 2014). Despite the theoretical and practical significance of optimism bias, its underlying neural and physiological functioning have not yet been completely identified, and its interplay with other cognitive biases, for instance, in attention or memory, remains to be determined.

Of note, taking other cognitive biases into account instead of studying optimism bias in isolation can fill several important gaps in the literature. Such an approach could (a) shed further light on the cognitive mechanisms underlying optimism bias, (b) allow investigation of why optimism bias exists and how it is maintained over time, and (c) help with the understanding of the extent to which the highly beneficial role of optimism bias is rooted in other cognitive biases. Moreover, studying optimism bias (known to play a role in mental health; Garrett et al., 2014; Korn et al., 2014) in relation to other cognitive biases could (d) uncover divergences and commonalities in health and psychopathology (first by comparing interplay among reward-related biases between the two populations; subsequently by also comparing reward-related and negative biases) and contribute to a better understanding of psychopathologies by (e) including potential mediating and moderating factors in models of psychiatric diseases, thereby fostering the understanding of complex disease-specific chains of causality, and (f) revealing how interacting cognitive biases constitute risk factors for psychopathologies and identifying the mechanisms impeding their treatment (Kraemer, Stice, Kazdin, Offord, & Kupfer, 2001). Furthermore, taking into account how different cognitive biases that are relevant in psychological disorders interact can (g) enhance prevention of psychopathology, (h) improve the effectiveness of state-of-the-art treatment (Aue & Okon-Singer, 2015; Everaert et al., 2012; Hirsch et al., 2006), and (i) lead to more fine-grained diagnosis of patients. In summary, studying optimism bias in relation to other cognitive biases could not only broaden our knowledge about the bias itself (a-c) but could also advance theoretical models in psychopathology (d-f) and provide help for clinical practice (h-i).

In order to take a first step toward filling these gaps in the literature, the present article aims to (a) set up a framework of neurocognitive processes that might influence or be influenced by biased optimistic expectancies and (b) stimulate future research in the field by outlining specific hypotheses within the framework that are yet to be examined. We concentrate on attentional processes with a specific focus on *reward-related* processes (for the sake of brevity, we use the term "attention bias" instead of "reward-related attention bias" in the remainder of this article). Several ways in which optimism bias and attention bias may interact and the extent to which they rely on shared neural mechanisms are outlined.

We specifically focus on the interplay between optimism bias and (reward-related) attention bias for several reasons: First, it is likely that optimism and attention biases interact to reach a common goal: A motivation to reach a rewarding goal has been suggested to underlie both biases and is associated with shared neural activations (optimism bias: Bateson, 2016; Buehler, Griffin, & MacDonald, 1997; Richter et al., 2012; attention bias: Mohanty, Gitelmann, Small, Mesulam, 2008; Pessoa & Engelmann, 2010; Small et al., 2005). Here, motivation represents the driving force for behavior that is directed to a specific goal (i.e., a desired outcome), whereas reward functions as an incentive that makes this goal desirable. Second, in the empirical literature and theories on psychopathology (Aue & Okon-Singer, 2015), attentional processes have been repeatedly suggested to influence (optimistic) expectancies, which further underscores our claim that both biases should be examined by using an integrative approach. For instance, certain brain activations have been proposed to contribute to optimism bias by biasing attention to positive stimuli (Aue, Nussbaum, Cacioppo, 2012; Sharot, 2011; Sharot et al., 2007). Third, the first evidence that processes present in optimism bias and attention bias are indeed causally associated has been provided (Kress, Bristle, & Aue, 2018; Peters et al., 2015). Specifically, induced state optimism has been causally related to biased attention away from negative stimuli (Peters et al., 2015), and induced optimistic expectancies have been shown to guide attention toward rewarding and away from punishing stimuli (Kress et al., 2018).

Although the main aim of the current paper is to stimulate research on the interplay of optimism and attention bias, we also discuss the potential role of biased memories in influencing the link between optimism and attention bias. Notably, because attention and memory are highly interactive processes (Chun & Turk-Browne, 2007) and biased memories have been associated with optimistic expectancies (Roy, Christenfeld, & McKenzie, 2005), consideration of memory bias provides additional important information about critical cognitive bias interplay. Therefore, we want not only to emphasize the role of other cognitive biases that may influence the link between optimism and attention bias, but also to motivate researchers to take additional biases into account in future investigations and theoretical models.

It is further important to note that our ideas build on past work from our laboratory on expectancy biases in fear and anxiety and their link to attention biases (Aue & Okon-Singer, 2015). Although the previous and current articles focus on biased expectancies as related to attention processes, the current article adds several new and important aspects: *a.* Optimism bias represents a specific form of future expectancies that stands out from other forms in terms of robustness (as shown by selective updating of pessimistic but not optimistic expectancies when people are confronted with disconfirming feedback; see Sharot et al., 2011, 2012b). *b.* Because optimism bias is suggested to play an important role in the maintenance of depression (Garret et al., 2014; Korn et al., 2014), in regard to implications for the clinical context, we concentrate on implications for depression in the current article, in contrast to anxiety in the previous article. *c.* The current article focuses on reward-related biases in information processing that likely derive from a motivation that is different from negativity biases, which are most often centered around various forms of punishment (including frustrating non-reward), the latter being the focus of the previous article. *d.* The current article proposes possible mechanisms of neural communication that link optimism bias and attention bias and therefore could advance future research paths not only in cognitive research but also in neuroscientific research.

After outlining the rationale for the current framework and its specific focus on optimism and attention bias, we next briefly introduce the two phenomena of interest. We emphasize their relevance and underlying neural networks, which constitute the basis on which we have built our framework. Of note, we keep these sections short, as both optimism bias and attention bias have been reviewed earlier (optimism bias: Sharot, 2011; reward-related attention bias: Pool et al., 2016a). In the present article, therefore, our primary focus is on the relation of the two cognitive biases and the neural foundations of the proposed relation. To further refine our model and inspire future research and theorizing in the area, we additionally propose that memory processes influence the interplay of the two biases of main interest.

2 Optimism bias

When trying to define optimism bias, one encounters a major problem: On the one hand, different terms (e.g., wishful thinking, unrealistic optimism, comparative optimism, and overoptimism) have been used to refer to the same psychological phenomenon (or at least highly similar phenomena), while on the other hand, the same terms have been used for slightly different phenomena in past research. Despite being aware that there are fine-grained differences between the different concepts, we pool them together by using the broad term optimism bias (as currently there is not enough literature on any of the subconcepts of optimism bias to focus our framework on just one of them). Representing the main character of all concepts mentioned, optimism bias is thus defined as an overestimation of positive future events and an underestimation of negative future events (this definition is used by all studies on optimism bias cited in this article). Moreover, in the present article, optimism bias is exclusively defined as a bias in expectancies directed toward the future (not the present or past), a definition that has been widely accepted in the literature (e.g., Armor & Taylor, 1998; Campbell, Greenauer, Macaluso, & End, 2007; Chambers, Windschitl, & Suls, 2003; Jefferson, Bortolotti, & Kuzmanovic, 2016; Sharot, 2011; Shepperd et al., 2013; Weinstein, 1980; for a more detailed discussion on the definition of optimism bias, see Bortolotti & Antrobus, 2015).

Moreover, it is important to note that optimism bias is closely linked to anticipation of reward (Sharot, 2011). In fact, in humans, optimistic expectancies are usually directed toward a rewarding goal (Bateson, 2016), and anticipating reward is the crucial motivating force in optimism bias shown by non-human animals (e.g., Matheson, Asher, & Bateson, 2008). One major component of reward is “wanting.” It describes individuals being motivated to strive for reward through both unconscious incentive salience processes and conscious desires for incentives or cognitive goals (Berridge & Kringelbach, 2008; Pool, Sennwald, Delaplanque, & Sander, 2016b). Because it represents the phase of reward expectation, wanting is an important factor in shaping optimism bias. In contrast to wanting (i.e., reward expectation), “liking” (i.e., reward consummation) represents the pleasure component of reward, and “learning” (i.e., reward satiety) refers to associations and representations about rewards (Berridge & Kringelbach, 2011). Both liking and learning might additionally contribute to optimism bias by determining the hedonic value of the expected reward and influencing subsequent predictions about future rewards. The three phases of Berridge and Kringelbach’s model can, therefore, be essential to the formation of optimism bias and its maintenance over time.

2.1 Relevance of optimism bias

In everyday life, optimism bias ensures that people engage in a task, a crucial and beneficial aspect when a task is difficult and its outcome self-relevant (Armor & Taylor, 1998; Shepperd et al., 2015). Hence, being optimistic about one´s future can help in obtaining rewards, which in turn justifies that optimism bias exists. In fact, optimism bias might even have derived from evolutionary advantages. More precisely, when a situation is uncertain and risky, optimism has been suggested to help people make better decisions and avoid mistakes, thereby contributing to survival (Bortolotti & Antrobus, 2015). In line with this idea, overly optimistic expectancies are not human specific, but have been reported in animals as well (Brydges, Leach, Nicol, Wright, & Bateson, 2011; Douglas, Bateson, Walsh, Bédué, & Edwards, 2012; Harding, Paul, & Mendl, 2004; Matheson et al., 2008; Richter et al., 2012).

In humans, optimism bias functions on a continuum, with normal stamping having great benefits and extreme stamping having dramatic negative consequences. For instance, optimism bias is thought to foster physical and mental health (Garrett et al., 2014; Hevey et al., 2014; Korn et al., 2014). Whereas healthy people display optimism bias and update their expectancies of future events selectively into an optimistic (i.e., desirable) direction when feedback suggests modifying them, patients with depression display no bias at all, or even pessimism bias, and update their expectancies in both the optimistic (i.e., desirable) and the pessimistic (i.e., undesirable) direction (note that causality of the association between depression and lowered optimism bias remains to be investigated; Garrett et al., 2014; Korn et al., 2014; Strunk et al., 2006). However, extreme optimism bias can also have dramatic negative consequences and costs emerging from it. Individuals characterized by optimism bias underestimate health risks (Weinstein, Marcus, & Moser, 2005; Weinstein, Slovic, & Gibson, 2004) and refrain from showing preventive health behavior (Davidson & Prkachin, 1997; Pligt, 1998), engage in risky activities because they are overly optimistic about future payoffs (e.g., Calderon, 1993; Linnet et al., 2012), and possibly consume substances because they overestimate the positive effects of a drug and underestimate its negative effects (e.g., Dillard, Midboe, & Klein, 2009; Fromme & D'Amico, 2000; Goldberg & Fischhoff, 2000). In conclusion, therefore, a systematic investigation of normal and pathological types of optimism bias is of great interest for individuals and society. Important insights can be gained by looking into the neurocognitive mechanisms underlying optimism bias.

2.2 Neural correlates of optimism bias

Recent functional magnetic resonance imaging (fMRI) studies investigated the neural mechanisms of optimism bias and found altered activity in the following key areas: (a) the rostral anterior cingulate cortex (rACC), possibly extending into the ventromedial prefrontal cortex (vmPFC); (b) the amygdala; and (c) the inferior frontal gyrus (IFG) (Blair et al., 2013; Sharot et al., 2007; see Figure 2.1 for visualization of peak voxel activations reported by studies referred to in this section and see Table 2.1 for included studies; note that these structures are not specific to optimism bias, but are relevant to many psychological characteristics such as emotion processing in general; Phan, Wager, Taylor, & Liberzon, 2002; Sabatinelli et al., 2011). Whereas increased activity in the rACC has been related to optimism bias for positive events (increased probability of positive events occurring to oneself compared with others), decreased activity in the dorsomedial prefrontal cortex and the insula has been associated with optimism bias for negative events (decreased probability of negative events occurring to oneself compared with others; Blair et al., 2013).

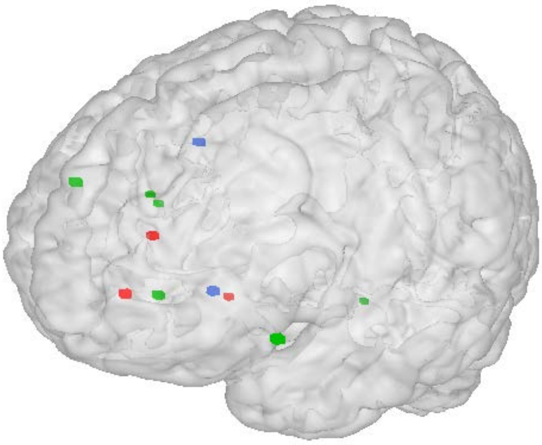
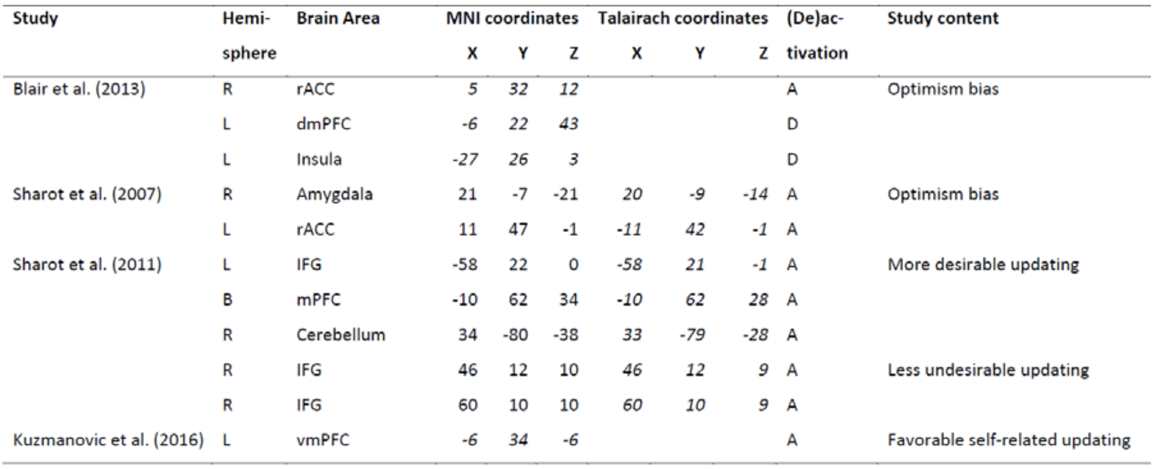


Figure 2.1. Peak voxel activations reported in studies on optimism bias. *See Table 2.1 for a list of included studies. Red dots represent stronger activations in optimism bias, blue dots represent stronger deactivations in optimism bias, and green dots represent stronger activations in biased optimistic updating. Only data reported by studies on healthy participants are displayed in the figure. Peak voxel coordinates are depicted as dots (size: 3 mm) on a Montreal Neurological Institute (MNI) brain, as provided in the Mango 4.0 Desktop Application for Windows (Research Imaging Institute, The University of Texas Health Science Center at San Antonio; http://ric.uthscsa.edu/mango/). If peak activations were originally reported in Talairach coordinates, either they were converted to MNI coordinates by using the Yale BioImage Suite Application (http://sprout022.sprout.yale.edu/mni2tal/mni2tal.html), or original MNI coordinates were requested from the study authors.*

Table 2.1. List of studies on optimism bias included in Figure 2.1. *The table shows the respective brain areas found and the coordinates of peak voxel activation in MNI and Talairach space. Coordinates that were originally reported in the studies are written in italics.*



Study	Hemi-sphere	Brain Area	MNI coordinates X	Y	Z	Talairach coordinates X	Y	Z	(De)ac-tivation	Study content
Blair et al. (2013)	R	rACC	*5*	*32*	*12*				A	Optimism bias
	L	dmPFC	*-6*	*22*	*43*				D	
	L	Insula	*-27*	*26*	*3*				D	
Sharot et al. (2007)	R	Amygdala	21	-7	-21	*20*	*-9*	*-14*	A	Optimism bias
	L	rACC	11	47	-1	*-11*	*42*	*-1*	A	
Sharot et al. (2011)	L	IFG	-58	22	0	*-58*	*21*	*-1*	A	More desirable updating
	B	mPFC	-10	62	34	*-10*	*62*	*28*	A	
	R	Cerebellum	34	-80	-38	*33*	*-79*	*-28*	A	
	R	IFG	46	12	10	*46*	*12*	*9*	A	Less undesirable updating
	R	IFG	60	10	10	*60*	*10*	*9*	A	
Kuzmanovic et al. (2016)	L	vmPFC	*-6*	*34*	*-6*				A	Favorable self-related updating

Along these lines, activity in the rACC and the amygdala has been shown to be highly correlated when participants are forming positive (compared with negative) expectancies about the future (Sharot et al., 2007). The amygdala is central for emotional processing (Ochsner, Silvers, & Buhle, 2012; Phelps, 2006) and assumed to index personal salience (Cunningham & Brosch, 2012; Liberzon, Phan, Decker, Taylor, 2003). Among other things, the amygdala is critically involved in many different aspects of emotions (e.g., development of fear, emotional appraisal and recognition, perception and memory of affective stimuli, reward learning and appetitive behavior; LeDoux, 2003; Wassum & Izquierdo, 2015) and may also be involved in forming emotional expectancies. Sharot and colleagues (2007) suggest that the rACC regulates emotional and motivational signals generated by (and stored in) the amygdala.

Although the rACC and the amygdala are considered fundamental, optimism bias may rely on characteristic activations and deactivations in additional areas. As described in section 2.1, healthy people show an updating asymmetry in an optimistic direction (only updating future expectancies in a desirable but not an undesirable direction when presented with disconfirming evidence; Sharot et al., 2011). Brain activity in the left IFG, left and right medial frontal cortex, right cerebellum, and vmPFC was positively correlated with desirable updating of expectancies (Kuzmanovic, Jefferson, & Vogeley, 2016; Sharot et al., 2011). Additionally, activity in the vmPFC and right IFG correlated negatively with undesirable updating of expectancies, thus further supporting the idea that undesirable information is not integrated when the right IFG is activated (Kuzmanovic et al., 2016; Sharot et al., 2011). In addition, optimism bias can be magnified by administering L-DOPA, thereby increasing dopamine function and impairing updating of undesirable information (Sharot et al., 2012a). Consistent with this picture, the right IFG, an area known to have projections from dopaminergic neurons (Fallon & Moore, 1978), has been shown to be involved when patients with depression update their beliefs toward an undesirable direction (Garret et al., 2014).

3 Reward-related attention bias

A reward-related bias is observed not only in expectancies (as described in section 2 on optimism bias), but also in attention. In line with the outlined relation between optimism bias and reward, recent studies imply that reward-associated (i.e., desirable) stimuli capture visual attention to a greater extent than neutral and sometimes negative stimuli do. This phenomenon has been shown by altered reaction times and biased eye movements when reward-related stimuli capture visual attention during a task (Anderson & Yantis, 2012; Theeuwes & Belopolsky, 2012). Attention capture is most often considered to be an automatic phenomenon, independent of strategic top-down control (Theeuwes & Belopolsky, 2012): Even when participants have a strong top-down goal to look for a specific target, a currently task-irrelevant but salient distractor can capture attention (Balcetis, Dunning, & Granot, 2012; Godijn & Theeuwes, 2002; Miendlarzewska, Bavalier, & Schwartz, 2016).

3.1 Relevance of reward-related attention bias

An attention bias to reward-related information enables people to efficiently detect events in an environment in which several stimuli compete for access to limited attentional resources (Pool et al., 2016a). Rewarding stimuli are suggested to have a positive hedonic value and therefore elicit wanting and approach behavior (Berridge & Kringelbach, 2008; Schultz, 2004). If people preferably attend to rewarding stimuli in their environment in everyday life, they are more likely to perceive chances to maximize future gains, which in turn contributes to survival fitness (Schultz, 2004). Having said this, it is correct to assume that attention bias to rewarding stimuli might have derived from an evolutionary benefit. In support of this idea, such biased attention does not seem to be human specific but is also displayed by animals (Paul, Harding, & Mendl, 2005; similar to optimism bias; see section 2.1).

In humans, biased attention toward reward-related stimuli plays an important role in the clinical domain. Mirroring research on optimism bias, attention bias toward rewarding stimuli is not shown by depressed or by dysphoric people, nor is it shown by formerly depressed people, in comparison to healthy controls (Duque & Vázquez, 2015; Gotlib et al., 2004; Joorman & Gotlib, 2007; Koster, de Raedt, Goeleven, Franck, & Crombez, 2005; Murphey et al., 1999). On the other hand, some clinical symptoms are characterized by the existence of positive biases, and these biases do not need to be restricted to the specific diagnosis. For example, patients with addictions are characterized by an attention bias not only for substance-related reward stimuli, but also for non-substance-related reward stimuli (Anderson, Faulkner, Rilee, Yantis, & Marvel, 2013). Moreover, neural indices of biased attention toward (socially rewarding) happy face pictures have been associated with a risk for psychiatric and behavioral symptoms such as rule breaking and social problems in anxious youth (Bunford et al., 2016). It is thus important to examine the neural underpinnings of normal and dysfunctional attention bias to better understand their respective underlying mechanisms.

3.2 Neural correlates of reward-related attention bias

Recent fMRI studies on the neural mechanisms underlying attention bias to reward-related stimuli have found altered activity in the following key areas: (a) the ACC, (b) the posterior cingulate cortex (PCC), (c) the posterior parietal cortex (PPC), (d) the amygdala, and (e) the orbitofrontal cortex (OFC) (Armony & Dolan, 2002; Hickey et al., 2010; Mohanty et al., 2008; Pool et al., 2016a; Small et al., 2005; see Figure 2.2 for visualization of peak voxel activations reported by studies referred to in this section and see Table 2.2 for a list of included studies).

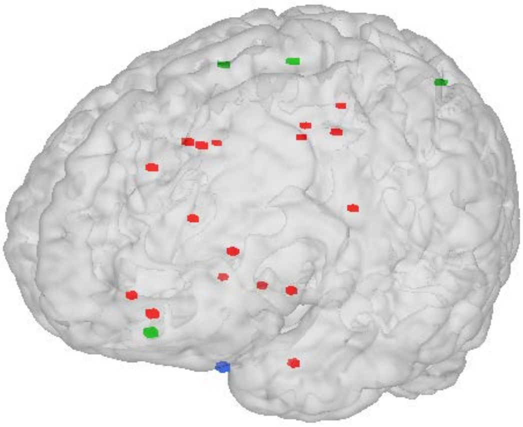


Figure 2.2. Peak voxel activations reported in studies on attention bias. *See Table 2.2 for a list of included studies. Red dots represent stronger activations in expectancy-related attention capture, blue dots represent stronger deactivations in expectancy-related attention capture, and green dots represent stronger activations in threat-related attention bias. Only data reported by studies on visual attention are displayed in the figure. Peak voxel coordinates are depicted as dots (size: 3 mm) on an MNI brain, as provided in the Mango 4.0 Desktop Application for Windows (Research Imaging Institute, The University of Texas Health Science Center at San Antonio; http://ric.uthscsa.edu/mango/). Peak activations that were originally reported in Talairach coordinates have been converted to MNI coordinates by using the Yale BioImage Suite Application (http://sprout022.sprout.yale.edu/mni2tal/mni2tal.html).*

Table 2.2. List of studies on attention bias included in Figure 2.2. *The table shows the respective brain areas found and the coordinates of peak voxel activation in MNI and Talairach space. Coordinates that were originally reported in the studies are written in italics.*

Study	Hemi-sphere	Brain Area	MNI coordinates			Talairach coordinates			(De)ac-tivation	Study content
			X	Y	Z	X	Y	Z		
Armony & Dolan (2002)	L	ACC	-13	-7	67	*-12*	*-2*	*60*	A	Negative attention bias
	R	ACC	4	8	64	*4*	*12*	*58*	A	
	L	Parietal cortex	-33	-54	63	*-32*	*-50*	*58*	A	
	L	OFC	-33	50	-8	*-32*	*46*	*-6*	A	
Small et al. (2005)	R	Inferior parietal lobule	*63*	*-27*	*27*				A	Motivated attention disengagement
	R	PCC	*21*	*-39*	*36*				A	Motivated visual spatial expectancy
	R	ACC	*9*	*30*	*30*				A	
	L	Parahippocampal gyrus	*-24*	*-9*	*-33*				A	
	R	Parahippocampal gyrus	*33*	*-15*	*-21*				A	
	L	OFC	*-18*	*42*	*-9*				A	
Mohanty et al. (2008)	L	PCC	*-9*	*-42*	*15*				A	Expectancy-related attention
	R	PPC	*21*	*-57*	*48*				A	
	R	mOFC	*21*	*30*	*-18*				A	
	L	lOFC	*-45*	*33*	*-18*				D	
Engelmann et al. (2009)	R	PCC	6	-29	43	*6*	*-26*	*40*	A	Expectancy-related attention
	L	PCC	-9	-31	43	*-8*	*-28*	*40*	A	
	R	ACC	4	20	39	*4*	*21*	*36*	A	
	L	ACC	-3	19	39	*-2*	*20*	*36*	A	
	R	Caudate	14	11	10	*13*	*9*	*11*	A	
	L	Caudate	-8	8	4	*-8*	*5*	*7*	A	
	R	Substantia nigra	9	-17	-17	*8*	*-18*	*-10*	A	
	L	Substantia nigra	-9	-17	-13	*-8*	*-18*	*-7*	A	

As is the case for optimism bias, the ACC, an area strongly interconnected with dopaminergic structures (Marín, Smeets, & González, 1998), turns out to be a critical structure underlying reward-related visual attention. For instance, the ACC response to reward feedback predicted the magnitude of reward-related attention bias in a visual search paradigm (Hickey et al., 2010). Reward-related mesolimbic dopamine might bias attention toward reward-associated stimuli rather than less beneficial stimuli. This was the case even when people knew that attending to reward-associated features would be counterproductive and result in suboptimal outcomes (Hickey et al., 2010; the process could again be triggered by wanting and is possibly mediated by optimistic expectancies formed in the ACC; see section 4.4 for further details).

Attention can be influenced by object saliency in a “bottom-up” manner, meaning that salient stimuli attract people´s attention automatically as an output of the sensitized dopaminergic system (i.e., in particular concerning initial orienting of attention; Field & Cox, 2008; Franken, 2003). Thus, the primary structures associated with processing of salient stimuli are the amygdala and insula. Whereas the amygdala has been observed to play a key role in the detection and attribution of salience (Liberzon et al., 2003), the insula is suggested to act as a hub structure within a bigger salience network (e.g., comprising the ACC). The purpose is to detect salient events, activate other brain structures needed to access attention and memory resources, and generate appropriate behavioral responses to salient stimuli (Menon & Uddin, 2010).

Moreover, attention can be controlled in a “top-down” manner (e.g., by monetary incentives signaling reward; Small et al., 2005). In this context, two processes of top-down attentional control were examined in a target detection task: visual spatial expectancy (the degree to which a predictive spatial cue benefits performance) and disengagement (the degree to which a misleading spatial cue diminishes performance). Whereas visual spatial expectancy was associated with activity in limbic regions and the PCC, disengagement was associated with activity in the inferior parietal lobule. These processes of the attention network were enhanced through monetary incentives. Findings show that expecting incentives (i.e., optimistic expectancies) can boost neural processing within the attention network in a top-down manner, which can be important in fulfilling the current behavioral goal (Small et al., 2005; Hahn & Gronlund, 2007). In summary, reward-related information seems to be integrated with spatial attention in the parietal and cingulate cortices.

In line with this assumption, stronger functional coupling between the PPC and PCC was present in attention bias toward reward-related targets (i.e., food images when participants were hungry) in a covert spatial attention paradigm (Mohanty et al., 2008). In this study, activity in the OFC, the intraparietal sulcus, and the PCC was correlated with how fast attention shifted toward reward-related targets after participants had seen spatial cues indicating the location at which they should expect the target. Supporting this finding, Engelmann and colleagues (2009) reported that reward-related incentives modulated attention, which accompanied increased activation in fronto-parietal sites, including the ACC and PCC, as well as nodes of the reward system such as the caudate and substantia nigra.

In conclusion, the PPC and PCC integrate motivational information with visual attention, a process that is essential in everyday life (Mohanty et al., 2008). Moreover, several structures, such as the amygdala, the ACC, and the PCC, have been demonstrated to play a key role in both optimism and attention bias. Along these lines, the studies by Mohanty and colleagues (2008) and Small and colleagues (2005) provide good examples of expectancy-attention interactions (e.g., visual spatial expectancy determining the top-down control of attention) and therefore give a good starting point for our interactive cognitive bias framework. We now introduce the theoretical and empirical work that further corroborates our suggestion that reward-related biases in expectancies and attention should be examined by using an integrative approach.

4 Possible interactions between optimism bias and attention bias

After reviewing the literature on optimism and attention bias in isolation, we now begin with the core focus of our article, namely, the link between optimism bias and attention bias. In what follows, we show that ideas derived from theoretical considerations converge with existing empirical data on the interplay between optimism and attention processes. These converging ideas, in concert with widely overlapping neural activations at the basis of optimism and attention bias (see sections 2, 3, and 4.3), give strong hints that the two phenomena interact, which is the central statement of our framework. To reveal the motivation for our framework, we first draw on theoretical models in favor of a link between optimism and attention bias (section 4.1). Thereafter, by first describing empirical support for such an association (section 4.2) and shared neural networks (section 4.3), we thoroughly outline our framework, which is organized around three core principles: First, optimism bias and attention bias do not work in isolation, but enforce each other in both directions. Second, both optimism bias and attention bias rely on activations in overlapping brain areas (such as the ACC and PCC). Third, both phenomena are characterized by similar underlying motivational processes (i.e., striving for reward possibly initiated by limbic structures), a fact likely related to the observation of shared neural activations of the two biases. In conclusion, we propose three mechanisms of neural communication between optimism bias and attention bias by taking into account the overlapping neural substrates that have been reviewed (section 4.4).

4.1 Theoretical models on the link between cognitive biases

As currently little empirical work has been done on the relation between optimism bias and reward-related attention bias, we substantially base our framework on theoretical models that are in favor of links between biases displayed in different domains of information processing. First, we explain how established models of psychopathology (Beck, Rush, Sahw, & Emery, 1979; Joorman, Yoon, & Zetsche, 2007; J. Williams, Watts, MacLeod, & Mathews, 1997), including the combined cognitive biases hypothesis (Hirsch et al., 2006), propose the general need to study cognitive biases in an integrative way. These theoretical approaches, hence, are fully in line with the rationale for our own framework. Second, we elaborate how predictive coding theory (C. Summerfield et al., 2006; Zelano, Mohanty, & Gottfried, 2011) and our interpretation of Broadbent's filter model of attention (1958) can provide further support for a connection between the two specific phenomena of interest in the present framework, namely, biased (optimistic) expectancies and attention. Third, we demonstrate the numerous important implications that an integrative view on cognitive biases will have for future research and clinical practice.

Influential models of psychopathology, such as Beck's cognitive theory of depression (1979), suggest that negativity biases are crucial for the development and maintenance of psychological disorders. Beck's cognitive triad refers to negative views about the self, the world (including aspects of attention), and the future (including expectancies) shown by patients with depression. According to Beck, these negative cognitions contribute to various symptoms of depression, such as apathy, paralysis of the will, and suicidal wishes. More recent models of depression additionally introduce the interactive nature of these cognitive biases. For instance, an interplay of biased attention, memory, and interpretation has been proposed to act at the basis for depression (Joorman et al., 2007; J. Williams et al., 1997). Together, these models of psychopathology have led to the evolution of the combined cognitive biases hypothesis in clinical research. It holds that negative cognitive biases (e.g., in attention, interpretation, and self-imagery) rarely exist in isolation (Everaert et al., 2012; Hirsch et al., 2006), but rather interact and mutually enforce each other. Recently, this perspective has been extended to additionally include negative expectancy biases (Aue & Okon-Singer, 2015).

Even though these models of psychopathology (Beck et al., 1979; Joorman et al., 2007; J. Williams et al., 1997) are widely accepted and implemented in psychotherapy, research on the influence of cognitive biases on psychopathological symptoms has mainly examined the different biases separately, thereby neglecting important information about their interactive effects (Everaert et al., 2017). Going beyond such restricted considerations, the combined cognitive bias hypothesis constitutes an important starting point for future integrative investigations on cognitive biases. Among other things, it guides research in the field by proposing possible mechanisms in psychopathology, including specific directions of interaction between diverse biases.

Studying interactive and mutually enforcing cognitive biases in psychopathology can have pivotal implications for clinical research and practice. In clinical research, it can, for instance, reveal how specific interactions among cognitive biases contribute to complex chains of causality that lead to psychopathologies or create conditions that impede successful treatment (e.g., because one bias mediates or moderates the association between another bias and certain psychopathological symptoms). Moreover, in clinical practice, it can lead to more fine-grained diagnoses of patients (e.g., by taking into account how the strength and time course of interacting cognitive biases influence the severity of symptoms) and can improve the effectiveness of contemporary treatment options by simultaneously targeting multiple cognitive mechanisms involved in the development and maintenance of psychological diseases (e.g., during focused cognitive bias modification training; Aue & Okon-Singer, 2015; Everaert et al., 2012; Hirsch et al., 2006). In sum, leading models of psychopathology, in particular the combined cognitive biases hypothesis described above, present strong arguments for the interaction of negative biases displayed in psychological disorders (Everaert et al., 2012; Everaert, Duyck, & Koster, 2014; Everaert, Tierens, Uzieblo, & Koster, 2013; Hirsch et al., 2006).

With the current framework, we extend this compelling perspective by suggesting that the same holds true for positive reward-related biases. Attention bias, which makes people preferably attend to reward-related information, can well accompany optimism bias, which makes people overly optimistic about future rewards. More precisely, we postulate that optimism bias increases when people preferably attend to rewarding information in their environment and that reward-related attention bias increases when people have overly optimistic expectancies about their future (for a more detailed outline of these causal links, see section 4.4). Furthermore, application of the combined cognitive biases hypothesis to reward-related biases implies that additional cognitive biases (e.g., in memory) interact with the proposed link between optimism and attention bias (see section 5 for further details). Effects of reward-related biases are proposed to mutually reinforce each other, thereby establishing and conserving a positive outlook and mental health in the long run. Therefore, interactions of reward-related biases are especially interesting for life quality (e.g., how mutually enforcing biases maintain well-being during the ups and downs of everyday life) but also for the prevention of psychopathology (e.g., how psychoeducation about causal influences among reward-related biases can prevent negative mutual enforcement and increase positive mutual enforcement before a disease is developed).

Compared with the combined cognitive biases hypothesis and models of psychopathology proposing that different cognitive biases are generally linked, predictive coding theory specifically emphasizes the interplay of expectancy and attention processes. Furthermore, its postulates are not restricted to negative cognitions. Predictive coding theory states that when expecting certain outcomes (of any valence) in the future, humans use prior experience to create a mental template or “search image” and then compare incoming sensory information to this template (e.g., C. Summerfield et al., 2006; Zelano et al., 2011). This interplay helps to efficiently process a wealth of sensory information and facilitates the choice of subsequent behavior. It has been suggested that the predictive template created in the brain is updated according to incoming information, implying that the process constantly repeats over time (Rao & Ballard, 1999).

Whether predictive coding theory can transfer to optimism bias and attention bias has yet to be examined empirically and therefore constitutes an interesting aspect that has just recently started to be investigated. It is imaginable that individuals characterized by overly optimistic expectancies create a mental image that directs their attention to confirming reward-related sensory input. In fact, empirical evidence supports such a mechanism (Kress et al., 2018; see section 4.2 for details). Although such confirming sensory input stabilizes optimism bias over time, disconfirming sensory input that reaches attentional awareness can lead to an update of the mental template (Rao & Ballard, 1999), thereby counteracting optimism bias. Empirical evidence about such processes that are implied by predictive coding theory will guide neurocognitive research in the field of cognitive bias interactions because it directly proposes a direction of influence (influence of expectancies on attention). Studying such causal influences of optimistic expectancies on attention allows, for instance, the investigation of how optimism bias is maintained over time (e.g., because optimistic expectancies guide attention toward confirming rewarding evidence, which, in turn, further strengthens optimism bias; see Kress et al., 2018, for supportive empirical findings).

In contrast to predictive coding theory that implies expectancy influences on attention, Broadbent's filter model of attention (1958) claims that selective attention acts as a sensory filter that prevents the information processing system from being overloaded. Prioritized selective attention to rewarding (often self-relevant) information then leads to preferable processing of such desirable information (Pessoa, 2005; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). This again should strengthen optimism bias because future expectancies are generally based on available information (Metcalfe, 1998). Empirical evidence for such influences of attention on optimism bias have outstanding implications. For instance, such evidence can reveal that optimism bias and its benefits, such as the initiation of goal-directed behavior, are rooted in underlying attentional mechanisms and that these benefits therefore cannot necessarily be solely attributed to optimism bias itself.

Broadbent's filter model basically implies the opposite direction of influence (influence of attention on expectancies) to that of predictive coding theory (influence of expectancies on attention). Both theories reveal the importance of examining causal relationships (i.e., directions of influence) between different biases and therefore guide future research in the field away from correlational and toward experimental studies. Only these studies can reveal the mechanisms underlying healthy and pathological functioning, such as specific circumscribed expectancy-attention interactions contributing to well-being or symptoms of psychopathology.

In summary, the three theoretical approaches presented in this section provide strong supportive evidence for a link between optimism and attention bias. Whereas models of psychopathology, particularly the combined cognitive biases hypothesis, suggest that different cognitive biases are generally linked and should be examined by using an integrative approach, predictive coding theory is in line with the idea of causal influences of optimism bias on attention bias, and Broadbent's filter model implies causal influences of attention bias on optimism bias. From an integration of these approaches, we postulate bi-directional influences between both biases (see section 4.4). After having outlined these theoretical models in favor of our framework, we now continue by briefly reviewing the first empirical findings that further substantiate our claim of a close association between optimism and attention bias.

4.2 Empirical evidence of optimism-attention associations

The first core principle of our framework states that optimism bias and attention bias do not work in isolation but enforce each other in both directions. In support of this principle, first empirical findings by Peters and colleagues (2015) revealed an effect of experimentally induced state optimism (i.e., temporarily increased optimistic expectancies induced through external manipulation; Peters et al., 2015) on attention to faces displaying different emotional expressions. Even though, in general, their optimism manipulation did not influence gaze behavior, the authors observed an effect of state optimism in a post hoc analysis: Those participants who displayed increased state optimism because of the manipulation looked at angry (i.e., socially punishing) faces for a significantly shorter time. Moreover, they looked at joyful (i.e., socially rewarding) faces for a nearly significant longer time. To our knowledge, this is the first study that has examined how visual attention is causally influenced by induced state optimism that likely shares important features with optimism bias (although both phenomena are characterized by optimistic expectancies about the future, these expectancies are not necessarily unrealistic or biased in state optimism), thus supporting our claim regarding the existence of optimism-attention bias interactions.

In line with this study, the first evidence from our own laboratory suggests that induced optimistic and pessimistic expectancies alter attention to rewarding and punishing stimuli, with optimistic expectancies having a stronger effect on attention deployment than pessimistic expectancies (Peters et al., 2015, induced state optimism at the beginning of the experiment; in contrast, we induced optimistic and pessimistic expectancies by verbal cues on a trial-to-trial basis in our study; Kress et al., 2018). Although optimistic expectancies strongly biased attention toward rewarding compared with punishing stimuli in our experiment, pessimistic expectancies had either no effect or a weaker effect on attention deployment to punishing versus rewarding stimuli. An important consideration is that this observation is generally in accordance with our framework's postulate of causal relations between optimism and attention bias. Moreover, this finding in our laboratory delineates important differences between biased reward- and punishment-related processing (e.g., optimism vs. pessimism) and strongly supports the idea that optimism has an outstanding impact on other types of cognitive processing (i.e., optimism exerts stronger influences on cognitive biases than pessimism). Such differences between reward- and punishment-related processing imply that influences among cognitive biases can be valence specific. Further details about how such valence-specific biased cognitive processing contributes to health and psychopathology can have crucial implications for everyday life and clinical practice.

Generally in line with the idea of causal influences of optimistic expectancies on attention (Kress et al., 2018), expectancy cues have been shown to guide visual attention to reward-related stimuli and to modify attention via top-down control outside the area of optimism bias research. In a covered attention shift paradigm, participants reacted faster to spatially cued reward-related targets that were motivationally relevant compared with those that were motivationally irrelevant (i.e., food pictures when participants were hungry vs. full; Mohanty et al., 2008). Other studies showed that attention to socially rewarding stimuli (happy as opposed to angry faces) could be enhanced through top-down modulation (i.e., by specific instructions or cues; Hahn & Gronlund, 2007; M. Williams, Moss, Bradsahw, & Mattingley, 2005). These studies thus give further hints that influences of expectancies on attention deployment exist in the reward-related domain. Even if these findings do not directly refer to optimism bias, they are supportive of our claim of expectancy-attention interactions because they touch upon expectancies about future outcomes. Furthermore, they correspond well with Peters and colleagues´ (2015) results concerning the influence of state optimism on attention to happy and angry faces.

One can find further inspiration from the literature on expectancy-attention interactions in the negative domain (Aue, Hoeppli, Piguet, Sterpenich, & Vuilleumier, 2013b; Aue & Okon-Singer, 2015; Mohanty, Egner, Monti, & Mesulam, 2009). For negative affective phenomena, a strong correlation between attention deployment and expectancies has already been revealed (Aue et al., 2013b). Moreover, experimentally manipulated expectancies, induced by prior cues in a visual search task, causally influenced attention to neutral stimuli, but – interestingly – not consistently to negative stimuli (Aue et al., 2016, 2013a; Burra & Kerzel, 2013; Mohanty et al. 2009). Similarities and divergences between positive and negative cognitive bias interactions still need to be revealed, an aspect that should substantially advance theorizing and prevention in clinical psychology, as well as the adaptation of individual treatments.

In summary, behavioral studies reported in this section provide supportive evidence that optimism bias and attention bias are related and that optimism causally influences attention deployment (similar interactions have been proposed in animal research; Mendl, Burman, Parker, & Paul, 2009). Behavioral studies revealed an association between expectancies and attention not only by using negative affective (Aue et al., 2013b; Mohanty et al., 2009) and neutral stimuli (Aue, Chauvigné, Bristle, Okon-Singer, & Guex, 2016; Aue, Guex, Chauvigné, & Okon-Singer, 2013a;

Burra & Kerzel, 2013), but also by using appetitive and reward-related stimuli in experiments that did not directly address optimism bias (Hahn & Gronlund, 2007; Mohanty et al., 2008; M. Williams et al., 2005). Most important, state optimism and induced optimistic expectancies – two manipulations representing important aspects of optimism bias – have recently been shown to causally influence subsequent attention deployment (Kress et al., 2018; Peters et al., 2015). Such evidence, which is in line with the idea of a link between optimism and attention bias, has yet to be corroborated by additional empirical data in the behavioral domain. Also of note is that, although we were able to outline supportive empirical evidence for causal influences of optimistic expectancies on attention, no empirical evidence is yet available on causal influences of attention on optimism bias. Thus, future studies should straightforwardly and systematically target this direction of influence.

The continuous adaption and combination of currently dominant experimental paradigms in each area will enable researchers to uncover the central interplay between cognitive biases. Demonstrating causal associations between biases has crucial implications for future cognitive research about both optimism and attention bias. Such a research strategy has, for instance, the potential to reveal fundamental operating principles at the basis of both biases, thereby contributing to our understanding of positively biased cognitions and current theorizing. Moreover, it should reveal important commonalities and divergences in the cognitive mechanisms underlying health and psychopathology. An important aspect of cognitive functioning in health and disease is that much can be learned from knowledge about the neural foundations of associations between cognitive biases. In the next sections, we therefore integrate findings from neuroimaging studies on optimism bias and attention bias (section 4.3) and propose different ways in which the corresponding neural mechanisms interact (section 4.4).

4.3 Shared neural networks in optimism bias and attention bias

The second core principle of our framework affirms that both optimism bias and reward-related attention bias rely on activations in overlapping and interacting brain areas. Key areas identified in research on optimism bias (section 2.2) and attention bias (section 3.2) do indeed overlap considerably. In line with this principle, recent fMRI studies on optimism bias also propose shared mechanisms and conform to the idea that biases in expectancies are shaped by biases in attention or vice versa (Sharot, 2011; Sharot et al., 2007). For instance, the ACC has been implicated in optimism bias (Blair et al., 2013; Sharot et al., 2007, 2011) and was suggested to guide attention toward rewarding information while people imagine future events (see Hickey et al., 2010; for its implication in reward-related enhancement of selective attention). Moreover, activity in this region has been found to vary as a function of amygdala activity in optimism bias (Sharot et al., 2007), suggesting that the salience of an anticipated outcome shapes the extent of the optimism bias displayed (Bastardi, Uhlmann, & Ross, 2011; Weinstein, 1980). Further supporting the idea of a link between optimism and attention bias, object saliency and associated amygdala activity have also been related to attentional capture (Field & Cox, 2002; Franken, 2003).

Besides amygdala and ACC activity, connectivity between occipital areas associated with visual attention and the human reward system (striatum), as well as with the PCC, has been observed to be at the basis of optimism bias (Aue et al., 2012). Again, there are convincing commonalities with findings on attention bias. For example, the PCC has been reported to be critically involved in selective attention (Corbetta & Shulman, 2002). Such an observation is consistent with the idea that the more the PCC is recruited when a specific piece of information is encoded, the more this information's valence will influence the overall impression formed (Schiller, Freeman, Mitchell, Uleman, & Phelps, 2009). Indeed, the PCC has been proposed to be a hub structure connecting motivation-related processing with top-down control of attention (Mohanty et al., 2008; Small et al., 2005). Thus, we suggest that the striatum and the amygdala, in concert with the PCC, initiate shifts in visual attention that then contribute to how future expectancies are formed (see section 4.4, first mechanism, for details).

Notably, in accordance with the findings outlined earlier and with our claims, Rolls (2013) proposes that attention and expectancies recruit a common neural network: Mediated by the ACC and the OFC, both "cognition" (including expectancies; original term used by Rolls, 2013) and attention exert top-down influences on the processing of bottom-up sensory inputs. These top-down influences can facilitate activation of selective neuronal assemblies and inhibit other neuronal assemblies in the early information processing stream. Consequently, certain stimulus representations will be enhanced and others suppressed (Desimone & Duncan, 1995). In this way, subsequent processing will be biased. Along these lines, selective attention can be assumed to influence activity in early visual processing areas, possibly mediated by the functional connectivity between fronto-parietal brain regions associated with attentional control and the human reward system (e.g., dorsal striatum; Padmala & Pessoa, 2011; Pessoa & Engelmann, 2010). What remains to be investigated is whether or not this is part of the mechanism by which attentional processes bias expectancies or vice versa.

Direct evidence for the neural mechanisms that we propose to underlie generally beneficial optimism-attention interactions will not just support behavioral findings in the field: Apart from revealing patterns of healthy neural processing, such findings also have the potential to pinpoint vulnerability factors for psychopathology by specifying activations that are responsible for a disruption of the generally healthy neural patterns. Moreover, documentation of neural interactions during the normal interplay of optimism and attention bias will have important implications for pharmacological treatment of psychological disorders in which none of the biases are displayed. For instance, drugs that influence the dopamine system can be used to alter important processes in the brain, thereby enhancing reward-related biases and their interplay (in line with this idea, L-Dopa has already been shown to enhance optimism bias; Sharot et al., 2012a).

Before these ultimate goals are reached, however, causal influences between optimism and attention bias and their neural correlates have yet to be purposefully examined. Because direct neuroscientific evidence about the association between optimistic expectancies and attention in the reward-related domain is to date missing, research on optimism-attention bias interactions might be inspired by research in the negative bias domain. In the negative domain, the association between visual attention and expectancies has indeed been shown to be mediated by activity in key regions such as the OFC, the ACC, and the precuneus (Aue et al., 2013b). Moreover, in a visual search task, in which attention to angry facial expressions was influenced by prior knowledge about the location and type of the target stimulus, spatially informative cues (predicting the location of a subsequent target) activated the fusiform gyrus and parts of the frontoparietal spatial attention network (such as the intraparietal sulcus and the frontal eye field), and emotionally informative cues (predicting angry faces) additionally activated limbic areas, including the amygdala (Mohanty et al., 2009). Notably, the authors propose that expectancy-related emotional information is essential to generate a top-down salience map that guides visual attention. Together, these findings suggest that the spatial attention network, in concert with limbic areas, constitutes the neural substrates at the basis of expectancy-driven emotional spatial attention.

As outlined in greater detail in the next section (section 4.4, second mechanism), we suggest that optimism bias can modulate attention toward rewarding stimuli in a highly similar way. Positive rewarding and negative threatening stimuli have been shown to recruit partly overlapping neural networks (including the amygdala and the OFC; Li, Howard, Parrish, & Gottfried, 2008; Murray, 2007; Pool et al., 2016a). Consequently, expectancies about significant positive future events likely recruit at least partly intersecting brain mechanisms and likewise generate a salience map that guides attention toward rewarding stimuli.

In conclusion, the neuroscientific literature on optimism and attention bias provides supportive evidence that both biases are closely related. Brain areas underlying optimism bias and reward-related attention bias overlap considerably. An interplay between the amygdala and the human-reward system with cingulate areas such as the ACC and PCC is proposed in both optimism (Aue et al., 2012; Sharot et al., 2007) and attention bias (Field & Cox, 2002; Franken, 2003; Hickey et al., 2010) and these areas can therefore represent critical underlying structures for bi-directional interactions between both biases. Yet, concrete empirical evidence on the neural mechanisms of causal links between optimism and attention bias is still needed. Such evidence will greatly advance knowledge about the neurocognitive mechanisms underlying optimism bias and therefore allows further investigation into why the bias exists and how it is maintained. Moreover, it will advance theories on cognitive bias interactions, such as the combined cognitive biases hypothesis, and will generate new hypotheses about the specific causal relations between optimism and attention bias by revealing the involved brain areas and their functional and structural connectivity (see Aue, Lavelle, & Cacioppo, 2009). Finally, research in the area has the potential to contribute to the identification of significant neural vulnerability factors in psychopathology and to impact on current treatment strategies.

4.4 Possible mechanisms of neural communication linking optimism bias and attention bias

Given that the ideas derived from fundamentally different sources (theoretical models outlined in section 4.1, empirical studies outlined in section 4.2, and neuroscientific evidence outlined in section 4.3) converge, it is more than timely to address the potential interplay between optimism and reward-related attention bias. In what follows, therefore, we outline three mechanisms of possible interaction between these biases. All three mechanisms are based on the idea that anticipated reward (i.e., positive outcomes) functions as an incentive that drives motivation. This hypothesis corresponds to the third core principle of our framework, namely, that both optimism bias and attention bias are characterized by similar underlying motivational processes (i.e., striving for reward, as initiated by limbic structures; see Bateson, 2016; Small et al., 2005). Moreover, this similar underlying motivation is proposed to be reflected in the shared neural activations of the two biases. Through this motivation to strive for reward, specific expectancy and attention systems are (re)directed to maximize reward consumption (for an overview of brain areas involved, see Figure 2.3).

Of note, all three proposed mechanisms imply that a minimum of attention is always needed to identify stimuli: In order to ignore or attend to individual pieces of information, it is necessary to know in advance whether they contain positive or negative value. However, we propose that the depth of processing of any given piece of evidence can be substantially modified by varying the amount of attention it receives, which influences optimism bias, on the one hand, and is influenced by optimism bias on the other. For instance, attention processes that exert a causal influence on optimism bias can be imagined in various situations. To illustrate, in Las Vegas, winning money can be perceived as a rewarding positive outcome that (re)directs our ongoing attention toward other people who just won money through gambling, consequently making us more optimistic about being the next one to win. Such a view is consistent with the first mechanism within our framework. At this point, it is important to note that the first mechanism (causal influences of attention bias on optimism bias) and the second mechanism (causal influences of optimism bias on attention bias) are not necessarily mutually exclusive; rather, based on the findings displayed in sections 4.1 to 4.3, we suggest the existence of bi-directional influences between optimism (expectancies) and attention bias.

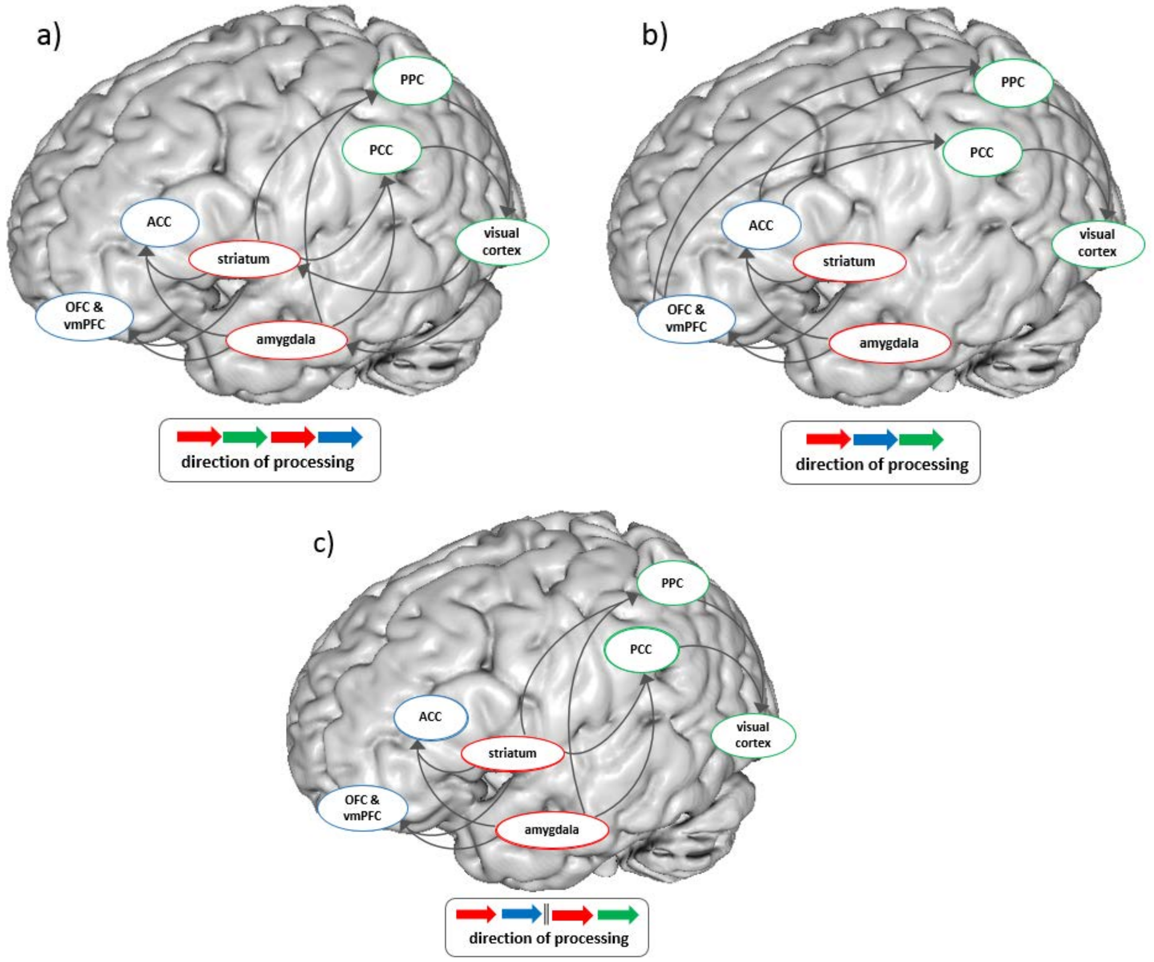


Figure 2.3. Brain regions that have been most consistently involved in the processing of optimistic expectancies and positive attention bias. *The proposed mechanisms of neural communication linking optimism bias and positive attention bias (see section 4.4) are illustrated in separate parts of the figure. Note that the depicted arrows show functional, not anatomical, connections. None of the mechanisms have been examined experimentally and are thus hypotheses of what underlying neural communication could look like. Different mechanisms and brain areas may be involved. The brain templates have been created with the sample MNI image, as provided in the Mango 4.0 Desktop Application for Windows (Research Imaging Institute, The University of Texas Health Science Center at San Antonio; http://ric.uthscsa.edu/mango/). Colored arrows display the suggested direction of processing. a) First mechanism: Causal influence of attention bias on optimism bias. Wanting (striatum, amygdala) is suggested to drive ongoing*

visual attention to rewarding stimuli. The critical structures to shift attention are the PPC and the PCC, and selective attention then affects how early visual input is processed (reflected in the primary visual cortex). By allocating selective attention, desirable evidence is processed preferably (striatum, amygdala), thus creating or strengthening optimism regarding goal achievement (ACC, OFC, and vmPFC). b) Second mechanism: Causal influence of optimism bias on attention bias. Wanting (striatum, amygdala) can directly shape optimism bias in order to further increase goal-directed appetitive motivation and task engagement; via top-down mechanisms (ACC, OFC, and vmPFC), optimism bias is then proposed to redirect currently ongoing visual attention (PCC, PPC, and visual cortex) toward supportive environmental evidence (while largely ignoring negative evidence) in order to facilitate pursuing the goal to obtain the reward. c) Third mechanism: No causal influence between optimism bias and attention bias. Wanting (striatum, amygdala) independently initiates supportive attentive (PPC, PCC, and visual cortex) and expectancy-related processes (ACC, OFC, and vmPFC) with no interaction between the two.

First mechanism: Causal influence of attention bias on optimism bias. In accordance with Broadbent´s filter model of attention (1958), we postulate that selectively attending to reward-related information (and away from negative information) leads to optimism bias, in that selective visual attention determines which part of the environmental information is preferably processed. Wanting (striatum, amygdala) drives ongoing visual attention to rewarding stimuli. This is in line with Berridge and Robinson’s (1998) incentive salience theory, in which mesolimbic and neostriatal dopamine functions to increase wanting of specific rewards and thereby shapes the attention-capturing quality and neural representation of reward-related stimuli. We propose that the critical structures to shift attention are the PPC and the PCC, and selective attention then impacts on how early visual input is processed (e.g., reflected in the primary visual cortex; Desimone & Duncan, 1995; Padmala & Pessoa, 2011; the suggested flow of information is depicted in Figure 2.3a). By allocating selective attention, desirable evidence is processed preferably (striatum, amygdala), thus creating or strengthening optimism regarding goal achievement (ACC, OFC, and vmPFC).

Coming back to our Las Vegas example, wanting to win a lot of money through gambling directs our ongoing visual attention preferably to smiling faces of people in the environment who just won a game, while mostly ignoring those who lost and look sad, thus making us more optimistic about winning money ourselves, for it seems to happen to so many other people. In contrast to this example of healthy processing, patients with depression do not show biased attention to rewarding stimuli (but rather to negative stimuli; Gotlib et al., 2004) and are simultaneously not characterized by an optimism bias (Garrett et al., 2014; Korn et al., 2014; Strunk et al., 2006). In fact, we suggest that biased attention to negative rather than positive stimuli among patients with depression leads to more negative expectancies about the future (in line with mechanisms involved in fear and anxiety described by Aue & Okon-Singer, 2015), thereby maintaining a generally negative view. On a neural level, it is imaginable that connections between the amygdala and striatum associated with wanting, on the one hand, and the PPC and PCC areas important for shifting attention, on the other, are missing or dysfunctional and therefore prevent the formation of an attention bias toward rewarding stimuli in patients with depression. Alternatively (or additionally), one can speculate that an interaction between reward-related biases in attention (PPC, PCC) and expectancies (ACC, OFC, vmPFC) is not established because of dysfunctional activity of the amygdala and the striatum. Such a deviation would also hinder the above proposed “normal” flow of information.

Second mechanism: Causal influence of optimism bias on attention bias. From the considerations outlined in the previous sections, we further suggest that wanting (striatum, amygdala) can directly shape optimism bias in order to further increase goal-directed appetitive motivation and task engagement. In line with postulates derived from predictive coding theory, we hypothesize that optimism bias, via top-down mechanisms (ACC, OFC, and vmPFC), redirects currently ongoing visual attention (PCC, PPC, and visual cortex) toward supportive environmental evidence (while largely ignoring negative evidence) in order to facilitate the pursuit of a goal to obtain a reward (see Figure 2.3b). Re-entrant neural processes in that sense have already been shown in the field of perception (Amaral & Price, 1984; Keil et al., 2009) and could apply to the redirection of attention in a highly similar fashion.

In our example, wanting to win money through gambling makes us highly optimistic about winning that money in the next game and having the best hand of cards, which then redirects ongoing attention toward supportive evidence, such as our friend smiling to encourage us. In contrast to this process suggested to be shown by healthy individuals, patients with depression or other psychopathologies do not display optimism bias in the first place (Garrett et al., 2014; Korn et al., 2014), but have negative expectancies about the future (Strunk et al., 2006). These expectancies can then lead to biased attention toward negative as opposed to positive stimuli (Gotlib et al., 2004), thereby generally maintaining negative cognitions. On a neural level, at least two dysfunctional scenarios are imaginable as being responsible for an absence of healthy optimism-attention interactions in psychopathology. On the one hand, malfunctioning connectivity of the amygdala and the striatum with the ACC, OFC, and vmPFC could prevent wanting from shaping optimism bias in the first place. On the other hand, it is conceivable that optimism bias does not exert top-down influences on attention because connections of the ACC, OFC, and vmPFC with the PCC, PPC, and visual cortex are dysfunctional.

Third mechanism: No causal influence between optimism bias and attention bias. Although we consider it improbable, at the moment we cannot rule out that wanting (striatum, amygdala) independently initiates supportive attentive (PPC, PCC, and visual cortex) and expectancy-related processes (ACC, OFC, and vmPFC) with no interaction between the two (Figure 2.3c). In our example, this would mean that wanting to win money in Las Vegas would (re)direct attention toward other people winning money and shape expectancies toward optimism about winning independently. However, research on the link between attention and expectancies in threatening and in reward-related situations suggests that both processes are highly correlated in salient situations, with attention causally influencing expectancies or vice versa (e.g., Aue et al., 2013b; Aue & Okon-Singer, 2015; Hahn & Gronlund, 2007; Mohanty et al., 2009; Peters et al., 2015; M. Williams et al., 2005). Therefore, we generally predict that the attention and expectancy systems are coordinated and mutually reinforce each other. In addition, although there is clear evidence that wanting affects both optimism and attention (Bastardi et al., 2011; Hickey et al., 2010; Weinstein, 1980), there is no reason to suspect that the impact of attention (optimistic expectancies) on optimistic expectancies (attention) is mediated by changes in wanting.

In sum, all three proposed mechanisms are imaginable. An important consideration, as mentioned earlier, is that the first and the second mechanism are not necessarily mutually exclusive. In fact, we anticipate that the first two mechanisms combine. The concrete direction of influence between the biases can be context dependent. In both cases, neural key activations would be expected in areas such as the striatum, amygdala, ACC and PCC, and primary visual cortex. However, from our review of the literature (sections 2.2 and 3.2), we hypothesize that causal influences of optimistic expectancies additionally recruit more frontal areas, whereas causal attention influences rely on supplementary parietal areas.

Investigating functional and structural connectivity between these areas will yield important insights into the nature of the neural networks that underlie normal and pathological relations between reward-related biases in expectancies and attention. Neuroscientific evidence on such causal relations between attention and optimism bias has further important implications for the treatment of psychopathology and can help intervene in mutually enforcing negative bias patterns displayed by patients with psychological diseases (Aue & Okon-Singer, 2015; Everaert et al., 2017; Hirsch et al., 2006). Information about the direction of influence between attention bias and optimism bias can, for instance, give hints on which biases should be targeted as a priority in psychotherapy (namely, those biases that can automatically alter other clinically relevant biases) and on their specific role in the causation of pathological symptoms. Moreover, knowledge about the specific neural structures involved in optimism-attention bias interplay and their functional connectivity can be decisive for the development of novel psychopharmacological treatments (see Fossati, 2008).

In conclusion, with the present framework, we propose that biased optimistic expectancies causally influence attention deployment, and attention bias causally influences optimism. Through this mutually re-enforcing interplay, reward-related biases are preserved in the long term and a positive view of the environment and the future is maintained. This framework can be used to understand previous and future neurocognitive work on optimism and attention bias because it will (a) help to integrate research on single reward-related biases into a bigger picture of interacting cognitive biases resulting from the overarching motivation to pursue reward (i.e., motivation to reach a reward that drives both biases in expectancies and attention); (b) make it easier to interpret pivotal findings in research that focus on only one phenomenon (e.g., updating asymmetry in optimism bias), which often partly represents effects additionally arising from another, simultaneously present, bias (e.g., attention bias; see Kress et al., 2018); (c) shed light on the mechanisms related to the development and maintenance of each bias (e.g., underlying attention processes contributing to biased optimistic expectancies and vice versa); (d) help to uncover divergences and commonalities in health and psychopathology (e.g., by testing how evidence on interacting negative cognitive biases displayed in psychopathology can be replicated in reward-related biases and whether health and psychopathology result from different or similar interactions between cognitive biases); and (e) inspire new, personally adapted, therapeutic interventions (e.g., by taking into account which specific biases are shown by an individual and how their interplay affects particular symptoms of disease).

5 Potential roles of memory in the interplay of optimism bias and attention bias

So far, we have argued that optimism and attention bias are linked. However, according to the combined cognitive biases hypothesis (introduced in section 4.1), additional information processing biases (i.e., in memory or interpretation) can come into play. In particular, there is evidence that expectancy and memory processes are highly related to each other (Aue & Okon-Singer, 2015) and that many optimistic expectancies we have as humans are based on our prior experiences (Metcalfe, 1998). At the same time, memory and attention processes are highly interactive processes, as evidenced by a large body of behavioral and neuroscientific research (Chun & Turk-Browne, 2007). It is for this reason that we now point out how memory processes have been observed to interact with optimism bias on the one hand and attention bias on the other. We then suggest how memory processes can influence the interplay of optimism and attention bias, one possibility being that memory functions as a mediator in the optimism bias–attention bias associations we put forth earlier. Evidence about such threefold interactions can reveal even more refined mechanisms underlying the benefits of reward-related biases and explain how a positive outlook is ultimately maintained in healthy individuals.

Concerning the relation between optimism and memory bias, it has been suggested that optimism bias is the result of memory-based processing heuristics. If – as proposed – people use all information at hand (e.g., evoked from memory) to build expectancies, optimism bias simply arises because the information at hand is not always correct and complete (Metcalfe, 1998). As a consequence, unreasonably positive memories can lead to biased expectancies in the form of optimism bias. Accordingly, in a meta-analysis on time estimations of future events, Roy and colleagues (2005) indeed found strong support for a positive association between biased memories and expectancies. Some famous examples of overoptimistic time expectancies have been observed in the time estimations for the construction of various important buildings, such as the Sydney Opera House or the Channel Tunnel between England and France. Specifically, the authors state that people base their predictions of future task duration on their memories of how long past events have taken, but these memories systematically underestimate the true duration. Although these links between memory and optimistic expectancies primarily concern temporal aspects, one also wants to consider the valence aspect. For instance, people who better remember positive events in their life than others do are likely prone to see their future more optimistically. Empirical evidence for such a mechanism will have wide-reaching implications for the treatment of psychopathology, as it implies the need to correct the absence of positive memory biases (e.g., through cognitive restructuring; Liang, Hsu, Hung, Wang, & Lin, 2011; Rinck & Becker, 2005; Watkins, Vache, Verney, & Mathews, 1996) to make patients see their future more optimistically.

In a similar vein, it has been suggested that attention processes are strongly related to memory processes (Chun & Turk-Browne, 2007). Numerous investigations have demonstrated that the current focus of attention determines which information is encoded in memory (e.g., Everaert et al., 2014; Fougnie, 2008) and that attention during memory retrieval predicts subsequent memory bias of positive information (Everaert & Koster, 2015). Therefore, preferably attending to positive stimuli in one's environment is likely closely related to the predominance of positive information in memory (see Tran, Hertel, & Joormann, 2011, for similar reflections on the relation between interpretation bias and memory bias).

In addition to these influences of attention on memory, the opposite direction of influence has also been proposed, namely, that past experience reflected in multiple memory systems guides attention (Chun & Turk-Browne, 2007). Evidence for this memory-guided attention allocation has been shown for implicit long-term memory experience (Johnson, Woodman, Braun, & Luck, 2007, J. Summerfield, Lepsien, Gitelman, Mesulam, & Nobre, 2006). In conclusion, memory and attention interact in both directions: First, memory has a limited capacity and therefore depends on selective attention processes that determine which pieces of information will be encoded. Second, memory about past experiences guides attention in order to secure optimal selection (Chun & Turk-Browne, 2007). Of note, the existence of bi-directional influences between memory and attention has important implications not just for the clinical context, because these influences contribute to the development and maintenance of psychological diseases (Everaert et al., 2014). Such interactions may be equally momentous for healthy processing by ensuring positive mood and well-being.

Even though there is evidence for both optimism-memory and attention-memory interactions, to our knowledge no studies have yet empirically examined the threefold relationship between optimism bias, attention bias, and memory bias. However, one can speculate that a threefold link exists (for similar reflections in the negative domain, see Aue & Okon-Singer, 2015). On the one hand, a positivity bias in memory has been suggested to initiate shifts in attention (e.g., Hutchinson & Turk-Browne, 2012) toward positive stimuli in the environment, which can then lead to biased optimistic expectancies about future events. On the other hand, it is also imaginable that biased memories directly shape optimistic expectancies about the future (Metcalfe, 1998; Roy et al., 2005), which then result in biased attention toward the internal and external environment (Kress et al., 2018; Peters et al., 2015). In applying this to affective disorders, one can assume that if depressed patients do not show a positivity bias in memory (Watkins et al., 1996), they also form less optimistic expectancies about their future. The latter is characteristic for patients with depression (Garrett et al., 2014; Korn et al., 2014) and has been suggested to bias attention less toward rewarding stimuli and more toward negative stimuli in the environment (Beck, 1976; B. Bradley, Mogg, & Lee, 1997; Koster et al., 2005; Leyman, de Raedt, Schacht, & Koster, 2007).

In line with mutual influences among the three biases, it is also conceivable that memory processes mediate the link between expectancies and attention. For instance, the current focus of attention determines which information is encoded in memory (Craik & Rose, 2012; Fougnie, 2008). Biased attention toward reward-related stimuli can, therefore, lead to a positivity bias in memory. Subsequently, expectancies about the future are too optimistic, as future expectancies derive at least partly from biased past experience (Metcalfe, 1998; Roy et al., 2005). Furthermore, memory bias can also mediate how expectancies influence attention. In this scenario, biased expectancies activate corresponding working memory content in the form of an a priori map or a mental template. This template then drives attention toward rewarding stimuli in a top-down manner (Kress et al., 2018; for related ideas in the negative domain and corresponding studies, see Aue et al., 2013a, 2016). Empirical evidence for such mediating mechanisms of memory content regarding the link between attention and optimism can explain further details about multifaceted cognitive bias interactions and contribute to a more nuanced view on how exactly these interactions are related to emotion regulation and mental health.

Further information regarding the determining mechanisms in these bias interactions can be gained from studying the neural correlates of the different biases. Critical brain structures underlying emotional memories usually consist of the amygdala (Morris, Öhman, & Dolan, 1998), the insula (Hamann, 2001), and the septo-hippocampal system (McNaughton & Corr, 2004), as well as prefrontal cortex regions such as the vmPFC (Dolcos, Denkova, & Dolcos, 2012; Phelps, Delgado, Nearing, & LeDoux, 2004). The amygdala, the ACC – an area often coactivated with the insula (Menon & Uddin, 2010) – and the prefrontal cortex areas have also been involved in optimism bias (Sharot et al., 2007, 2011) and attention bias (Mohanty et al., 2008; Naghavi & Nyberg, 2005). This points to similar neural networks at the basis of the different cognitive biases and therefore further supports the idea of intimately intertwined processes. Consequently, studying the neurophysiological nature of a link between all three biases is of high interest.

One promising approach for uncovering the neurophysiological nature of multiple bias interactions has been provided by Soto and colleagues (2008). They suggest that neurons in the prefrontal and more posterior brain regions are active when certain stimuli are held in working memory. Such neural activation has been proposed to drive attention in a top-down manner. According to these authors, "the sustained enhancement of cells tuned to particular features might provide the neural correlate of expectancies that influence subsequent selection, leading to enhanced responding when the item in memory is represented in a search display" (p. 346). This is one possible neural mechanism that explains the threefold link between biased expectancies, memory, and attention. However, Soto and colleagues (2008) do not explicitly refer to optimism bias, which is why further research is still needed. Together, the theoretical considerations outlined in this section strongly call for an integrated view of overlapping processes related to memory, attention, and expectancies. Revealing the underlying neural mechanisms of optimism-attention-memory interplay can stimulate hypotheses for future neurocognitive research (e.g., regarding functional and structural connectivity among specific brain areas) and has the potential to improve current psychopharmacological treatment options (Fossati, 2008).

6 Concluding remarks and future directions

Optimism bias represents a – usually – highly beneficial cognitive phenomenon that not only is associated with mental and physical health (Hevey et al., 2014; Garrett et al., 2014; Korn et al., 2014) but that also has a high impact on our society. However, in order to identify the mechanisms underlying optimism bias, it is important for other cognitive biases and their neural correlates to be taken into account. Studying different cognitive biases in an integrated approach helps us understand causalities and connections that are still unclear and thereby contributes to a more advanced view of each bias, improves theoretical models, and provides help for clinical practice. One promising approach is to investigate the link between optimism and attention bias. The outlined framework of bi-directional interplay between optimism and attention bias can be used to (a) understand prior and future research, (b) guide future work in the field by emphasizing methodological advice for and specific hypotheses to be tested in future empirical research, and (c) outline a number of open questions that might lead to further refinement of the current framework.

Regarding improved understanding of prior and future research, our theoretical framework implies that isolated studies that examine cognitive biases, especially optimism bias and attention bias, should be evaluated with caution. Attention processes can be present but not detected in studies on optimism and vice versa. For instance, taking attention bias into account can extend, alter, or explain past findings on optimism bias (e.g., updating asymmetry in optimism bias being shown because of biased attention processes; see Kress et al., 2018). Moreover, the current framework calls for caution in interpreting neuroscientific findings on optimism and attention bias in isolation. We have shown that neural correlates of optimism and attention bias widely overlap and can therefore be attributed to either of the two biases or their interplay. This aspect is thus evidently of great importance for the interpretation of existing data in terms of specific study questions.

In order to distinguish biased expectancy and attention processes and to ensure that reliable conclusions can be drawn from studies on interacting cognitive biases, the current framework calls for fundamental methodological changes to guide future research in the field. To date, correlational methods are often used to examine associations between optimism and attention bias. However, additional consideration of causality is imperative in order to identify the cognitive processes underlying optimism bias and should thus be emphasized. Causal relations can be examined by manipulating one of the biases and measuring its effect on the other, just as was done in the study of Peters and colleagues (2015). Such causal influences should be investigated in both possible directions (i.e., optimism bias on attention bias and attention bias on optimism bias). The first evidence from our laboratory suggests that manipulated optimistic and pessimistic expectancies alter attention to rewarding and punishing stimuli. More important, optimistic expectancies repeatedly had a stronger effect on attention deployment than pessimistic expectancies did, thereby emphasizing the powerful effects of optimism on other types of information processing (Kress et al., 2018). Whether causal influences of attention on optimism bias, as suggested by our framework, exist in a similar manner is yet to be investigated in empirical studies.

By additionally proposing a network of brain areas serving as the underlying neural correlate of cognitive bias interplay, our framework helps generate specific hypotheses to be tested in future empirical research. The suggested network includes the amygdala, which generates emotions, on the one hand, and the fronto-parietal and cingulate cortices, which are involved in emotion regulation and attentional control, on the other. Different mechanisms regarding the relationship between optimism and attention bias are conceivable, but there are most likely bi-directional influences. For instance, wanting can lead visual attention to rewarding stimuli driven by the PPC and PCC and can strengthen optimism regarding goal achievement. We also postulate that wanting can directly shape optimism bias, which then exerts top-down influences (ACC, OFC, and vmPFC) on visual attention and activity in the visual cortex.

Both of these mechanisms of neural communication are driven by goal-directed behavior toward reward (Bateson, 2016; Small et al., 2005), a central underlying motivational factor for optimism and attention bias that we emphasize in our framework. It is for this reason that we have specifically focused on reward-related attention processes. In this regard, the dominant role of neurotransmitters, especially dopamine, in reward processing (Berridge & Robinson, 1998) has to be investigated because this has been shown to have important implications in both optimism and attention bias (Field & Cox, 2008; Franken, 2003; Sharot et al., 2012a) and could reveal crucial information about the neural mechanisms underlying their interplay (e.g., concerning the question of whether administration of L-DOPA enhances not only optimism bias, but also its interplay with attention bias; Sharot et al., 2012a). Moreover, even though we propose a pivotal role for reward as a motivational factor in our framework, future theoretical and empirical investigation should determine whether optimism-attention interplay extends to non-reward-related forms of positive attention bias, such as biased attention to stimuli, which have a positive value but no direct relevance for the observer (e.g., pictures displaying sport scenes; Pool et al., 2016a; see Armstrong & Olantunji, 2012, and Peckham, McHugh, & Otto, 2010, for meta-analyses on this broader view of positive attention bias).

The proposed framework can still be extended in different directions. Therefore, we discuss a number of open questions to be answered by future theoretical and empirical work in the remainder of this section. According to a recent taxonomy by Chun and colleagues (2011), attention processes can be classified as internal or external (internal attention refers to internal cognitive representations, whereas external attention refers to the external, perceptual world). Within these two areas, one can further distinguish between selection, modulation, and vigilance. Because of limited processing capacity, people need to select which information they attend to from numerous competing stimuli. After a piece of information is selected from these competing options, attention modulation refers to how this selected piece is processed (influencing subsequent behavior and memory). Whereas modulation refers to the current, immediate effects on attention processing, vigilance refers to the ability to sustain attention over time (Chun, Golomb, & Turk-Brown, 2011). Future research on the interplay of optimism and attention bias should take these different processes into account to shed further light on the question of whether particular attention processes are differently influenced by, or can differently influence, optimism bias. It will be an important benefit to the literature if prospective empirical research in the field of interacting cognitive biases distinguishes between the different aspects of attention represented in selection, modulation, and vigilance.

In a similar vein, the proposed framework may need to be adapted to specific forms of optimism bias (e.g., unrealistic optimism, wishful thinking; see section 2) that, in the present article – because of limited numbers of studies in any area – were pooled together under the broad term optimism bias. Findings on the interplay between optimism bias and attention and memory processes could differ if one differentiates between subconcepts of optimism bias instead of working with a possibly multifaceted concept, as we did in the current framework.

Likewise, it will be interesting to further study whether a possible link between attention, expectancy, and memory biases applies equally to optimism and pessimism. It is assumed that, because of its adaptive and beneficial use in human life, optimism bias is a unique cognitive bias (support for this is provided by Kress et al., 2018). Thus, the processes underlying pessimism can indeed be different. However, one problem in examining pessimism is that it is often defined as the opposite of optimism. It can sometimes even be assessed on the same scales as optimism, which then automatically leads to the detection of comparable mechanisms (Mehrabian & Ljunggren, 1997; Scheier, Carver, & Bridges, 1994). Similarly, to distinguish between optimism and pessimism, future research needs to determine whether valence-specific biases in attention and memory have a differential impact on other cognitive biases (e.g., whether reward-related and punishment-related biases in attention and memory differently influence or are influenced by expectancies).

In addition, as we have emphasized, the role of memory processes in possibly influencing attention and optimism bias, or their association, needs to be examined in greater detail. This is because forming biased expectancies about the future has been suggested to be based on biased memories, which also appear to be related to biased attention (see section 5 for additionally proposed causal influences between the three biases). Moreover, interpretation bias is another phenomenon that is possibly linked to the cognitive biases mentioned earlier, which calls for the need to extend our framework to include even more cognitive biases. For example, it has been shown that imagery of positive events could lead to a positive interpretation bias (Holmes, Lang, & Shah, 2009; Pictet, Coughtrey, Mathews, & Holmes, 2011; Torkan et al., 2014) and that interpretation bias modification training affects memory (Tran et al., 2011). However, interpretation biases toward positive information in general and their neural correlates have been examined to a much lesser extent than have memory biases; hence, this is the reason that we focused on optimism, attention, and memory.

Furthermore, when investigating the threefold relationship between optimism, attention, and memory bias, one also has to be aware that on the one hand, different changes in one bias might lead to the same outcome in another bias (equifinality), and on the other, the same change in one bias in different contexts might lead to different outcomes in another bias (multifinality). These concepts of equifinality and multifinality are commonly used in developmental research (Cichetti, & Rogosch, 1996) and can well apply to research on multidirectional influences between cognitive biases. For instance, it is conceivable that various forms of reward-related biases in attention (e.g., during selection, modulation, and vigilance; Chun et al., 2011) and memory (e.g., during encoding and retrieval; Everaert et al., 2014; Everaert & Koster, 2015; Fougnie, 2008) can result in optimism bias. At the same time, the same single form of reward-related bias in attention and memory displayed at different moments in time or in different contexts does not necessarily result in a comparable optimism bias. Whether the concept of equifinality and multifinality really applies to cognitive bias interplay and which specific (neural) circumstances might lead to equifinal and multifinal outcomes in the relation between attention, memory, and optimism bias could be the topic of intriguing questions in future neurocognitive research and theoretical considerations.

Finally, differentially salient situations and stimuli have been suggested to correspond with differences in cognitive processing (Corbetta & Shulman, 2002; Menon & Uddin, 2010). Investigations should therefore be made into how a possible link between attention and optimism differs when highly salient stimuli are used compared with low salient stimuli. This is particularly interesting for an application in the clinical context. Stimuli that are relevant for biased expectancies and attention in clinical settings (e.g., cigarettes or drugs) are often highly salient for the person concerned, whereas stimuli frequently used in attention tasks in nonclinical settings (e.g., colored letters or graphical objects) are of comparatively low personal saliency even if they are associated with small monetary incentives. However, how stimulus saliency affects the link between attention and optimism is also relevant in everyday life. For instance, companies should use highly salient stimuli when advertising their products to increase people's attention, hence making potential customers more optimistic about the benefits of their products.

In summary, positivity biases in the past, present, and future – i.e. memories, attention, and expectancies – share specific characteristics. They are important for goal-directed behavior and related to well-being and health. It is therefore reasonable to suggest that these biases are intimately intertwined and interact or mutually influence each other. Notably, because the simultaneous consideration of different biases has very much advanced research, insights, and therapeutic interventions in the negative domain (e.g., regarding anxiety disorders), a combined cognitive biases approach cannot be ignored by researchers when examining optimism bias. Determining exactly how reward-related cognitive biases interact will have a large impact on theoretical considerations as well as on practical applications. For instance, solving the question of whether the relation between these biases has a specific direction or acts bi-directionally will reveal important mechanisms for the prevention of psychopathology. Moreover, a more profound understanding of the interactive nature of cognitive biases and their neural determinants not only will help explain how psychological disorders such as depression, addiction, and mania are developed and maintained, but will also reveal possible mechanisms to be targeted in psychotherapy.

Chapter 3

Seeing Through Rose-Colored Glasses: How Optimistic Expectancies Guide Visual Attention

Laura Kress, Mirko Bristle, and Tatjana Aue

Abstract

Optimism bias and positive attention bias have important highly similar implications for mental health but have only been examined in isolation. Investigating the causal relationships between these biases can improve the understanding of their underlying cognitive mechanisms, leading to new directions in neurocognitive research and revealing important information about normal functioning as well as the development, maintenance, and treatment of psychological diseases. In the current project, we hypothesized that optimistic expectancies can exert causal influences on attention deployment. To test this causal relation, we conducted two experiments in which we manipulated optimistic and pessimistic expectancies regarding future rewards and punishments. In a subsequent visual search task, we examined participants' attention to positive (i.e., rewarding) and negative (i.e., punishing) target stimuli, measuring their eye gaze behavior and reaction times. In both experiments, participants' attention was guided toward reward compared with punishment when optimistic expectancies were induced. Additionally, in Experiment 2, participants' attention was guided toward punishment compared with reward when pessimistic expectancies were induced. However, the effect of optimistic (rather than pessimistic) expectancies on attention deployment was stronger. A key characteristic of optimism bias is that people selectively update expectancies in an optimistic direction, not in a pessimistic direction, when receiving feedback. As revealed in our studies, selective attention to rewarding versus punishing evidence when people are optimistic might explain this updating asymmetry. Thus, the current data can help clarify why optimistic expectancies are difficult to overcome. Our findings elucidate the cognitive mechanisms underlying optimism and attention bias, which can yield a better understanding of their benefits for mental health.

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Introduction

Charlie Chaplin once said that “you’ll never see a rainbow, if you’re looking down”. His famous saying implies that we do not notice the good things around us with a pessimistic attitude. Is that true? Does being optimistic or pessimistic influence which parts of our environment we pay attention to? To answer this question, we focus on the interplay between two important cognitive phenomena displayed by humans: optimism bias and positive attention bias.

Research has shown that approximately 80 % of humans overestimate the likelihood of positive events and underestimate the likelihood of negative events in their future – a phenomenon called optimism bias (Sharot, 2011; Weinstein, 1980). In contrast to healthy people, who tend to be overly optimistic, patients suffering from depression do not display an optimism bias and are rather realistic about their future (Korn et al., 2014). Therefore, optimism bias is broadly viewed as a necessary psychological adaptation that promotes mental health (Garrett et al., 2014; Korn et al., 2014) and ensures motivation for goal-directed behavior (Armor & Taylor, 1998; Shepperd et al., 2015). However, being too optimistic can also have dramatic negative consequences and might lead to criminal or addictive behavior, especially when people underestimate the negative consequences of committing a crime or consuming drugs (Dillard et al., 2009; Weinstein et al., 2005).

Notably, optimism bias is displayed even considering contradictory information (Sharot et al., 2011). People find it more difficult to adapt their expectancies regarding important future life events when they receive feedback that is worse than expected (bad news such as that the average likelihood to incur serious health problems is higher than the individual had initially predicted for herself) than when it is better than expected (good news such as that the average likelihood to incur serious health problems is lower than the individual had initially predicted for herself; Sharot et al., 2011). Such selective updating could explain why optimistic outlooks are maintained over time and shows that optimism-related processing in healthy individuals is distinct from other forms of future expectancies (i.e., pessimism) in terms of robustness.

Although selective updating has been proposed to maintain optimism bias, the cognitive mechanisms underlying optimism bias and its pervasiveness – even in light of existing contradictory information – are still unclear. We know that optimism bias exists but we do not know precisely *why* it exists and *how* it is maintained. Here, we suggest that investigation of the interactions between different types of cognitive biases can provide information about these mechanisms. We argue that examining optimistic expectancies in relation to attention deployment could yield a better understanding of optimism bias and its benefits in everyday life as in the clinical domain.

Our postulate that biased expectancies and attention deployment are interdependent is based on two points; the first is observational and the second is theoretical in nature. First, a positivity bias not only exists in regard to future expectancies (as in optimism bias) but also in regard to visual attention: Positive and rewarding stimuli attract people´s visual attention more than neutral (and sometimes negative) stimuli do (Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Pool et al., 2016a). This has been shown by more rapid reaction times (RTs) and captured eye movements to rewarding than neutral information in different attention paradigms. Happy faces, for instance, have been proposed to "pop out" of crowds in visual search tasks (Becker et al., 2011). Moreover, positive attention bias, comparable to optimism bias, has been demonstrated to hold important implications for mental health (Everaert et al., 2012).

Preferably attending to positive rather than neutral stimuli enables people to efficiently detect events in an environment in which several stimuli compete for access to their limited attention resources. If people´s attention is biased toward positive stimuli in their environment, they are more likely to perceive chances to maximize beneficial output. From an evolutionary point of view, this could contribute to fitness for survival (Berridge & Kringelbach, 2008; Schultz, 2004). However, how biased expectancies relate to biased attention (e.g., whether expectancies modulate biased attention or vice versa) has not been investigated. The discovery of interactions between the two biases under investigation would yield a better understanding of optimism bias and positive attention bias.

Second, according to the combined cognitive biases hypothesis, negative cognitive biases (e.g., in attention, interpretation, and self-imagery) usually interact and mutually enforce each other (Hirsch et al., 2006; see Everaert et al., 2012 for considerations on the combined cognitive biases hypothesis in depression, and Aue & Okon-Singer, 2015 for the interplay of expectancies and attention in anxiety). This theory mainly focuses on associations between negative biases. Recently, similar interactions between different cognitive biases have been proposed in the positive domain (Kress & Aue, 2017). Revealing such causal relations between cognitive biases in the positive domain allows for investigation of why positive cognitive biases exist and how they are maintained over time. These investigations broaden our knowledge about normal functioning and the development of psychological disorders as well as their treatment and uncover divergences and commonalities between cognitive bias interactions in health and psychopathology.

Investigating the relation between optimism bias and positive attention bias is especially interesting because causal influences of optimistic expectancies on attention can elucidate how certain stimuli are processed when people are optimistic (e.g., concerning their processing depth).

For instance, optimism-driven attention deployment could directly explain important phenomena shown in optimism bias such as the selective updating described above (Sharot et al., 2011). This selective updating could be caused by optimistic expectancies shifting attention to rewarding (i.e., good news) rather than punishing (i.e., bad news) evidence, thereby determining the processing depth of the respective evidence. This should have retroactive, stabilizing effects on the initial optimism displayed. For example, it is conceivable that people displaying optimism bias might be particularly attentive when being told that their likelihood to incur a serious health problem is lower than they had initially predicted (good news) whereas they are less attentive when being told that their likelihood to incur a serious health problem is higher than they initially predicted (bad news). This will lead to a deeper processing of the good news (e.g., by further thinking about the new information). Consequently, people could selectively integrate good news when updating their expectancies and neglect bad news. Asymmetric attention deployment to good vs. bad news following optimistic expectancies would thus have significant feedback effects on these initial expectancies, thereby stabilizing optimistic tendencies in the long run.

If one assumes that the processing depth of rewarding or punishing stimuli can be influenced by optimistic expectancies, it is especially important to distinguish between various stages of attention deployment (e.g., initial orientation and maintenance of attention) and determine at which stage such differential processing takes place. The use of eye tracking allows for such a distinction (Armstrong & Olatunji, 2012) and could therefore reveal insights into the concrete attentional mechanisms that are crucial for selective updating processes in optimism bias. For instance, one could imagine that, when being optimistic, people initially orient their attention (primarily an automatic process) toward both good and bad news but later maintain attention (primarily a controlled process) selectively on good news (see Caseras, Garner, Bradley, & Mogg, 2007 for differences in attention orientation and maintenance on emotional stimuli shown by dysphoric participants). Such a finding would have crucial implications for a more profound understanding of the concrete nature of biased expectancy-attention interplay in healthy individuals and may fundamentally inspire psychotherapy. For instance, it could uncover the specific mechanisms to be targeted in depressive patients, who do not show a beneficial updating asymmetry (Korn et al., 2014).

There is no substantial empirical evidence for a causal link between biased optimistic expectancies and attention. However, examples in the literature show that expectancies can guide visual spatial attention in the positive domain (Hahn & Gronlund, 2007; Mohanty et al., 2008; M. Williams et al., 2005). Spatial attention could be influenced by expectancy cues when using motivationally relevant (rewarding) target pictures in a covered attention shift paradigm

(Mohanty et al., 2008). Participants reacted faster to cued food targets when they were motivationally relevant (i.e., when participants were hungry compared with when they were full). The same effect was not present for motivationally irrelevant tool targets. Other findings suggest that attention to happy faces can be modulated in a top-down manner through instructions that presumably impact expectancies (Hahn & Gronlund, 2007; M. Williams et al., 2005; see Aue et al., 2013a, 2016, and Burra & Kerzel, 2013 for similar effects with neutral stimuli). These findings are in line with predictive coding theory (C. Summerfield et al., 2006; Zelano et al., 2011), which states that expectancies allow people to create a mental template of expected information that is then compared with sensory input. During this comparison, attention might be biased to information that fits with the created template. However, it is important to note that the respective expectancies in the abovementioned studies (Hahn & Gronlund, 2007; Mohanty et al., 2008; M. Williams et al., 2005) were unrelated to optimism and pessimism (e.g., because participants were explicitly instructed to search for a happy or sad face; Hahn & Gronlund, 2007; M. Williams et al., 2005).

Even though there are no studies directly linking optimism bias and positive attention bias, a few studies examine the link between trait optimism (typically assessed with the Life Orientation Test (LOT-R; Scheier et al., 1994) or similar personality scales) and attention deployment. Whereas trait optimism describes a stable disposition of having an optimistic yet not necessarily unrealistic life orientation, optimism bias describes unrealistic expectancies regarding specific future situations that can be manifold (e.g., concerning health, relationships, and wealth). Although trait optimism and optimism bias are different constructs, trait optimism might increase an individual's readiness to demonstrate optimism bias in specific circumscribed situations (Armor & Taylor, 1998; Sharot, 2011). Notably, trait optimism has been related to an attention bias toward positive and away from negative stimuli, shown by altered reaction times in a Stroop paradigm (Karademas, Kafetsios, & Sideridis, 2007; Segerstrom, 2001) and biased eye movements (Isaacowitz, 2005; Peters et al., 2015). Unfortunately, all reviewed results on the link between trait optimism and attention are of correlational nature and thus do not provide information on causal relationships.

To our knowledge, only one study attempted to manipulate participants' optimistic expectancies experimentally and provide information about the direction of influence between optimism and attention. Peters and colleagues (2015) induced state optimism, measured by the Future Expectancies Scale, in half of their participants using the Best Possible Self (BPS) manipulation. During this BPS manipulation, participants imagined a future life in which everything had gone well while the other half of the participants underwent a neutral control manipulation. Next, both groups performed a passive viewing task in which their attention deployment was assessed. Although optimism manipulation did not influence gazing behavior in general, post-hoc analyses showed that, in contrast to non-responders, participants whose state optimism increased after the state optimism or control manipulation gazed significantly shorter at angry faces and nearly significantly longer at joyful faces than participants whose state optimism did not increase (Peters et al., 2015). These data indicate that state optimism, which most likely instigates optimism bias, might bias attention deployment toward positive and away from negative stimuli. However, additional research is needed to substantiate such a causal association.

It is generally difficult to directly manipulate optimism bias because (a) it is unclear how to reliably provoke such a bias across individuals and situations because it depends on a combination of many different aspects (some of which are impossible to manipulate, e.g., personal experience, individual preferences; Weinstein, 1980); (b) a bias is always relative to some other measure (e.g., overly optimistic expectancies in comparison with other people or reality), which makes it difficult to be evoked and measured; and (c) some types of manipulations may rely on simultaneous control of expectancies and attention. Thus, research on optimism bias and other cognitive biases has mostly been of a correlational nature. A first step toward demonstrating that optimism bias and positive attention bias are causally associated may be to demonstrate that optimistic expectancies (which are not necessarily biased) influence attention deployment and/or vice versa (Peters et al., 2015).

In the current studies, therefore, we manipulated optimistic and pessimistic expectancies that are present in optimism bias (Bateson, 2016) (instead of operationalizing optimism bias per se) and investigated their respective causal influences on attention deployment. If the findings show that variations in experimentally induced expectancies successfully generate changes in visual attention, it may be assumed that biases in expectancies can generate biases in attention. In our studies, expectancies were manipulated by verbal cues presented prior to a visual search task (see Aue et al., 2013a, 2016 for studies using a similar paradigm with neutral and threatening stimuli). During the presentation of expectancy cues, the change in participants' pupil diameter (measure of autonomic arousal; M. Bradley, Miccoli, Escrig, & Lang, 2008) was measured to demonstrate that cues elicited an affective response that can be attributed to optimistic and pessimistic expectancies. During the visual search task, two different components of attention were measured. First, attention orientation was measured by (a) RTs in the visual search task and (b) time to first hit on a target revealed by eye tracking data (i.e., the moment when the participant's gaze was registered to be first on the target). These measures of attention orientation were intended to investigate more automatic effects of optimistic expectancies on attention deployment. Second, attention maintenance during the visual search task was measured by how long participants looked at a target half a second after the first hit. Attention maintenance reveals information on how deeply stimuli signaling reward and punishment were processed following optimistic expectancies (Carretie, Martin-Loeches, Hinojosa, & Mercado, 2001; Craik, 2002) and can provide information on more controlled attention processes that explain the selective updating shown in optimism bias. We chose to acquire eye tracking in addition to RTs as it represents a more direct measure of attention and can reveal effects that are not visible in RT data (Fashler & Katz, 2014). Moreover, we measured participants' self-reported comparative optimism bias (Weinstein, 1980) to determine how individual differences in self-reported optimism bias are related to optimism-induced attentional biases revealed by our experiments.

We conducted two experiments using different stimuli (Experiment 1: happy, sad, and neutral faces and Experiment 2: letters of different colors) in the respective visual search tasks. The letter experiment was conducted in addition to the first experiment because the happy and sad faces themselves contain fixed valences. In the second experiment, valence was assigned by verbal instructions to neutral letter stimuli and "reward" and "punishment" connotations for the different stimuli were balanced across participants to avoid rigid stimulus-valence associations.

The aim of the present studies was to determine if experimentally induced optimistic and pessimistic expectancies regarding future gains and losses causally impact attention deployment to stimuli signaling reward (i.e., gain) and punishment (i.e., loss). For both experiments, we hypothesized that (1) gain and loss cues presented during the expectancy phase of the experiments elicit an affective response that can be attributed to optimism and pessimism (manipulation check). We hypothesized a larger increase in pupil diameter when participants were presented with gain or loss cues than when they were presented with ambiguous cues (control condition that should not contain a specific affective dimension). This hypothesis was drawn from past research that has shown differential pupil diameter change for gain and loss cues compared with neutral cues (Seymour, Daw, Dayan, Singer, & Dolan, 2007).

Furthermore, we hypothesized that (2) induced optimistic expectancies guide attention toward reward compared with punishment whereas pessimistic expectancies guide attention toward punishment compared with reward (differences between attention orientation and maintenance were examined exploratively as we did not have specific hypotheses). We anticipated that (2a) gain cues enhance attention to gain targets in comparison with loss cues, (2b) loss cues enhance attention to loss targets in comparison with gain cues (*cue congruency* *hypothesis*), (2c) gain cues enhance attention to gain in comparison with loss targets, and (2d) loss cues enhance attention to loss in comparison with gain targets (*target congruency hypothesis*).

Moreover, we hypothesized that (3) optimistic expectancies guide attention more toward reward compared with punishment than pessimistic expectancies guide attention toward punishment compared with reward because optimistic expectancies have been shown to be more robust (i.e., more resistant against disconfirming feedback) than pessimistic expectancies (Sharot et al., 2011; *optimism robustness hypothesis*). Therefore, even though we hypothesized an influence of pessimistic expectancies on attention toward punishment compared with reward, we anticipated this influence to be much weaker than the influence of optimistic expectancies on attention to reward compared with punishment.

Last, we hypothesized that (4) this optimism robustness in attention (i.e., stronger guidance of attention to reward compared with punishment through optimistic expectancies than to punishment compared with reward through pessimistic expectancies) is positively related to participants' self-reported comparative optimism bias (*comparative optimism bias hypothesis;* Weinstein, 1980).

Experiment 1: Methods and materials

Participants

Thirty-two healthy psychology students recruited via the participant pool at the University of Bern took part in this RT and eye tracking study. Wearing hard contact lenses or reporting the use of psychoactive substances served as exclusion criteria. Participants had normal or corrected-to-normal vision and were reimbursed with course credit and 5 Swiss francs for participation. One participant was excluded because of a technical error in data logging, leaving a final sample of 31 students (4 male, age: *M* = 21.19 years; *SD* = 1.60 years; range = 19 – 26 years). All participants gave written informed consent according to the ethical standards guidelines of the Declaration of Helsinki and were told that they could end the experiment at any time. All procedures were approved by the local ethical review board of the Faculty of Human Sciences at the University of Bern, Switzerland.

Stimuli

Visual search task (attention): Forty-eight face stimuli taken from the NimStim Face Stimulus Set (Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002) served as stimuli. Sixteen different faces (half male and female) each displayed happy, sad, and neutral facial expressions. In every trial, eight faces were shown on a white background on a circle around the position where the fixation cross had been presented before (Figure 3.1, top). The participants' task was to find the deviant (happy or sad) target face among seven neutral distractor faces. Happy and sad faces appeared equally probable in any of the eight different locations on the circle and signaled gain (i.e., reward) and loss (i.e., punishment) of money, respectively. The stimuli were matched for luminance and contrast and displayed in color.

Cues (expectancy): Three different verbal cues were presented: “gain 90 %”, “loss 90 %”, or “gain loss 50 %” (“loss gain 50 %” for half of the participants). These cues indicated the probability that the to-be detected target in a subsequently presented search array is a happy or sad face. The gain 90 % (loss 90 %) cue condition referred to a probability of 67 % (64 trials) that there would be a happy face (sad face) among seven neutral faces in the subsequent search array. In the remaining cases, a sad face (happy face) was presented (32 trials). In the 50 % cue condition, happy and sad faces were equally likely to be the target in the search array (64 trials, 32 happy face targets and 32 sad face targets). This 50 % cue was included as a control condition inducing ambiguous expectancies with maximum uncertainty. E-Prime 2.0 Professional (Psychology Software Tools, Pittsburgh, PA) was used to present stimuli and record the participants' responses.

Experimental procedure

After providing written informed consent, participants read the instructions in which the experiment was described as a gamble task with the opportunity to gain or lose money. They were told that they would gain 25 Swiss cents in addition to a starting amount of 5 Swiss francs upon seeing a happy face in the visual search array and lose 25 Swiss cents upon seeing a sad face. Participants were told that the cues in the beginning of each trial described an average probability of a happy or sad face being presented subsequently but the computer randomly picked a target out of a pool of 100 targets (for 90 % gain [loss] cues, this pool consisted of 90 happy [sad] and 10 sad [happy] faces). Therefore, the real probabilities could differ from the average value displayed as the expectancy cue. Before starting the experiment, participants performed six practice trials to become familiar with the task.

Figure 3.1 (top) shows the timing and sequence of one example trial. In each trial, participants were presented a fixation cross for 2000 - 3000 ms followed by a cue word that was presented for 1500 ms. The cue indicated how probable it was that the to-be detected target in the subsequently presented search array would be a happy or a sad face (see the preceding section for details regarding the expectancy cues). After the cue was presented, another fixation cross appeared for 2000 - 3000 ms. The search array consisting of eight pictures (seven neutral faces and either a happy [gain] or sad [loss] face) was then shown for 2500 ms. During the visual search task, participants had to indicate whether the target was presented on the left or right side of the screen by pressing 1 or 2 on the number pad of the computer keyboard. The participants were instructed to react as quickly and correctly as possible. After the detection period had elapsed, another fixation cross was presented for 0 - 2000 ms before the next trial.

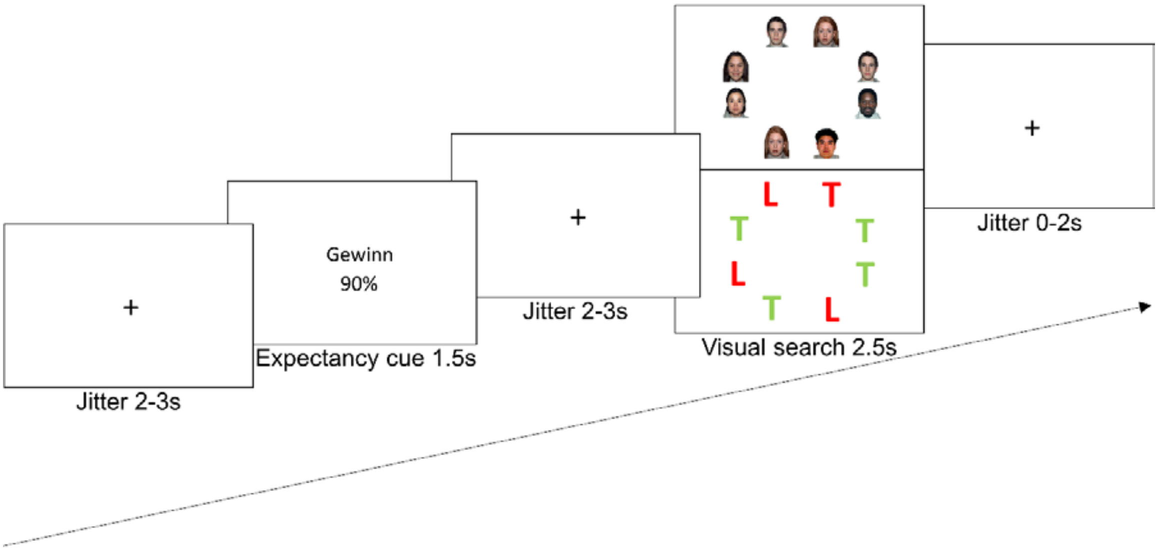


Figure 3.1. Task sequence. *An example of a gain-90 % cue (Gewinn [German word for gain] 90 %) followed by a search array depicting a gain target (happy face [Experiment 1, top] or red T [Experiment 2, bottom]). Participants were told that the cues described the likelihood of seeing a gain or loss target in the search array. They were also told that they would gain (lose) 25 Swiss cents in addition to a starting amount of 5 Swiss francs when seeing a gain (loss) target. Participants were asked to respond as quickly and accurately as possible according to the target (i.e., gain or loss target). Due to the copyright regulations of the NimStim face stimuli (Tottenham et al., 2002), faces that were not used in Experiment 1 were displayed for illustration (top) and two faces are shown twice although the same face was never repeated in any trial of Experiment 1.*

Two hundred forty-four experimental trials were presented in random order in four blocks of 61 trials with short pauses in between. The frequencies of trials of different types (cues, targets) were comparable between blocks. In total, participants both gained and lost 32 Swiss Francs, leaving them with the starting amount of 5 Swiss Francs. Participants were not informed about the progression of their gains and losses during the experiment.

After the experiment, participants completed a post-experimental questionnaire consisting of specific questions about how they perceived and conducted the task (e.g., whether they had employed a specific strategy during the search task [and if so, which strategy], see Analysis S.3.1 for further details). Participants also completed different personality questionnaires (LOT-R; Scheier et al., 1994; Comparative Optimism Scale [COS]; Weinstein, 1980; Future Expectancy Scale [FEX]; Hanssen, Vancleef, & Peters, submitted; Satisfaction With Life Scale

[SWLS]; Diener, Emmons, Larsen, & Griffin, 1985; Positive And Negative Affect Schedule [PANAS]; Watson, Clark, & Tellegen, 1988; Emotion Regulation Questionnaire [ERQ]; Gross & John, 2003; Behavioral Inhibition System/Behavioral Activation System Scales [BIS/BAS]; Carver & White, 1994; 10-Item Big Five Inventory [BFI–10]; Rammstedt, 2007), were debriefed, and received their "gain" of 5 Swiss francs.

Eye tracking

Eye tracking data were acquired with a Tobii Pro X2-60 remote eye tracker (Tobii AB, Stockholm, Sweden). The system used the corneal reflection light source (corneal reflex method) to measure the eye's orientation. Eye movements were recorded binocularly with a 60 Hz sampling rate and an accuracy of .4°. The system was controlled by Tobii Studio (version 3.1.6) to register ocular movements.

Manipulation check

As a manipulation check, affective arousal during the presentation of expectancy cues was measured by the change in participants' pupil diameter. For pupil diameter analysis, five 0.5-s intervals from 0 to 2.5 s after cue onset were considered. Pupil diameter during the 0.5 s before the appearance of the cue (presentation of fixation cross) served as baseline. Pupil diameter baseline scores were subtracted from the scores during cue presentation to obtain difference scores describing changes from the presentation of the different cues. On average, 19 % of pupil diameter data per time interval were excluded from the analysis because missing eye gaze data made up > 50 % of the samples. Moreover, outliers (deviating more than 3 *SD*s from the average diameter of a given participant during a particular time interval) were eliminated (on average, 0.8 % of the remaining pupil diameter data per time interval).

Dependent variables

One dependent variable that measured attention orientation during the visual search task consisted of participants' RTs for correct responses (in ms); errors comprised ~ 5.5 % of responses. The dependent eye tracking variables during the visual search task consisted of two components: attention orientation was measured by the time to first hit on the target (in ms; note that it was possible to detect the target in the visual search task without performing a saccade, which is why we cannot rule out effects of covert attention that might have interfered with this measure of attention orientation; however, this should only have weakened the effects of interest in our study) and attention maintenance was measured by the percentage of gazing at the target half a second after the first hit (in % of overall looking at the screen). Hits were defined as gaze points on the area of interest, which consisted of the target picture and 10 % of the picture size added to each side. The employed measures and time intervals are commonly used in eye tracking research (Palanica & Itier, 2011; Wieser, Pauli, Weyers, Alpers, & Muhlberger, 2009). Trials in which participants did not gaze at the target at all were excluded from eye tracking analyses (an additional ~ 4.6 % of all trials). Peripheral attention to target stimuli possibly led to these trials in which participants responded correctly even though they did not hit the target. For the percentage of gaze analysis, ~ 7.4 % of all trials were additionally excluded because participants did not hit the target within the first 2000 ms of the presentation of the visual search task (and therefore the time spanning half a second after first hit would have exceeded the presentation of stimuli). In addition, ~ 2.2 % of all trials were excluded due to missing eye gaze data of greater than 40 % of the sample (mostly due to eye blinks).

Data analysis

We hypothesized that (1) gain and loss cues elicit a stronger affective response, demonstrated by a larger increase in pupil diameter, than do ambiguous cues that serve as a control cue and should not contain a specific affective dimension (manipulation check). To test this hypothesis, we conducted a 3 × 5 analysis of variance (ANOVA) with the within-subject factors expectancy (gain cue [gain 90 %], loss cue [loss 90 %], ambiguous cue [gain loss 50 %/loss gain 50 %]) and time (0-0.5 s, 0.5-1 s, 1-1.5 s, 1.5-2 s, 2-2.5 s) on the pupil diameter change data. Our hypothesis should be reflected in a significant main effect of expectancy cue, as well as in a significant expectancy cue × time interaction. Significant main effects of expectancy cue and significant interactions of expectancy cue and time were further investigated by post-hoc pairwise comparisons.

Moreover, we hypothesized that (2a) gain cues, rather than loss cues, enhance attention to gain targets and (2b) loss cues, rather than gain cues, enhance attention to loss targets (cue congruency hypothesis). In addition, we predicted that (2c) gain cues enhance attention to gain targets rather than loss targets and (2d) loss cues enhance attention to loss targets rather than gain targets (target congruency hypothesis). To test these hypotheses, we conducted a 3 × 2 ANOVA with the within-subject factors expectancy (gain cue [gain 90 %], loss cue [loss 90 %], ambiguous cue [gain loss 50 %/loss gain 50 %]), and target (gain, loss) on RTs, the time to first hit on the target (attention orientation), and percentage of gazing at the target half a second after the first hit (attention maintenance). We also performed analyses on logarithmic RTs and excluded outliers (± 3 *SD*s from individual average RT). However, the effects observed in the current study were not affected by these data transformations. Therefore, only the results for the original RT data are described. Ambiguous cues that served as a control condition with maximum uncertainty in our experiment were included as an anchor in the analyses. If true, our hypotheses should be reflected in a significant interaction of the expectancy cue and target. Significant interaction effects were further investigated by post-hoc (Sidak corrected) pairwise comparisons. An α-level of .05 (two-tailed) was applied to all analyses (unless otherwise specified). Reported effect sizes are partial η^2 and noted as η^2_p. If the sphericity assumption was violated, Greenhouse-Geisser corrected values are reported.

Furthermore, we hypothesized that (3) optimistic expectancies guide attention more toward gain targets compared with loss targets than pessimistic expectancies guide attention toward loss targets compared with gain targets (optimism robustness hypothesis). Therefore, two difference scores between four of our experimental conditions were computed:

$$\text{DiffGainCue} = [\text{Gain cue, loss target}] - [\text{Gain cue, gain target}]$$
$$\text{DiffLossCue} = [\text{Loss cue, gain target}] - [\text{Loss cue, loss target}]$$

We anticipated larger difference scores for optimistic expectancies than for pessimistic expectancies (DiffGainCue > DiffLossCue) for the RTs and the time to first hit (attention orientation). We anticipated smaller difference scores for optimistic expectancies than for pessimistic expectancies (DiffGainCue < DiffLossCue) for the percentage of looking at the target half a second after the first hit (attention maintenance). The last measure was expected to show negative difference scores because it was inverted to the RTs and time to first hit (i.e., enhanced attention results in shorter RTs and time to first hit but a larger percentage of looking at the target half a second after the first hit). To test the optimism robustness hypothesis, DiffGainCue and DiffLossCue were compared using pairwise t-tests with an α-level of .05 (one-tailed). The reported effect sizes are Cohen's d and are denoted by *d*.

Last, we hypothesized that (4) optimism robustness scores in our experiment are positively associated with participants' self-reported comparative optimism bias (cf. comparative optimism bias hypothesis). Comparative optimism bias was operationalized as overly optimistic expectancies about future life events for oneself compared with a person of the same age and gender measured by the COS (Weinstein, 1980). Optimism robustness scores were computed with the following formula for the three attention measures (RTs, time to first hit, percentage of looking at target half a second after first hit):

$$\text{Optimism Robustness Score} = \text{DiffGainCue} - \text{DiffLossCue}$$

Because a large sample is needed to investigate inter-individual differences, we merged participants in the two studies ($N = 63$). A Pearson product-moment correlation was run to determine the relationship between participants' mean score on the COS (Weinstein, 1980) and the optimism robustness score for each of the three measures of attention as revealed by our experiments. The α-level was set to .05 (one-tailed).

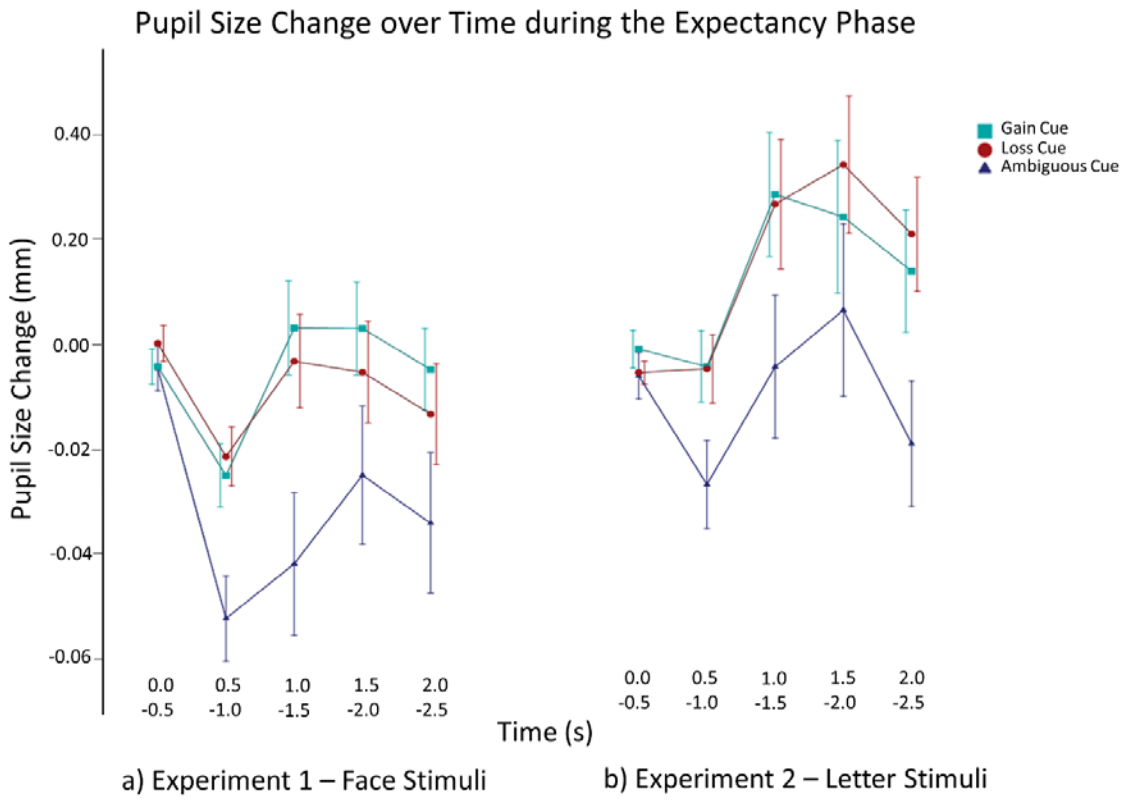
Experiment 1: Results

The results of our experiments are reported in two sections – one devoted to analyses of the expectancy phase of our experiment (manipulation check: pupil diameter change) and another to analyses of the visual search phase (RTs, time to first hit the target and percentage of gazing at the target half a second after first hit revealed by eye tracking, and relation to comparative optimism bias). The mean values, standard errors and 95 % confidence intervals for all experimental conditions from the described analyses are shown in Tables S.3.1 and S.3.2. The difference scores related to the optimism robustness hypothesis are given in Table S.3.3. *F*-values and effect sizes are only reported for significant results of the ANOVAs. Statistical values for all effects (including non-significant results) can be found in Tables S.3.4 and S.3.5. *P*-values for all post-hoc pairwise comparisons can be found in Tables S.3.6 and S.3.7.

Expectancy Phase

Pupil diameter change

Pupil diameter change during the presentation of expectancy cues is shown in Figure 3.2a. As predicted, the main effect of expectancy cue was significant, $F_{(1.44)} = 11.854$, $p < .001$, $\eta^2_p = .283$. Gain and loss cues elicited a smaller decrease in pupil diameter than did ambiguous cues (gain vs. ambiguous cues: $p = .001$, loss vs. ambiguous cues: $p = .007$, as revealed by post-hoc pairwise comparisons). In addition, there was a significant main effect of time, $F_{(2.50)} = 4.098$, $p = .029$, $\eta^2_p = .120$. Moreover, the predicted interaction expectancy × time was significant, $F_{(5.148)} = 9.052$, $p < .001$, $\eta^2_p = .232$. Post-hoc pairwise comparisons showed that the differential effect of expectancy condition on pupil diameter change started between 0.5 and 1 s following the onset of the expectancy cues and remained stable until the end of the analysis interval. The pupil diameter increase was larger and the decrease was smaller for gain and loss cues than for ambiguous cues (0.5-1 s, 1-1.5 s, 1.5-2 s, 2-2.5 s: gain vs. ambiguous cues: *p*s = .005, < .001, = .002, = .004, respectively; loss vs. ambiguous cues: *p*s = .001, .001, .057, .072, respectively, as revealed by post-hoc pairwise comparisons).



a) Experiment 1 – Face Stimuli b) Experiment 2 – Letter Stimuli

Figure 3.2. Pupil diameter change during the expectancy phase as a function of time and expectancy cue. *Gain cue, loss cue, and ambiguous cue refer to the gain 90 %, loss 90 %, and gain loss [loss gain] 50 % cues, respectively. The error bars depict standard errors.*

Visual Search Phase

Reaction times

The RTs are shown in Figure 3.3a. The RTs did not differ between gain and loss targets or between the three expectancy conditions, *p*s > .08. Notably, the predicted expectancy × target interaction was significant, $F_{(2.60)} = 8.324$, $p = .001$, $\eta^2_p = .217$. As anticipated by our cue congruency hypothesis, participants reacted faster to loss targets when they expected to lose than when they expected to gain or had ambiguous expectancies (i.e., when neither optimistic nor pessimistic expectancies dominated; loss vs. gain cues: *p* = .001, loss vs. ambiguous cues: *p* = .041, as revealed by post-hoc pairwise comparisons). In line with our target congruency hypothesis, participants reacted faster to gain targets than to loss targets when they expected to gain (*p* = .001). Participants' RTs did not differ significantly between any of the remaining conditions (all *p*s > .093). The optimism robustness hypothesis had to be rejected: Expecting to gain did not shorten RTs to gain targets compared with loss targets more than expecting to lose shortened RTs to loss targets compared with gain targets, even though there was a trend in the anticipated direction, *t*(30) = 1.602, *p* = .060, *d* = .381.

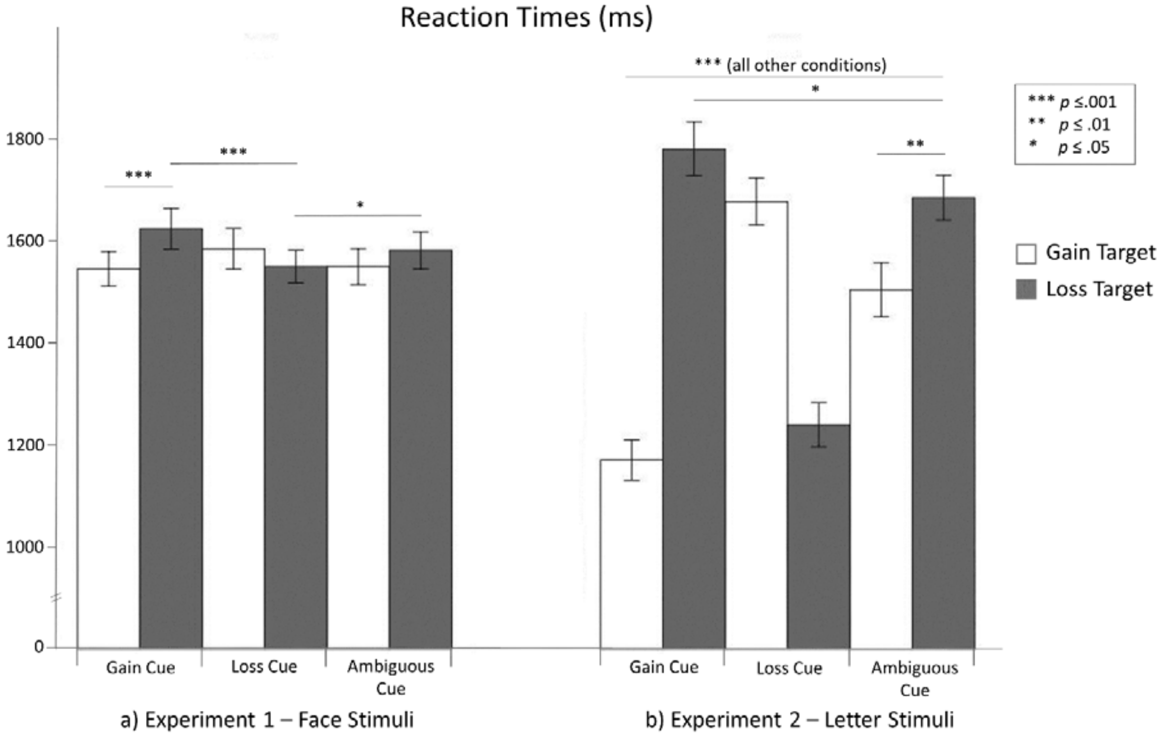


Figure 3.3. Reaction times. *The error bars depict standard errors. The line labeled "all other conditions" indicates that all pairwise comparisons of the conditions encompassed by the line revealed highly significant differences (if not otherwise indicated).*

Eye tracking: Time to first hit the target

The time to first hit the target for the experimental conditions is shown in Figure 3.4a. The time to the first hit did not differ between gain and loss targets or between the three expectancy conditions, *p*s > .180. Contrary to our cue and target congruency hypotheses, the expectancy × target interaction was not significant, *p* = .849. Moreover, the optimism robustness hypothesis had to be rejected: Expecting to gain did not reduce the time to first hit gain targets compared with loss targets more than expecting to lose reduced the time to first hit loss targets compared with gain targets (*p* = .327).

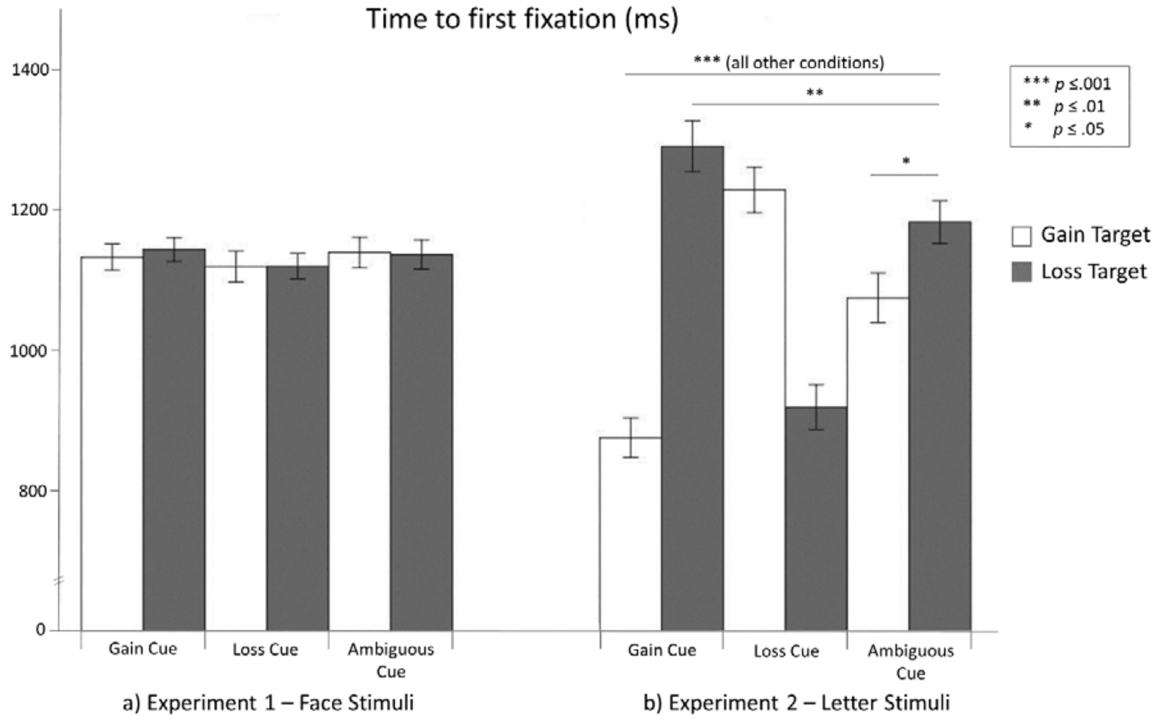


Figure 3.4. Time to first hit. *The error bars depict standard errors. The line labeled "all other conditions" indicates that all pairwise comparisons of the conditions encompassed by the line revealed highly significant differences (if not otherwise indicated).*

Eye tracking: Percentage of gazing at the target half a second after the first hit

Figure 3.5a depicts the amount of time (in %) participants spent gazing at the target half a second after the first hit. Where participants gazed in this time span did not differ between gain and loss targets or between the three expectancy conditions, *p*s > .155. However, the predicted expectancy × target interaction was significant, $F_{(2.50)} = 7.482$, $p = .002$, $\eta^2_p = .200$. In line with our cue congruency hypothesis, participants gazed more at gain targets within half a second after the first hit when they expected to gain than when they expected to lose ($p = .009$, as revealed by post-hoc pairwise comparisons). In line with our target congruency hypothesis, when participants expected to gain, they subsequently gazed longer at gain targets than at loss targets during the half second after the first hit ($p = .001$). The amount of time participants gazed at the target in the half second after the first hit did not differ among the remaining conditions (all *p*s > .066).

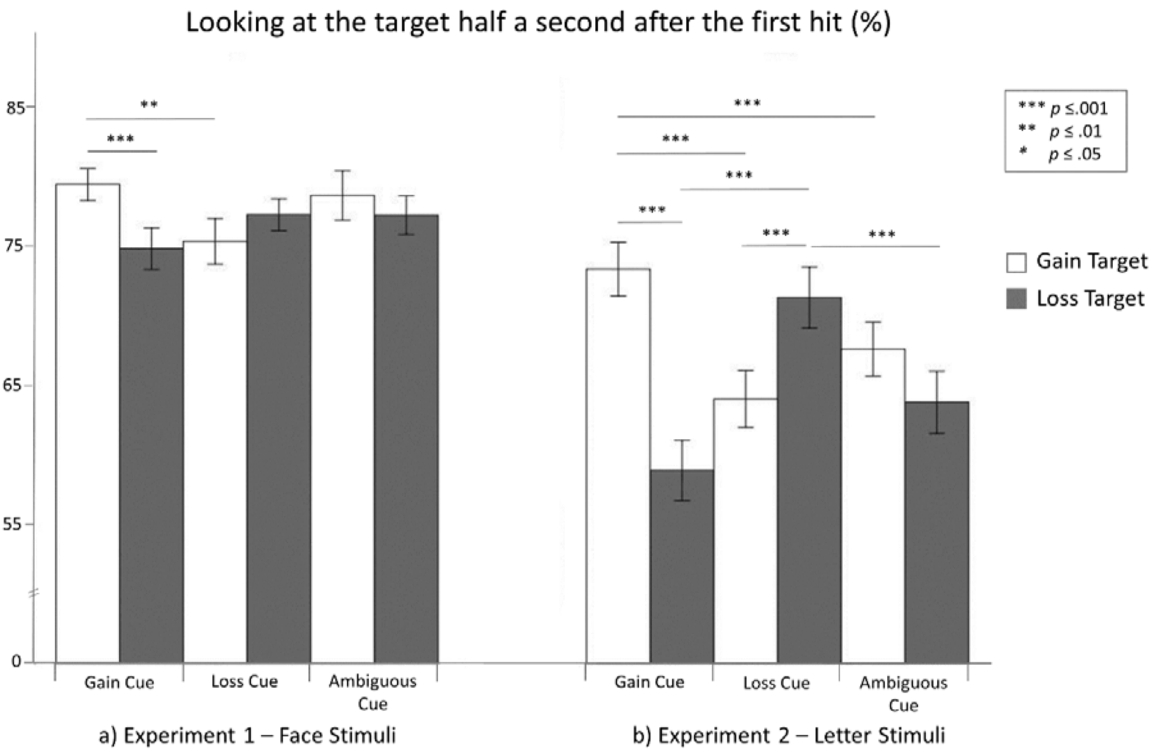


Figure 3.5. Percentage of gazing at the target half a second after the first hit. *The error bars depict standard errors.*

The optimism robustness hypothesis had to be rejected. However, expecting to gain showed a trend to increase the percentage of gazing at gain targets compared with loss targets more than expecting to lose increased the percentage of gazing at loss targets compared with gain targets half a second after the first hit, $t(30) = 1.507$, $p = .071$, $d = .173$.

Relation with Comparative Optimism Bias

Scatterplots of the correlations between optimism robustness scores and mean scores of the COS (Weinstein, 1980) for participants of both experiments are shown in Figure 3.6. As predicted in our comparative optimism bias hypothesis, there were significant weak, positive correlations between the mean score of the COS (Weinstein, 1980) and the optimism robustness score for all three measures of attention: RTs ($r_p = .274$, $p = .015$), time to first hit ($r_p = .274$, $p = .015$), and percentage of gazing at the target half a second after the first hit ($r_p = .245$, $p = .027$).

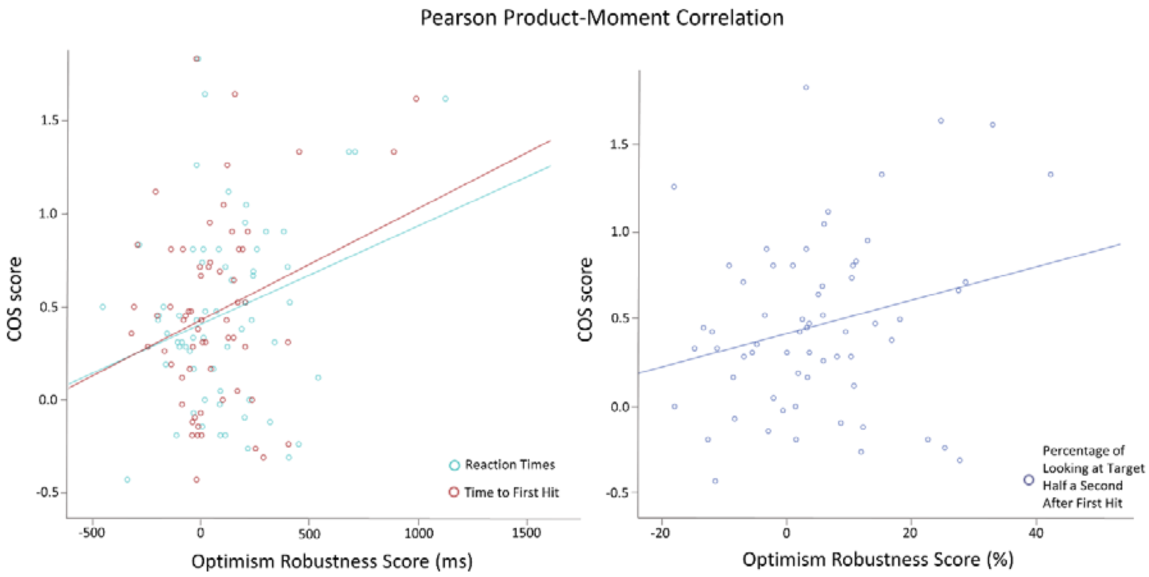


Figure 3.6. Correlation between participants' mean COS score and their optimism robustness scores revealed by the two experiments. *Data of participants in Experiments 1 and 2 have been merged for this analysis in order to have a large enough sample size to investigate inter-individual differences. A score of zero represents no bias, a positive score represents a positivity bias, and a negative score represents a negativity bias in both measures.*

Experiment 1: Discussion

As a manipulation check, we anticipated a larger increase in pupil diameter when participants were presented with gain or loss cues compared with ambiguous cues (control condition) because gain and loss cues were meant to elicit an affective response (i.e., optimistic and pessimistic expectancies). In line with our hypothesis, participants showed a significantly larger increase in pupil diameter for gain cues than for ambiguous cues during two of the analyzed time intervals (1-1.5 s and 1.5-2 s) in Experiment 1. In general, pupil diameter decreased in response to cue presentation and this decrease was significantly larger for ambiguous than for gain and loss cues. Therefore, the pupils were relatively more dilated during the presentation of gain and loss cues than during the presentation of ambiguous cues, indicating a stronger affective response elicited by gain and loss cues.

Moreover, in accordance with our predictions, optimistic expectancies modulated attention, as apparent in the RT and eye gaze data. Participants reacted faster to loss targets when they were pessimistic rather than optimistic and optimistic expectancies shortened RTs to gain targets compared with loss targets (attention orientation). No significant differences in RTs were detected between gain and loss targets when pessimistic or ambiguous expectancies were induced. Moreover, RTs to gain targets did not differ when optimistic expectancies were induced in comparison with pessimistic expectancies.

However, similar results were not seen for the time to first hit (attention orientation) in our eye tracking data. One possible explanation for this is that because of the numerous visual inputs participants received, they tried to obtain an overview in the beginning by gazing at all faces but then reacted faster to gain targets following gain cues even if they had only paid peripheral attention to those targets. However, more focused attention may subsequently have been diverted to gain targets following gain cues during later stages of attention. Consistent with such a view, the results for the percentage of gazing at the target half a second after the first hit (attention maintenance) were very similar to the effects seen in RTs. Participants looked more at gain targets when they had optimistic expectancies compared with pessimistic expectancies and optimistic expectancies made participants look more at gain targets compared with loss targets within a half second after the first hit at a target. Similar to the RTs, the percentage of looking at gain and loss targets half a second after the first hit did not differ when pessimistic or ambiguous expectancies were induced. Moreover, the percentage of looking at loss targets did not differ when optimistic expectancies were induced in comparison with pessimistic expectancies. In conclusion our cue and target congruency hypotheses could only be confirmed for optimistic expectancies, not for pessimistic expectancies.

Notably, although in our first hypothesis we had predicted that pessimistic expectancies guide attention toward punishment compared with reward, this result is congruent with our second hypothesis that optimistic expectancies have a stronger influence on subsequent attention to reward and punishment than pessimistic expectancies do. In line with our optimism robustness hypothesis, we found a small effect that optimistic expectancies shortened participants' RTs to gain targets compared with loss targets more than pessimistic expectancies shortened participants' RTs to loss targets compared with gain targets (attention orientation). A similar effect was seen in our eye tracking measure for attention maintenance. Optimistic expectancies made participants look more at gain targets compared with loss targets than pessimistic expectancies made participants look more at loss targets compared with gain targets half a second after the first hit. However, the trend for both effects was non-significant. Therefore, whether optimistic expectancies had a stronger effect on attention deployment to congruent confirming compared with disconfirming information than pessimistic expectancies was not clearly shown in our data and requires further investigation. In summary, our cue and target congruency hypotheses were only partly confirmed for attention orientation (RTs) and maintenance (percentage of gazing at target half a second after first hit) and the optimism robustness hypothesis was rejected for both attention measures.

As hypothesized, participants' optimism robustness score for all three measures of attention revealed by our experiments is significantly positively correlated with the mean score of the COS (Weinstein, 1980). This supports the idea that processes present in optimism bias also play a role in the robustness of optimistic expectancies and their influences on attention in our experiments.

Even though the results of Experiment 1 are promising, one problem with the stimuli used in this experiment is that happy and sad faces could not be assigned to be gain or loss targets differentially across participants. Happy faces always have a positive valence and sad faces always have a negative valence and it would not have been meaningful to tell participants they lose money when seeing a happy face. These salient stimulus-specific attributes could have differentially influenced attention deployment. For instance, in everyday life, we have repeatedly learned that a happy face indicates important emotional information (e.g., a smiling doctor telling us we are completely healthy or a happy supervisor complementing us on our work), making happy faces particularly salient stimuli that might be processed preferably regardless of the context in which they are presented. Therefore, independently of assigning happy and sad faces as gain and loss targets in our experiment, the face stimuli might have captured participants' attention differently, making them less prone to variations in expectancies. Thus, we conducted a second experiment to replicate our effects using non-social and inherently non-emotional stimuli.

Experiment 2: Methods and materials

Experiment 2 was a replication of Experiment 1 with different stimuli. As both experiments were highly similar, we describe only the details that differ from Experiment 1. If not otherwise indicated, the procedures were identical to Experiment 1.

Participants

Thirty-two healthy psychology students (7 male, age: *M* = 22.19 years; *SD* = 3.00 years; range = 19 - 36 years) who had not participated in Experiment 1 were recruited via the participant pool at the University of Bern and took part in this RT and eye tracking study.

Stimuli

Visual search task (attention): The stimuli consisted of a green and a red "L" and a green and a red "T". The green "L" and the red "T" served as target stimuli and the red "L"s and green "T"s served as distractor stimuli. In each trial, eight red and green “L”s and “T”s were shown on a white background on a circle around the position where the fixation cross was presented. There was an equal probability for the single green “L” or the single red “T” to appear in any of the eight different locations on the circle. The participants’ task was to find the deviant target letter (green “L” or red “T”) among seven neutral distractor letters (red “L”s and green “T”s). In contrast to Experiment 1, in which the stimuli in the visual search array had to be compared using a rather complex attribute comprising many different features (emotional facial expression), the stimuli in Experiment 2 only had to be compared using two clearly separable features (color and shape). However, because the emotional face stimuli used in Experiment 1 are highly familiar and overlearned in everyday life, they may generally produce a stronger pop-out effect among neutral distractor faces than the letter stimuli used in Experiment 2.

Experimental procedure

The procedure was identical to that of Experiment 1 (Figure 3.1, bottom). The only difference was that letters were presented as stimuli in the visual search task instead of faces. For half of the participants, the green “L” represented gain (loss) and the red “T” represented gain (loss) for the other half.

Manipulation check

Three participants were excluded from pupil diameter change analysis because on average, more than 50 % of their trials per time interval had to be excluded because of too much missing eye gaze data. On average, we excluded 21.7 % of pupil diameter data per time interval from the analysis because missing eye gaze data made up > 50 % of the samples. In addition, outliers (deviating more than 3 *SD*s from the average diameter of a given participant during a particular time interval) were eliminated (on average 0.9 % of the remaining pupil diameter data per time interval).

Dependent Variables

Errors comprised ~ 7.7 % of responses and were excluded from the RT analysis. For the eye tracking analyses, ~ 13.2 % of trials were additionally excluded because participants did not hit the target. For the percentage of gaze analysis ~ 4.5 % of trials were additionally excluded because participants did not hit the target within the first 2000 ms of the presentation of the visual search task. Additionally, ~ 4.3 % of trials were excluded because missing eye gaze data comprised > 40 % of the samples.

Experiment 2: Results

Expectancy phase

Pupil Diameter Change

Pupil diameter change during the presentation of expectancy cues is shown in Figure 3.2b. As predicted, the main effect of expectancy cue was significant, $F_{(2.56)} = 12.438$, $p < .001$, $\eta^2_p = .308$. As anticipated, gain and loss cues elicited a larger pupil diameter increase than did ambiguous cues (gain vs. ambiguous cues: $p < .001$, loss vs. ambiguous cues: $p = .001$, as revealed by post-hoc pairwise comparisons). In addition, there was a significant main effect of time, $F_{(2.43)} = 4.284$, $p = .029$, $\eta^2_p = .133$.

Moreover, the predicted interaction expectancy × time was significant, $F_{(4.120)} = 4.988$, $p = .001$, $\eta^2_p = .151$. Post-hoc pairwise comparisons showed that the differential effect of expectancy condition on pupil diameter change started between 1 and 1.5 s (0.5-1 s for loss vs. ambiguous cues) following the onset of the expectancy cues and remained stable until the end of the analysis interval. As anticipated, pupil diameter increase was larger for gain and loss cues than for ambiguous cues (0.5-1 s, 1-1.5 s, 1.5-2 s, 2-2.5 s: gain vs. ambiguous cues: *p*s = .080, < .001, = .009, < .001, respectively; loss vs. ambiguous cues: *p*s = .005, = .005, = .005, < .001, respectively).

Visual search phase

Reaction Times

The RTs are shown in Figure 3.3b. Participants reacted faster to gain targets than to loss targets, showing a main effect of target, $F_{(1.31)} = 12.582$, $p = .001$, $\eta^2_p = .289$. Moreover, participants reacted faster when they expected to gain or lose than when they had ambiguous expectancies, showing a main effect of expectancy, $F_{(2.46)} = 28.227$, $p < .001$, $\eta^2_p = .477$. In addition, the predicted expectancy × target interaction was significant, $F_{(1.43)} = 79.723$, $p < .001$, $\eta^2_p = .720$.

In accordance with our cue congruency hypothesis, participants reacted faster to gain targets when they expected to gain than when they expected to lose or had ambiguous expectancies (gain vs. loss cues: $p < .001$, gain vs. ambiguous cues: $p < .001$, as revealed by post-hoc pairwise comparisons). Moreover, participants reacted faster to gain targets when they had ambiguous expectancies than when they expected to lose ($p < .001$). Participants reacted faster to loss targets when they expected to lose than when they expected to gain or had ambiguous expectancies (loss vs. gain cues: $p < .001$, loss vs. ambiguous cues: $p < .001$). In addition, participants reacted faster to loss targets when they had ambiguous expectancies than when they expected to gain (p = .015).

As predicted by our target congruency hypothesis, when participants expected to gain, they reacted faster to gain targets rather than loss targets (p < .001); when they expected to lose they reacted faster to loss targets rather than gain targets (p < .001); and when they had ambiguous expectancies, they reacted faster to gain targets rather than loss targets (p = .002). The last effect is consistent with the idea of an attention bias for positive stimuli. Moreover, in line with our optimism robustness hypothesis, expecting to gain shortened RTs to gain targets compared with loss targets more than expecting to lose shortened RTs to loss targets compared with gain targets, $t(31)$ = 3.019, p = .003, d = .501.

Eye tracking: Time to first hit the target

The time to first hit the target results mostly mirror the RT results and are shown in Figure 3.4b. Participants took less time to first hit gain targets compared with loss targets, showing a main effect of target, $F_{(1.31)} = 7.247$, p = .011, η^2_p = .189. Moreover, they took less time to hit the target when they expected to lose than when they had ambiguous expectancies, showing a main effect of expectancy, $F_{(2.62)} = 4.918$, p = .010, η^2_p = .137. Notably, the predicted expectancy × target interaction was significant, $F_{(2.49)} = 72.432$, p < .001, η^2_p = .700.

In line with our cue congruency hypothesis, participants first hit gain targets faster when they expected to gain than when they expected to lose or had ambiguous expectancies (gain vs. loss cues: p < .001, gain vs. ambiguous cues: p < .001, as revealed by post-hoc pairwise comparisons). Moreover, participants hit gain targets faster when they had ambiguous expectancies than when they expected to lose (p < .001). Furthermore, as anticipated, participants hit loss targets faster when they expected to lose than when they expected to gain or had ambiguous expectancies (loss vs. gain cues: p < .001, loss vs. ambiguous cues: p < .001). In addition, participants hit loss targets faster when they had ambiguous expectancies than when they expected to gain (p = .003).

As predicted by our target congruency hypothesis, when participants expected to gain, they hit faster at gain targets rather than loss targets (p < .001) and when they expected to lose they hit faster at loss targets rather than gain targets (p < .001). When participants had ambiguous expectancies, they hit faster at gain targets rather than loss targets (p = .019), in agreement with the idea of an attention bias for positive stimuli. Finally, as stated in our optimism robustness hypothesis, expecting to gain reduced the time to hit at gain targets compared with loss targets more than expecting to lose reduced the time to hit at loss targets compared with gain targets, $t(31)$ = 2.091, p = .023, d = .424.

Eye tracking: Percentage of gazing at the target half a second after the first hit

The amount of time (in %) participants spent gazing at the target half a second after the first hit is shown in Figure 3.5b. Participants gazed more at gain targets than loss targets in this time span, showing a main effect of target, $F_{(1.31)} = 7.464$, $p = .010$, $\eta^2_p = .194$, but the amount of time participants spent gazing at the target did not differ among the three expectancy conditions ($p = 224$). Notably, the predicted expectancy × target interaction was significant, $F_{(2.50)} = 31.007$, $p < .001$, $\eta^2_p = .500$.

As hypothesized by our cue congruency hypothesis, participants gazed more at gain targets within a half second after the first hit when they expected to gain than when they expected to lose or had ambiguous expectancies (gain vs. loss cues: $p < .001$, gain vs. ambiguous cues: $p = .001$, as revealed by post-hoc pairwise comparisons). Moreover, participants gazed more at loss targets within a half second after the first hit when they expected to lose than when they expected to gain or had ambiguous expectancies (loss vs. gain cues: $p < .001$, loss vs. ambiguous cues: $p < .001$). In line with our target congruency hypothesis, when participants expected to gain, they gazed more at gain targets than at loss targets within a half second after the first hit ($p < .001$). When participants expected to lose, they gazed more at loss targets than at gain targets within a half second after the first hit ($p = .001$). The amount of time participants spent gazing at the target a half second after the first hit did not differ among the remaining conditions (all *p*s > .063).

Finally, consistent with our optimism robustness hypothesis, expecting to gain increased percentage of gazing at gain targets compared with loss targets half a second after the first hit more than expecting to lose increased percentage of gazing at loss targets compared with gain targets half a second after the first hit, $t(31) = 2.713$, $p = .006$, $d = .595$.

Experiment 2: Discussion

As hypothesized, a larger pupil diameter increase was evoked by gain and loss cues than by ambiguous cues in Experiment 2. This indicates that gain and loss cues elicited an affective response in our participants that can be attributed to the induction of optimistic and pessimistic expectancies, whereas ambiguous cues did not (manipulation check). Thus, differential effects of attention in our experiment can be attributed to the induction of optimistic and pessimistic expectancies.

In accordance with our predictions, the expectancies in Experiment 2 modulated attention deployment, as apparent in the RT and eye gaze data. Participants reacted faster to gain and loss targets when congruent expectancies were induced compared with incongruent expectancies. Furthermore, optimistic and pessimistic expectancies shortened RTs to congruent targets compared with incongruent targets (attention orientation). In the eye gaze data, the same effects were observed for the time to first hit the target (attention orientation) and the percentage of looking at the target half a second after the first hit (attention maintenance).

In line with the idea of a general attention bias to positive stimuli, participants payed more attention to gain compared with loss targets when ambiguous expectancies were induced. This attention bias could be explained by a natural Pavlovian tendency to approach reward stimuli. Research has shown that approaching (i.e., initiating a response to) punishment is more difficult than approaching reward (Guitart-Masip et al., 2011; Guitart-Masip, Duzel, Dolan, & Dayan, 2014). Therefore, a Pavlovian facilitation to approach reward could make people pay more attention to gain compared with loss targets when having ambiguous expectancies.

In contrast to Experiment 1, the optimism robustness hypothesis was clearly supported: Optimistic expectancies biased participants' attention more strongly toward gain targets in comparison with loss targets than pessimistic expectancies biased participants' attention toward loss targets in comparison with gain targets, as shown by the RTs, time to first hit, and percentage of gazing at the target half a second after the first hit. The described Pavlovian tendency to approach reward but not punishment information could also represent an underlying mechanism of this optimism robustness effect because it explains why it might be more difficult to pay attention to loss targets when expecting to gain than to gain targets when expecting to lose. In conclusion, our cue and target congruency hypotheses and our optimism robustness hypothesis were confirmed for both attention orientation (RTs, time to first hit) and attention maintenance (percentage of gazing at the target half a second after the first hit).

General discussion

Affective states that can be attributed to optimistic and pessimistic expectancies were successfully induced in the experiments reported here. Both experiments demonstrate that optimistic expectancies guide attention toward positive compared with negative stimuli. This was revealed in the RTs and eye gaze behavior during the visual search task in Experiment 1 for emotional face stimuli (except for the time to first hit) and in Experiment 2 for non-social letter stimuli. Moreover, in Experiment 2 we clearly demonstrated that pessimistic expectancies guide attention toward negative compared with positive stimuli. As predicted, optimistic expectancies had a stronger influence on attention deployment than pessimistic expectancies – shown by small-to-medium effects in the RT analyses of both experiments and the eye tracking analyses of Experiment 2.

Moreover, this stronger influence of optimistic than pessimistic expectancies on attention was positively associated with individual differences in self-reported comparative optimism bias (Weinstein, 1980).

Modulation of attention by expectancy cues is in line with predictive coding theory, which states that humans create a mental template while expecting certain outcomes in their future and compare sensory information with this template (C. Summerfield et al., 2006; Zelano et al., 2011). Furthermore, our findings correspond to empirical work on the interplay between expectancies and attention deployment to neutral stimuli (Aue et al., 2013a, 2016; Burra & Kerzel, 2013).

In both studies, we show that optimistic expectancies guide attention toward positive in contrast to negative stimuli, a finding that is in line with Peters and colleagues´ (2015) results, even though different methods to induce optimism were used. Peters and colleagues (2015) showed that participants whose state optimism was increased by the Best Possible Self Manipulation (and those whose state optimism had unexpectedly increased by a presumably neutral control manipulation) gazed less at angry faces and more at joyful faces; we showed that optimism induced by cues signaling reward biased participants' attention toward rewarding compared with punishing stimuli (apparent in the RTs and eye gaze behavior). Therefore, inducing state optimism in the beginning of an experiment or inducing optimistic expectancies through cues on a trial-to-trial basis successfully bias subsequent attention deployment. Notably, Peters and colleagues (2015) could only show rather weak effects of state optimism on attention in post-hoc analyses on alternatively created experimental groups whereas we demonstrated much stronger effects of optimistic expectancies on attention to reward and replicated the effects using non-social stimuli.

In addition to replicating results that show optimistic expectancies guide attention toward reward in contrast to punishment, in our second experiment, we demonstrated that pessimistic expectancies guide attention toward stimuli signaling punishment in contrast to stimuli signaling reward. Notably, this effect was only present when non-social letter stimuli were used. This finding initially arose in Experiment 2 (which generally led to stronger effects), which appears to be counterintuitive as social face stimuli would better represent real life situations in which expectancies rely on information with an intrinsic affective meaning. A possible explanation lies in participants' answers to the post-hoc questionnaire about the experiments. Participants in Experiment 2 reported expectancy cues to be more helpful and important for the subsequent visual search task than participants in Experiment 1 (see Analysis S.3.1). It is conceivable that the search task in Experiment 2 was simply more difficult because letter target stimuli stood out less among distractors than the face stimuli did in Experiment 1. Therefore, participants probably had to rely more strongly on the information given during the expectancy phase of the experiment. However, in some conditions, the RTs in Experiment 1 were longer than those in Experiment 2. Thus, it is also possible that social stimuli captured attention to a greater extent (which is likely due to the stimuli's social interaction significance; potentially influential factors: emotional display signaling action intent, attractiveness, or gender). This implies that participants could withdraw attention from letters more easily than from faces. Because different participants were included in Experiments 1 and 2, it is difficult to draw final conclusions in this respect.

In both experiments, optimistic expectancies had a stronger influence on attention deployment than did pessimistic expectancies and this asymmetry in attention deployment was positively related to participants' self-reported optimism bias. Whereas in Experiment 1 only optimistic expectancies influenced subsequent attention to rewarding and punishing stimuli, in Experiment 2 both optimistic and pessimistic expectancies influenced attention but the effect was stronger for optimistic than for pessimistic expectancies (optimism robustness hypothesis). This robustness of optimistic expectancies was present in measures of attention orientation and attention maintenance. Therefore, both more automatic and more controlled or strategic types of stimulus processing during the different stages of attention were strongly influenced by optimistic expectancies. This finding underscores the outstanding relevance of optimism in determining attention processes that rely on very different mechanisms (such as salience detection during attention orientation and emotion regulation during attention maintenance; see Cisler & Koster, 2010 for details on the mechanisms underlying different stages of attention bias).

Emotion regulation goals may explain why optimistic expectancies influenced attention more than pessimistic expectancies in our experiments: First, pessimistic expectancies may have been overridden (especially when stimuli were processed in a more controlled manner during attention maintenance; Cisler & Koster, 2010). In this case, strategic attention on rewarding stimuli (represented by no or smaller effects of pessimistic expectancies compared with optimistic expectancies on attention in our experiments) might be an emotion regulation strategy serving to maintain a positive affective state, which could ultimately provoke a positive feedback effect on initially positively biased expectancies, thereby generating and stabilizing optimism bias.

Second, it is conceivable that people with optimistic expectancies do not want to confront themselves with disconfirming negative evidence and thus avoid attending to stimuli signaling punishment, enhancing attention for rewarding evidence. In this case, avoidance of punishing stimuli with coexistent attention on rewarding stimuli following optimistic expectancies represents an emotion regulation strategy that maintains optimism bias. As explained in the introduction, optimism bias is primarily viewed as a protective mechanism and people are highly motivated to remain optimistic even considering contradictory information (Korn et al., 2014; Sharot et al., 2011; Sharot, 2011).

Observations from our two studies imply that optimism bias and attention bias are strongly interrelated with dynamic bi-directional influences between each other that might vigorously strengthen both biases in the long run. Notably, our data might elucidate why people maintain their overly optimistic expectancies even when confronted with disconfirming information whereas they overcome pessimistic expectancies (Sharot et al., 2011). Attention processes apparently play a crucial role in this highly interesting phenomenon in optimism bias. As seen in our experiments, people pay less attention to disconfirming punishing feedback ("bad news"; compared with rewarding feedback) when they are optimistic than to disconfirming rewarding feedback ("good news"; compared with punishing feedback) when they are pessimistic (optimism robustness hypothesis). This asymmetry in attention deployment can explain why people update their expectancies when receiving good news but not when receiving bad news. Bad news might not be processed as deeply as good news, resulting in selective updating of expectancies when good news is received.

To strengthen this interpretation of our data, we performed additional analyses on the evolution in RTs over the time course of our experiment (Analysis S.3.2). When participants were confronted with disconfirming rewarding feedback while they were pessimistic, they adapted their orientation of attention quite rapidly over the course of the experiment, as shown by faster RTs in the second block of the experiment (steep learning curve). In contrast, when participants were confronted with disconfirming punishing feedback while they were optimistic, they adapted their orientation of attention rather slowly, as shown by faster RTs only in the third and fourth blocks of the experiment (flat learning curve). Slower learning regarding necessary attentional switching when being optimistic might also be related to updated expectancies over the course of the experiment. In conclusion, our novel findings suggest an underlying cognitive (i.e., attention-related) mechanism for asymmetric updating of expectancies, a crucial phenomenon implicated in the maintenance of optimism bias, with direct implications for mental health (Garrett et al., 2014; Korn et al., 2014; Sharot et al., 2011).

Some methodological features of this work might limit the conclusions that can be drawn about how optimistic and pessimistic expectancies influence attention deployment. First, most participants learned that gain and loss cues in our studies did not really represent a 90 % chance of gaining or losing. This might have weakened the influence of expectancy cues on participants. In our design, we had to reduce the actual chances of gaining or losing to obtain enough incongruent trials for data analysis. However, several important considerations show that the expectancy cues in our studies influenced participants: (a) in most of the announced “90 % cue” trials (in 67 % of these trials) the expectancy cues correctly predicted the subsequent target. Moreover, participants were informed that the computer randomly chose a target, possibly leading to probabilities that differed from the announced average value of 90 %, thus reducing the likelihood that participants distrusted the cues; (b) past experiments have shown that instructions about proportions can be sufficient to produce corresponding behavioral effects (Entel, Tzelgov, & Bereby-Meyer, 2014, Experiment 1) even if the given information does not represent the true proportions; and (c) even if participants did not consciously believe the expectancy cues, the (possibly unconscious) effect of these cues on attention was still visible in the RTs and eye gaze behavior, thereby demonstrating their effectiveness.

Second, one might argue that the expectancy cues used in our studies did not actually induce optimistic and pessimistic expectancies. It would be possible that participants only drew on the predictive cognitive information the cues entailed (i.e., which specific target to search for) when performing the visual search task. This would imply that the differences in attention deployment we found solely derive from the cue’s predictive information not from optimistic or pessimistic expectancies induced by the cues. However, such an interpretation of the data cannot explain the differential effect that gain compared with loss cues had on attention deployment in our studies (optimism robustness hypothesis) because the predictive cognitive information of the gain and loss cues was equal. Moreover, we demonstrate that participants with higher optimism bias scores as revealed by the COS (Weinstein, 1980) showed a stronger influence of gain compared with loss cues on their attention deployment. This implies that optimism and pessimism did indeed play a role in our experiments. Future studies might directly circumvent any doubts on whether the gain and loss cues in the present experimental design induce optimistic and pessimistic expectancies by adding a control condition containing a cue that is predictive of the target’s identity but is not associated with gains or losses.

Third, we told participants that there will always be a target present in the visual search array. Consequently, some participants in Experiment 1 reported in the post-experimental questionnaire to have first looked at one side of the screen and pressed the button for the opposite side if the target was not present on the first side without further looking for the target. However, this strategy was not reported to be used in Experiment 2, which led to greatly overlapping results, making it very likely that this search strategy did not actually influence results. Moreover, even though some participants noted the use of this strategy in Experiment 1, eye tracking data showed that our expectancy manipulation influenced attention maintenance, implying that even if participants reported that they only looked at one half of the search array, they possibly unconsciously gazed at the target. Notably, there is no reason to suspect that employment of such a strategy would have had differential implications for optimistic and pessimistic expectancies. Thus, none of the limiting features mentioned here should have greatly influenced the findings reported in this paper.

In general, the findings are an important contribution to a more nuanced view of the processes at the basis of optimism bias. Modulation of subsequent attention processes from optimism bias is especially interesting because of its beneficial effects for mental health. Knowing that biased attention processes underlie important phenomena (such as selective updating) in optimism bias, which in turn are related to mental health, could ultimately yield a better understanding of psychological disorders and possible treatments. For instance, in contrast to healthy people, patients suffering from depression update their expectancies in both optimistic and pessimistic directions (Korn et al., 2014). Patients with depression do not display a positive attention bias but attend preferably to negative information (Gotlib et al., 2004). Maladaptive attention processes caused by an absence of optimism bias and/or resulting in an absence of selective updating of expectancies in patients could be addressed by attention bias modification training or even training that targets both future expectancies and attention deployment (Aue & Okon-Singer, 2015; Everaert et al., 2012; Hirsch et al., 2006). This approach is particularly important as optimistic biases in expectancies and attention might mutually reinforce and strengthen each other over time. The relationship of optimistic expectancies and attention is also important in non-clinical settings. For instance, when having a rough day, people can engage in a form of emotion regulation that incorporates active attempts at thinking positively and being optimistic about the future, thereby automatically driving their focus of attention to rewarding things in their environment, which likely results in enhanced well-being.

In conclusion, our data show that optimistic and pessimistic expectancies influence how we see the world around us and which aspects of our environment we direct attention to. Optimistic expectancies appear to be very powerful in biasing our attention to rewarding information, which underscores the uniqueness of optimism-related processing in humans and might provide information on which cognitive mechanisms are essential for the benefits of optimism bias. This can be central for fostering individual well-being and mental health. As we have shown that being optimistic or pessimistic influences which parts of our environment we pay attention to, we agree with Charlie Chaplin’s famous words and know that we should look up and use all the optimism we can muster to ensure we see the beautiful rainbow.

Supplementary Information

Analysis S.3.1. Differences between participants' answers to questionnaires in Experiments 1 and 2.

Data Analysis

The participants indicated if (a) they had paid attention to the expectancy cues, (b) the cues were important to prepare their answer, (c) the cues helped them to answer as quickly and correctly as possible, and (d) the cues influenced the difficulty to find the targets on a post-experimental questionnaire. To obtain information on whether participants' experience of the task might have differed among the two experiments, the differences between participants' answers ("yes" or "no") on the post-experimental questionnaire in Experiments 1 and 2 were investigated with a $\chi 2$ test (df = 1). An α-level of .05 (two-tailed) was applied.

Moreover, participants completed the German version of the LOT-R (Scheier et al., 1994) measuring trait optimism. To ensure that trait optimism did not differ between participants in the two experiments, the LOT-R scores (Scheier et al., 1994) were compared between participants in Experiments 1 and 2 using a t-test for independent samples (two-tailed).

Results

In the post-experimental questionnaires of both Experiments 1 and 2, most participants reported that they paid attention to the expectancy cues, indicating that they followed the task instructions well (Experiment 1: 74 %, Experiment 2: 88 %). The answers to the post-experimental questionnaire are shown in Table S.3.8.

In contrast to Experiment 1, most participants in Experiment 2 reported that the expectancy cues presented in the beginning of each trial were important to prepare their reaction ($\chi^2 = 19.693$, $p < .001$), helped them to answer as quickly and correctly as possible ($\chi^2 = 15.276$, $p < .001$), and influenced how difficult it was to find a target ($\chi^2 = 9.958$, $p = .002$; see Table S.3.8 for details). Trait optimism did not differ between participants of Experiments 1 and 2, $t_{(61)} = .024$, $p = .981$ ($M_{\text{Exp 1}} = 22.710$ and $M_{\text{Exp 2}} = 22.688$).

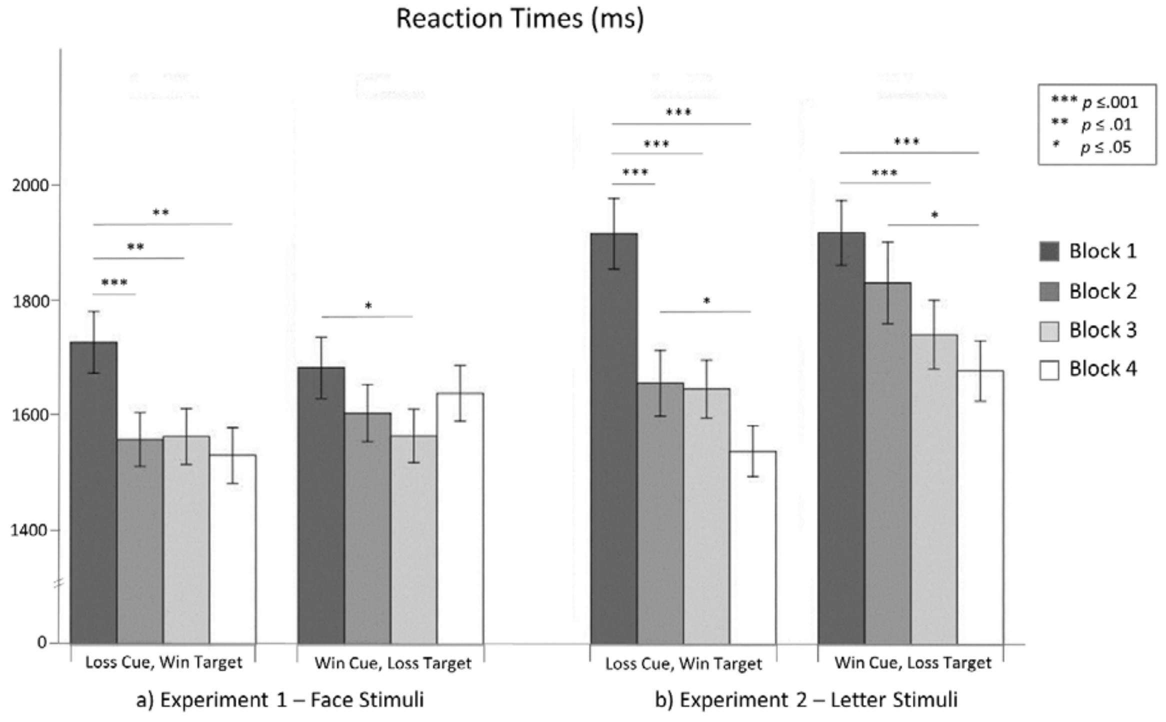
Conclusion

Even though participants in both experiments followed the task instructions, participants in Experiment 2 found the expectancy cues to be more helpful for the subsequent visual search task than participants in Experiment 1. This might show why the effects of expectancies on attention deployment were generally stronger in Experiment 2 than in Experiment 1. However, because different participants were included in Experiments 1 and 2, it is difficult to draw conclusions about the distinct mechanisms employed in the experiments.

Analysis S.3.2. Evolution of RTs over time.

Data Analysis

To further examine our optimism robustness hypothesis, we analyzed the changes in RTs over time. The evolution of RTs in the two incongruent conditions (gain cue, loss target and loss cue, gain target) could reveal differential updating mechanisms when incongruent feedback is given, underscoring the robustness of optimistic expectancies in contrast to pessimistic expectancies. Therefore, time was added to the ANOVA as a within-subject factor. As a result, a 4 × 3 × 2 ANOVA with the within-subject factors time (block 1, block 2, block 3, and block 4), expectancy (gain cue [gain 90 %], loss cue [loss 90 %], ambiguous cue [gain loss 50 %/loss gain 50 %]), and target (gain, loss) was conducted on the RTs. The focus of this analysis was on the development of RTs in the two incongruent conditions (gain cue, loss target and loss cue, gain target), which are depicted in Figure S.3.1. Therefore, only post-hoc tests that reveal information on the development of these two conditions over time were reported.



a) Experiment 1 – Face Stimuli
b) Experiment 2 – Letter Stimuli

Figure S.3.1. RT development of incongruent conditions over four blocks. *To simplify the graph, the remaining conditions are not depicted although statistics were run on all experimental conditions. The error bars depict standard errors.*

Results

Experiment 1: Participants reacted faster in block 3 than in block 1, showing a main effect of time, $F_{(3.84)} = 5.902$, $p = .001$, $\eta^2_p = .174$. There was a significant time × expectancy interaction, $F_{(6.168)} = 3.211$, $p = .005$, $\eta^2_p = .103$, and a significant expectancy × target interaction, $F_{(2.56)} = 6.497$, $p = .003$, $\eta^2_p = .188$. In addition, there was a trend for a time × expectancy × target interaction, $F_{(6.168)} = 1.876$, $p = .088$, $\eta^2_p = .063$. Post-hoc pairwise comparisons showed that when participants expected to gain, they only reacted significantly faster to loss targets in block 3 compared with block 1 ($p = .032$). In contrast, when participants expected to lose, they reacted significantly faster to gain targets in blocks 2, 3, and 4 compared with block 1 (block 1 vs. block 2: $p = .001$, block 1 vs. block 3: $p = .005$, block 1 vs. block 4: $p = .002$).

Experiment 2: Participants reacted faster in blocks 2, 3, and 4 than in block 1 and faster in blocks 3 and 4 than in block 2, showing a main effect of time, $F_{(3.78)} = 27.609$, $p < .001$, $\eta^2_p = .471$. Moreover, participants reacted faster when they expected to gain or lose than when they had ambiguous expectancies, showing a main effect of expectancy, $F_{(2.46)} = 26.697$, $p < .001$, $\eta^2_p = .463$. Participants reacted faster to gain targets than to loss targets, showing a main effect of target, $F_{(1.31)} = 13.089$, $p = .001$, $\eta^2_p = .297$. Additionally, there was a significant expectancy × target interaction, $F_{(1.43)} = 81.530$, $p < .001$, $\eta^2_p = .725$, and a significant time × expectancy × target interaction, $F_{(5.144)} = 3.752$, $p = .004$, $\eta^2_p = .108$. Post-hoc pairwise comparisons showed that when participants expected to gain, they reacted significantly faster to loss targets in blocks 3 and 4 than in block 1 (block 1 vs. block 3: $p = .001$, block 1 vs. block 4: $p < .001$) and faster in block 4 than in block 2 ($p = .032$). When participants expected to lose, they reacted significantly faster to gain targets in blocks 2, 3, and 4 than block 1 (block 1 vs. block 2: $p < .001$, block 1 vs. block 3: $p < .001$, block 1 vs. block 4: $p < .001$) and faster in block 4 than block 2 ($p = .022$).

Conclusion

In line with our optimism robustness hypothesis, analyses of the evolution of RTs in incongruent conditions showed that when participants received disconfirming rewarding feedback while being pessimistic, they updated their attention quite rapidly (from the first to the second block, a steep learning curve). In contrast, when participants received disconfirming punishing feedback while being optimistic, they updated their attention more slowly over the course of the experiment (only in the third and fourth blocks, a flat learning curve). These results underscore the robustness of optimistic expectancies compared with pessimistic expectancies when being confronted with disconfirming feedback.

Table S.3.1

Table S.3.1. Mean values, standard errors, and 95 % confidence intervals (CIs) of pupil diameter change for the three expectancy cue conditions during five analyzed 0.5-s time intervals following cue onset in Experiments 1 (N = 31) and 2 (N = 32).

Condition		**Experiment 1**					**Experiment 2**				
		0.0 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0 - 2.5	0.0 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0 - 2.5
Gain Cue	M	- .004	- .025	.003	.003	- .005	- .001	- .004	.029	.024	.014
	SE	.003	.006	.009	.009	.008	.004	.007	.012	.015	.012
	95 %	- .011	- .037	- .015	- .015	- .021	- .008	- .018	.004	- .006	- .010
	CI	.003	- .013	.022	.021	.011	.006	.010	.053	.054	.038
Loss Cue	M	.000	- .021	- .003	- .005	- .013	- .005	- .005	.027	.034	.021
	SE	.003	.006	.009	.010	.010	.002	.007	.012	.013	.011
	95 %	- .007	- .033	- .021	- .025	- .033	- .010	- .018	.001	.008	- .001
	CI	.007	- .010	.015	.015	.006	- .001	.009	.052	.061	.043
Ambiguous Cue	M	- .005	- .052	- .042	- .025	- .034	- .006	- .027	- .004	.007	- .019
	SE	.004	.008	.014	.013	.013	.004	.008	.014	.016	.012
	95 %	- .013	- .069	- .070	- .052	- .062	- .015	- .044	- .032	- .027	- .043
	CI	.004	- .036	- .014	.002	- .007	.003	- .009	.024	.040	.006

Table S.3.2

Table S.3.2. Mean values, standard errors, and 95 % confidence intervals (CIs) of reaction times, time to first hit, and percentage of gazing at the target half a second after the first hit are summarized for all experimental conditions in Experiments 1 (N=31) and 2 (N=32).

Condition		Reaction times (in ms)		Time to first hit (in ms)		Percentages of gazing at the target half a second after the first hit (in %)	
		Exp. 1	*Exp. 2*	*Exp. 1*	*Exp. 2*	*Exp. 1*	*Exp. 2*
Gain cue	M	1585.47	1476.27	1137.37	1082.26	77.10	66.10
	SE	35.51	35.60	15.64	25.28	1.20	1.70
	95 %	1512.94	1403.67	1105.44	1030.70	74.70	62.60
	CI	1657.99	1548.87	1169.31	1133.82	79.50	69.60
Loss cue	M	1568.11	1459.27	1118.89	1073.00	76.30	67.70
	SE	34.79	32.10	18.24	22.44	1.20	1.90
	95 %	1497.06	1393.81	1081.63	1027.22	73.80	63.90
	CI	1639.16	1524.73	1156.14	1118.76	78.80	71.40
Ambiguous cue	M	1566.54	1595.50	1137.16	1128.03	77.90	65.70
	SE	33.92	40.59	18.10	24.50	1.40	1.80
	95 %	1497.26	1512.72	1100.20	1078.07	75.00	61.90
	CI	1635.82	1678.29	1174.13	1177.99	80.80	69.40
Gain target	M	1560.80	1451.49	1129.71	1058.89	77.80	68.30
	SE	34.82	38.72	18.53	25.29	1.30	1.70
	95 %	1489.68	1372.52	1091.88	1007.31	75.10	64.80
	CI	1631.92	1530.46	1167.55	1110.46	80.50	71.80
Loss target	M	1585.95	1569.21	1132.57	1129.97	76.40	64.70
	SE	34.80	37.70	15.84	25.21	1.20	1.90
	95 %	1514.88	1492.32	1100.22	1078.55	74.00	60.80
	CI	1657.02	1646.09	1164.92	1181.39	78.90	68.50
Gain cue, gain target	M	1546.18	1171.08	1131.92	875.00	79.40	73.30
	SE	33.88	39.62	18.88	28.38	1.20	1.90
	95 %	1476.98	1090.28	1093.37	817.11	77.00	69.40
	CI	1615.38	1251.87	1170.47	932.89	81.80	77.30
Gain cue, loss target	M	1624.75	1781.46	1142.82	1289.52	74.80	58.90
	SE	39.90	52.90	16.86	36.32	1.50	2.20
	95 %	1543.26	1673.58	1108.39	1215.45	71.80	54.50
	CI	1706.23	1889.34	1177.26	1363.59	77.80	63.30
Loss cue, gain target	M	1585.62	1678.16	1118.60	1227.47	75.30	64.00
	SE	39.87	45.67	21.87	32.37	1.60	2.00
	95 %	1504.20	1585.01	1073.93	1161.46	72.00	59.90
	CI	1667.04	1771.31	1163.28	1293.49	78.70	68.20
Loss cue, loss target	M	1550.61	1240.38	1119.17	918.50	77.20	71.30
	SE	32.17	43.03	18.03	32.24	1.10	2.20
	95 %	1484.91	1152.62	1082.34	852.75	74.90	66.80
	CI	1616.30	1328.14	1156.00	984.25	79.60	75.80
Ambiguous cue, gain target	M	1550.59	1505.23	1138.61	1074.18	78.60	67.60
	SE	35.26	53.17	21.70	34.05	1.80	1.90
	95 %	1478.59	1396.78	1094.31	1002.70	75.00	63.30
	CI	1622.59	1613.67	1182.92	1145.67	82.20	71.60
Ambiguous cue, loss target	M	1582.49	1685.78	1135.71	1181.88	77.20	63.80
	SE	36.29	43.50	20.91	30.20	1.40	2.20
	95 %	1508.37	1597.06	1093.01	1120.29	74.40	59.20
	CI	1656.61	1774.50	1178.42	1243.47	80.00	68.30

Table S.3.3

Table S.3.3. Difference scores of reaction times, time to first hit, and percentage of gazing at the target half a second after the first hit are summarized for Experiments 1 and 2.

Difference score	Reaction times (in ms)		Time to first hit (in ms)		Percentage of gazing at the target half a second after the first hit (in %)	
	Exp. 1	*Exp. 2*	*Exp. 1*	*Exp. 2*	*Exp. 1*	*Exp. 2*
[Gain cue, loss target] – [Gain cue, gain target]	78.57	610.39	10.90	414.52	-4.60	-14.46
[Loss cue, gain target] – [Loss cue, loss target]	35.02	437.78	-.56	308.97	-1.90	-7.29

Table S.3.4

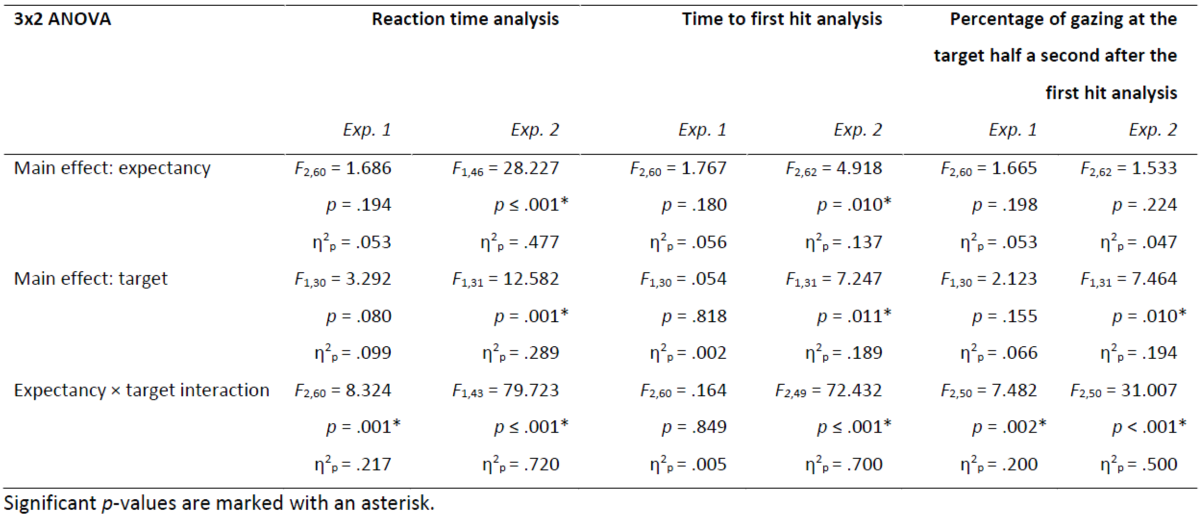
Table S.3.4. Statistical values from the 3 (expectancy: gain, loss, ambiguous) x 5 (time: 0-0.5 s, 0.5-1 s, 1-1.5 s, 1.5-2 s, 2-2.5 s) ANOVA are given for the pupil diameter change analysis from Experiments 1 and 2.

3x5 ANOVA	**Pupil diameter change**	
	Exp. 1	*Exp. 2*
Main effect: expectancy	$F_{1,44} = 11.854$	$F_{2,56} = 12.438$
	$p \leq .001$*	$p \leq .001$*
	$\eta^2_p = .283$	$\eta^2_p = .308$
Main effect: time	$F_{2,50} = 4.098$	$F_{2,43} = 4.284$
	$p = .029$*	$p = .029$*
	$\eta^2_p = .120$	$\eta^2_p = .133$
Expectancy × time interaction	$F_{5,148} = 9.052$	$F_{4,120} = 4.988$
	$p \leq .001$*	$p = .001$*
	$\eta^2_p = .232$	$\eta^2_p = .151$

Note: Significant *p*-values are marked with an asterisk.

Table S.3.5

Table S.3.4. Statistical values from the 3 (expectancy: gain, loss, ambiguous) x 2 (target: gain, loss) ANOVA are given for the reaction time analysis, time to first hit analysis, and percentage of gazing at the target half a second after the first hit analysis from Experiments 1 and 2.

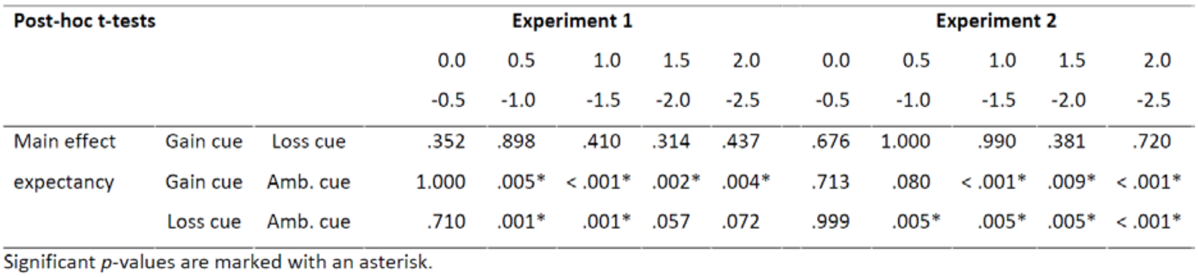


3x2 ANOVA	Reaction time analysis		Time to first hit analysis		Percentage of gazing at the target half a second after the first hit analysis	
	Exp. 1	*Exp. 2*	*Exp. 1*	*Exp. 2*	*Exp. 1*	*Exp. 2*
Main effect: expectancy	$F_{2,60}$ = 1.686	$F_{1,46}$ = 28.227	$F_{2,60}$ = 1.767	$F_{2,62}$ = 4.918	$F_{2,60}$ = 1.665	$F_{2,62}$ = 1.533
	p = .194	$p \leq$ .001*	p = .180	p = .010*	p = .198	p = .224
	η^2_p = .053	η^2_p = .477	η^2_p = .056	η^2_p = .137	η^2_p = .053	η^2_p = .047
Main effect: target	$F_{1,30}$ = 3.292	$F_{1,31}$ = 12.582	$F_{1,30}$ = .054	$F_{1,31}$ = 7.247	$F_{1,30}$ = 2.123	$F_{1,31}$ = 7.464
	p = .080	p = .001*	p = .818	p = .011*	p = .155	p = .010*
	η^2_p = .099	η^2_p = .289	η^2_p = .002	η^2_p = .189	η^2_p = .066	η^2_p = .194
Expectancy × target interaction	$F_{2,60}$ = 8.324	$F_{1,43}$ = 79.723	$F_{2,60}$ = .164	$F_{2,49}$ = 72.432	$F_{2,50}$ = 7.482	$F_{2,50}$ = 31.007
	p = .001*	$p \leq$ .001*	p = .849	$p \leq$ .001*	p = .002*	$p <$ .001*
	η^2_p = .217	η^2_p = .720	η^2_p = .005	η^2_p = .700	η^2_p = .200	η^2_p = .500

Significant *p*-values are marked with an asterisk.

Table S.3.6

Table S.3.6. P-values from post-hoc pairwise t-tests (Sidak corrected) comparing pupil diameter change for the different expectancy cues during five 0.5-s time intervals following cue onset in Experiments 1 and 2.



Post-hoc t-tests			Experiment 1					Experiment 2				
			0.0 -0.5	0.5 -1.0	1.0 -1.5	1.5 -2.0	2.0 -2.5	0.0 -0.5	0.5 -1.0	1.0 -1.5	1.5 -2.0	2.0 -2.5
Main effect expectancy	Gain cue	Loss cue	.352	.898	.410	.314	.437	.676	1.000	.990	.381	.720
	Gain cue	Amb. cue	1.000	.005*	< .001*	.002*	.004*	.713	.080	< .001*	.009*	< .001*
	Loss cue	Amb. cue	.710	.001*	.001*	.057	.072	.999	.005*	.005*	.005*	< .001*

Significant *p*-values are marked with an asterisk.

Table S.3.7

Table S.3.7. P-values from post-hoc pairwise t-tests (Sidak corrected) comparing different experimental conditions are given for reaction time analysis, time to first hit analysis, and percentage of gazing at the target half a second after the first hit analysis from Experiment 1 and 2.

Post-hoc t-tests			**Reaction time analysis**		**Time to first hit analysis**		**Percentage of gazing at the target half a second after the first hit analysis**	
			Exp. 1	*Exp. 2*	*Exp. 1*	*Exp. 2*	*Exp. 1*	*Exp. 2*
Main effect expectancy	Gain cue	Loss cue	.446	.500	.245	.905	.693	.435
	Gain cue	Amb. cue	.364	< .001*	1.000	.085	.780	.983
	Loss cue	Amb. cue	.997	< .001*	.406	.037*	.233	.267
Expectancy × target interaction	Gain target	Gain vs. loss cue	.191	< .001*	.784	< .001*	.009*	< .001*
		Gain vs. amb. cue	.993	< .001*	.969	< .001*	.899	.001*
		Loss vs. amb. cue	.117	< .001*	.606	< .001*	.117	.104
	Loss target	Gain vs. loss cue	.001*	< .001*	.355	< .001*	.163	< .001*
		Gain vs. amb. cue	.143	.015*	.979	.003*	.066	.096
		Loss vs. amb. cue	.041*	< .001*	.657	< .001*	1.000	< .001*
	Gain vs. loss target	Gain cue	.001*	< .001*	.536	< .001*	.001*	< .001*
		Loss cue	.093	< .001*	.973	< .001*	.180	.001*
		Amb. cue	.171	.002*	.898	.019*	.339	.063

Significant *p*-values are marked with an asterisk.

Table S.3.8

Table S.3.8. Number (percentage) of participants answering “yes” and “no” to questions on the post-experimental questionnaire in Experiments 1 and 2.

Question	**Experiment 1**		**Experiment 2**	
	yes	no	yes	no
Did you pay attention to probability cues in the beginning of each trial?	23 (74 %)	8 (26 %)	28 (88 %)	4 (12 %)
Were probability cues in the beginning of each trial important to prepare your answer?	9 (29 %)	22 (71 %)	27 (84 %)	5 (16 %)
Do you feel that probability cues helped you to answer as fast and correct as possible?	9 (29 %)	22 (71 %)	25 (78 %)	7 (22 %)
Did probability cues influence difficulty to find the gain or loss targets?	11 (36 %)	20 (64 %)	24 (75 %)	8 (25 %)

Chapter 4

The Interplay of Optimism Bias and Attention Bias: Neural and Behavioral Correlates

Laura Kress, Laurent Schuepbach, Roland Wiest, Erno Hermans, and Tatjana Aue

Abstract

Optimism bias and positive attention bias are crucial features of healthy information processing. They have mostly been examined separately, although recent findings suggest dynamic bi-directional optimism-attention interactions. The current study investigated neural mechanisms underlying such interactions. We hypothesized that optimistic and pessimistic expectancies guide attention to expected information and enhance salience network (SN) and executive control network (ECN) activity (e.g., insula, anterior cingulate cortex, posterior parietal cortex) during processing of unexpected information. Moreover, based on previous findings on the unique nature of optimism-attention interactions, we anticipated that optimistic expectancies have a stronger impact on attention and SN/ECN activity than pessimistic expectancies do. Optimistic and pessimistic expectancies were induced with verbal cues in 50 participants (both genders) before testing attention to reward and punishment in a visual search task while participants underwent functional MRI. As hypothesized, expectancy cues automatically guided attention to expected information (revealed in fast reactions), whereas processing of unexpected information enhanced SN/ECN activity. More important, these effects were stronger for optimistic than for pessimistic expectancy cues. Hence, although unexpected punishment following optimistic expectancies is thoroughly processed in the brain, it might inhibit behavioral responses. Our findings suggest that optimistic expectancies involve particularly strong predictions of reward, causing automatic guidance of attention to reward and great surprise about unexpected punishment. Maintenance of attention on reward following optimistic expectancies – as revealed by prior evidence – likely reduces the salience of disproving punishment to maintain initial strong predictions of reward. Thus, optimism bias can instigate a robust, self-sustaining upward spiral of positivity.

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Introduction

Most of us are overly optimistic about our future (Sharot, 2011; Weinstein, 1980). This optimism bias and similar cognitive phenomena such as positive attention bias (preferably attending to positive vs. neutral information; Pool et al., 2016a) determine the way we see the world. Optimism bias and positive attention bias have mostly been examined separately, even though both biases are crucial features of healthy information-processing (Joormann & Gotlib, 2007; Raila, Scholl, & Gruber, 2015; Sharot, 2011) and the combined cognitive biases hypothesis suggests that cognitive biases usually interact and mutually enforce each other (Aue & Okon-Singer, 2015; Hirsch et al., 2006). In line with this theory, we have suggested that (a) optimistic expectancies guide attention to positive information in the environment and (b) directing attention to positive information enhances optimism bias (Kress & Aue, 2017). Notably, these suggestions are supported by recent empirical findings revealing an interplay between optimistic expectancies and attention deployment (Kress et al., 2018). Dynamic bi-directional optimism-attention interactions may result in a self-sustaining upward spiral of positivity (Booth et al., 2017; Garland et al., 2010). However, the neural mechanisms supporting this dynamic interplay have not been investigated yet, even though they can substantially increase our understanding of how optimism and attention bias maintain over time and boost mental health (Kress & Aue, 2017).

Prior neuroimaging work revealed that attention processes rely on activity in large-scale neural networks (e.g., Kim et al., 1999). Specifically, the salience network (SN: e.g., insula, dorsal anterior cingulate cortex [dACC]) has been suggested to be crucially involved in the detection of salient information and initial orientation of attention. Furthermore, the SN elicits dynamic shifts between the executive control network (ECN; e.g., dorsolateral prefrontal cortex [dlPFC], posterior parietal cortex [PPC]) and the default mode network (DMN; e.g., ventromedial prefrontal cortex, posterior cingulate cortex [PCC]). Whereas the ECN is typically activated during cognitively demanding tasks (involved in attention maintenance and the modulation of information in working memory), the DMN is typically deactivated during cognitively demanding tasks (Menon, 2015b; Menon & Uddin, 2010). Studies investigating the impact of expectancies on attention indicate that nodes of these large-scale neural networks (particularly of the SN and ECN, e.g., insula, dlPFC, PPC, and PCC) are active when spatial attention is shifted to positive information following predictive cues (Mohanty et al., 2008; Small et al., 2003; Small et al., 2005). However, the predictive cues in these studies induced expectancies about the spatial location of relevant information (i.e., the target will be on the left/right) rather than the information's valence (i.e., the target will be positive/negative). Thus, even though prior findings provide first hints on brain regions underlying the influence of spatial expectancies on attention, they do not reveal how emotional expectancies (e.g., optimism/pessimism) guide attention (see Aue, Guex, Chauvigné, Okon-Singer, & Vuilleumier, in press for investigations of behavioral and neural mechanisms underlying such emotional expectancies on attention in relation to anxiety).

Therefore, the present fMRI study investigated the impact of optimistic and pessimistic expectancies on attention and activity in large-scale neural networks. We induced expectancies about future gains and losses and examined their influence on attention deployment to stimuli signaling reward (i.e., gain) and punishment (i.e., loss). First, we hypothesized that induced optimistic, pessimistic, and ambiguous expectancies differentially modulate attention and activity in SN/ECN nodes during processing of reward versus punishment (interaction hypothesis). Second, we anticipated that optimistic and pessimistic expectancies guide attention to congruent rather than incongruent information (optimistic expectancies to reward rather than punishment and pessimistic expectancies to punishment rather than reward), whereas processing of incongruent information enhances SN/ECN activity (congruency hypothesis; den Ouden, Kok, & Lange, 2012). Third and most important, based on prior findings on the unique nature of optimism-attention interactions (Kress et al., 2018), we hypothesized that optimistic expectancies have a stronger impact on attention and SN/ECN activity than pessimistic ones do (asymmetry hypothesis). Fourth, we anticipated that behavioral and neural responses reflecting this asymmetry are positively related (asymmetry association hypothesis).

Methods and materials

Participants

Fifty healthy participants (19 male, age: *M* = 25.06 years; *SD* = 4.68 years; range = 18 – 39) recruited at the University of Bern took part in this functional magnetic resonance imaging (fMRI) study. Based on previously published behavioral data obtained with an identical experimental design (Kress et al., 2018), we calculated a minimum sample size of 40 participants to detect a medium effect (d_z = .534, α = .05, 95 % power) for our main analysis of interest (asymmetry hypothesis) in an a priori power analysis (using G*Power Version 3.1; Faul, Erdfelder, Lang, & Buchner, 2007). Because we expected considerable participant drop-out due to head movement in the scanner, ten additional participants were tested. Self-reported neurological disorders, mental disorders, severe medical diseases, MRI contraindications, use of psychoactive substances, or left-handedness served as exclusion criteria. Moreover, color blind participants (tested with Ishihara plates; Ishihara, 1917) were excluded. All participants had normal or corrected-to-normal vision and were reimbursed with course credit or 25 Swiss francs per hour in addition to 5 Swiss francs (their “gain” from the gambling task). Participants gave written informed consent according to the guidelines of the ethical standards of the Declaration of Helsinki and were told that they could end the experiment at any time. All procedures were approved by the ethics commission of the canton of Bern, Switzerland.

Procedure

After obtaining written informed consent, participants read the instructions in which the experiment was described as a gambling task with the opportunity to gain or lose money. They were told to gain 25 Swiss cents in addition to a starting amount of 5 Swiss francs upon seeing a gain target in a visual search array and lose 25 Swiss cents upon seeing a loss target. Participants were told that cues (e.g., “90 % gain”) at the beginning of each trial describe an average expectancy value of a gain or loss target being subsequently presented in a visual search array. In reality, the expected target appeared less frequently than the cues indicated (real expectancy value ~ 67 % in order to have enough incongruent trials for data analysis, see Experimental Design section for further details). To reduce participant´s distrust in the cues, they were told that the computer randomly picked a target out of a pool of 100 targets (for 90 % gain [loss] cues this pool consisted of 90 gain [loss] and 10 loss [gain] targets) and that for this reason the real expectancy value may differ from the average value displayed as cues. Next, participants performed six practice trials to become familiar with the task. If they had no questions, they were comfortably positioned in an MRI scanner and the experimental task was performed. For visual stimulation, an LCD projector (PT-L711E, Panasonic, Kadoma, Japan) projected the stimuli onto a screen in front of the scanner that was viewed through a mirror mounted to the head coil.

Stimuli and the experimental task of the current study are identical to Experiment 2 reported in Kress and colleagues (2018). Figure 4.1 shows the timing and sequence of one example trial. In each trial, participants were presented with a fixation cross for 2000 – 3000 ms (jittered presentation) followed by a verbal cue presented for 1500 ms. The cue indicated how probable it was that the target in the subsequently presented search array would be a gain or loss a target. After the cue was presented, another fixation cross appeared for 2000 – 3000 ms. Next, a search array consisting of eight stimuli (seven distractors and either a gain or loss target) was shown for 2500 ms. During the visual search task, participants had to indicate whether the target was presented on the left or right side of the screen by pressing with respectively the index or middle finger of the right hand on a button box connected to a response box outside the scanner (Lumina LP400, Cedrus Corporation, San Pedro, CA). Participants were instructed to react as quickly and accurately as possible. After the detection period had elapsed, another fixation cross was presented for 0 – 2000 ms before the next trial appeared (intertrial interval: 10 s). E-Prime 2.0 Professional (Psychology Software Tools, Sharpsburg, PA, USA) was used to present stimuli and record participants' responses.

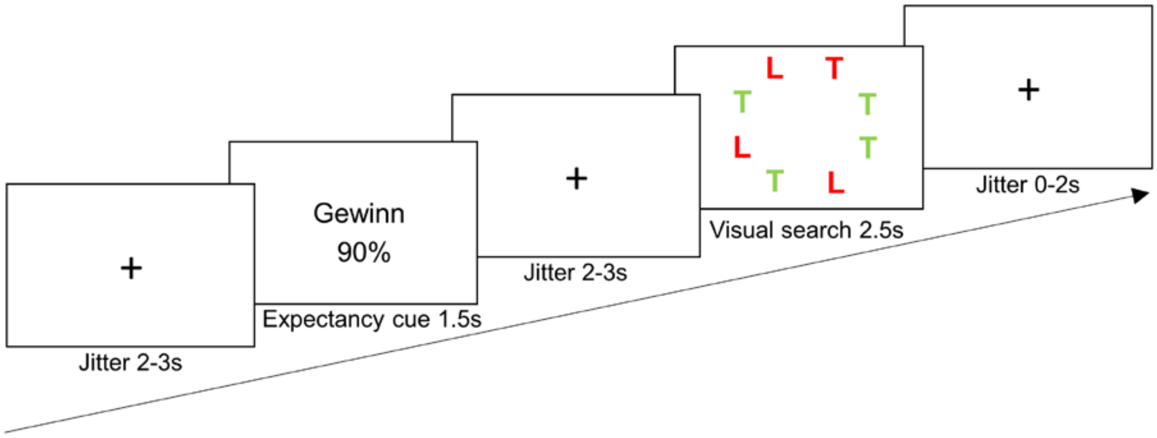

Figure 4.1. Trial structure. *An example of a gain cue (Gewinn [German word for gain] 90%) followed by a search array depicting a gain target (here a red "T"). Participants were told that the cues described the likelihood of seeing a gain or a loss target in the search array. They were also told that they would gain (lose) 25 Swiss cents in addition to a starting amount of 5 Swiss francs when seeing a gain (loss) target. Participants were asked to respond as quickly and accurately as possible according to the target (i.e., gain or loss target).*

A total of 256 experimental trials (128 congruent trials, 64 incongruent trials, 64 ambiguous trials) were presented in random order in four sessions of 64 trials (around 11 minutes) with short pauses in between. The frequencies of trials of different kinds (different cues/targets) were comparable between sessions. In total, participants both gained and lost 32 Swiss francs, leaving them with the starting amount of 5 Swiss francs. Participants were not informed about the progression of their gains and losses during the experiment. After the experiment, participants completed a post-experimental questionnaire as well as additional affect and personality questionnaires that were assessed for a larger project on individual differences associated with optimism bias. Then, participants were debriefed and received their "gain" of 5 Swiss francs.

Experimental Design and Statistical Analysis

Experimental Design

The experimental task represents a 3 × 2 repeated-measures design with the within-subject factors expectancy (gain/loss/ambiguous cue), and target (gain/loss). In the expectancy phase, one of three different verbal cues was presented to induce optimistic ("gain 90 %"), pessimistic ("loss 90 %"), or ambiguous expectancies ("gain loss 50 %" ["loss gain 50 %" for half of the participants]). These cues indicated the probability that the target in a subsequently presented visual search array would be a gain or a loss target. Because we had to include enough incongruent trials for data analysis, the “gain 90 %” (loss 90 %”) cue referred to an actual probability of 67 % that there would be a gain target (loss target) among seven neutral distractor stimuli in the search array presented afterward. In the remaining cases, a loss target (gain target) was presented. In the 50 % cue condition, gain and loss targets were equally likely to be the target in the search array. This 50 % cue was included as a control condition inducing ambiguous expectancies with maximum uncertainty.

Stimuli in the visual search phase consisted of a green and a red “L” and a green and a red “T”. In each trial, eight red and green “L”s and “T”s were shown on a white background on a circle around the position where the fixation cross was presented before. A single green “L” or a single red “T” served as target stimulus and signaled gain (i.e., reward) and loss (i.e., punishment) of money, respectively. For half of the participants, the green “L” represented a gain and the red “T” represented a loss, whereas for the other half the red “T” represented a gain and the green “L” represented a loss. The target stimulus appeared with equal probability in any of the eight different locations on the circle. The participants’ task was to detect the deviant target stimulus (green “L” or red “T”) among seven neutral distractor stimuli (red “L”s and green “T”s) as quickly as possible.

Behavioral Data Analysis

Behavioral data were analyzed with IBM SPSS Statistics, Version 24 (International Business Machines Corporation, Armonk, NY, USA). The dependent variable of attention orientation during the visual search task consisted of participants’ reaction times (RTs) for correct responses (in ms); errors comprised ~ 7.4 % of responses. We hypothesized that (1) gain, loss, and ambiguous expectancy cues differentially influence RTs to gain and loss targets (interaction hypothesis). To test this hypothesis, we conducted a 3 × 2 analysis of variance (ANOVA) with the within-subject factors expectancy (gain cue [gain 90 %], loss cue [loss 90 %], ambiguous cue [gain loss 50 %/loss gain 50 %]), and target (gain, loss) on RTs. We also performed analyses on logarithmic RTs or data with outliers (± 3 *SD*s from individual average RT) excluded. However, the effects observed in the current study were not affected by these data transformations. Therefore, only the results for original RT data are described. Ambiguous cues that served as a control condition with maximum uncertainty in our experiment were included as an anchor in the analysis. If true, our hypothesis should be reflected in a significant interaction of the expectancy cue and target, which was further investigated by post-hoc comparisons. An α-level of .05 (two-tailed) was applied. Reported effect sizes are partial eta squared and noted as η^2_p. If the sphericity assumption was violated, Greenhouse-Geisser corrected values are reported.

More specifically, we hypothesized that (2) gain and loss expectancy cues guide attention to congruent rather than incongruent targets (congruency hypothesis). This congruency hypothesis would be demonstrated by faster RTs to expected (i.e., gain targets following gain cues and loss targets following loss cues) than unexpected targets (i.e., loss targets following gain cues and gain targets following loss cues) and was tested with a planned comparison (pairwise t-test) between RTs in the congruent and incongruent conditions.

Furthermore, we hypothesized that (3) this congruency effect would be stronger for optimistic than for pessimistic expectancies (i.e., gain cues guide attention more to gain compared to loss targets than loss cues guide attention to loss compared to gain targets [asymmetry hypothesis]). Therefore, difference scores between RTs of incongruent and congruent conditions were computed for both gain and loss cues:

$$\mathrm{DiffGainCue} = [\text{Gain cue, loss target}] - [\text{Gain cue, gain target}]$$

$$\mathrm{DiffLossCue} = [\text{Loss cue, gain target}] - [\text{Loss cue, loss target}]$$

We anticipated larger difference scores for optimistic expectancies than for pessimistic expectancies ($\mathrm{Diff}_{\mathrm{GainCue}} > \mathrm{Diff}_{\mathrm{LossCue}}$). This asymmetry hypothesis was tested with a planned comparison (pairwise t-test) between $\mathrm{Diff}_{\mathrm{GainCue}}$ and $\mathrm{Diff}_{\mathrm{LossCue}}$. Pairwise *t*-tests were conducted with an α-level of .05 (one-tailed) and reported effect sizes are Cohen's *d,* denoted by *d*.

FMRI Data Analysis

All MRI images were acquired using a 3 Tesla Siemens Magnetom Prisma Scanner (Siemens, Erlangen, Germany) with a 64-channel head coil. Volumes were registered using a T_2*-weighted multi-band echo-planar imaging sequence (multi-band EPI) with 48 slices covering the whole brain (slice thickness = 2 mm; 0.5 mm gap; interleaved slice order; TR = 1000 ms; TE = 30 ms; flip angle = 80°; field of view = 192x192 mm; matrix size = 96 x 96; voxel size = 2 x 2 x 2.5 mm; PAT mode GRAPPA; acceleration factor 2; multiband factor = 3). An anatomical scan (MP-RAGE; 1 mm isotropic voxels; TR = 2300 ms; TE = 2.98 ms; flig angle = 9°; matrix size = 256 x 256) was conducted before the functional run to get highly resolved structural information for the normalization procedure.

Statistical Parametric Mapping software (SPM12, Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm) implemented in Matlab R2015b (Mathworks Inc., Sherborn, USA) was used for data analysis. Calculations were performed on

UBELIX (https://ubelix.unibe.ch/docs), the high performance computing cluster at the University of Bern. After slice time correction (middle slice acquisition was used as a reference slice), unwarping and spatial realignment (4th-degree b-Spline interpolation), retrospective noise correction was carried out using the Functional Image Artefact Correction Heuristic Package (FIACH; Tierney et al., 2016) implemented in R (R Development Core Team, 2008). Moreover, six principal components of physiological noise regressors were calculated with FIACH. Next, functional data were co-registered to each participant's anatomical image, normalized to the standard space of the Montreal Neurological Institute (MNI) EPI template to permit group analyses, and spatially smoothed with an isotropic three-dimensional Gaussian filter with a full-width at half maximum (FWHM) of 6 mm.

For statistical analyses, event-related signal changes were modeled separately for each participant, using the general linear model (GLM) as implemented in SPM 12. The following regressors were included in the first-level model separately for each of the four sessions: gain cue, loss cue, ambiguous cue (expectancy phase; duration: 0 s); gain cue–gain target; gain cue–loss target; loss cue–loss target; loss cue–gain target; ambiguous cue–gain target; ambiguous cue–loss target (target phase; duration: 0 s). A parametric modulator that described the modulation of the hemodynamic response in the target phase by the participants' behavioral responses (as indicated by standardized RTs) was added for each of the six target phase regressors. Moreover, one regressor for participants' errors, six movement parameters of the realignment procedure, six physiological noise parameters obtained during noise correction with FIACH (all regressors of no interest), and a constant covariate representing the session-specific mean over scans were implemented in the first-level model. The model included a high-pass filter of 128 s to remove low-frequency drift of the scanner and first-order auto-regressive corrections for auto-correlation between scans.

To test our interaction hypothesis (1) single-subject contrast maps obtained from first-level analyses for the six target phase conditions were entered into a second-level factorial ANOVA to detect interaction effects between the factors expectancy cue (gain, loss, ambiguous) and target (gain, loss) on the group level. Moreover, specific contrasts of interest between incongruent and congruent targets (congruency hypothesis [2]) as well as between incongruent and congruent targets following gain compared with loss cues (asymmetry hypothesis [3]) were calculated on an individual level and analyzed in second-level random effects analyses (one-sample *t*-tests). Furthermore, simple regression analyses were conducted to evaluate the association of neural and behavioral (standardized RTs) responses for this asymmetry contrast ($\text{Diff}_{\text{GainCue}}$ - $\text{Diff}_{\text{LossCue}}$; asymmetry association hypothesis [4]).

For exploratory whole-brain analyses, we report peak-voxel t or F statistics for activations that are significant at $p < .05$ after whole-brain family-wise error (FWE) random-field theory-based corrections, with an additional cluster-extent threshold of 10 voxels (at the same clustering threshold). For regions-of-interest (ROI) analyses, we report peak-voxel statistics using small-volume corrections for reduced search volumes ($p < .05$, FWE-SVC), and report cluster sizes using a clustering threshold of $p_{\text{uncorr}} < .001$. Such ROI analyses were performed for the insula, the dACC, the dlPFC, and the PPC using the small volume correction option of SPM12. Bilateral masks of the insula (Automated Anatomical Labeling atlas, Tzourio-Mazoyer et al., 2002), the dACC (created with the MARINA software package; Walter et al., 2003), the dlPFC and the PPC (components identified from the left and right executive control network templates provided by the Functional Imaging in Neuropsychiatric Disorders Laboratory; Shirer, Ryali, Rykhlevskaia, Menon, & Greicius, 2012) were used for ROI analyses.

Results

Interaction hypothesis

Reaction time data revealed a significant main effect of expectancy cue, $F_{(2,76)} = 19.379$, $p < .001$, $\eta^2_p = .283$ (participants reacted faster following optimistic [$M = 1537$ ms/$SE = 44$ ms] and pessimistic expectancies [$M = 1521$ ms/$SE = 40$ ms] than following ambiguous expectancies [$M = 1619$ ms/$SE = 41$ ms]; *p*s ≤ .001 as revealed by post-hoc pairwise comparisons), and a main effect of target, $F_{(1,49)} = 11.567$, $p = .001$, $\eta^2_p = .191$ (participants reacted faster to gain targets [$M = 1492$ ms/$SE = 45$ ms] than to loss targets [$M = 1625$ ms/$SE = 45$ ms]). More important and as predicted, RTs showed a significant interaction between the factors expectancy cue and target, $F_{(1,70)}$ 70.441, $p < .001$, $\eta^2_p = .590$ (optimistic expectancies led to faster RTs to gain [$M = 1295$ ms/$SE = 56$ ms] compared to loss targets [$M = 1778$/$SE = 45$ ms], pessimistic expectancies led to faster RTs to loss [$M = 1387$ ms/$SE = 57$ ms] compared to gain targets [$M = 1655$ ms/$SE = 42$ ms], and ambiguous expectancies led to faster RTs to gain [$M = 1526$ ms/$SE = 49$ ms] compared to loss targets [$M = 1711$ ms/$SE = 46$ ms]; all *p*s < .001; see Figure 4.2).

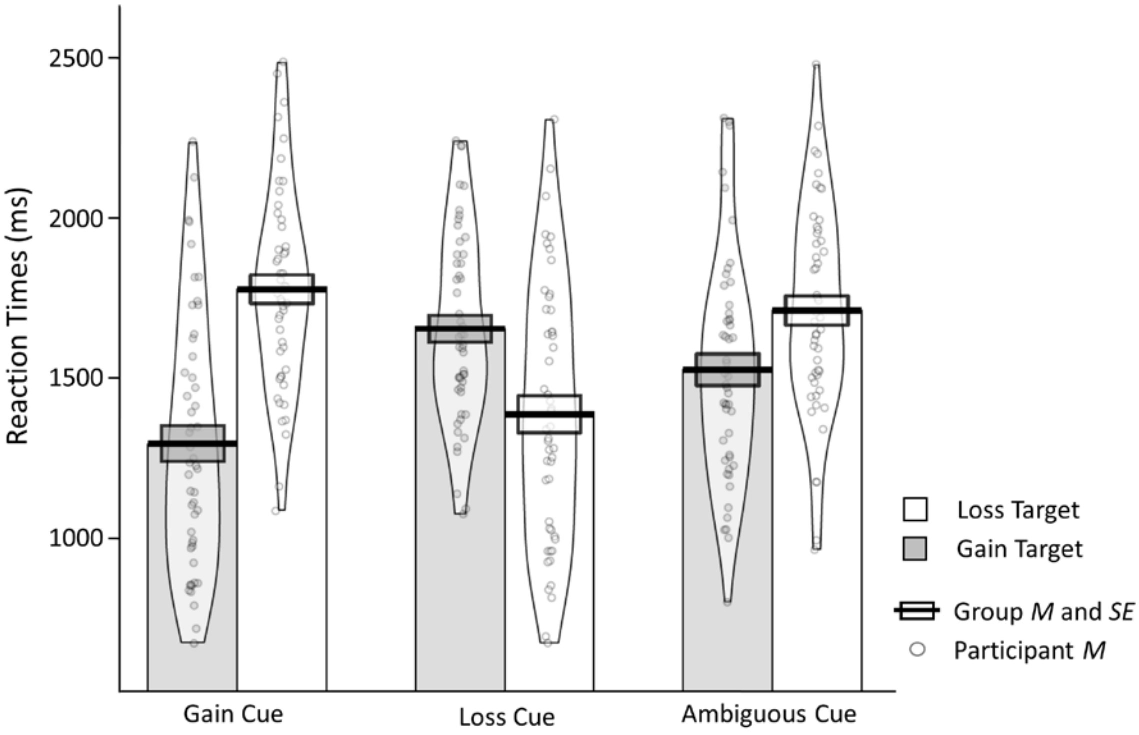

Figure 4.2. Reaction Times. *Bold lines and bands depict mean reaction times and standard errors of all participants (N = 50). Points depict the mean reaction time of each participant. Beans depict smoothed density. Plots were created with the pirate plot function of the Yarrr package Version 0.1.5 (https://CRAN.R-project.org/package=yarrr) in R (R Development Core Team, 2008).*

On a neural level, the expectancy × target interaction revealed differential activations in the left and right anterior insula (a prominent structure of the SN), a large bilateral cluster comprising of the posterior parietal cortex (PPC; superior and inferior parietal lobule, node of the ECN) extending into occipital areas (middle and superior occipital gyrus), a bilateral cluster comprising of supplementary motor area extending into the medial frontal gyrus and midcingulate area, bilateral clusters comprising of frontal lobe areas (precentral gyrus [PreCG], inferior frontal gyrus [IFG], middle frontal gyrus [MFG], superior frontal gyrus [SFG]), a cluster in the left cerebellum, left and right supramarginal gyrus, bilateral clusters in the visual cortex (calcarine sulcus and lingual gyrus), as well as a bilateral cluster in the medial orbitofrontal cortex (all whole-brain analyses). Moreover, ROI analyses for the expectancy cue × target interaction revealed differential activations in the bilateral anterior insula and dACC (nodes of the SN) as well as the dlPFC and PPC (nodes of the ECN; see Table 4.1 for a summary of all activated clusters for this interaction and further activated clusters for main effects and Table 4.2 for respective post-hoc tests of significant interactions and main effects).

Table 4.1. Areas displaying differential activation for the interaction between expectancy cue and target, and the main effects for expectancy cue and for target during the visual search phase.

H	Brain Region	*k*	x	y	z	F_{max}	p_{FWE}
	Expectancy × Target Interaction Whole-Brain Analysis						
R	INS	212	33	25	-3	44.85	<.001
B	SPL, IPL, MOG, SOG, PCU, ANG	2378	-30	-61	45	44.32	<.001
B	SMA, MeFG, MCA	653	-4	14	50	39.19	<.001
L	INS	105	-34	21	-5	34.75	<.001
L	PreCG, IFGpo, IFGpt, MFG	824	-46	12	33	31.67	<.001
R	PreCG, IFGpo, IFGpt, MFG	433	47	25	30	30.62	<.001
R	MFG, SFG	104	29	0	55	23.51	<.001
L	CB	17	-8	-73	-23	22.27	<.001
R	SMG, STG	46	68	-24	20	19.61	.002
L	STG, SMG	24	-59	-28	20	19.57	.002
R	CAL	36	13	-67	13	19.16	.002
L	LING, CAL	19	-2	-75	5	18.55	.004
B	MOFC	36	-6	47	-10	18.44	.004
L	CAL	17	-16	-69	5	17.09	.012
	Expectancy × Target Interaction Region-of-Interest Analysis						
R	INS	280	33	25	-3	44.85	<.001
L	INS	248	-34	21	-5	34.75	<.001
R	DACC	134	5	27	40	17.60	<.001
L	DACC	39	-8	14	43	17.21	<.001
R	DLPFC	550	47	25	30	30.62	<.001
R	DLPFC	108	29	10	58	20.37	<.001
L	DLPFC	134	-46	17	33	25.74	<.001
L	DLPFC	18	-6	29	45	16.44	<.001
L	DLPFC	35	-26	12	58	12.41	.010
R	PPC	439	35	-61	48	33.68	<.001
L	PPC	306	-32	-61	45	39.67	<.001
	Expectancy Main Effect Whole-Brain Analysis						
L	LING, CAL, IOC, MOG	54	-14	-90	-10	32.92	<.001
R	LING, CAL, IOC	49	19	-88	-5	28.32	<.001
	Target Main Effect Whole-Brain Analysis						
	no significant results						

Note. All coordinates (x, y, z) of peak voxel activation are given in Montreal Neurological Institute (MNI) space; *k* = cluster size in number of voxels (voxel size = 2 x 2 x 2.5 mm); L = left, R = right, B = bilateral; for exploratory whole-brain analyses, a clustering threshold of *p* <.05, whole-brain FWE corrected, and an additional cluster-extent threshold of 10 voxels was used; for ROI analyses, a clustering threshold of *p* <.001, uncorrected, was used; *ANG* = Angular Gyrus, *CAL* = Calcarine Sulcus, *CB* = Cerebellum, *DACC* = Dorsal Anterior Cingulate Cortex, *DLPFC* = dorsolateral Prefrontal

Cortex, *IFGpo* = Inferior Frontal Gyrus - pars opercularis, *IFGpt* = Inferior Frontal Gyrus – pars triangularis, *INS* = Insula, *IPL* = Inferior Parietal Lobule, *LING* = Lingual Gyrus, *MCA* = Midcingulate Area, *MeFG* = Medial Frontal Gyrus, *MFG* = Middle Frontal Gyrus, *MOFC* = Medial Orbitofrontal Cortex, *MOG* = Middle Occipital Gyrus, *PCU* = Precuneus, *PreCG* = Precentral Gyrus , *PPC* = Posterior Parietal Cortex, *SFG* = Superior Frontal Gyrus, *SOG* = Superior Occipital Gyrus, *SMA* = Supplementary Motor Area, *SMG* = Supramarginal Gyrus, *SPL* = Superior Parietal Lobule, *STG* = Superior Temporal Gyrus, as defined by the automated anatomical labeling of activations in SPM (Tzourio-Mazoyer et al., 2002) or anatomical region-of-interest masks (see Methods and Materials for further details).

Table 4.2. Areas displaying differential activation for post-hoc comparisons of the interaction between expectancy cue and target and the main effect for expectancy cue during the visual search phase.

H	**Brain Region**	***k***	**x**	**y**	**z**	T_{max}	p_{FWE}
	Expectancy × Target Interaction						
	Optimistic expectancies: Gain Target > Loss Target						
	Whole-Brain Analysis						
R	SMG, STG	45	64	-22	25	6.6	.002
L	MOFC	20	-2	45	-10	6.24	.008
	Optimistic expectancies: Loss Target > Gain Target						
	Whole-Brain Analysis						
R	SMA, MeFG, MCA	426	-4	14	48	8.78	<.001
R	INS	102	33	25	-3	8.22	<.001
L	INS	38	-34	21	-5	8.09	<.001
L	SOG, MOG, SPL, IPL, PCU	625	-24	-73	38	7.82	<.001
L	PreCG, FGpo, IFGpt	360	-38	0	50	7.78	<.001
R	SOG, MOG, SPL, IPL, PCU, ANG	471	27	-63	40	7.66	<.001
R	MFG, SFG	68	33	2	58	7.45	<.001
L	SFG, MFG, PreCG	112	-24	0	63	7.41	<.001
R	SMG	14	41	-39	43	6.87	.001
R	IFGpo, PreCG	11	37	6	30	6.34	.006
	Pessimistic expectancies: Gain Target > Loss Target						
	Whole-Brain Analysis						
R	MeFG	55	5	35	53	7.46	<.001
L	IPL, SPL, SOG, MOG	295	-36	-51	43	7.28	<.001
R	SPL, SOG, ANG	165	25	-69	53	7.15	<.001
R	INS	36	35	23	-3	6.84	.001
R	IFGpt	14	49	25	30	6.3	.006
	Pessimistic expectancies: Loss Target > Gain Target						
	Whole-Brain Analysis						
	no significant results						
	Ambiguous expectancies: Gain Target > Loss Target						
	Whole-Brain Analysis						
	no significant results						

Ambiguous expectancies: Loss Target > Gain Target							
Whole-Brain Analysis							
no significant results							
Expectancy Main Effect							
Optimistic expectancies > pessimistic expectancies							
Whole-Brain Analysis							
no significant results							
Pessimistic expectancies > optimistic expectancies							
Whole-Brain Analysis							
no significant results							
Optimistic expectancies > ambiguous expectancies							
Whole-Brain Analysis							
L	LING, CAL, IOC	38	-14	-90	-10	8.53	<.001
R	LING, CAL, IOC	53	19	-92	-5	8.05	<.001
Ambiguous expectancies > optimistic expectancies							
Whole-Brain Analysis							
no significant results							
Pessimistic expectancies > ambiguous expectancies							
Whole-Brain Analysis							
R	CAL, LING, IOC	48	19	-90	-3	8.01	<.001
L	CAL, LING, IOC, MOG	31	-14	-92	-8	7.41	<.001
Ambiguous expectancies > pessimistic expectancies							
Whole-Brain Analysis							
no significant results							

Note. All coordinates (x, y, z) of peak voxel activation are given in Montreal Neurological Institute (MNI) space; *k* = cluster size in number of voxels (voxel size = 2 x 2 x 2.5 mm); L = left, R = right, B = bilateral; for exploratory whole-brain analyses, a clustering threshold of *p* <.05, whole-brain FWE corrected, and an additional cluster-extent threshold of 10 voxels was used; *ANG* = Angular Gyrus, *CAL* = Calcarine Sulcus, *CB* = Cerebellum, *DACC* = Dorsal Anterior Cingulate Cortex, *DLPFC* = dorsolateral Prefrontal Cortex, *IFGpo* = Inferior Frontal Gyrus - pars opercularis, *IFGpt* = Inferior Frontal Gyrus – pars triangularis, *INS* = Insula, *IPL* = Inferior Parietal Lobule, *LING* = Lingual Gyrus, *MCA* = Midcingulate Area, *MeFG* = Medial Frontal Gyrus, *MFG* = Middle Frontal Gyrus, *MOFC* = Medial Orbitofrontal Cortex, *MOG* = Middle Occipital Gyrus, *PCU* = Precuneus, *PreCG* = Precentral Gyrus , *PPC* = Posterior Parietal Cortex, *SFG* = Superior Frontal Gyrus, *SOG* = Superior Occipital Gyrus, *SMA* = Supplementary Motor Area, *SMG* = Supramarginal Gyrus, *SPL* = Superior Parietal Lobule, *STG* = Superior Temporal Gyrus, as defined by the automated anatomical labeling of activations in SPM (Tzourio-Mazoyer et al., 2002) or anatomical region-of-interest masks (see Methods and Materials for further details).

Congruency hypothesis

As anticipated, optimistic and pessimistic expectancies guided attention to congruent compared to incongruent information. Participants reacted significantly faster to congruent than to incongruent targets, $t(49) = 9.230$, $p < .001$, $d = 1.095$ (congruent: $M = 1341$ ms/$SE = 53$ ms, incongruent: $M = 1716$ ms/$SE = 38$ ms). On a neural level, processing of incongruent compared to congruent targets resulted in stronger activation in the left and right anterior insula (SN), a large bilateral cluster comprising of the PPC (superior and inferior parietal lobule; ECN) extending into occipital areas (middle and superior occipital gyrus), a bilateral cluster comprising of supplementary motor area extending into the medial frontal gyrus and midcingulate area, bilateral clusters comprising of frontal lobe areas (PreCG, IFG, MFG, SFG), as well as bilateral clusters in the visual cortex (calcarine sulcus and lingual gyrus; all whole-brain analyses). Moreover, ROI analyses revealed that processing of incongruent targets resulted in stronger activation in the bilateral anterior insula and dACC (nodes of the SN) and the dlPFC and PPC (nodes of the ECN; see Figure 4.3 for a visualization of activations). In contrast, processing of congruent compared to incongruent targets resulted in stronger activation in a bilateral cluster in the medial orbitofrontal cortex and the left and right supramarginal gyrus (whole-brain corrected; see Table 4.3 for a summary of all activated clusters).

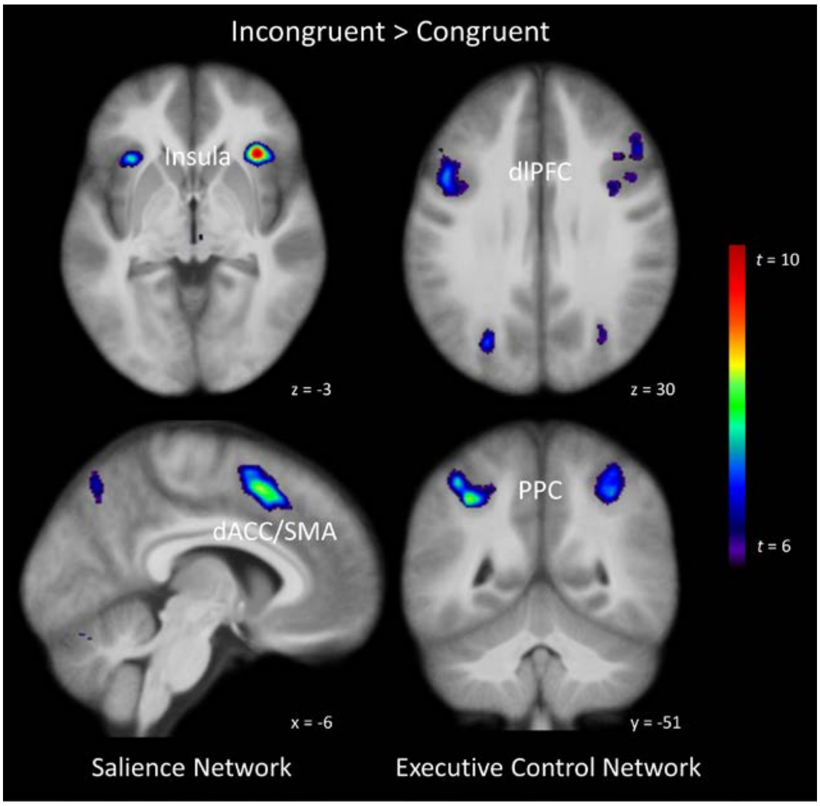

Figure 4.3. Brain areas displaying differential activation on viewing incongruent compared with congruent information during the visual search phase. *Processing incongruent information elicits stronger activation in nodes of the salience network (insula, dorsal anterior cingulate cortex [dACC]) and of the executive control network (dorsolateral prefrontal cortex [dlPFC], posterior parietal cortex [PPC]) than processing congruent information following both optimistic and pessimistic expectancies. Statistical parametric maps are thresholded at p <.05, whole-brain corrected.*

Table 4.3. Areas displaying differential activation for incongruent versus congruent information during the visual search phase following both optimistic and pessimistic expectancies.

H	Brain Structure	k	x	y	z	t_{max}	p_{FWE}
	Incongruent > Congruent						
	Whole-Brain Analysis						
R	INS	192	35	25	-3	10.03	<.001
B	SOG, MOG, SPL, IPL, PCU, ANG (R)	2141	29	-65	45	9.24	<.001
B	SMA, MeFG, MCA	597	-4	12	53	8.64	<.001
L	PreCG, IFGpo, IFGpt, MFG	404	-44	6	35	8.29	<.001
L	INS	88	-32	21	-5	8.09	<.001
R	MFG, SFG	94	31	2	58	7.28	<.001
R	CAL, LING	66	11	-65	10	6.87	.001
L	MFG, SFG	63	-24	0	60	6.84	.001
R	IFGpo, IFGpt	86	49	25	30	6.75	.001
L	CAL, LING	51	-14	-71	8	6.53	.003

R	PreCG, IFGpo	22	37	6	30	6.32	.006
R	PreCG, IFGpo	32	49	10	33	6.27	.007
L	LING	18	-2	-75	5	6.25	.008
R	IOC	13	31	-85	-5	6.22	.009
Region-of-Interest Analysis							
R	INS	301	35	25	-3	10.03	<.001
L	INS	289	-32	21	-5	8.09	<.001
B	DACC	234	-6	14	43	6.65	<.001
R	DLPFC	673	49	25	30	6.75	<.001
L	DLPFC	158	-46	17	33	7.05	<.001
L	DLPFC	27	-4	31	43	5.17	.004
R	PPC	463	35	-63	53	7.16	<.001
L	PPC	354	-42	-51	50	7.26	<.001
Congruent > Incongruent							
Whole-Brain Analysis							
B	MOFC	110	-2	41	-13	7.07	<.001
L	SMG, STG	38	-65	-30	30	6.66	.002
R	SMG, STG	37	64	-24	20	6.64	.002

Note. All coordinates (x, y, z) of peak voxel activation are given in Montreal Neurological Institute (MNI) space *k* = cluster size in number of voxels (voxel size = 2 x 2 x 2.5 mm); L = left, R = right, B = bilateral; for exploratory whole-brain analyses, a clustering threshold of *p* <.05, whole-brain FWE corrected, and an additional cluster-extent threshold of 10 voxels was used; for ROI analyses, a clustering threshold of *p* <.001, uncorrected, was used; *ANG* = Angular Gyrus, *CAL* = Calcarine Sulcus, *DACC* = Dorsal Anterior Cingulate Cortex, *DLPFC* = Dorsolateral Prefrontal Cortex, *IFGpo* = Inferior Frontal Gyrus - pars opercularis, *IFGpt* = Inferior Frontal Gyrus – pars triangularis, *INS* = Insula, *IOC* = Inferior Occipital Cortex, *IPL* = Inferior Parietal Lobule, *LING* = Lingual Gyrus, *MCA* = Midcingulate Area, *MeFG* = Medial Frontal Gyrus, *MFG* = Middle Frontal Gyrus, *MOFC* = Medial Orbitofrontal Cortex, *MOG* = Middle Occipital Gyrus, *PCU* = Precuneus, *PreCG* = Precentral Gyrus, *PPC* = Posterior Parietal Cortex, *SFG* = Superior Frontal Gyrus, *SOG* = Superior Occipital Gyrus, *SMA* = Supplementary Motor Area, *SMG* = Supramarginal Gyrus, *SPL* = Superior Parietal Lobule, *STG* = Superior Temporal Gyrus, as defined by the automated anatomical labeling of activations in SPM (Tzourio-Mazoyer et al., 2002) or anatomical region-of-interest masks (see Methods and Materials for further details).

Asymmetry hypothesis

In line with our asymmetry hypothesis, attention deployment to congruent compared to incongruent targets differed following optimistic and pessimistic expectancies. Optimistic expectancies accelerated reactions to gain compared to loss targets more than pessimistic expectancies accelerated reactions to loss compared to gain targets, $t(49) = 2.760$, $p = .004$, $d = .541$ ($\text{Diff}_{\text{GainCue}}$: $M = 483$ ms/$SE = 52$ ms, $\text{Diff}_{\text{LossCue}}$: $M = 267$ ms/$SE = 60$ ms). On a neural level, ROI analyses revealed stronger activation of the left anterior insula ($k = 12$; MNI coordinates: x = -

26, y = 19, z = 10; $t_{\max} = 4.87$; $p_{\text{FWE}} = .010$), a prominent structure of the salience network, when participants reoriented attention to loss compared to gain targets following optimistic expectancies than when participants reoriented attention to gain compared to loss targets following pessimistic expectancies (Figure 4.4a).

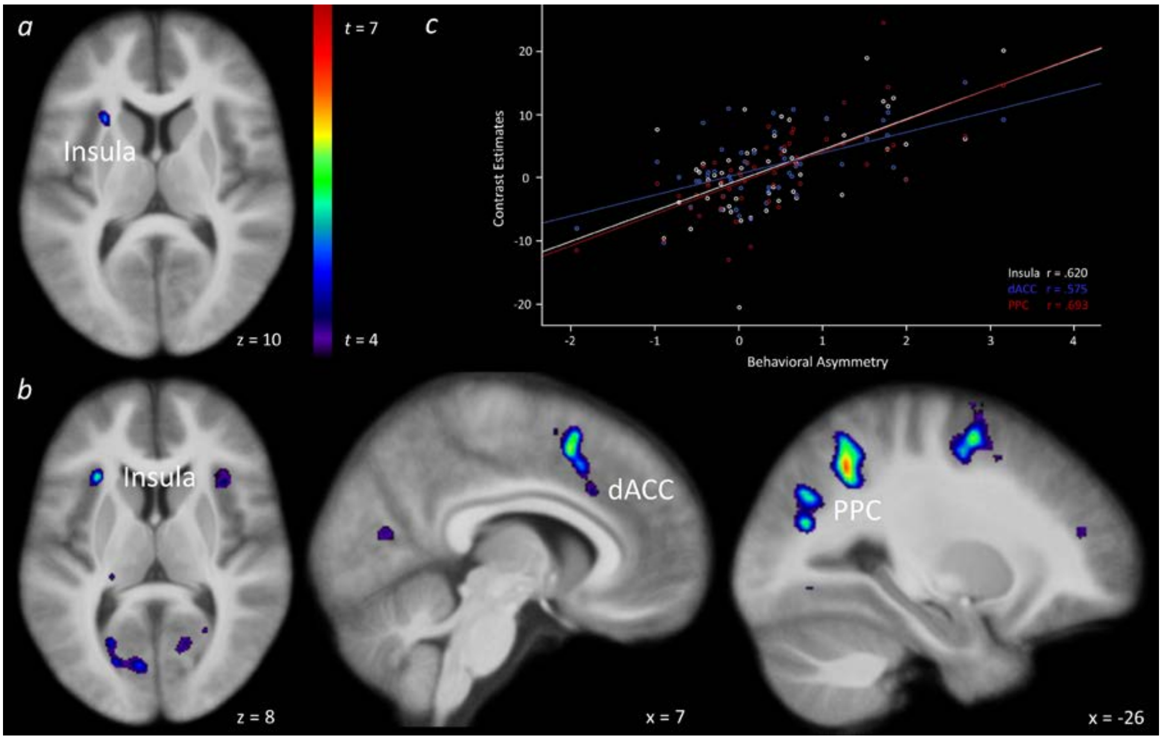

Figure 4.4. Brain areas displaying differential activation on viewing incongruent vs. congruent information following optimistic vs. pessimistic expectancies during the visual search phase. *a. Processing unexpected punishing (compared to expected rewarding) information following optimistic expectancies elicits stronger insula activity than processing unexpected rewarding (compared to expected punishing) information following pessimistic expectancies. b. Participants demonstrating strongest asymmetric attention deployment following optimistic vs. pessimistic expectancies (indicated by RTs) also show the strongest activity in nodes of the salience network (insula, dorsal anterior cingulate cortex [dACC]) and the executive control network (posterior parietal cortex [PPC]) when processing unexpected vs. expected information following optimistic vs. pessimistic expectancies. Statistical parametric maps are thresholded at p <.001, uncorrected, for visualization purposes. See Table 4.4 for corrected inferential statistics. c. Positive correlations between behavioral and neural responses representing an asymmetric processing of expected and unexpected information following optimistic versus pessimistic expectancies.*

Asymmetry association hypothesis

Participants' RTs reflecting asymmetric attention deployment following optimistic and pessimistic expectancies was predicted by *enhanced* activation in bilateral clusters in frontal lobe areas

(PreCG, IFG), bilateral SMA, and clusters comprising of the left PPC (SPL, IPL, nodes of the ECN) as well as MFG and SOG when processing incongruent information following optimistic vs. pessimistic expectancies (whole-brain analyses). Moreover, ROI analyses revealed that behavioral responses reflecting asymmetric attention deployment were predicted by *enhanced* activation in the left insula and the right dACC (nodes of the SN) when reorienting attention to incongruent information following optimistic vs. pessimistic expectancies (Figure 4.4b and c).

Furthermore, behavioral responses reflecting asymmetric attention deployment were predicted by *reduced* activation in the left angular gyrus when processing incongruent information following optimistic vs. pessimistic expectancies (whole-brain corrected; see Table 4.4 for a summary of all activated clusters).

Table 4.4. Areas displaying differential activity to unexpected punishment (vs. expected reward) following optimistic expectancies compared to unexpected reward (vs. expected punishment) following pessimistic expectancies in the visual search phase predicting asymmetric attention deployment following optimistic compared to pessimistic expectancies indicated by RTs ($\text{Diff}_{\text{GainCue}} > \text{Diff}_{\text{LossCue}}$).

H	Brain Structure	k	x	y	z	t_{max}	p_{FWE}
	Positive Correlation						
	Whole-Brain Analysis						
L	IFGpo, PreCG	72	-40	4	28	7.56	<.001
L	PreCG, PostCG	32	-42	-6	45	7.27	<.001
B	SMA	61	0	10	60	6.83	.001
L	SPL, IPL	18	-26	-55	45	6.66	.002
L	SOG, SPL	10	-20	-71	40	6.59	.002
R	IFGpo, PreCG	12	43	2	30	6.45	.004
L	PreCG, MFG	16	-30	-6	55	6.2	.010
	Region-of-Interest Analysis						
L	INS	57	-30	23	8	5.47	.002
R	DACC	42	7	17	43	4.86	.008
	Negative Correlation						
	Whole-Brain Analysis						
L	ANG	48	-61	-57	25	6.39	.005

Note. All coordinates (x, y, z) of peak voxel activation are given in Montreal Neurological Institute (MNI) space; *k* = cluster size in number of voxels (voxel size = 2 x 2 x 2.5 mm); L = left, R = right, B = bilateral; for exploratory whole-brain analyses, a clustering threshold of *p* <.05, whole-brain FWE corrected, and an additional cluster-extent threshold of 10 voxels was used; for ROI analyses, a clustering threshold of *p* <.001, uncorrected, was used; *ANG* = Angular Gyrus, *DACC* = Dorsal Anterior Cingulate Cortex, *IFGpo* = Inferior Frontal Gyrus - pars opercularis, *INS* = Insula, *IPL* = Inferior Parietal Lobule, *MFG* = Middle Frontal Gyrus, *MTG* = Middle Temporal Gyrus, *PostCG* = Postcentral Gyrus, *PreCG* = Precentral Gyrus, *SOG* = Superior Occipital Gyrus, *SMA* = Supplementary Motor Area, *SPL* = Superior Parietal Lobule, as defined by the automated anatomical labeling of activations in SPM (Tzourio-Mazoyer et al., 2002) or anatomical region-of-interest masks (see Methods and Materials for further details).

Discussion

The current study replicates prior behavioral findings showing that optimistic (and pessimistic) expectancies causally influence attention deployment (Kress et al., 2018; Peters et al., 2015). Furthermore, it reveals the importance of large-scale neural networks underlying such expectancy-attention interactions. Specifically, induced optimistic and pessimistic expectancies guide attention to congruent information and result in enhanced activity in SN (anterior insula, dACC) and ECN (dlPFC, PPC) nodes during processing of incongruent information. Whereas the SN underlies the detection of salient (in this case incongruent) information, the ECN underlies further processing (e.g., modulation) of such salient information (Menon, 2015b; Menon & Uddin, 2010). These findings suggest that optimistic and pessimistic expectancies create a mental template that facilitates the detection of expected information and enhances neural processing of unexpected information (allowing the brain to devote relatively little resources to expected information as proposed by predictive coding theory; den Ouden et al., 2012; Gottlieb, 2007; Molenberghs, Mesulam, Peeters, & Vandenberghe, 2007; C. Summerfield et al., 2006; Zelano et al., 2011). Our results are in line with recent findings indicating that attention deployment to neutral information and associated brain activity in frontal/parietal areas is modulated by prior expectancies (Aue et al., in press). Notably, we additionally found strong insula and dACC activity during processing of unexpected information following optimistic and pessimistic expectancies, conforming with theoretical considerations on the neurophysiological basis of optimism-attention interactions (Kress & Aue, 2017). The anterior insula plays a crucial role in the subjective awareness of positive and negative feelings (Damasio et al., 2000; Menon & Uddin, 2010; Phan et al., 2002) and may, therefore, be particularly important for the salience detection of unexpected reward/punishment compared with unexpected neutral information.

More important, the observed expectancy-attention interactions show a clear asymmetry: Both behavioral and neural effects were stronger for optimistic than for pessimistic expectancies. Optimistic expectancies guided attention particularly fast to reward and resulted in particularly strong insula activity during processing of unexpected punishment. This asymmetry was even more pronounced when taking individual differences into account. Participants who demonstrated the strongest asymmetry in behavioral responses (i.e., attention deployment indicated by RTs) following optimistic and pessimistic expectancies also demonstrated the strongest asymmetry in neural responses (note that our neural model incorporated RTs, thereby ensuring that the observed effects are not due to motor responses). Thus, people whose reactions to reward were particularly fast following optimistic expectancies also displayed particularly strong SN and ECN activation during processing of unexpected punishment. The validity of these findings is supported by three arguments: First, the asymmetry observed in the present RT data replicates prior findings obtained with different samples (Kress et al., 2018); second, interindividual differences in asymmetric (behavioral) attention deployment following optimistic/pessimistic expectancies were positively related to asymmetric neural processing; third, the brain areas observed to underlie asymmetric attention deployment following optimistic/pessimistic expectancies are co-activated in a wide range of cognitive tasks (e.g., anterior insula and dACC; Menon & Uddin, 2010) and together form large-scale neural networks that have been extensively described to relate to attention (re)orientation and maintenance in the literature (Menon, 2015b).

Furthermore, asymmetric attention deployment and neural processing of incongruent information following optimistic and pessimistic expectancies complement prior findings on asymmetric information-processing related to optimism bias (Sharot et al., 2011, 2012b). People selectively update future expectancies following positive feedback but not following negative feedback – a key process maintaining optimism bias over time (Sharot, 2011). Selective attention to reward and strong neural processing of unexpected punishment following optimistic expectancies as revealed by our study can uncover cognitive mechanisms underlying this updating asymmetry. Whereas our behavioral data reveal the exceptional power of optimistic expectancies in automatically guiding attention to reward, our neural data suggest that unexpected punishment elicits strong expectancy violation (Shulman et al., 2009) and is especially surprising/salient when people are optimistic (i.e., leading to enhanced SN activity). Even though unexpected punishment following optimistic expectancies is thoroughly processed in the brain, it might be so surprising that it cannot easily be translated into behavior (e.g., fast reaction to surprising punishment; Wessel & Aron, 2017).

Our findings suggest that initial predictions of reward are stronger when people are optimistic than predictions of punishment when people are pessimistic (i.e., optimism leads to greater SN activity when processing unexpected information; in line with the idea that prediction errors enhance neural processing; den Ouden et al., 2012). Therefore, automatic attention is guided more strongly to reward when people are optimistic than to punishment when they are pessimistic (i.e., optimism leads to faster reactions to reward). Later, more controlled attention maintenance on reward following optimistic expectancies (as observed in Kress et al., 2018) can then act as a form of emotion regulation reducing surprising punishing information´s salience

(Wadlinger & Isaacowitz, 2008). Strategic attention deployment (e.g., distraction/attentional avoidance) is an important emotion regulation strategy (Cisler & Koster, 2010; Gross, 1998; Koole, 2009), supporting the idea that attention maintenance on reward following optimistic expectancies can decrease the impact of salient punishment. In a similar vein, ECN activity has been suggested to underlie emotion regulation via attention processes and to manipulate information in working memory for sustained goal-relevant and adaptive processing (Martin & Ochsner, 2016; Menon, 2015a; Miller & Cohen, 2001). ECN nodes observed to be active in the current study may, therefore, be involved in the down-regulation of punishing information's salience following optimistic expectancies.

Taken together, our data imply that optimistic expectancies are particularly robust even in the presence of punishing information (i.e., minimal attention is directed to disproving punishment to maintain initial strong predictions of reward). In contrast, weaker pessimistic expectancies could be more easily disrupted by rewarding information (i.e., relatively more attention is directed to such an unexpected reward, thereby interfering with initial punishment predictions). Such asymmetric attention deployment and neural processing following optimistic and pessimistic expectancies can, in turn, explain why people selectively update future expectancies into an optimistic, not a pessimistic direction following feedback: Strong reward predictions automatically guide and maintain attention on reward, thereby reducing disproving punishing information's salience and prioritizing rewarding information when updating expectancies. This process can maintain optimism over time (in line with recent ideas on the interplay between attention and expectancy updating during reinforcement learning; Leong, Radulescu, Daniel, DeWoskin, & Niv, 2017).

The neural mechanisms underlying optimism-attention interactions uncovered by the current study provide a more nuanced view on how optimism bias is maintained. Whereas purely behavioral observations easily led to the conclusion that asymmetric updating of expectancies after receiving positive feedback (Sharot et al., 2011, 2012b) is rooted in more thorough processing of positive reward following pessimistic expectancies (Kress et al., 2018), our neural data imply that actually the opposite is true. Even though optimistic expectancies strongly guide attention to reward on a behavioral level, disproving punishing information following optimistic expectancies is thoroughly processed in the brain. Thorough processing of salient negative information following optimistic expectancies can be crucial to differentiate between relevant negative information (e.g., situations in which fast detection of threatening stimuli ensures survival/optimistic expectancies should be overridden; Aue et al., in press; Ledoux & Phelps, 2008) and irrelevant negative information (e.g., situations in which punishing information does not require instant action but diminishes motivation and adaptive processing; Kress & Aue, 2017). In the latter scenario, more controlled attention processes (attention maintenance on reward) may serve the purpose to reduce unexpected punishment´s salience, thereby regulating negative emotions and maintaining an optimistic outlook (Cisler & Koster, 2010; Fenske & Raymond, 2016; Gross, 1998; Koole, 2009; Wadlinger & Isaacowitz, 2008). Thus, the current fMRI study highlights the potential importance of such controlled attention processes for dynamic optimism-attention interactions.

Unfortunately, we did not directly measure attention maintenance in the present fMRI study, which limits the conclusions we can draw on these processes. However, we have previously shown that people maintain attention on rewarding information following optimistic expectancies in two independent studies using a similar experimental design (Kress et al., 2018). Because findings on attention orientation (RTs) in the current study replicated our previous work, one can strongly assume that the same would be true for attention maintenance. Nevertheless, it is important that future research simultaneously assesses both attention orientation and attention maintenance (e.g., through eye tracking) in addition to neural and further physiological responses to provide an even more elaborative view on asymmetric attention deployment following optimistic and pessimistic expectancies.

In conclusion, the present findings further expand our understanding of the mechanisms underlying dynamic optimism-attention interactions. Our data indicate that even though optimistic expectancies automatically guide attention to reward, unexpected punishment signals high saliency and is profoundly processed in the brain. These results emphasize the importance of additional mechanisms (i.e., controlled attention maintenance on reward to reduce the salience of unexpected punishment) and can, therefore, give first hints on how interacting positive cognitive biases may be interrupted in psychopathology (e.g., a failure to downregulate salience of punishment through attention maintenance leading to more pessimistic expectancies and initiating a downward spiral of negativity). Thus, the present findings have brought us a significant step further to unraveling *why* most of us are overly optimistic about our future and how attention processes contribute to this positive outlook.

Chapter 5

Learning to Look at the Bright Side of Life: Attention Bias Modification Training Enhances Optimism Bias

Laura Kress and Tatjana Aue

Abstract

Identifying cognitive mechanisms underlying optimism bias is essential to understand its benefits for well-being and mental health. The combined cognitive biases hypothesis suggests that biases (e.g., in expectancies and attention) interact and mutually enforce each other. Even though, in line with this hypothesis, optimistic expectancies have been shown to guide attention to positive information, reverse causal effects have not been investigated yet. Revealing such bi-directional optimism-attention interactions could explain how cognitive biases contribute to a self-sustaining upward spiral of positivity. We hypothesized that extensive training to direct attention to positive information enhances optimism bias. To test this hypothesis, 149 participants underwent a two-week attention bias modification training (ABMT) to accepting and away from rejecting faces or a neutral control training. Comparative optimism bias and state optimism were measured before, after one, and after two training weeks via questionnaires. ABMT enhanced comparative optimism bias, whereas control training did not. Our findings reveal that ABMT to positive social information causally influences comparative optimism bias and may, thereby, trigger the biases' benefits for well-being and mental health. In times of rising numbers of patients with psychological disorders, positive ABMT can be a low-cost and easy-to-access support for psychotherapy.

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Introduction

People are usually overly optimistic about their future (optimism bias) and preferably attend to positive information around them (attention bias; Pool et al., 2016a; Weinstein, 1980). Even though both behaviours relate to benefits in everyday life (maintaining motivation) and clinical domains (protecting mental health; Joormann & Gotlib, 2007; Sharot, 2011), we know little about how optimism and attention bias interact and mutually enforce each other (Kress & Aue, 2017). If we knew that one bias increases the other (bi-directional interplay) instigating a self-perpetuating upward spiral of positive emotions (Garland et al., 2010), we could employ the biases' benefits in everyday life and clinical applications.

Theories such as the combined cognitive biases hypothesis suggest that cognitive biases (e.g., in expectancies and attention) interact and mutually enforce each other (Aue & Okon-Singer, 2015; Hirsch et al., 2006; Kress & Aue, 2017). The hypothesis is supported by empirical findings showing that optimistic expectancies indeed guide visual attention toward rewarding information (Kress et al., 2018). If bi-directional optimism-attention interactions exist, the reverse causal influence must be demonstrated as well.

Attention bias modification training (ABMT: repeated training to attend to specific target stimuli and ignore others) may help to investigate such causal influence of attention on optimism, because it promises to modify attention (bias) and affect emotions (MacLeod & Mathews, 2012). However, recent meta-analyses question the efficacy of ABMT and reveal methodological challenges (e.g., Cristea, Kok, & Cuijpers, 2015; Grafton et al., 2017; Heeren, Mogoașe, Philippot, & McNally, 2015; see E. Jones & Sharpe, 2017 for an overview).

Most studies in these meta-analyses used threat-avoidance ABMT to reduce pre-existing attention biases to threat in anxiety, but these biases are not consistently shown in ABMT studies (and can therefore not be modified; Mogg, Waters, & Bradley, 2017). This constraint (and observations that control trainings often elicit similar benefits) raises the question whether bias modification indeed drives beneficial emotional outcomes of ABMT. Notably, ABMT also increases attentional control, a top-down process that may be just as relevant for anxiety as bottom-up bias modification according to theories (Heeren, Mogoaşe, McNally, Schmitz, & Philippot, 2015). Similarly, both top-down and bottom-up attention play a key role for the optimism-attention interactions that are in the current work's focus (Kress & Aue, 2017).

Based on the controversies concerning appropriateness, efficacy, and driving attention processes of threat-avoidance ABMT, a novel approach (positive-search ABMT) has been proposed as more promising in eliciting beneficial emotional outcomes. Positive-search ABMT works more reliably in home settings and elicits emotional benefits without exclusively relying on changes in attention bias (Mogg et al., 2017). Here, we used a particular positive-search ABMT (developed to improve people's ability to inhibit social rejection and approach social acceptance information by training to find the smiling face among frowning faces (Dandeneau & Baldwin, 2004) in order to boost optimism bias.

People's attention was biased away from negative and toward positive social information after completing positive-search ABMT in most (Dandeneau & Baldwin, 2004, 2009; Dandeneau, Baldwin, Baccus, Sakellaropoulo, & Pruessner, 2007; Voogd et al., 2016; Voogd, Wiers, Prins, & Salemink, 2014; Waters, Pittaway, Mogg, Bradley, & Pine, 2013) but not all studies (Waters et al., 2015) assessing attentional changes following training. More important, positive-search ABMT elicited several beneficial emotional outcomes (lower perceived stress, enhanced self-esteem/positive self-regulation; Dandeneau et al., 2007; Dandeneau & Baldwin, 2009; reduced anxiety/social phobia; Voogd et al., 2014; Waters et al., 2013, 2015, 2018; but see Voogd et al., 2016 for null-findings). These beneficial outcomes are also associated with optimism bias (e.g., self-esteem and self-regulation; Armor & Taylor, 1998; Hoorens, 1996). Thus, positive-search ABMT constitutes a promising tool to examine effects of positive attention processes on optimism bias.

The present work investigates whether repeatedly directing attention toward positive and away from negative social information during training causally influences optimism bias. Participants were randomly assigned to ABMT or control training. Before, after one, and after two training weeks, all participants completed the Comparative Optimism Scale (Weinstein, 1980; measuring optimism bias via social comparison) and the Future Expectancy Scale (Peters et al., 2015; measuring current optimistic states that are not necessarily biased but likely instigate optimism bias; see Garland et al., 2010 for details on how momentary emotional experiences trigger durable changes in emotional systems/affective styles). Because optimistic states vary across situations, ABMT directing attention to positive aspects of a situation may particularly trigger such state optimism. In addition to these optimism bias measures (primary outcomes), we assessed participants' mood with the Positive and Negative Affect Schedule (Watson et al., 1988; secondary outcome) during the two-week training period. Prior research has shown that the ABMT does not affect mood state (Dandeneau et al., 2007; Dandeneau & Baldwin, 2004). Thus, we assessed mood in the current study to replicate this finding and rule out the possibility that potential training effects on optimism bias arose because of changes in mood.

Whereas comparative optimism bias was measured to uncover the importance of social and self-enhancing components in relation to attention processes, state optimism was measured to examine whether attention processes elicit optimistic states that then instigate the biases' formation. By measuring these different aspects, the current study can uncover crucial determining factors for the influence of attention processes on optimism bias (social comparisons and/or transient optimistic states). If repeatedly directing attention to positive information through training enhanced optimism bias, then people's level of comparative optimism bias and state optimism should increase after participating in positive-search ABMT but not after the control training.

Methods

Participants

Based on a recent systematic review of meta-analyses on the efficacy of ABMT on emotional outcomes, we anticipated a small effect of ABMT on optimism bias (E. Jones & Sharpe, 2017, because effect sizes varied considerably, we chose the most modest assumption of a small effect). A minimum sample size of 128 to detect such small effect ($\eta^2_p = .02$) was determined with a power analysis ($\alpha = .05$, power = .95). Because we expected high drop-out rates over the two training weeks, 20 additional participants were tested. Thus, 149 healthy participants with normal/corrected-to-normal vision, who did not report using psychoactive substances took part in this online study. Sixteen participants were excluded from data analysis because of technical errors in data logging (N = 2), or because they did not complete the training on more than two days (N = 14) , leaving a final sample of 133 participants for completer analysis[1] (experimental group: N = 71, 26 male, age: $M_{Exp} = 22.17$ years, $SD_{Exp} = 3.92$ years, control group: N = 62, 16 male, age: $M_{Con} = 23.35$ years, $SD_{Con} = 3.16$ years). Participants were randomly assigned to a group and did not differ in age ($t_{(131)} = -1.904$, $p = .059$) or dispositional optimism (i.e., LOT–R sum scores; Scheier et al., 1994; $t_{(131)} = -1.920$, $p = .057$, $M_{\text{Exp}} = 22.61$, $SD_{\text{Exp}} = 3.89$, and $M_{\text{Con}} = 23.89$, $SD_{\text{Con}} = 3.78$). Furthermore, the two groups did not demonstrate baseline differences in any of the analyzed outcome measures (i.e., optimism or mood; all ps ≥ .283). Participants gave written informed consent according to the guidelines of the ethical standards of the Declaration of Helsinki and were told that they could end the experiment at any time. All procedures were approved by the local ethical review board.

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[1] For results of an intention-to-treat analysis including all participants see Analysis S.5.

Procedure

For two weeks, participants underwent daily five-minute online training[2] (see Figure 5.1 for details) and indicated whether they had performed the training completely, partly, or not at all on an online questionnaire. Moreover, participants completed personality questionnaires (see Information S.5) before, one week, and two weeks after training began (to prevent suggestibility effects, participants were not informed about different training versions or that effects on optimism were investigated). Participants received a daily email containing links to their version of the training and questionnaires. If participants had not answered the questionnaires by evening they were reminded. After the last training participants were debriefed.

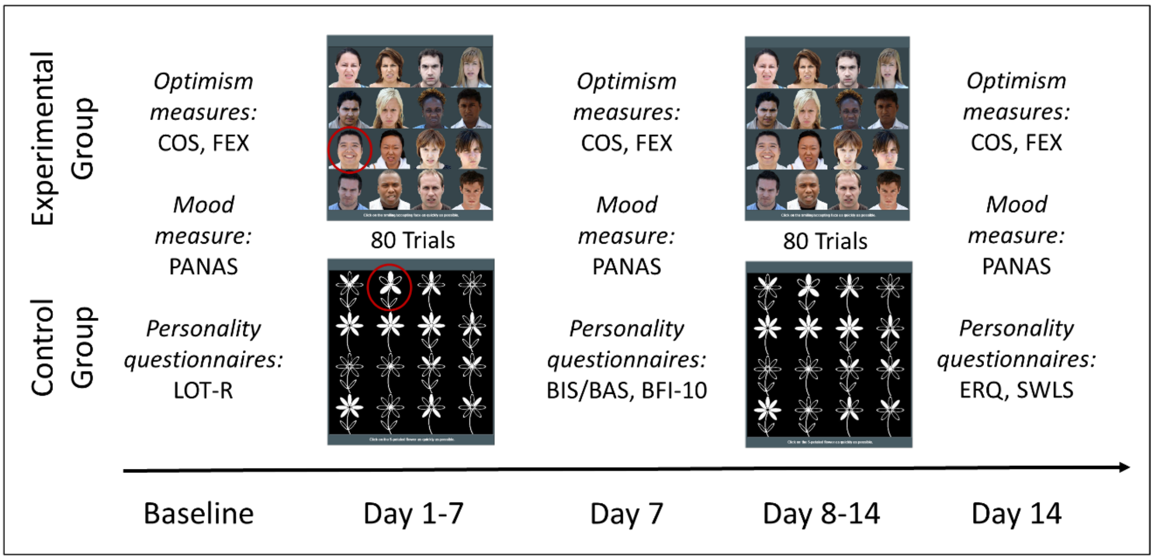

Figure 5.1. Schematic sequence of the experimental procedure. *At baseline all participants completed the COS (Weinstein, 1980) and FEX (Peters et al., 2015) as optimism bias measures (primary outcome), the PANAS (Watson et al., 1988) as mood measure (secondary outcome), and the LOT-R (Scheier et al., 1994). The following fourteen days participants completed a daily 80-trial ABMT or control attention training. During ABMT participants were instructed to click on the smiling face (here circled in red) among 15 frowning faces on a 4-by-4 matrix as quickly as possible (in total 16 face pictures [half female] were presented and the target appeared at random location within the matrix but equally often in each cell); during control training participants were instructed to click on the 5-petaled flower (here circled in red) among 15 7-petaled flowers as quickly as possible (controlling for activity of engaging in a visual search while not directing attention toward smiling/away from frowning faces). In both trainings the next trial followed directly after participants had clicked on the preceding trial's target (no inter-trial interval; trainings are based on Dandeneau & Baldwin, 2004). On day seven, all participants completed the*

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[2] The attention bias modification training and control training used in the current study can be accessed via the following links:
ABMT - http://baldwinlab.mcgill.ca/labmaterials/materials_16fa_c_80.html
Control training - http://baldwinlab.mcgill.ca/labmaterials/materials_16fl_80.html.

optimism bias/mood measures, the BIS/BAS (Carver & White, 1994), and the BFI–10 (Rammstedt, 2007). On day 14, all participants completed the optimism bias/mood measures, the ERQ (Gross & John, 2003), and the SWLS (Diener et al., 1985). BIS/BAS, BFI-10, ERQ, and SWLS have been conducted for a larger project on individual differences associated with optimism bias.

Dependent variables

Primary outcomes (optimism): On the COS (Weinstein, 1980) participants indicated the likelihood to experience 18 positive (e.g., "Marrying someone wealthy") and 23 negative future life events (e.g., "Having a heart attack") for themselves compared to another person of the same age and gender on a scale ranging from -3 (much less likely) to 3 (much more likely). On the FEX (Peters et al., 2015), measuring state optimism, participants indicated the likelihood of experiencing 10 positive (e.g., "You will get a lot of satisfaction out of life") and 10 negative future events (e.g., "You will have health problems") on a 7-point Likert scale ranging from 1 ("not at all likely to occur") to 7 ("very likely to occur"). Sub-scores representing comparative optimism bias and state optimism about future positive events were computed using mean scores of participants' answers to positive items of the COS and FEX.[3]

Secondary outcome (mood): On the PANAS (Watson et al., 1988) participants indicated how strongly they experience 10 positive (e.g., "excited") and 10 negative feelings (e.g., "distressed") at the moment on a 5-point scale ranging from 1 ("not at all") to 5 ("very much"). Sub-scores representing positive and negative mood were computed using sum scores of participants' answers to positive and negative items of the PANAS.

Data analysis

Primary outcomes (optimism): We hypothesized that performing positive-search ABMT increases comparative optimism bias and state optimism, whereas performing neutral control training does not. We performed two 3 × 2 ANOVAs with the within-subject factor time (baseline, one training week, two training weeks) and the between-subject factor group (experimental, control) on positive sub-scores of COS (Weinstein, 1980) and FEX (Peters et al., 2015). Support for our hypothesis should be reflected in significant time × group interactions.

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[3] Optimism bias for positive and negative events do not seem to be two sides of the coin but represent different aspects with independent motivating factors (e.g., self-enhancement vs. impression management; Weinstein, 1980; Hoorens, 1996). Self-esteem, for instance, is particularly correlated with optimism bias for positive but not for negative events. As the goal of the current study was to examine cognitive mechanisms of self-enhancing positivity, we focus on optimism bias for positive events.

Secondary outcome (mood): We also performed two 3 × 2 ANOVAs with the within-subject factor time (baseline, one training week, two training weeks) and the between-subject factor group (experimental, control) on positive and negative sub-scores of the PANAS (Watson et al., 1988). However, we did not hypothesize an effect of either positive-search ABMT or neutral control training on positive or negative mood.

Significant interactions were further investigated by post-hoc (Sidak corrected) pairwise comparisons. An α-level of .05 (two-tailed) was applied to all analyses. Reported effect sizes are partial eta-squared and noted as η^2_p. If the sphericity assumption was violated, Greenhouse-Geisser corrected values are reported.

Results

Training adherence

On average participants completed 13 of 14 training sessions and training adherence did not differ between the experimental and the control group ($t_{(145)} = .770$, $p = .442$, $M_{\text{Exp}} = 13.05$, $SD_{\text{Exp}} = 2.41$, and $M_{\text{Con}} = 12.76$, $SD_{\text{Con}} = 2.22$). Of the 147 participants that initially enrolled in the study and had no technical errors during data collection, 81 participants (55.1 %) completed all 14 training sessions, 38 participants (25.9 %) completed 13 of 14 training sessions, 13 participants (8.8 %) completed 12 of 14 training sessions, and one participant completed 11 of 14 training sessions and started the other three training sessions without finishing (adding up to the 133 participants included in the completer analysis). The remaining 14 participants (10.2 %) completed 1 (N = 2), 2 (N = 2), 4 (N = 1), 8 (N = 1), 9 (N = 1), 10 (N = 1), or 11 (N = 6) of the 14 training sessions (for results of intention-to-treat analyses including all 147 participants see Analysis S.5).

Primary outcome (optimism)

Comparative optimism bias did not generally differ between groups, $F_{(1,131)} = .442$, $p = .507$, $\eta^2_p = .003$, but it increased over time, $F_{(2,228)} = 4.178$, $p = .021$, $\eta^2_p = .031$. Notably, the predicted time × group interaction was significant, $F_{(2,228)} = 4.653$, $p = .014$, $\eta^2_p = .034$ (Figure 5.2a). In line with our hypothesis, comparative optimism bias increased from before to after two training weeks and showed a trend to increase from before to after one training week when people performed daily ABMT (baseline vs. two training weeks: $p = .001$, baseline vs. one training week: $p = .062$, as revealed by post-hoc pairwise comparisons), but not when people performed neutral control training (baseline vs. two training weeks: $p = 1.000$, baseline vs. one training week: $p = .969$). State optimism did not differ between groups; main effect of group, $F_{(1,131)} = 2.255$, $p = .136$, $\eta^2_p = .017$;

time × group interaction, $F_{(2,228)} = .507$, $p = .577$, $\eta^2_p = .004$. It only decreased over time, $F_{(2,228)} = 5.628$, $p = .006$, $\eta^2_p = .041$ (Figure 5.2b).

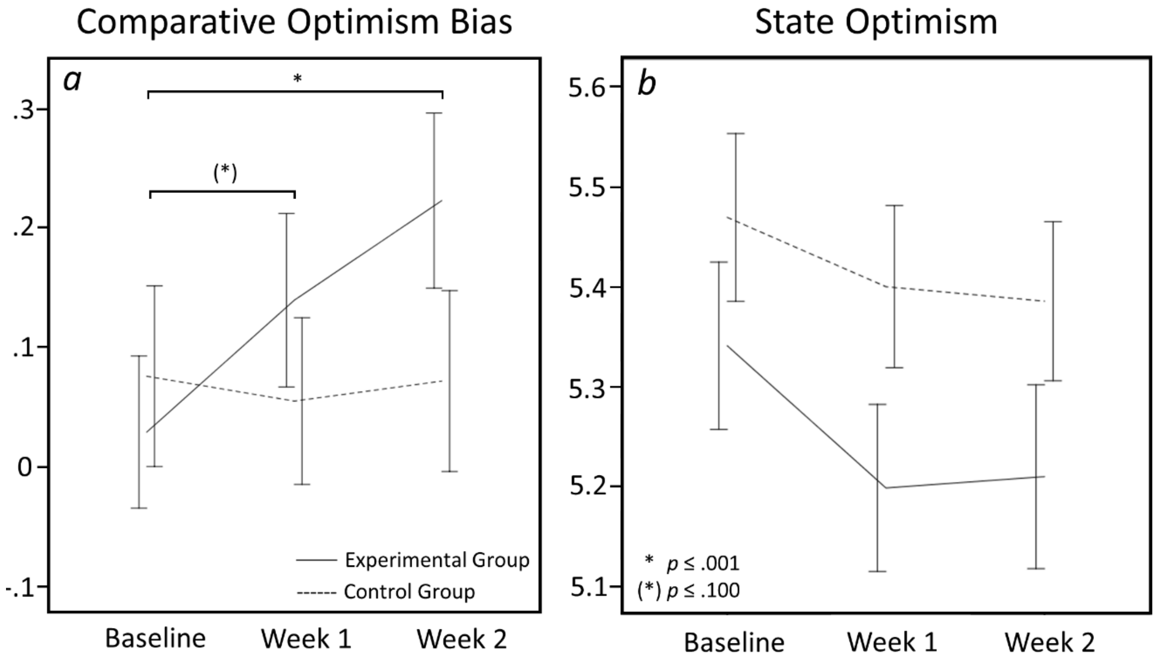

Figure 5.2. Change in comparative optimism bias and state optimism over the two training weeks in the experimental/control group. *Error bars depict standard errors. a. Comparative optimism bias significantly increases over the two-week training period in the experimental group but does not change in the control group. b. State optimism significantly decreases over the two-week training period in both the experimental and the control group.*

Secondary outcome (mood)

Positive mood did not differ between groups; main effect of group, $F_{(1,131)} = .095$, $p = .759$, $\eta^2_p = .001$; time × group interaction, $F_{(2,262)} = .671$, $p = .512$, $\eta^2_p = .005$; or change over time, $F_{(2,262)} = .418$, $p = .659$, $\eta^2_p = .003$ (Figure 5.3a). Similarly, negative mood did not differ between groups; main effect of group, $F_{(1,131)} = .377$, $p = .540$, $\eta^2_p = .003$; time × group interaction, $F_{(2,232)} = .313$, $p = .705$, $\eta^2_p = .002$; or change over time, $F_{(2,232)} = 2.423$, $p = .091$, $\eta^2_p = .018$ (Figure 5.3b).

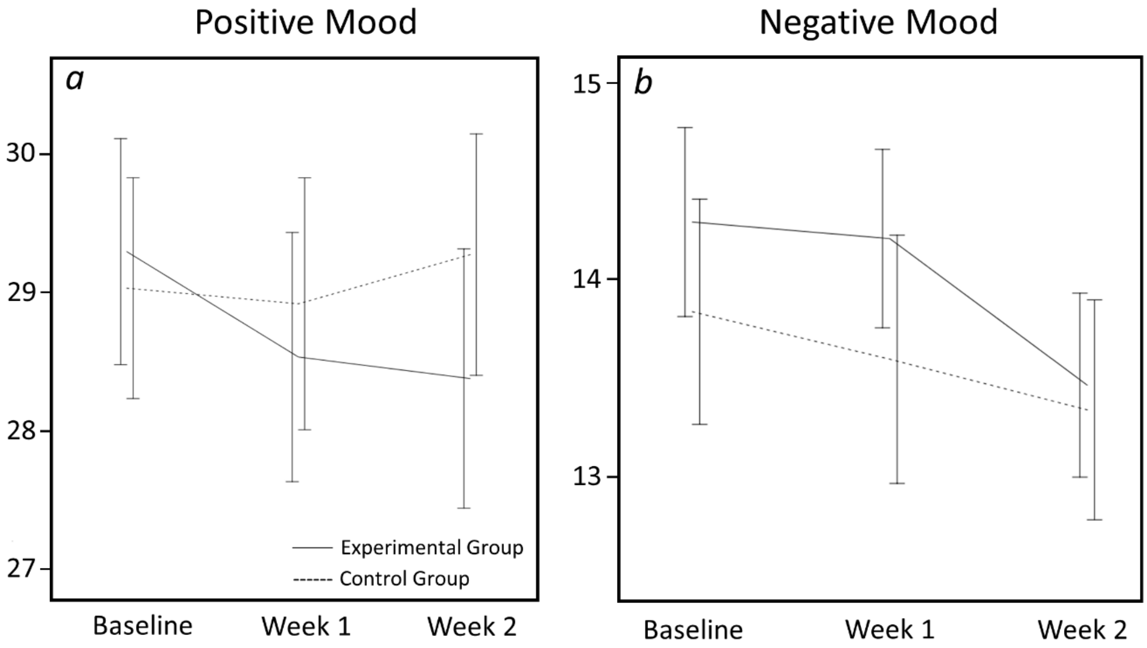

Figure 5.3. Change in positive and negative mood over the two training weeks in the experimental/control group. *Error bars depict standard errors. a. Positive mood does not change over the two-week training period in the experimental or control group. b. Negative mood does not change over the two-week training period in the experimental or control group.*

Discussion

The present experiment demonstrates that repeatedly directing attention to smiling faces and away from frowning faces over two weeks enhances comparative optimism bias, whereas performing neutral control attention training does not (Weinstein, 1980). Adherence of the online attention training used in the present study was generally high (about 90 % of participants completed all or the great majority of training sessions). Furthermore, enhanced optimism bias could not be attributed to peoples' mood (i.e., positive and negative feelings did not change over the training period), and beneficial training effects on optimism bias remained stable when analysing data of all participants that initially enrolled in the study (i.e., intention-to-treat analysis; see Analysis S.5). Thus, training a cognitive habit to pay attention to positive social information not only increases self-esteem and reduces stress but also enhances optimism bias, an important protective factor for mental health (Dandeneau et al., 2007; Sharot, 2011). This finding supports the combined cognitive biases hypothesis and implies that (a) expectancy biases are an essential part of the hypothesis (despite being rarely considered in past research Aue & Okon-Singer, 2015) and (b) cognitive bias interactions are not only present in psychological disorders but extend to positivity biases in healthy individuals (Kress & Aue, 2017).

However, our findings suggest that performing ABMT does not generally enhance optimism (i.e., it did not increase state optimism), but has specific effects on comparative optimism bias. There are two possible explanations for this distinction. First, items of the FEX (Peters et al., 2015) used to measure state optimism are more general than items of the COS (Weinstein, 1980) and might therefore rather uncover temporary variations in dispositional optimism (i.e., a general positive life orientation that is not necessarily biased such as the belief that good things will happen) than in optimism bias (i.e., biased expectancies about the likelihood of specific future life events such as being more likely to live past 85 years than other people). Even though dispositional optimism might increase someone's readiness to display optimism bias, the two phenomena represent separate concepts (Shepperd et al., 2015).

Second, it is possible that the ABMT used in the current study specifically influenced self-enhancing aspects of comparative optimism bias related to social comparison (Hoorens, 1996). The ABMT has shown to increase self-esteem (Dandeneau & Baldwin, 2004), which plays an important role in social comparison (A. Jones & Buckingham, 2005) and might, therefore, mediate the relation between positive attention processes and comparative optimism bias. Furthermore, the ABMT's social stimuli might have had specific effects on the strong social component of comparative optimism bias (i.e., social comparison). A more general ABMT (e.g., using words) potentially also influences state optimism. To draw final conclusions on such mediating factors, future research should directly examine the relationship between social and non-social ABMT, different measures of optimism bias, and self-esteem.

Two methodological features of this work might limit the conclusions to be drawn. First, information on training adherence was based on participants' self-report. However, questionnaires were self-administered online, which reduces social desirability bias (Nederhof, 1985). Furthermore, there is no reason to suspect that social desirability bias would differ between participants in the experimental and control condition. Thus, the effects observed in the current study should not be limited by self-reported adherence data.

The second potential shortcoming relates to the fact that we did not assess if and how ABMT changed attention processes in the current study (e.g., whether attention bias or attentional control changed throughout the training). Because previous research has already shown that positive-search ABMT changes attention bias and that this change is not due to mere stimulus exposure (Dandeneau et al., 2007), we focused on the training's outcome in the current study (i.e., whether extensively training a cognitive habit to direct attention to positive information enhances optimism bias) instead of the exact attentional mechanisms causing this outcome.

Following controversies on traditional threat-avoidance ABMT's reliability in modifying attention bias and emotional outcomes, it has been suggested to rather adapt ABMT based on theoretical considerations and investigate its benefits for emotional outcomes (Mogg & Bradley, 2018). Once these novel ABMT approaches reliably elicit emotional benefits, attentional mechanisms potentially underlying these benefits should be investigated with multiple measures (e.g., initial attention orienting, attention maintenance, attention bias variability, attentional control; Mogg et al., 2017; Mogg & Bradley, 2016; Waters et al., 2018). Notably, from a theoretical view both controlled top-down and automatic bottom-up attention processes potentially targeted by the ABMT are relevant for the mutually enforcing optimism-attention interactions we aimed to investigate (Kress & Aue, 2017). However, to draw final conclusions on which exact attentional mechanisms cause benefits of positive-search ABMT on optimism bias, future research needs to investigate (a) how training affects multiple attentional processes and (b) how these relate to changes in optimism bias. Such investigation can then further refine positive-search ABMT to make it more effective.

In general, the present findings contribute to a more nuanced view on the cognitive processes underlying optimism bias. A cognitive habit to pay attention to positive information is likely involved in the development and maintenance of optimism bias and, therefore, reveals how it can be triggered and maintained (Kress & Aue, 2017). We have previously shown that optimistic expectancies strongly guide attention toward reward (Kress et al., 2018) and hypothesized that subsequent attention on positive information stabilizes optimism bias. Such supportive attention processes could explain why future expectancies are selectively updated into an optimistic (not a pessimistic) direction following feedback (Sharot, 2011). The current results independently reveal the crucial missing piece of information corroborating our idea that attention processes maintain optimism bias over time: Directing attention to positive information does indeed enhance optimism bias and can, thereby, provoke positive feedback effects on initial optimistic expectancies. Together these findings argue for dynamic bi-directional optimism-attention interactions that maintain positivity and contribute to well-being and mental health.

Even though the attentional mechanisms underlying optimism bias are an important contribution to our understanding of its maintenance over time, future research should additionally consider the neural basis underlying this optimism-attention-interplay. Neuroimaging studies can identify brain areas involved in dynamic cognitive-bias-interactions, and point to neurotransmitter systems that might be triggered by pharmacological interventions if these interactions are malfunctioning (i.e., in psychological disorders), thereby revealing valuable insights for such interactions' application in the clinical domain and in everyday life.

In everyday life the present findings imply that focussing on positive aspects of the environment can boost motivation concerning a difficult task; in the clinical domain the findings imply that changing one aspect of biased cognition can alter other aspects, thereby improving overall conditions for prevention and treatment of psychological disorders. ABMT can be a low-cost, standardized, and easy-to-access support for psychotherapy. Online trainings that do not require therapist contact constitute a first intervention for people with contact anxiety (e.g., social phobia) and for patients who have to wait months before seeing a psychotherapist due to an overstrained health system.

In conclusion, our data show that repeatedly directing attention to positive and away from negative social information enhances comparative optimism bias. Uncovering such cognitive processes underlying optimism bias is essential for employing its benefits for mental health. Positive-search ABMT could trigger a self-sustaining upward spiral of positivity (through dynamic optimism-attention interactions), making our findings central for individual well-being as well as the prevention and treatment of psychological disorders (Garland et al., 2010; Kress & Aue, 2017). The present findings reveal that paying attention to positive information around us makes us more optimistic about our future; and the findings lead to some practical advice: If we want to look into a great future, we should start looking at the good things around us right now.

Supplementary Information

Information S.5. List of personality questionnaires participants completed during the study.

Life Orientation Test – Revised (LOT-R; Scheier et al., 1994)
Behavioral Inhibition System/Behavioral Activation System Scales (BIS/BAS; Carver & White, 1994)
10-Item Big Five Inventory (BFI-10; Rammstedt, 2007)
Emotion Regulation Questionnaire (ERQ; Gross & John, 2003)
Satisfaction with Life Scale (SWLS; Diener, Emmons, Larsen, & Griffin, 1985)

Analysis S.5. Intention-to-treat analysis.

Methods

To take into account that not all participants completed the attention training in our study, we additionally performed intention-to-treat (ITT) analyses on all 147 participants that initially enrolled and did not have technical errors in data logging (experimental group: N = 77, 28 male, age: M_{Exp} = 22.19 years, SD_{Exp} = 3.78 years, control group: N = 70, 17 male, age: M_{Con} = 23.21 years, SD_{Con} = 3.14 years). Experimental and control group did not differ in age ($t_{(145)}$ = -1.768, *p* = .079) but the control group displayed higher dispositional optimism than the experimental group (i.e., LOT–R sum scores (Scheier et al., 1994; $t_{(145)}$ = -2.166, *p* = .032, M_{Exp} = 22.74, SD_{Exp} = 3.85, and M_{Con} = 24.10, SD_{Con} = 3.75). However, the two groups did not demonstrate baseline differences in any of the reported outcome measures (i.e., optimism or mood; all *p*s ≥ .236). The last data point carried forward method was used to replace missing data in this ITT analysis (Waters et al., 2014).

Results

Primary outcomes (optimism)

Comparative optimism bias did not generally differ between groups, $F_{(1,145)}$ = 1.212, *p* = .273, η^2_p = .008, but it increased over time, $F_{(2,264)}$ = 5.419, *p* = .006, η^2_p = .036. Notably, the predicted time × group interaction was significant, $F_{(2,264)}$ = 3.164, *p* = .049, η^2_p = .021. In line with our hypothesis, comparative optimism bias increased from before to after two training weeks and showed a trend to increase from before to after one training week when people performed daily ABMT (baseline vs. two training weeks: *p* = .001, baseline vs. one training week: *p* = .065, as revealed by post-hoc pairwise comparisons), but not when people performed neutral control training (baseline vs. two training weeks: *p* = .929, baseline vs. one training week: *p* = .988). State optimism did not differ between groups; main effect of group, $F_{(1,145)}$ = 2.878, *p* = .092, η^2_p = .019; time × group interaction, $F_{(2,255)}$ = 1.026, *p* = .352, η^2_p = .007. It only decreased over time, $F_{(2,255)}$ = 5.440, *p* = .007, η^2_p = .036

Secondary outcome (mood)

Positive mood did not differ between groups; main effect of group, $F_{(1,145)}$ = .000, *p* = .992, η^2_p = .000; time × group interaction, $F_{(2,290)}$ = .325, *p* = .723, η^2_p = .004; or change over time, $F_{(2,290)}$ = .599, *p* = .550, η^2_p = .004. Similarly, negative mood did not differ between groups; main effect of group, $F_{(1,145)}$ = .182, *p* = .670, η^2_p = .001; time × group interaction, $F_{(2,265)}$ = .658, *p* = .505, η^2_p = .005; or change over time, $F_{(2,265)}$ = 1.250, *p* = .286, η^2_p = .009.

Discussion

The results of this ITT analysis confirm that comparative optimism bias increases when participants perform a two-week ABMT whereas it does not change when participants perform a neutral control attention training. Thus, beneficial effects of ABMT on optimism bias revealed by our completer analysis remain stable when including all participants that initially started with the training. Similar to the results of our completer analysis, performing the ABMT did not enhance state optimism. Furthermore, as expected neither the ABMT nor the control training influenced positive or negative mood, demonstrating that the beneficial training effects on optimism bias do not merely result from changes in mood.

Chapter 6

General Discussion

Discussion

The findings reported in the present thesis yield corroborative evidence for dynamic bi-directional optimism-attention interactions. The theoretical framework presented in chapter 2 integrates prior behavioral and neuroimaging findings of studies that investigated optimism bias and reward-related attention bias separately. This integrative framework highlights important commonalities between the two biases and their underlying neural mechanisms. Based on these commonalities, influential theoretical accounts, and first empirical data on optimism-attention interactions, the presented theoretical framework postulates (a) that optimism bias and reward-related attention bias enforce each other in both directions, (b) that the two biases recruit a common underlying neural network (e.g., comprising of the ACC as well as frontal and parietal brain regions), and (c) that both biases are characterized by similar motivational processes (i.e., a motivation to strive for reward initiated by limbic brain regions). Hence, the theoretical framework emphasizes that future research should examine optimism bias and reward-related attention bias together and investigate dynamic interactions between the two. Such innovative investigations can reveal how positive cognitive bias interactions contribute to mental health and psychopathology, thereby significantly advancing our understanding of normal functioning as well as the development and maintenance of mental disorders (Kress & Aue, 2017).

Based on the postulates derived from this theoretical framework, a series of empirical studies examining bi-directional optimism-attention interactions in healthy people was conducted in the present thesis (chapters 3-5). These studies revealed that (a) optimistic expectancies guide attention to confirming rewarding information in the environment, whereas they (b) enhance neural processing of unexpected punishing information and that (c) repeatedly paying attention to positive social information, in turn, enhances optimism bias about the future. In particular, the experiments described in chapter 3 demonstrated that both induced optimistic and pessimistic expectancies guide attention to expected (rewarding or respectively punishing) information. This effect was shown for automatic orientation of attention and controlled maintenance of attention. More important, optimistic expectancies had a stronger influence on attention orientation and maintenance than pessimistic ones did (i.e., people paid more attention to rewarding versus punishing information following optimistic expectancies than to punishing versus rewarding information following pessimistic expectancies). This stronger influence of optimistic compared to pessimistic expectancies on attention (i.e., asymmetric attention guidance) was particularly pronounced in people with high levels of optimism bias (Kress et al., 2018).

Chapter 4 reports an fMRI study that replicated these behavioral effects and additionally revealed important neural processes underlying causal influences of optimistic expectancies on attention. Specifically, the study demonstrated that both optimistic and pessimistic expectancies guide attention to expected (rewarding or respectively punishing) information, whereas processing of unexpected information enhances salience and executive control network activity (e.g., comprising of the insula, dACC, dlPFC, and PPC). Notably, these behavioral and neural effects were stronger for optimistic than for pessimistic expectancies. In particular, people oriented their attention particularly fast to expected rewarding information following optimistic expectancies (asymmetric attention guidance), whereas processing of unexpected punishing information following optimistic expectancies elicited particularly strong insula activity – a prominent node of the salience network (asymmetric neural processing). Furthermore, this asymmetry was particularly pronounced when taking individual differences into account (i.e., people who oriented their attention fastest to reward following optimistic expectancies also demonstrated strongest salience and executive control network activity when processing unexpected punishment). Hence, although unexpected punishment following optimistic expectancies is thoroughly processed in the brain, it might inhibit behavioral responses (Kress, Schuepbach, Wiest, Hermans, & Aue, submitted).

Finally, the training study reported in chapter 5 investigated the opposite direction of influence between optimism and attention, namely causal effects of a positive attention training on optimism. In this study, people either performed an extensive two-week online training in which they guided attention to positive, accepting (i.e., smiling) and away from negative, rejecting (i.e., frowning) face stimuli or a neutral control training in which they guided attention to five-petaled and away from seven-petaled flower pictures. As expected, performing the positive attention training enhanced optimism bias whereas performing the neutral control training did not. However, similar training benefits were not shown for state optimism or mood, indicating that the positive attention training may specifically instigate optimism bias (Kress & Aue, submitted). Taken together, the findings reported in the present thesis provide empirical support for dynamic bi-directional optimism-attention interactions for the first time. Such mutually enforcing optimism-attention interactions can maintain optimism bias and attention bias over time.

Toward an updated model of dynamic optimism-attention interactions

The results of the present thesis provide a more nuanced view on the neurocognitive mechanisms underlying causal interrelations between optimism bias and attention bias and call for an update of the behavioral model presented in chapter 1 (Figure 1.1). The behavioral model demonstrated that both optimism bias and positive attention bias are associated with mental health (Joormann & Gotlib, 2007; Sharot, 2011) but did not contain any information on how the two biases interact (Kress & Aue, 2017). However, the model already suggested an important mechanism that maintains optimism bias: people selectively update their expectancies into an optimistic direction when receiving positive (desirable) feedback about a given future prediction (e.g., their likelihood to get a good job after graduation is higher than initially predicted), but they do not update their expectancies into a pessimistic direction when receiving negative (undesirable) feedback (e.g., their likelihood to get a good job after graduation is lower than initially predicted; Sharot et al., 2011).

Notably, the attentional processes following optimistic expectancies revealed by the present thesis can explain *why* this updating asymmetry arises. Specifically, people selectively attend to positive feedback following optimistic expectancies, which may prevent negative feedback from being considered during expectancy updating (see Leong et al., 2017 for evidence on similar dynamic interactions between attention and expectancy updating during reinforcement learning). The present findings suggest that optimistic expectancies involve particularly strong predictions of reward and automatically guide attention to rewarding information in the environment (more than pessimistic expectancies do; asymmetric attention orientation to positive feedback). In contrast, unexpected punishing information following optimistic expectancies causes great surprise and elicits strong processing in the brain's salience network (again more than unexpected rewarding information following pessimistic expectancies does; asymmetric neural processing of negative feedback). The salience network is involved in the detection of salient information in the environment and elicits dynamic shifts between additional brain networks that need to be activated or deactivated during further processing of such information (Menon & Uddin, 2010). Even though unexpected punishment signals saliency and is strongly processed in the brain when people are optimistic, it might be so surprising that people cannot instantly react to such salient punishment. Thus, the strong neural response to unexpected punishment following optimistic expectancies does not translate into behavior (i.e., reaction times reveal that people automatically orient their attention to expected rewarding compared to unexpected punishing information; Kress et al., submitted).

Importantly, people also maintain their attention on rewarding information following optimistic expectancies (again more than they maintain attention on punishing information following pessimistic expectancies; asymmetric attention maintenance on positive feedback). Such more controlled attention maintenance on reward following optimistic expectancies may act as a form of emotion regulation that reduces the salience of surprising punishment and impedes deeper processing of it (Cisler & Koster, 2010; Fenske & Raymond, 2016; Wadlinger & Isaacowitz, 2008). Thereby, particularly strong guidance of attention to positive feedback following optimistic expectancies results in a positive attention bias (i.e., more attention on positive than on negative feedback). Such attention bias to positive information may, in turn, strengthen optimistic expectancies (i.e., optimism bias) by preventing negative information from being integrated into the formation of new expectancies (asymmetric expectancy updating). The present thesis revealed empirical evidence for this idea by demonstrating that repeatedly directing attention to positive social information while inhibiting negative social information during an extensive two-week online training enhances optimism bias (Kress & Aue, submitted). Together, the findings of the present thesis suggest dynamic bi-directional interactions between optimism bias and attention bias (Figure 6.1) that can result in an upward spiral of positivity protecting mental health (Garland et al., 2010).

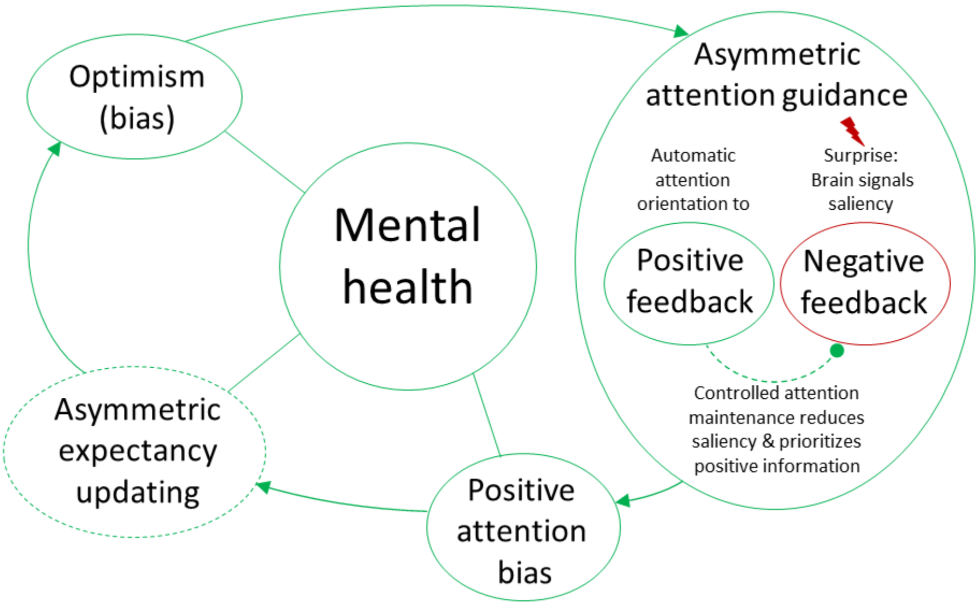

Figure 6.1. An updated model of positive cognitive bias interactions. *Healthy people have overly optimistic expectancies about their future (i.e., optimism bias). Following such optimistic expectancies they automatically orient attention to positive information and strongly process unexpected negative information in the brain (stronger influence of optimistic than pessimistic expectancies; asymmetric attention guidance). In addition, people strongly maintain their attention on positive information following optimistic expectancies, which may reduce the salience of unexpected negative information and lead to a positive bias in attention. Paying more attention*

to positive than to negative information in turn enhances optimism bias (potentially by preventing negative information from being integrated into new expectancies; asymmetric expectancy updating). At this point the circuit starts from the beginning again, thus resulting in an upward spiral of positivity that can protect mental health. Note, however, that there is no clear starting point in this circuit (i.e., optimism bias and positive attention bias mutually enforce each other and could both initiate the upward spiral).

Limitations and future directions

Because the specific methodological limitations of the reported studies on optimism-attention interactions have already been pointed out in chapters 3-5, this section will focus on more conceptual limitations and important questions that were not directly investigated or answered by the present thesis. Thereby, crucial aspects that should be targeted by future research on positive cognitive bias interactions will be identified.

For instance, even though the theoretical framework presented in chapter 2 suggests that positive memory biases may influence the link between optimism bias and attention bias, memory processes were not investigated in the empirical studies reported in chapters 3-5 of the present thesis. However, memory bias as well as additional positive cognitive biases (e.g., during interpretation) should be investigated in addition to optimism and attention in future research. Considering these additional cognitive processes can further clarify the exact mechanisms underlying positive cognitive bias interactions and refine the integrative model proposed here (Figure 6.1). In particular, future research should investigate the direct and indirect relations between various positivity biases (e.g., whether one bias mediates/moderates the relation between other biases). Such potentially indirect relations between different positivity biases were proposed in the theoretical framework in chapter 2 (Kress & Aue, 2017) and have already been shown in negative cognitive bias interactions (i.e., attention bias may influence memory via interpretation bias in subclinical depression; Everaert et al., 2013).

Moreover, previous findings on negative cognitive bias interactions in depression (Everaert et al., 2017) and the neuroimaging findings of the present thesis highlight the potential role of emotion regulation processes in positive cognitive bias interactions (Kress et al., submitted). Thus, future studies should investigate emotion (regulation) processes that may cause or result from positive cognitive bias interactions. For example, the question whether controlled attention maintenance on reward serves the purpose to regulate negative emotions arising from surprising, salient punishment should be directly examined in the future. Future studies also need to investigate whether attention training to positive information enhances optimism bias via improved emotion regulation or increased self-esteem.

Likewise, future research should directly address the influence of mutually enforcing positive cognitive bias interactions on well-being and positive emotions (i.e., by examining causal relations instead of correlations). Whereas the studies in the present thesis demonstrated that optimism bias and positive attention bias mutually enforce each other, beneficial effects of such optimism-attention interactions on well-being and mental health were not directly investigated in the present thesis (prior research has shown that both optimism bias and positive attention bias are positively associated with mental health though; Joormann & Gotlib, 2007; Sharot, 2011). Directly investigating causal relations between positive cognitive bias interactions and well-being is essential to facilitate the development of specific interventions to improve well-being and prevent mental health.

Apart from investigating how positive cognitive bias interactions causally influence well-being, it is further important to examine how an excess or absence of these positivity biases contributes to the development of mental disorders. For instance, future research should examine how interactions between excessive positive biases (e.g., extreme optimism bias instead of the moderate optimism bias shown by healthy people) interact and contribute to manic episodes in patients with bipolar disorder. Furthermore, it needs to be investigated how an absence of optimism bias in patients with depression influences the way they process information in the environment (i.e., do they show symmetric attention guidance to both positive and negative feedback or even an asymmetry toward negative feedback?).

In this regard, it is especially important to examine the transition between adaptive positive cognitive bias interactions (i.e., upward spiral; Figure 6.2, right) and maladaptive negative cognitive bias interactions (i.e., downward spiral; Figure 6.2, left) and identify specific processes that allow for a shift from one spiral to the other. This transition is ideally investigated in healthy populations that are vulnerable to mental disorders, such as trauma patients who have an elevated risk for developing chronic emotional problems. Experiencing trauma may initiate a shift from adaptive to maladaptive information processing, thus allowing for direct examination of such negative transitions. Future research investigating these negative transitions can crucially inform the development of interventions aimed to prevent mental disorders in at risk populations. Such potential future interventions could, for instance, involve neuro stimulation, pharmacological treatments, and/or cognitive training methods.

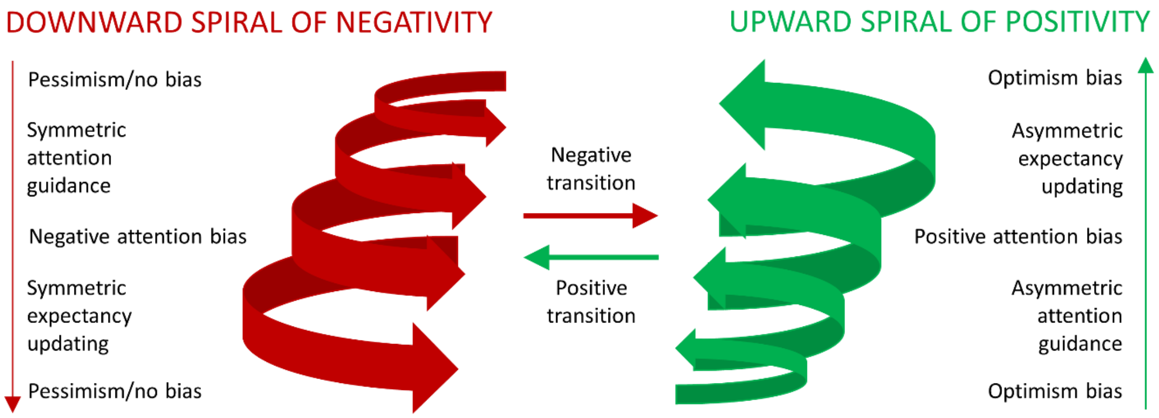

Figure 6.2. Downward spiral of negativity in patients with depression (left) and upward spiral of positivity in healthy people (right). *Whereas the interplay of negative biases in expectancies and attention may lead to a downward spiral of negativity via symmetric expectancy updating and symmetric attention guidance in patients with depression, the interplay of positive biases in expectancies and attention may lead to an upward spiral of positivity via asymmetric expectancy updating and asymmetric attention guidance in healthy people.*

For the development of future interventions it is further crucial to take individual differences into account. Positive cognitive bias interactions may influence well-being and the development of mental disorders quite differently in various people. In line with this idea, genetic risk factors have been suggested to play an important role in determining the impact of cognitive bias interactions on later mental health (Booth et al., 2017). Investigating individual differences (e.g., genetics, self-esteem, and emotion regulation skills) that may influence how cognitive biases impact well-being and mental health will uncover ways to personalize future interventions and, thus, make them most effective for each patient.

Furthermore, apart from applying positive cognitive bias interactions in interventions related to mental health and psychopathology, it is equally important to consider their usefulness in boosting performance or motivation in healthy people (e.g., in the sports context). For instance, future research should investigate whether positive cognitive bias interactions enhance motivation and self-esteem in athletes. Such investigations can inspire the development of cognitive enhancement trainings aimed at boosting performance. Cognitive enhancement trainings may, for instance, help to recover motivation, reestablish mental resources, and boost team spirit when a football team has lost the first half time and needs to turn an important match in the second half time. However, to ensure an efficient translation of positive cognitive bias interactions to both mental health preventions and cognitive enhancement trainings in the sports context, the trainings that are currently used in research need to be significantly improved. Currently used trainings are usually perceived as dull and repetitive (Beard, Weisberg, & Primack, 2012; Dennis & O'Toole, 2014) and need to be leveraged into attractive gamified trainings that will be more motivating and, therefore, effective.

Conclusion

In conclusion, the present thesis yields, for the first time, empirical evidence for a dynamic interplay between positive cognitive biases, in particular, optimism bias and positive attention bias. These dynamic optimism-attention interactions reveal important neurocognitive processes underlying healthy information processing. Thereby, the findings of the present thesis serve as a starting point for further investigations on how interacting positive cognitive biases protect well-being and prevent the development of mental disorders. The findings reported in the present thesis have only scratched the surface of much more fundamental interrelations between biased, emotional systems, and mental health. Investigating positive cognitive bias interactions within a larger context will have far-ranging impact on our everyday life and may strongly impact the way we preserve well-being and treat mental disorders in the future. Till then, let us keep our glass half full, put on those rose-colored glasses, and walk through the opening door to reach the light at the end of the tunnel and look forward to a life worth living!

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