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Review article

# Happy heart, smiling eyes: A systematic review of positive mood effects on broadening of visuospatial attention

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ABSTRACT

Positive mood contributes to mental and physical wellbeing. The broaden-and-build theory (Fredrickson, 2001) proposed that the beneficial effects of positive mood on life quality result from attentional broadening. In this article, we systematically review (following PRISMA guidelines; Moher et al., 2009), a host of studies investigating the nature and extent of attentional changes triggered by the experience of positive mood, with a focus on vision. While several studies reported a broadening of attention, others found that positive mood led to a more diffuse information processing style. Positive mood appears to lessen attention selectivity in a way that is context-specific and bound to limitations. We propose a new framework in which we postulate that positive mood impacts the balance between internally and externally directed attention, through modulations of cognitive control processes, instead of broadening attention per se. This novel model is able to accommodate discrepant findings, seeks to translate the phenomenon of the so-called broadening of attention with positive mood into functional terms, and provides plausible neurobiological mechanisms underlying this effect, suggesting a crucial role of the anterior and posterior cingulate cortex in this interaction.

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Even though we all are familiar with the pleasantness and joy intrinsic to the experience of positive mood, we do not always acknowledge its far-reaching effects on a myriad of mental operations. However, experiencing positive affect actually contributes to psychological (Tice et al., 2007), intellectual (Isen, 2000), physical (Burton and King, 2009), and social wellbeing (Berry and Hansen, 1996), increasing the likelihood of experiencing positive affect in the future (Fredrickson and Joiner, 2002). Moreover, experiencing positive feelings stimulates resilience to stress (Ong et al., 2006; Philippe et al., 2009; Tugade et al., 2004) and contributes to an improved overall quality of life (Cohn et al., 2009). Interestingly, it has been proposed that these beneficial effects of positive mood are mediated primarily by broadening of attention and increased flexibility of cognitive functioning (Fredrickson, 2001; Xu et al., 2015). However, while the effects of positive affect on cognitive control (see Chiew and Braver, 2011; Goschke and Bolte, 2014), executive functions (Mitchell and Phillips, 2007), and thinking styles (see Bolte and Goschke, 2010) have been extensively described in different reviews, modulatory effects of positive mood on attention mechanisms (and more specifically the putative broadening of attention accompanying this mood state) have not been brought together and scrutinized yet. Hence, whether or not positive mood broadens attention remains an open question in the affective science literature. In this review, we aimed at filling this gap by investigating in detail the effects positive mood can have on perception and attention. In doing so, we discuss plausible mechanisms underlying these effects, by comparing results, task designs and contextual factors of the studies included in this work.

## 1. Scope of the review

In this review, we discuss the current state-of-the-art of positive mood influences on perception and attention to eventually summarize a large body of recent empirical studies on this matter into a new theoretical framework. More precisely, we explore whether the attentional effects triggered by the experience of positive mood genuinely reflect a broadening of attention, or if other mechanisms might be driving the modulation of attention by positive mood. Along this path, we try to provide meaningful answers to several unanswered questions such as: how does feeling happy change the way we perceive the world? Is it always beneficial for us to experience positive mood in terms of perception and attention, or can positive mood be related to costs during information processing and selective attention? What might be the cognitive processes and neurobiological mechanisms by which positive mood can influence (visual) perception?

In this review, we provide a systematic overview of recent findings on broadening of attention in positive mood. We focus here on the influence of mood on visuospatial attention, referring to the selection of relevant locations in the visual field which subsequently receive prioritized processing (Carrasco, 2011). Studies on positive mood and visuospatial attention have operationalized the broadening of the attentional scope as either an expansion of the attentional focus (e.g., Rowe et al., 2007), or as a diffuse form of attention with an equal distribution of resources over the spatially selected visual field (e.g., Dhinakaran et al., 2013); two (non-mutually exclusive) phenomena expressing a decreased attentional selectivity. Other types or dimensions of attention, such as attention to emotional *information* (see Pourtois et al., 2013; Zadra and Clore, 2011 for recent reviews), temporal attention (e.g., attentional blink; see Olivers and Nieuwenhuis, 2006; Rokke and Lystad, 2015 or Vermeulen, 2010) or spatial attention effects occurring in other sensory modalities than vision (e.g., Pacheco-Unguetti and Parmentier, 2015, or across different sensory modalities in crossmodal attention; see Driver and Spence, 1998) are beyond the scope of this review. In addition, we focus here on behavioral, electrophysiological, and neuroimaging studies investigating the influence of *induced* positive mood on visuospatial attention, as opposed to natural fluctuations in the mood of the observer. Moreover, studies investigating pathological or abnormal affective states and their influence on attention are not considered in this review. Last, we only take into account studies that contribute to a better understanding of how positive *mood*, and not positive emotions or affect in general, can influence spatial attention.

In the following section, we define what is exactly entailed by positive mood in this review, and how this mood can be experimentally induced in the laboratory. In Section 3, we provide a short overview of the main theories describing the influence of positive mood on attention processes. The main part of this review (Section 4) consists of a detailed discussion of the studies investigating broadening of attention by positive mood, which we identified following the guidelines provided in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009). In this section, we outline specific methodological considerations that need to be taken into account when investigating the broadening of attention following mood manipulations. In Section 5, the implications of the discussed studies are synthesized and translated into new propositions about the psychological processes giving rise to the complex interaction between mood and attention. We discuss this interaction using the classical (dual-process) framework of top-down and bottom-up attentional control mechanisms (Corbetta and Shulman, 2002) and the broader distinction between internal and external attention processes (Chun et al., 2011). Additionally, we explore the possible role of cognitive control processes in mediating the strength of the link between positive mood and attention. There, we also briefly discuss effects of negative mood on spatial attention, for comparison purposes with positive mood. Finally, we briefly describe plausible neurobiological mechanisms supporting a broadening of attention in positive mood. In Section 6, we speculate on the likely functional meaning of attentional broadening in positive mood, and in the closing section we formulate general conclusions and highlight future avenues of research in this domain.

## 2. Positive mood

Mood can refer to multiple processes and aspects of emotional life. Just like emotions, mood can be defined in terms of duration, intensity, and the extent to which they vary on different emotional dimensions or axes, such as valence and arousal (Knutson et al., 2014). Although often used interchangeably in the literature, mood can be distinguished from the constructs of affect and emotion. Here, we use the term *mood* to indicate rather diffuse, low intensity, and long-lasting affective states, not elicited by a specific event or object (Beedie et al., 2005; Larsen, 2000). *Emotions* on the other hand are brief but intense, elicited by a specific external cause, and are associated with distinct physiological, behavioral and, expressive reactions (Beedie et al., 2005; Gross, 1998; Larsen, 2000). Affect can be conceptualized as the subjective feeling of moods and emotions, that are felt as positive/good or negative/bad, and as wanting to approach or withdraw (Larsen, 2000). Given that emotions have been investigated more extensively than moods, we use research on emotions to highlight the fundamental properties and underlying dimensions that are thought to be shared between them.

### *2.1. Dimensions: valence, arousal and motivation*

Emotion is often described by positioning it along the dimensions of valence and arousal (Knutson et al., 2014). In such a framework, valence and arousal are considered to be relatively independent of each other, and conceived as continuous dimensions, ranging from positive to negative and from sleepy to aroused, respectively (Barrett, 1998; Russell et al., 1989). Alternatively, emotion can also be described in terms of approach or avoidance motivational drives (Cacioppo and Gardner, 1999; Lang et al., 1998). In this latter framework, positive emotions are usually associated with the motivation to approach rewarding stimuli or potential opportunities, while negative emotions can be paired with either tendency (e.g., anger with approach, and fear with avoidance of possible threats). Nonetheless, some positive emotions do not elicit strong approach tendencies, such as “amusement” (Gable and Harmon-Jones, 2013) and “contentment” (Fredrickson and Branigan, 2005). Importantly, emotions that are highly motivating are typically also arousing (Gable and Harmon-Jones, 2013), and as a corollary, stimuli aimed at inducing positive affect high in approach-motivation are often high in arousal too (Gable and Harmon-Jones, 2008, 2010b). However, approach motivational tendencies are typically induced by presenting emotional stimuli and are thus elicited by specific events, while positive moods are internally generated states that are relatively independent of external triggers or events and less intense.

### *2.2. Positive mood vs. reward*

Emotion and motivation circuits are tightly intertwined (Koelsch, 2011; Pessoa, 2008). This makes it difficult to disentangle reward from positive affect, as well as their respective underlying mechanisms. Some researchers advocated that they are two sides of the same coin and therefore can simply not be separated from one another. They argued that positive and negative emotions are elicited by rewarding and punishing reinforcing signals, respectively (Burgdorf and Panksepp, 2006; Rolls, 2000), and that the experience of emotions is a result of the activation of brain circuits specialized in coping with such signals (Lang and Bradley, 2010). Positive mood can be conceptualized as a reward system itself, biasing people to learn new contingencies, associate freely and broaden their cognition (Bar, 2009; Carver, 2003), in line with the link between reward-sensitivity and positive emotionality (Tellegen et al., 1999). On the other hand, positive affect cannot be reduced to reward either. Neuroimaging studies showed that positive affect consists of separate facets, associated with different underlying neural systems. More precisely, “wanting” reflects the motivational aspect to acquire a reward, and “liking” the subjective experience of pleasure (Berridge et al., 2009). In addition, experiencing positive feelings also encompasses a conscious subjective affective experience (Barrett et al., 2007; Kringelbach, 2005). However, this line of reasoning does not deny the close ties between reward and positive mood, but rather posits that positive mood evolved from reward and partially shares the same brain mechanisms (Kringelbach, 2010).

Consistent with the existence of partly non-overlapping brain systems for positive mood and reward, effects of positive mood on cognitive functions seem qualitatively different and dissociable from the influences of reward (e.g., Chiew and Braver, 2011; Goschke and Bolte, 2014). However, no study to date directly compared effects of positive mood and reward on perception and attention. The substantial methodological and theoretical differences between the two lines of research probably contributed to this gap in the literature. For instance, experimental paradigms using reward typically imply the use of goal-directed behavior aimed at attaining specific rewards (see Lang and Bradley, 2010; Roseman, 2011). Hence, in studies assessing effects of reward on cognition, the reward is usually contingent on certain aspects of the task or the participants’ behavior. In contrast, positive mood is not associated with a specific goal, but rather reflects the preparation of the organism for a multitude of actions (Roseman, 2011). Therefore, the modulatory effects of reward on behavior might be more intense and phasic (i.e., tightly bound to the rewarded task aspect), whereas positive mood is usually mild, lasts for several minutes or hours (i.e., tonic) and does not (necessarily) influence the intensity of task-involvement. While the role of reward has not been analyzed in positive *mood* specifically, recent reviews comparing independent findings on reward and positive *affect* concluded that they can have similar, different, or even opposite effects on various cognitive functions (Chiew and Braver, 2011; Goschke and Bolte, 2014). One of the reasons accounting for this discrepancy might be the task-relatedness of affective manipulations and rewards (see Braem et al., 2013): rewards that are not contingent upon performance yield effects that are more similar to the ones elicited by positive mood, compared to the influence of performance-contingent reward (Fröber and Dreisbach, 2014).

Possibly contributing to the confusion is the differential time-course of the emotional response and the activation of additional brain structures in positive mood (Berridge and Kringelbach, 2011), when compared to reward processing and its well-circumscribed functional neuroanatomy (Schultz, 2006; Wise, 2008). Another factor possibly explaining this discrepancy is the lack of specification regarding positive affect (Chikazoe et al., 2014). As with negative affective states, different kinds of positive mood likely coexist (although they strongly correlate with each other; Lucas et al., 2009), such as gratitude (Bartlett and DeSteno, 2006), pride (Tracy and Robins, 2007), hope (Horton and Wallander, 2001), joy (Panksepp, 2007), love (Diener et al., 1995), interest and contentment (Fredrickson and Levenson, 1998). These different types of positive affective experiences may rely in different degrees on reward (Shiota et al., 2014), and exert different influences on cognition and behavior.

### *2.3. Positive mood inductions*

Previous research in the affective sciences has employed various mood induction procedures (MIPs) to elicit changes in the mood state of participants and study its effects on cognition and behavior. MIPs are usually used to experimentally induce a transient change in mood, mimicking to some degree mood fluctuations we naturally experience in everyday life (Jallais and Gilet, 2010). Many different types of MIPs have been validated in the past, and MIPs for the induction of negative mood have generally been found to be more effective or potent than positive ones (Mayer et al., 1995; Westermann et al., 1996). This phenomenon is often attributed to the positive baseline mood usually exhibited by healthy people (Diener and Diener, 1996) that might be difficult to elevate.

Moreover, the experience of positive mood might not be trivial and deliberately activated, as some studies showed that the overt pursuit of happiness can actually backfire (Mauss et al., 2011; Schooler et al., 2003). The observation that the same procedures are not equally effective for inducing pleasant and unpleasant moods (Zhang et al., 2014) might also be imputed to the fact that most MIPs were primarily devised to induce negative affect. More recently, thanks to increased scientific interest in positive affect (and more generally positive psychology; see Csikszentmihalyi, 1999; Seligman et al., 2005), a wide range of MIPs designed to provoke the experience of positive emotions in standard laboratory conditions has been validated in the literature.

MIPs developed for inducing positive moods can be subdivided into three main categories depending on how cognitively demanding the procedures are, and this factor seems inversely related to the extent to which they directly rely on reward processing. Many MIPs for inducing positive mood depend directly on the use of reward, and they consist of receiving gifts (Carpenter et al., 2013; Yang et al., 2013), winning points or money in games (Gable and Harmon-Jones, 2010a, 2011) or the presentation of biologically relevant approach-motivating stimuli, such as tasty food or appetitive stimuli (Gable and Harmon-Jones, 2008). However, while these MIPs induce positive affect rather automatically, they also necessarily activate approach motivation. Hence, these MIPs give rise to an important confound in research on positive affect (i.e., modulatory effects of mood on cognition cannot be ascribed to a change in mood valence only). A second main strategy to induce positive mood is based on the processing of positive images (Anderson et al., 2011), sometimes with the instruction to use them to adopt the targeted mood (Kohn et al., 2014), or funny video clips (Johnson et al., 2010; Van der Stigchel et al., 2011). However, both humor (Berns, 2004; Franklin and Adams, 2011; Vrticka et al., 2013) and the processing of positive images (Sabatinelli et al., 2007) are also largely related to reward (processing). In addition, both classes of MIPs rely strongly on emotional reactions to external stimuli, while moods are mostly generated internally. Finally, a third class of MIPs aims at inducing a mild and longer-lasting internally generated positive mood, manipulated independently of the task, and encompassing a more "cognitive" component. Here, participants read positive stories, recall positive memories and think about them, or use mental imagery of positive scripts or autobiographic memories (Goritz and Moser, 2003; Huntsinger, 2012; Zhang et al., 2014), such as to be immersed in a specific flow of thoughts and actively re-experience the targeted mood.

In summary, each of these three classes of MIPs are rewarding for the participants in some way, however, the nature of the reward and how it is used differs considerably between them (Shiota et al., 2014). While watching video clips and reading stories are effective methods to induce positive mood (Gerrards-Hesse et al., 1994; Westermann et al., 1996), writing or thinking about, or imagining positive personal memories might lead to more authentic changes in positive affect, given that they are "customized" for every participant thanks to their reliance on autobiographical information. This element is especially important in light of the large inter-individual differences in the ability to change mood effectively in general (see Kohn et al., 2014) and in the susceptibility to positive moods specifically (Gomez et al., 2000), as well as genetic differences predicting reactivity to positive information (Haase et al., 2015). Importantly, such MIPs do not reward or encourage any specific behavior, and they are not relevant in terms of task goals or demands. Hence, moods elicited with such "cognitive" MIPs might be closer to everyday mood fluctuations without specific external triggers.

In the next sections, where we investigate the interaction between mood and attention, we therefore include studies using any of the MIPs outlined here above. We note that systematic comparisons between the MIPs are impossible because of the paucity of studies. However, all studies reviewed here share that they manipulated mood orthogonally to the task participants had to complete. In addition, most studies included a neutral mood group as (active) control condition to allow for interpretation of the direction of the mood-related effects observed.

## 3. Theories on mood-attention interaction

In this field, the broaden-and-build theory (Fredrickson, 2001) stands out as an influential framework able to accommodate a wide range of effects exerted by positive mood on cognition and behavior, including attention. The broaden hypothesis posits that experiencing positive affect can generate a broadened cognitive processing and thinking style. A broad cognitive style can be understood as "zooming out" and paying attention to the globality of concepts, situations or objects. According to this theory, such broadening effect can occur at all levels of cognitive functioning. In higher-order cognitive tasks, a broad cognitive style can be conceptualized as a more inclusive and flexible thinking style, the use of broader semantic categories and enhanced creativity. Earlier studies investigating cognitive broadening showed that experiencing positive mood can stimulate a thinking style that is open (Estrada et al., 1997), creative (Chermahini and Hommel, 2012b; Isen et al., 1987), integrative (Isen et al., 1991), and flexible (Isen and Daubman, 1984). At the level of attention, broadening is defined as an attentional focus encompassing a large portion of the visual field and the encoding of global rather than local features of an object. Here, the theory builds on previous ideas about affect-attention interactions from Easterbrook (1959) and Derryberry and Tucker (1994), who proposed that experiencing emotions has specific effects on the size of the attentional scope. However, the effects of positive mood on attention and cognition are not clearly operationalized in this framework, and phenomena such as "broad cognitive style" can be interpreted in various ways.

Other models have suggested different perspectives on positive mood modulation of attention. For instance, the affect-as-information theory hypothesizes that a specific mood "tunes" a specific context for cognitive processing (Schwarz, 1990). In this model, positive mood informs a person that the environment is safe, leading to a less effortful and more heuristic information processing style. An extension of this model is the mood-as-input hypothesis (Clore et al., 1994), proposing that people in a positive mood tend to find tasks more enjoyable and feel more easily satisfied with their performance. This would in turn cue them to reduce effort expenditure, for example by a diminished adjusting of processing style across changing task contexts. Evidence supporting this theory shows that people spend less efforts on the evaluation (Schwarz, 1990) or categorization of stimuli (Park and Banaji, 2000) after a positive mood induction. Alternatively, the hedonic contingency theory proposes that in positive mood, people carefully assess the affective consequences of a task, in order to make decisions that do not jeopardize their pleasant mood (Hirt et al., 2008). According to this theory, people make efforts to protect or even improve their mood when feeling happy. Accordingly, a broad processing style appears to be congruent with the experience of positive mood, and could thus reinforce this affective state (see Bar, 2009; Brunye et al., 2013; Chermahini and Hommel, 2012).

Altogether, while these different theories differ regarding the proposed underlying mechanisms accounting for changes in the attentional focus as a function of (positive) mood, they share the assumption that mood reliably influences this interaction. Here, we focus on positive mood defined as a pleasant feeling low in approach motivation (such as joy and happiness), for which these theories concur and predict an enlargement of the attentional focus following the induction of this specific affective state.

While different theories exist on what effects positive mood could exert on attention, they usually do not provide plausible neurobiological mechanisms accounting for the puzzling effects seen at the behavioral level. In this context, the older neuropsychological model proposed by Ashby et al. (1999) stands out as a valuable exception. Inspired by research showing a link between positive mood and the intake of dopamine (DA) stimulating drugs, and that (cues predicting) unexpected rewards trigger phasic bursts of DA activity in midbrain structures (see Schultz, 2002), these authors proposed that positive affect is associated with an increased DA release in midbrain reward centers. This increased DA activation would then propagate its effects via dopaminergic projections throughout the brain (in particular the prefrontal cortex), affecting various cognitive functions. However, more recently, doubts have been raised about the likelihood that DA is directly involved in mood effects on cognitive operations such as attention (see Leyton, 2010 for an extensive discussion), although it is not excluded that DA influences the interaction between positive mood and selective attention mainly by regulating the activity of various other neurons (i.e., as a neuromodulator, see Kiyatkin and Rebec, 1996). In sum, although the neuropsychological theory of positive affect (Ashby et al., 1999) has proven useful to stimulate research on effects of positive mood on cognition, the putative association between DA and the mood-attention link is probably too simplistic to account for the somewhat discrepant findings that have been reported in the affective science literature regarding the broadening of attention after the induction of positive mood.

## 4. Positive mood influences on attention: empirical evidence

In this review, we investigate the effects of positive mood on the broadening of attention. A prevailing strategy to capture these effects in standard laboratory conditions is by using global-local processing tasks. In such a task, a big letter (e.g., the letter T) consists of smaller letters (e.g., F) and participants have to report either the global (i.e., a big T) or the local letter (i.e., small Fs; Navon, 1977). In another task, a similar approach is used with geometric figures: a geometric shape (e.g., a square) is built up from smaller figures (e.g., triangles; Kimchi and Palmer, 1982). Participants are asked to make a similarity judgment between the geometric figure and two other figures that match either its global form (i.e., a square) or its local element (i.e., a triangle). These paradigms are aimed at measuring the extent to which information is processed globally or locally. A global mode of processing is believed to facilitate the recognition of the overall shape, compared to a local processing mode meant for processing of details (at a lower spatial scale). Studies on the influence of mood on global-local information processing showed that people who transiently experience positive mood were more inclined to process the stimuli globally compared to both neutral (Fredrickson and Branigan, 2005; however, see Finucane and Whiteman, 2007) and sad moods (Gasper and Clore, 2002). Moreover, trait positive mood and optimism were found to correlate positively with a global and negatively with a local processing bias (Basso et al., 1996). However, a state-dependent preference for either local or global processing might not be informative about the actual ability to dynamically adapt the attentional span to focus on these global or local elements (Caparos et al., 2013). Hence, the use of global-local paradigms to investigate changes in the attentional scope depending on (positive) mood provides only limited understanding of the nature of the changes occurring at the attentional level as a result of the experience of positive mood.

Several metaphors have been introduced to explain the mechanisms of selective attention, including a spotlight (Broadbent, 1982), zoom lens (Eriksen and St-James, 1986) or gradient of attention (Mangun and Hillyard, 1988). These metaphors all emphasize the importance of spatial attention, which can be conceptualized as the selection of and focus on a specific location in the visual field that can occur either overtly or covertly (i.e., without moving the eyes; see Corbetta, 1998; Posner, 1980). Several studies have addressed the influence of positive mood on overt attention. For example, eye-tracking studies showed attentional preferences for positive stimuli in people experiencing positive affect (Wadlinger and Isaacowitz, 2006) and trait happy individuals (Raila et al., 2015), in line with other studies measuring correlates of overt attention showing such mood-congruent bias towards positive stimuli when experiencing happy feelings (Becker and Leinenger, 2011; Ford et al., 2010; Tamir and Robinson, 2007). However, given the focus of this review on changes in the size of the attentional scope (i.e., broadening of attention) or changes in how the selected space is processed (i.e., diffuse attention), and not in re-orienting (i.e., moving the attentional focus over the visual field to a new stimulus or position; see Corbetta et al., 2008; Derryberry and Tucker, 1994), here we confine our review to studies focused on covert (spatial) attention. To reliably assess correlates of covert attention, as a prerequisite, overt attention (i.e., the gaze) should be anchored at one location in the visual field (Carrasco, 2011). Moreover, to investigate the efficiency of selective attention specifically, one can either contrast the processing of stimuli at fixation with stimuli in the periphery, or with overlapping stimuli. This can be achieved by making participants anchor overt attention at one location (e.g., by instructions or a task at fixation) while presenting stimuli in the periphery. This way, only covert attention can be allocated to the spatially non-overlapping stimuli in the peripheral visual field. Another way to investigate the selectivity of attention is to assess the differential treatment of overlapping relevant and irrelevant stimuli. Accordingly, in this review, we only included studies implementing one of these two approaches.

### 4.1. Literature search

This review was performed in accordance with the PRISMA guidelines (Moher et al., 2009; see Appendix A). We identified potentially relevant studies (1) by a systematic search of Google Scholar until May 29, 2015 using following combinations of search terms: (a) "spatial attention", "broadening" and "positive mood", (b) "positive mood" and "attentional networks" and (c) "positive affect" and "modulation of attention", as well as (2) by screening the references of publications used in this review and by (3) searching for other publications of the first author of the studies found with the first two search strategies in Web of Science[1].

### 4.2. Inclusion criteria

A study was included in the review if it met the following criteria: (a) the research article was written in English and published in a peer-reviewed journal; (b) experimental studies in which positive mood was experimentally induced (as opposed to natural fluctuations in mood) in a within-subjects or between-subjects design; (c) the used paradigm allowed measuring attentional breadth (i.e., spatial attention was measured; tasks included stimuli in the periphery of the visual field or overlapping stimuli; overt atten-

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[1] We opted for Web of Science to search other publications of the first author. Our choice was motivated by the fact that this search strategy yielded numerous unrelated hits in Google Scholar, while the article list obtained with the more conservative Web of Science contained less irrelevant articles (i.e., from other authors). Besides the first author, we also indicated in Web of Science to only look for research articles (and not for instance reviews and meta-analyses).

tion was controlled) using behavioral, electrophysiological and/or neuroimaging methods.

### 4.3. Selection of studies

Following PRISMA guidelines (Moher et al., 2009), studies were selected in different steps (see Fig. 1 for a visualization of the selection process from identification to inclusion of studies). The search yielded a total of 1374 articles (master theses, PhD dissertations, book chapters and conference abstracts were not included), which resulted in 1002 articles after duplicates were removed. A first selection of potentially relevant studies was performed based on the title and then on the abstract, resulting in a selection of 27 articles. Full copies of these articles were read to check if the studies complied with the inclusion criteria. This resulted in the final inclusion of 21 articles (see Table. 1 for the final list of included articles). In what follows, we discuss these studies with the aim to investigate if and how positive affective states can influence selective attention (focusing on the putative broadening of the attention focus), and to delineate the specific conditions that allow for such positive mood-related effects on spatial attention.

### 4.4. Broadening inferred from cognitive interference tasks

Often, the influence of positive mood on attention has been investigated using interference paradigms, such as the flanker task (Eriksen and Eriksen, 1974) and the selective attention component of the Attention Network Task (Fan et al., 2002). In these tasks, participants are instructed to focus on and respond to a centrally presented target that is flanked on the right and the left side by peripheral distractors, named flankers. When flankers are mapped to a different response compared to the target (i.e., incompatible flankers), they cause more interference then compatible flankers, resulting in increased reaction times (RTs). It is hypothesized that if attentional focus is broad enough to encompass the flankers in addition to the centrally presented target, interference of these flankers should be greater compared to a narrow scope of attention. This line of research was initiated by Rowe et al. (2007), who used a modified flanker task to investigate positive mood effects on the broadening of attention. They manipulated the distance between the central target and the peripheral flankers, and found that positive mood triggered a stronger slowing effect on RTs to central targets compared to neutral and negative affect when flankers were presented far from fixation (it is however not clear whether this effect was also observed when flankers were presented closer to fixation). Rowe et al. (2007) concluded that the influence of incompatible flankers was stronger in positive mood because of a larger attentional scope, better encompassing eccentric flankers and thus allowing them to more strongly interfere with (central) target processing. A similar task was used by Moriya and Nittono (2011) in an electro-encephalogram (EEG) study (the EEG results of this study are discussed in Section 4.6.). These authors found that while the interference effect of incompatible flankers became significantly smaller with increasing eccentricity of flankers in neutral and negative moods, flanker spacing did not influence the effect of compatibility on task performance in the positive mood group. This result is in line with both a broadened attentional scope in positive mood and/or use of diffuse attention. More precisely, all stimuli falling within the attentional scope were processed up to a similar extent, regardless of their position in the visual field, while a normal spatial gradient of attention would result in a decreased processing with increasing eccentricity of the stimulus. However, many other studies failed to find an influence of positive mood on flanker compatibility effects (Finucane et al., 2010; Jiang et al., 2011; Martin and Kerns, 2011; McConnell and Shore, 2011; Wegbreit et al., 2015), even when an exact replication of the task was used (Bruyneel et al., 2013; see Table 1). Importantly, while no effects of mood were found in these studies, their manipulation checks confirmed successful induction of positive affective states.

One possible explanation accounting for these discrepant results was offered recently by Huntsinger (2012, 2013). He proposed that positive mood does not induce a broad processing style per se, but merely enhances the dominant attentional focus. The assumption that positive mood broadens attention stems from a default broad focus observed in healthy people, that is simply enhanced by inducing positive mood. Accordingly, this model predicts that positive mood will reinforce whatever focus is dominant at the moment (i.e., broaden attention when a broad attentional scope is present, and narrow attention when a narrow scope dominates).

The difference in results might also be related to methodological aspects of these studies. First of all, different MIPs were used across the studies. While the first two studies applied either music without any instructions (Rowe et al., 2007) or combined with the processing of emotional images (Moriya and Nittono, 2011), the other studies implemented more elaborate procedures to install a reliable positive mood (with the exception of Finucane et al., 2010 and McConnell and Shore, 2011), such as listening to music while generating mood-congruent thoughts (Jiang et al., 2011) and showing funny videos (Martin and Kerns, 2011; Wegbreit et al., 2015). Bruyneel et al. (2013) even used various mood inductions in different experiments (i.e., listening to music while retrieving positive episodes from autobiographic memory, receiving positive feedback on a social stress inducing task, and funny videos combined with reflecting on mood induction statements while listening to music) before participants completed the flanker task (Eriksen and Eriksen, 1974) or the Attention Network Task (Fan et al., 2002) in order to capture mood effects on attentional broadening. However, despite the use of different ecologically valid MIPs, no effects of mood on performance were found with these tasks. Hence, less demanding MIPs preceding task execution, as used in Rowe et al. (2007) and Moriya and Nittono (2011), might actually be qualitatively different and activate distinct processes compared to more elaborate MIPs. Second, the operationalization of "peripherally presented stimuli" is problematic in these earlier studies. Foveal vision is thought to encompass about 2° of visual angle (Palmer, 1999). However, the studies discussed above used around 1,5° of visual angle (Jiang et al., 2011; Moriya and Nittono, 2011) or the size of two small-typed letters (Bruyneel et al., 2013; Huntsinger, 2012; Martin and Kerns, 2011; Rowe et al., 2007) as the farthest distance between target and flankers. Hence, "peripheral vision", and accordingly a broadening of attention towards visual stimuli in the periphery, was not operationalized appropriately in these studies. Rather, the stimulus configurations were consistent with the use of the fovea to resolve the task, an element which inevitably complicates the interpretation of the results in terms of a broader attentional focus in positive mood. Moreover, given the proximity of target and flanker stimuli, the stimuli might be grouped in visual cortex (Egly et al., 1994; Khoe et al., 2006). Hence, the use of these tasks does not allow to differentiate a genuine broadening of the visual focus, or a spreading of attention within one object (see Richard et al., 2008). However, spatial attention and object-based attention depend on partly different brain processes (He et al., 2008). Therefore, it should be attempted in future studies to specifically target or isolate the broadening of spatial attention (in positive mood), without the possible confound of concurrent changes in object-based attention mechanisms. Importantly, specific characteristics of interference tasks might also explain in part these discrepant findings. These tasks are typically used to measure other processes besides selective attention, including cognitive control and executive functions (Botvinick et al., 2001). Hence, they might capture effects of mood on attention, executive functions and/or cognitive control concurrently, which might each go in different directions depending on

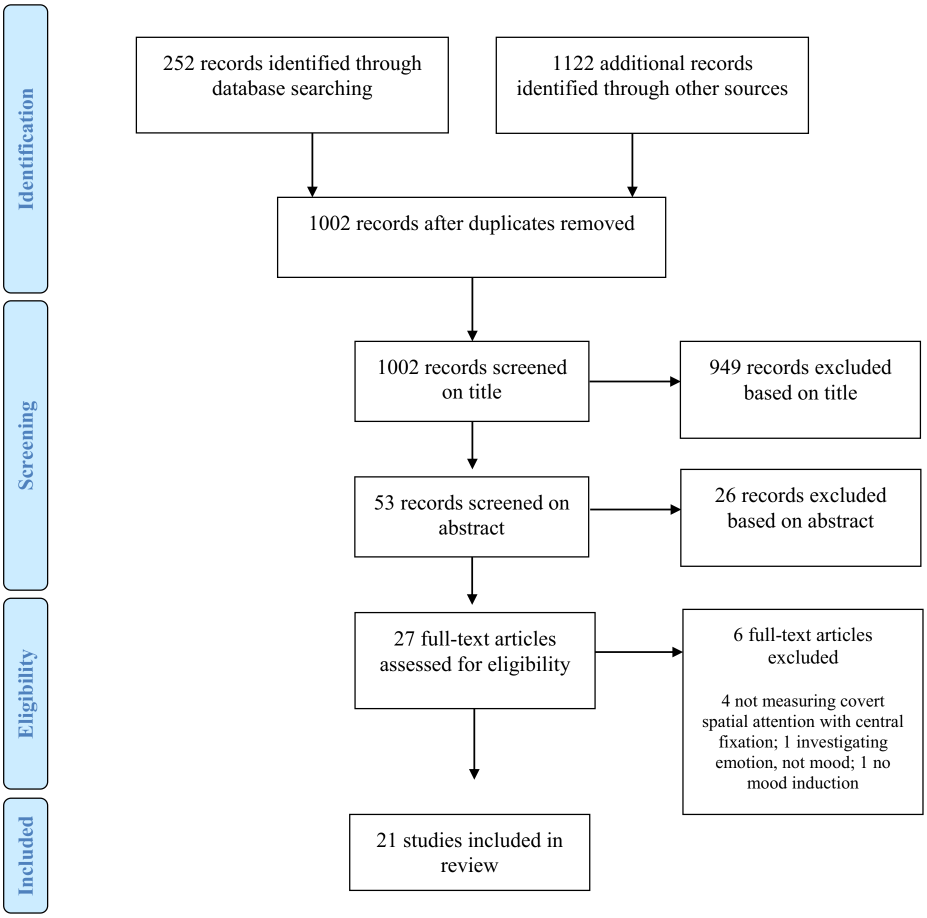

**Fig. 1.** PRISMA flow diagram representing the selection of included studies (adapted from http://www.prisma-statement.org/PRISMAStatement/FlowDiagram.aspx).

the exact task context. Hence, interference tasks might not provide appropriate experimental paradigms to study effects of positive mood on selective attention. This conjecture was corroborated in a recent study (Phaf, 2015), using a modified flanker task. Mood was induced by writing about emotional episodic memories while listening to a mood-congruent music fragment of choice. Interestingly, Phaf (2015) found that positive mood gave rise to stronger flanker interference at longer flanker-target intervals compared to negative mood, and concluded therefore that the effect of positive mood on flanker interference likely reflected a higher flexibility in switching between targets and flankers, as opposed to a broader attention focus per se.

In sum, while interference tasks are used in the majority of studies on positive mood and attention, most of them do not observe the expected broadening effect. As listed above, a number of possible explanations and methodological factors may account for the lack of consistent findings. Several other studies have also tested positive mood effects on selective attention, using alternative approaches and experimental paradigms. In what follows, we first discuss behavioral studies before we turn to psychophysiological and neuroimaging studies informing about the neural underpinnings of the process under scrutiny. The most important aspects and main results of these studies are summarized in Table 2.

### *4.5. Alternative paradigms: behavioral evidence for attentional broadening in positive mood*

In a recent study, an attention-demanding conjunction task was used in which participants were instructed to process two peripheral targets simultaneously, while fixation was required between these two stimulus locations (Huttermann and Memmert, 2015). By systematically varying the positions of the stimuli and the distance between them (between 5° and 40° on the horizontal, vertical or diagonal axes), the authors could calculate the maximum broadening of the attentional scope (i.e., by quantifying the maximum distance between targets at which the task could still be performed accurately in 75% of the trials). The task was performed before and after a MIP, which consisted of listening to neutral, sad or positive music in a between-subjects design. Results showed a larger attentional scope in the positive compared to the negative mood group in the post-MIP measurement. However, the size in the positive mood group did not differ from the post-MIP measurement in the neutral mood group, nor from its own baseline measured before the MIP, suggesting that the effect was limited to a narrowing of the attentional scope in the negative mood group. Nonetheless, a numerically larger scope was found in the positive mood group and the small sample size of the study (26 participants, divided over three mood groups) might have obscured a mild broadening of attention with positive mood.

In two studies from our group, either a positive or a neutral mood was induced using a MIP combining mental imagery of (positive or neutral) autobiographic memories and music (Grol and De Raedt, 2014; Grol et al., 2014). Next, participants performed the Attentional Breadth Task (ABT), in which stimuli were shown at fixation together with a target in one of 16 locations presented in two concentric circles, either close to (at 10° of visual angle) or far (at 25°) from fixation (Bosmans et al., 2009). In one study, sad, neutral or positive faces were presented at fixation and participants had to identify the emotion of the face as well as to localize the peripheral target concurrently (Grol and De Raedt, 2014). Because no evidence

**Table 1**
Description and main results of studies using interference tasks. N = Final number of participants; ANT = Attention Network test; B = Behavioral; Neu = Neutral; Pos = Positive; Neg = Negative; Y = Yes; N = No.

| First author (year) | N | Task | Methods | Mood comparison (design) | MIP | Broadening? |
|---|---|---|---|---|---|---|
| Bruyneel et al. (2013) Exp. 1: | 33 | Flanker with spacing | B | Neu–Pos (within) | Music + retrieving autobiographical memories (Neu: reading about Belgium) | N |
| Exp. 2: | 38 | Flanker with spacing | B | Pos–Neg (within); | Pos feedback after stress induction | N |
| Exp. 3: | 23 | ANT | B | Neu–Pos–Neg (within) | Film + instruction to get into a mood with Velten statements + film music | N |
| Finucane et al.(2010) | 180 | ANT | B | Neu–Pos–Neg (between) | Emotional images | N |
| Huntsinger (2012) Exp. 1: | 315 | Flanker after induction of global/local focus | B | Pos–Neg (between) | Read story | N, dominant focus in positive mood |
| Exp. 2: | 189 | Emotional interference task with target focal and distractor emotional faces | B | Pos–Neg (between) | Music | N, dominant focus in positive mood |
| Jiang et al. (2011) | 36 | ANT | B | Neu–Pos–Neg (within) | music + mood-congruent thought generation in Pos and Neg condtion; reading facts about China in Neu condition | N |
| Martin and Kerns (2011) Exp. 2: | 104 | Flanker | B | Neu–Pos (within) | Video | N |
| McConnell (2011) Exp. 2: | 66 | ANT | B | Pos, high arousal–Pos, low arousal–Neg, high arousal–neg, low arousal | Music | N |
| Moriya and Nittono (2011) | 18 | Flanker with spacing | B + EEG (ERPs) | Neu–Pos–Neg (within) | Emotional images | Y |
| Phaf (2015) | 40 | Flanker with different SOAs + masking | B | Pos–Neg (between) | Writing about autobiographical event + listening to chosen music fragment | Y, but interpreted as flexibility, not broadening |
| Rowe et al. (2007) | 24 | Flanker with spacing | B | Neu–Pos–Neg (between) | Music + Generating mood-congruent thoughts | Y |
| Wegbreit et al. (2015) Exp. 1: | 34 | Colour flanker Flanker letters had either the same or a different color then the target letter; the letters' colour was task-irrelevant. | B | Pos–Neg (within) | Video | N (i.e., no effect of colour on performance in positive mood) |
| Exp. 2: | 33 | Colour flanker | B | No MIP | Control experiment to determine in which group the effect was present in Exp. 1. | N |

was found that the induction of positive mood triggered a broadening of attention, auxiliary moderation analyses were performed to take into account the inter-individual differences in the extent mood changed according to self-report before compared to after the MIP. Additionally, scores on the Beck Depression Inventory (Beck et al., 1996) were taken into account to control for potential influences of depression scores. These supplementary analyses showed that increased levels of positive mood were related to greater attentional broadening towards positive information, but only in participants who reported no or very mild depressive symptoms. Participants reporting more depressive symptoms (around the cut-off score for mild depression) displayed an attentional narrowing with positive mood when positive information was presented at fixation, while no effect of mood on the attentional scope was found at moderate levels of reported depressive symptoms. Hence, these results indicate that the amount of reported depressive symptoms can influence the direction and the strength of the association between positive mood and attentional scope. In the second study using the ABT task (Grol et al., 2014), a larger increase in positive mood was associated with a broadening of attention only when the information at fixation was self-related, compared to when it was not. Together, these two studies suggest that the broadening

**Table 2**
Description and main results of studies complying with criteria. Grol 1 (2014) refers to Grol and De Raedt (2014); Grol 2 (2014) refers to Grol et al., 2014. N = Final number of participants; ABT = Attentional Breadth Task; B = Behavioral; Neu = Neutral; Pos = Positive; Neg = Negative; Y = Yes; N = No.

| First author (year) | N | Task | Methods | Mood comparison (design) | MIP | Broadening? |
|---|---|---|---|---|---|---|
| Biss and Hasher (2011) | 64 | 1-back task followed by fragment completion task | B | Pos–Neu (between) | Emotional images + music | Y |
| Biss et al. (2012) | 60 | 1-back task followed by fragment completion task | B | Pos–Neu (between) | Emotional images + music | Y |
| Dhinakaran et al. (2013) | 32 | Stimuli tagged by different frequencies | EEG (ssVEPs) | Pos–Neg (between) | Emotional images | N |
| Grol 1 (2014) Exp. 2 | 55 | ABT; with self-related or others-related words presented at fixation, participants identify these words and the location of the peripheral target in one of the dots | B | Neu–Pos (between) | Imagery of autobiographical memory + music | Y, but only with self-related information at fixation |
| Grol 2 (2014) | 40 | ABT; sad, neutral or positive faces presented at fixation, participants identify the emotion of the face and the location of the peripheral target in one of the dots | B | Neu–Pos (between) | Imagery of autobiographical memory + music | Y, but only in participants with no or very mild depressive symptoms |
| Huttermann and Memmert (2015) Exp. 2 | 26 | Attention-window paradigm; an attention-demanding conjunction task in which subjects have to simultaneously focus on two peripheral targets + systematically varying the stimulus positions and the distance between them. | B | Neu–Pos–Neg (between) | Music in Pos and Neg condition, reading basic facts about their country in Neu condition | N |
| Kuhbandner et al. (2011) | 63 | Iconic memory task; a circle of letters presented around fixation (in the peripheral visual field), participants indicate the letter at the indicated position after a delay | B | Neu–Pos–Neg (between) | Recalling autobiographical memory + music in Pos and Neg condition; Recalling a typical Wednesday morning (without music) in the Neu condition | Y, better performance in Pos condition + participants in Pos condition showed equal performance regardless of stimulus position, especially with short delays between stimulus and cue |
| Schmitz et al. (2009) | 13 | Participants attend a small face picture at fixation and report the gender of the face, while ignoring the bigger image of the house beneath the face. | B + fMRI | Neu–Pos–Neg (between) | Emotional images | Y, although no increased activation in the PPA, the greatest amount of repetition suppression in positive mood + increased perceptual encoding of unattended peripheral stimuli and a greater co-activation of PPA and primary visual cortex |
| Uddenberg and Shim (2014) | 12 | Luminance change detection task at fixation while simultaneously detecting a target moving direction of peripherally presented dots | B | Neu–Pos–Neg (between) | Music + Generating mood-congruent thoughts | Y |
| Vanlessen et al. (2013) Exp. 1 | 33 | Oddball task at fixation + peripheral distractors | B + EEG (ERPs) | Neu–Pos (between) | Imagery of autobiographical memory + music | Y, equal early processing of peripheral distractors regardless of position |
| Exp. 2 | 35 | Oddball task at fixation + identification small elements in peripheral stimuli | B | Neu–Pos (between) | Imagery of autobiographical memory + music | Y, decreased distinguishing between local features in periphery |
| Vanlessen et al. (2014) | 40 | Oddball task at fixation + localization of peripheral distractors | B + EEG (ERPs) | Neu–Pos (between) | Imagery of autobiographical memory + music | Y, stronger early spatial encoding stimuli + faster RTs (+bigger P3 = better discrimination at fixation) |

of attention with positive mood is flexible and varies depending on specific situational (task-related) as well as dispositional (subject-specific) effects.

The same MIP was used in two EEG studies (EEG results are discussed in Section 4.6.) investigating the influence of positive mood on the broadening of attention (Vanlessen et al., 2013, 2014). In these studies, participants performed a demanding oddball detection task at fixation, while peripheral stimuli were presented at different eccentricities from fixation in the upper visual field (ranging from 5,3° to 10,3° of visual angle). At the behavioral level, positive mood yielded both beneficial and detrimental effects on the identification of different aspects of the peripheral stimuli:

while a RT advantage was found for positive (relative to neutral) mood when participants had to localize the peripheral stimuli (Vanlessen et al., 2014), accuracy significantly dropped when they were asked to discriminate fine-grained details of the peripheral textures (Vanlessen et al., 2013). These results suggest that positive mood can influence the trade-off between coarse and detailed analysis of these peripheral stimuli. Such decline in detailed processing of information in positive mood was also found in a study on attention to motion (Uddenberg and Shim, 2014). In this study, participants performed a luminance change detection task at fixation while they simultaneously had to detect peripherally presented dots moving in a target direction. In a within-subjects design, participants listened to sad, neutral or positive music while they generated mood-congruent thoughts in order to induce the matching mood before executing the task. Results showed that positive mood was associated with more false alarms, a lower discrimination sensitivity and wider tuning curves (calculated by plotting the probability of a response to a certain motion direction) relative to neutral or sad mood. Hence, these results demonstrate that positive mood can interfere with the processing of low-level stimulus features (as suggested by a decreased selectivity for directions of motion with positive mood in this study), while increasing the readiness of participants to identify “globally” stimuli as targets, consistent with a broadening of attention in this mood. Although perhaps counterintuitive at first sight, both beneficial and detrimental effects are actually in line with a broadened attentional scope. Given the existence of a trade-off between the size of the attentional focus and the resolution of visual processing (Castiello and Umilta, 1990; Ivry and Robertson, 1998), a lower capacity to discriminate small differences can be expected with a broader focus of attention because spatial selection of a part of the visual field implies no more competition between separate elements within that zone (Desimone and Duncan, 1995). This might result in the processing of the stimulus as one uniform texture, instead of a pattern of several smaller elements, likely explaining why a broad focus was associated with an impaired identification of local details (i.e., a drop in spatial resolution). In addition, a broader focus also implies the spreading of available resources over a larger part of the visual field, decreasing absolute processing strength at any given location within that selected part (Carrasco, 2011; Muller et al., 2003). Hence, detailed processing logically decreases when the attentional scope encompasses a larger portion of the (attended) visual field. Conversely, if the task requires to coarsely localize the entire texture in the upper visual field as a whole, then a broader attentional focus in positive mood is presumably beneficial and thus associated with a behavioral gain, compared to a control mood with a neutral content (see Vanlessen et al., 2014).

Of note, while these studies were designed primarily to investigate the influence of positive mood on mechanisms of selective attention (i.e., resolution and broadening of the attentional focus), iconic memory is another important process at work in these tasks. This memory stores sensory information for a short time period before attention selects information for further processing (Long, 1980). One study investigated the effects of happiness on the breadth of iconic memory, by showing peripheral letter stimuli around a central fixation cross (5,2° of visual angle) and instructing participants to report the letter at the cued position after a varying delay (Kuhbandner et al., 2011). Mood influenced iconic memory performance, in such a way that it was increased in the positive compared to the neutral condition (and to a lesser, non-significant extent also compared to the negative mood condition). In addition, performance was strongly influenced by target position in the neutral and negative mood groups in trials with very short stimulus-cue intervals, but not in positive mood, again consistent with a more diffuse (sensory) processing in this mood. Hence, besides its influence on attention resolution, positive mood also seems able to alter stimulus representations held in iconic memory.

### 4.6. *Changes in visual cortex as an index of a broader attention scope with positive mood*

While the behavioral studies reviewed above are very informative regarding the nature and extent of changes in attention control mechanisms following the induction of positive mood, electrophysiological and neuroimaging studies provide crucial complementary information to gain insight into the neurobiological basis of this effect. For instance, the extent to which peripheral stimuli capture attention with behavioral measures cannot be directly measured at the behavioral level, because the behavioral response reflects the outcome of many processing stages (including non-attentional processes). Moreover, behavioral measures require in most cases that responses are recorded to these stimuli and are thus task-relevant, which implies the need to use specific paradigms, such as dual tasks. However, one could argue that the processing of task-relevant stimuli cannot provide an answer to the question if positive mood can change the attentional scope, given that participants have to encompass these stimuli in their attentional focus in order to perform the task. Electrophysiological and neuroimaging studies on the other hand allow the recording of brain responses to task-irrelevant stimuli (i.e., without participants responding to them). Hence, other processes of attention can be investigated, such as the spillover of attention to irrelevant distractors (Lavie, 1995).

Spatial selective attention operates by selecting a circumscribed part of the visual field in which visual stimuli receive priority in the competition for further processing and awareness, while the processing of stimuli falling outside the attentional focus (i.e., at an unattended location) is suppressed (Hillyard et al., 1998; Kastner and Ungerleider, 2000). Moreover, when attention is directed to a specific location, baseline activity in visual cortex accounting for the unattended part of the visual field is decreased (Smith et al., 2000). The use of event-related potentials (ERPs) is extremely valuable in this context, allowing for a precise characterization of the time-course of mental processes unfolding following stimulus onset and the assessment of their sensitivity to changes in attention (and/or mood). Spatial attention mechanisms can modulate stimulus processing in visual cortex, affecting several visually evoked potentials (VEPs). Classically, the P1 (a positive deflection peaking between 80 and 130 ms post-stimulus) and N1 (a negative component peaking between 120 and 180 ms) were considered to be the first VEPs influenced by manipulations of spatial attention (Hillyard and Anllo-Vento, 1998; Luck et al., 2000). The above mentioned study of Moriya and Nittono (2011) investigated the effects of positive mood on these two components. In their flanker task, they presented a task-irrelevant white dot on one of the letters in 80% of the trials and measured the ERPs elicited by these dots. As hypothesized, the P1 measured in the trials with a dot was significantly larger in the positive compared to the neutral mood condition, demonstrating a stronger processing of the stimuli, in line with a gain control mechanism of attention in extrastriate visual cortex (Martínez et al., 1999). Based on a study (Handy et al., 2001) showing a decreased P1 amplitude for stimuli presented close to a central target in a condition triggering a narrowing of attention (i.e., high perceptual load, Lavie and Tsal, 1994), Moriya and Nittono (2011) interpreted the increased P1 amplitude for the white dots in their study as a result of a broadened attention. In addition, these authors found that the lateralization of the N1 component was less pronounced in the positive compared to the negative mood condition, although no difference was found between these two affective conditions and the neutral one. In line with a previous study showing an altered lateralization of the N1 when attention spreads to the non-attended visual field (Kasai, 2010), they interpreted the diminished lateralization of the N1 as a spreading of attention to the unattended hemifield (Vogel and Luck, 2000), and thus indirectly a broader attentional scope.

Recent evidence shows that top-down attention modulations also influence information processing before the P1 and N1, namely at the level of the C1 (see Rauss et al., 2011 for a review). The C1 is the first VEP following stimulus onset, peaking between 60 and 100 ms, and is presumably generated in the topographically organized fundus of the calcarine fissure (V1; Clark et al., 1995; Jeffreys and Axford, 1972). Therefore, the polarity and amplitude of the C1 vary with the position of the stimulus in the visual field. Our ERP studies described above (Vanlessen et al., 2013, 2014) capitalized directly on these peculiar electrophysiological characteristics. More specifically, we recorded VEPs to stimuli that were presented in the upper visual field at different distances from fixation, while participants performed an oddball task meant to anchor overt attention at fixation. In a first study (Vanlessen et al., 2013), these peripheral stimuli were fully task-irrelevant, allowing to assess bottom-up attentional capture. We found that positive mood altered the earliest stage of stimulus processing at the level of the C1 (Rauss et al., 2011), in such a way that it blurred the expected modulation of this early striate component as a function of spatial position. In the positive mood group, in contrast to the neutral mood group, the C1 did not decrease with increasing eccentricity of the stimulus. Rather, the component remained unchanged regardless of stimulus position, in line with a putative spreading of attention over a larger portion of the upper visual field and thus a broadened attentional scope in this condition. In a follow-up study (Vanlessen et al., 2014), the peripheral stimuli were made task-relevant to investigate if positive mood could still change the processing of these peripheral stimuli when they were attended (i.e., task-relevant). Results showed that the C1 was enhanced in the positive mood group for all peripheral stimuli, regardless of their position, demonstrating a stronger processing in V1 of stimuli selected by the attentional focus. In sum, both studies showed a dynamic tuning of early visual cortex by the current affective state. Remarkably, the stimuli had no biological or motivational significance, suggesting that these mood effects were caused by alterations in the internal state of the participant that changed the expression of specific gain control mechanisms operating in the visual cortex rapidly following stimulus onset (as opposed to emotional attention effects, Vuilleumier, 2005). Moreover, later components were not modulated by mood in these two studies, suggesting that this specific mood state boosted the early spatial encoding of the peripheral stimuli in V1 selectively before classical top-down attention control mechanisms exerted their gating effects in extrastriate visual cortex (see Vanlessen et al., 2014 for details).

### *4.7. Broadening of attention defined as a diffuse mental state*

The discussed ERP results are compatible with a more uniform distribution of attentional resources or a “diffuse mental state” in positive compared to neutral mood (Olivers and Nieuwenhuis, 2006). One strategy for directly assessing a diffuse mental state is to present overlapping stimuli and measure the extent to which participants can selectively attend to one stimulus stream while filtering out the other one. Using such approach, a recent study explicitly investigated if positive mood could give rise to such diffuse mental state (Dhinakaran et al., 2013). In this study, different stimulus streams were tagged in visual cortex by flickering them at different frequencies, enabling to disentangle the processing of spatially overlapping stimuli. Importantly, this oscillatory response or steady state VEPs (ssVEPs) is increased for attended compared to unattended stimuli (Müller et al., 1998). Dhinakaran et al. (2013) hypothesized that if positive mood is associated with a uniform processing of information, simultaneously presented and spatially overlapping (task-relevant- and irrelevant) stimuli should yield more similar processing in positive compared to neutral mood. However, contrary to predictions, no difference in processing strength was found between the positive and neutral condition. Two features of the paradigm might explain this null finding. First of all, affective states were induced by showing an image with a specific emotional valence at the beginning of each trial, and not by means of a MIP installing a longer-lasting emotional experience. Second, stimuli were restricted to a very small portion of the visual field at fixation (with the largest stimuli measuring 2,11° × 1,94° of visual angle), not spreading to the periphery. As already alluded to earlier in this review (see Section 4.1.), the use of genuine peripheral visual stimuli is needed in order to establish with confidence whether attention is broadened or not following the induction of positive mood.

The hypothesis that positive mood yields a less selective processing mode in (object-based) visual cortex was also tested in a study using a 1-back task with geometrical figures and superimposed irrelevant words (Biss and Hasher, 2011; Biss et al., 2012). The authors reasoned that if positive mood broadens attention, then participants experiencing positive mood would encode the superimposed words to a greater extent compared to a neutral mood. Participants performed the task after a MIP consisting of watching valenced pictures while listening to mood-compatible sound extracts in a between-subjects design, followed by a fragment completion task. Results showed that participants in the positive mood group used more irrelevant words from the 1-back task to complete the fragments compared to the neutral mood group. The authors concluded that this was due to improved encoding of the irrelevant superimposed words, supporting the notion of a more diffuse attention. Based on the observation that the mood ratings did not differ anymore between the groups at the moment of the fragment completion task, the authors argued that this effect was truly related to the encoding of the words and not due to an improved retrieval of information from memory.

A similar approach was implemented in a study using fMRI to distinguish the processing of distractor from target stimuli (Schmitz et al., 2009). More precisely, participants were instructed to attend a small picture of a face at fixation and to discriminate its gender, while ignoring the bigger image of the house presented underneath it. To investigate to what extent the irrelevant house images were processed, cortical activation was measured in the parahippocampal place area (PPA), a brain area known to process place and scene information specifically (Epstein and Kanwisher, 1998). Affect was induced by showing series of either positive, neutral or negative stimuli before participants performed the task. In line with Dhinakaran et al. (2013), the authors did not find increased activation in the PPA in the positive compared to the neutral mood condition, which would have indicated a less selective processing of the target. However, the greatest amount of repetition suppression (i.e., habituation to repeated stimuli resulting in decreased brain activation; see Grill-Spector et al., 2006) was found in positive mood, suggesting a stronger initial processing of peripheral information in this condition. Moreover, greater reported positive affect predicted increased perceptual encoding of unattended peripheral stimuli, and a greater connectivity between PPA and V1, suggesting a facilitated flow of sensory information between these two regions.

### *4.8. Interim conclusions*

Collectively, most studies using paradigms suited for measuring a less selective or broader attentional focus support the notion of a state dependent modulation of attention by positive mood. Differences between interference tasks and these paradigms might potentially explain why the former seem to be less effective than the latter in capturing broadening effects on attention. Most problematic is the reliance on cognitive functions besides spatial attention in these interference tasks, more precisely, cognitive control and possibly also object-based attention. For instance, one could argue that studies that did not report a broadening of attention with positive mood might presumably have included an object-based attention component in the experimental paradigm, besides spatial attention only, while studies that did report such an effect focused on this latter process selectively. Further, for studies using interference tasks and reporting a change in the focus of spatial attention with positive mood, it remains difficult to ascertain that the size of the attentional scope was modified, as positive mood could also facilitate grouping of objects (or flexibility) for example, which would be in line with a global processing bias associated with this mood (Basso et al., 1996). To our knowledge, this alternative explanation has not been systematically investigated in the literature yet but is worthwhile exploring in future studies. On the other hand, it is also possible that given the paradigms we deem as more suitable to test a broadening of attention were developed for testing this specific hypothesis, null-results might be less often published because the paradigms are not as established as interference tasks, possibly leading to a publication bias towards significant findings.

Generally, the studies using other paradigms lend support to the assumption of a systematic change of the attentional focus following the induction of positive mood, with notable exception of the studies performed by Huttermann and Memmert (2015) and Dhinakaran et al. (2013), for reasons which are not fully clear at this stage. Nevertheless, we can conclude that the majority of studies reviewed here did demonstrate a positive mood-dependent modulation of attentional processes for peripheral visual stimuli, expressed either as enhanced processing or alternatively as more uniform processing of stimuli, regardless of their actual relevance or location in the visual field. Positive mood thus seems to create opportunities to encounter (potentially interesting) information, either by broadening the attentional scope when it is narrow or by processing attended stimuli to a stronger extent when the attentional focus is already stretched over a larger part of the visual field. In other words, positive mood sensitizes the visual system for information or enhances its propensity to explore. These studies also emphasize the flexibility and context sensitivity of attentional broadening by positive mood, an element that was not explicitly incorporated in the broaden-and-build theory (Fredrickson, 2001). In the next section, we provide the layout and building blocks of a refined framework, able to accommodate the findings reviewed, and that can be used to generate new testable predictions regarding modulatory effects of positive mood on mechanisms of visuospatial attention.

## 5. Effects of positive mood on attention: towards an alternative theoretical framework for mood-related tuning of spatial attention

Although accumulating evidence suggests that positive mood broadens attention and in turn influences the way information available in the environment is attended and processed higher up in the hierarchy, two fundamental questions remain currently unanswered: How and why is attention broadened when feeling happy? Obviously, the answer to these two complementary questions is not trivial, especially when bearing in mind the likely existence of links between visual perception on the one hand and affective states on the other (Zadra and Clore, 2011). Below we propose tentative answers to these challenging queries and we outline plausible mechanisms explaining the complex relationship between positive mood and spatial attention. First, we focus on the "how"-question, by pinpointing the position of positive mood within the well-established taxonomy of attention control processes and the classical division between bottom-up and top-down components. Next, we discuss plausible functional meanings of broadening of attention with positive mood, addressing the "why"-question. Finally, we briefly discuss the specific neurobiological architecture possibly enabling these effects.

### *5.1. Positive mood as a separate attention control mechanism?*

Attention selection is usually governed by both external stimuli (bottom-up) and internal processes (top-down; Corbetta and Shulman, 2002; Desimone and Duncan, 1995). Accounts explaining affective influences on attention in terms of top-down and bottom-up control usually encompass that affect depends on either mechanism (or the balance between them, see Bishop, 2007), or rather constitutes a third, separate pathway influencing attention (Pourtois et al., 2013). Top-down mechanisms for affective influences on perception have been put forward by accounts of arousal-biased (Mather and Sutherland, 2011) and affect-biased competition (To et al., 2012). In these frameworks, affective arousal guides the allocation of attention in a top-down manner, based on the individual's history of what is motivationally relevant at a given moment in time. These theories are based on the processing of emotional stimuli and predict that top-down modulation of affective arousal accentuates the dissociation between relevant vs. irrelevant stimuli in terms of processing, or in other words, potentiates the enhancement of attended and the suppression of unattended stimuli (Mather et al., 2015; Phelps et al., 2006). Conversely, positive mood does not trigger an amplification of "normal" attention processes, which also encompass the suppression of irrelevant information (Hillyard and Anllo-Vento, 1998; Hillyard et al., 1998). Rather, a positive internal state seems to enhance coarse processing of all stimuli, in a less selective way. Bottom-up attentional processing is modulated by positive mood, as shown by increased attentional capture by task-irrelevant peripheral distractors (Moriya and Nittono, 2011; Schmitz et al., 2009; Vanlessen et al., 2013). This suggests that attentional broadening in positive mood is not dependent on goal-oriented mechanisms of selection, reflecting an independent mechanism of selection driven by positive mood. On the other hand, positive mood can also influence processing of peripheral task-relevant stimuli, for better or for worse, providing evidence for a mood influence on top-down attention control (Grol and De Raedt, 2014; Grol et al., 2014; Uddenberg and Shim, 2014; Vanlessen et al., 2014). Taken together, these results show that positive mood can influence both bottom-up and top-down attention processes. These effects appear to arise through a separate pathway, that is at least partly dissociable from either processes and their respective neural substrates (Brosch et al., 2011; Markovic et al., 2014; Pourtois et al., 2013). We propose several mechanisms below that could be involved in such pathway enabling positive mood influences on attention and perception.

### *5.2. From the inside out: does positive mood tip the balance between internal and external attention?*

Studies showing modulatory effects of positive mood on attention usually show enhanced (sensory) processing of peripheral information occurring rapidly following stimulus onset in the visual cortex. One could expect that this would be compensated by deteriorated processing in dual tasks, in line with the assumption of decreased task shielding in positive mood (Zwosta et al., 2013). A trade-off between the quality of performing the task at fixation on the one hand, and the processing strength of the peripheral stimuli on the other (i.e., a stronger processing of peripheral stimuli at the expense of foveal task performance), would jeopardize the interpretation of a broadened attention. Instead, this would indicate a reorientation of resources from the fovea to the periphery, or an increased distraction by peripheral stimuli. However, some of the studies reviewed above allow to rule out the existence of such trade-off (Biss and Hasher, 2011; Grol and De Raedt, 2014; Grol et al., 2014; Uddenberg and Shim, 2014; Vanlessen et al., 2013, 2014). On the contrary, one of these studies even found that participants experiencing positive mood made less errors in the task at fixation (Schmitz et al., 2009). In addition, in our EEG studies we found that the boost in early sensory processing for peripheral stimuli (C1 generated in V1 rapidly following stimulus onset) was not compensated by a drop in accuracy or processing of stimuli at fixation, as reflected by unchanged (Vanlessen et al., 2013) or even larger P3 amplitudes to targets (Vanlessen et al., 2014), the latter indicating an enhanced efficiency or updating in this task (see Polich, 2007).

Thus, strikingly, enhancement of one process by positive mood is not compensated by a drop or impairment in the other process. Hence, it looks like positive mood generates *more* resources compared to neutral mood. However, such account goes against the well-established notion of capacity limits and suggests the involvement of mechanisms beyond the classical dissociation between top-down and bottom-up attentional processes. Alternatively, positive mood might not mobilize additional resources, but simply prompt a change in their application to resolve the task at hand. At the broadest level, the reviewed findings are compatible with a change in the balance between external and internal attention (Chun et al., 2011). More precisely, it is possible that positive mood stimulates a mobilization of resources towards external instead of internal attention (see Fig. 2), at least when engaged in a demanding perceptual task[2]. This account is in line with the broaden-and-build theory: experiencing positive affect broadens attention in order to learn from the environment and foster its exploration (Fredrickson, 2001).

### 5.3. *The pivotal role of cognitive control*

A prevailing, however rarely tested, hypothesis explaining positive mood effects on the breadth of attention is that the changes at the perceptual and attentional level might actually stem from weaker cognitive control (Rowe et al., 2007). Indeed, cognitive control has been shown to be influenced by positive mood (see Chiew and Braver, 2011; Fröber and Dreisbach, 2014). More precisely, positive mood might impair prefrontal, top-down (attention) control, allowing for an amplified processing of incoming stimuli regardless of their task-relevance. Involvement of cognitive control processes in the broadening of attention with positive mood can also account for the context-sensitivity of this effect. This account entails that effects of positive mood on attention are not direct, but instead mediated by processes higher-up in the hierarchy, like prefrontal-based cognitive control and flexibility (Duncan, 2001).

The involvement of cognitive control might in part define to what extent stimulus processing and other task-related operations are influenced by positive mood (see Fig. 2). Our studies reviewed above give a hint on how such mechanism might look like, because we used a very similar paradigm either with a single task (Vanlessen et al., 2013) or a task requiring additional control (Vanlessen et al., 2014). These studies showed that only when low or moderate engagement of cognitive control was required, bottom-up processes were modulated by positive mood (Vanlessen et al., 2013). On the other hand, when control processes were more actively involved in a demanding task, the facilatory effect for target processing also spread to the task at fixation, as reflected by enhanced decision-related processing at the level of the P3 component (Vanlessen et al., 2014). This was even the case in a third, unpublished study (Vanlessen et al., in prep.), in which we manipulated the perceptual load of the oddball task at fixation (i.e., a low load and a high load condition), while participants had to detect stimuli presented at a specific location in the upper peripheral field. While processing at fixation was again enhanced in the positive mood group for both load conditions in this task, no mood effects were observed on processing of peripheral stimuli. These results suggest that the knowledge that there were two levels of task difficulty prompted a different management of resources to ensure good performance throughout the task. They also indicate a limitation to the broadening effect induced by positive mood: tasks signaling a high need for control seem to block the influence that positive mood can have on the processing of peripheral stimuli in situations that require less control.

In this framework, the distinction between proactive and reactive control (Braver, 2012) appears especially valuable, as it might provide insight into the hypothesized involvement of cognitive control mechanisms in effects of positive mood on perception and attention. More precisely, the proposed obstruction of these effects in tasks requiring strong attentional control can be deemed a form of proactive control. At this level, control processes ensure in a proactive way that task demands do not exceed available resources. This guarantees proper task performance despite the tendency of positive mood to allocate (additional) resources to the processing of (external visual) stimuli despite their possible task-irrelevance (e.g., Schmitz et al., 2009), or a processing of task-relevant stimuli that is excessive compared to what is necessary to execute the task (e.g., Vanlessen et al., 2014). More precisely, the influence of positive mood would be blocked in this case to ensure proper task resolution when the risk is eminent that positive mood modulations of perceptual and attentional processing are damaging to task performance (i.e., when the task is demanding). However, in the condition that task demands do not exceed resources, extra cognitive control processes are not recruited and thus positive mood can freely exert its influence during visual attention task performance, whether beneficial or not. In this case, positive mood can impact on perception and attention. Several studies have reported a greater reactive control component in positive mood (see Chiew and Braver, 2011), possibly to compensate for lower proactive control (Vanlessen et al., 2015). Such pattern of weaker proactive and stronger reactive control is in line with the robust finding that positive mood gives rise to increased cognitive flexibility, which is only possible with a system allowing for swift, last-minute adaptations such as provided by reactive control processes (Dreisbach, 2006; Dreisbach and Goschke, 2004). In a recent study, we found that positive mood was associated with an unspecified preparatory activity in anticipation of the target in an antisaccade task, regardless of the level of control that was required in a specific trial (Vanlessen et al., 2015). Speculatively, a similar mechanism could be at play in the attention domain: the broadening of attention, often associated with a stronger processing of coarse information regardless of its benefits or disadvantages for the task at hand might stem from a general preparedness to process incoming stimuli stronger (initially), regardless of its usefulness. In line with the proposition of Rowe et al. (2007), such mechanism could potentially be explained by a general lowered inhibition (of task-irrelevant information processing) at this stage of processing, although this conjecture requires further empirical validation.

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[2] Note that studies focused on mood influences on “internal” processes suggest a similar flow of resources to processes such as creativity and decision making (Baas et al., 2008; To et al., 2012; Carpenter et al., 2013; Estrada et al., 1994, 1997; Isen, 2000; Isen et al., 1987; Isen et al., 1991). This interpretation is in line with the proposition that positive mood can change the balance between internally and externally directed processing.

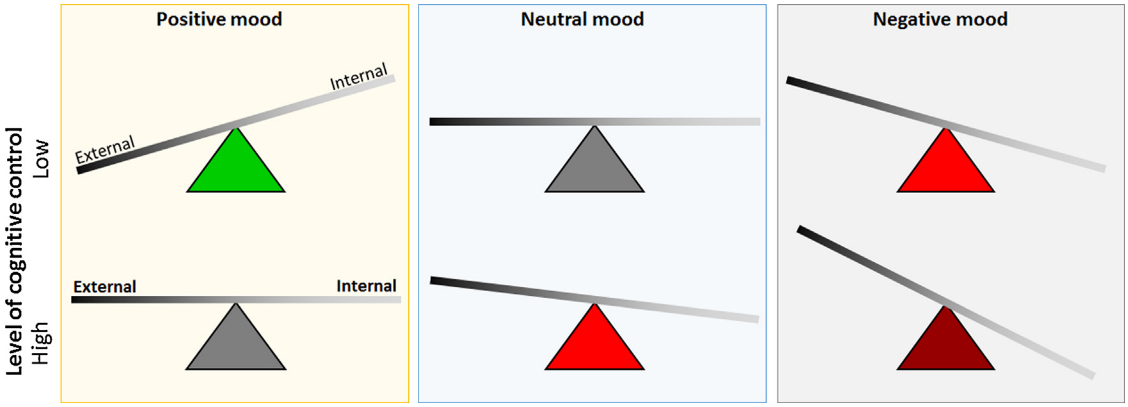

**Fig. 2.** Changes in the balance between internal vs. external attention in positive, neutral and negative mood as a function of cognitive control. The upper row represents for each mood state the balance between internal and external attention when engagement of cognitive control by the task is presumably low, while the lower row shows the change in this balance when it is high. Noteworthy, mood content and cognitive control interact dynamically to determine whether inward or outward attention prevails, as depicted by the color of the triangle. When cognitive control is low, positive mood favors exploration and outward attention (green pivot), an effect that can eventually lead to a broadening of attention. This attention bias disappears however when cognitive control is heightened (for example because of increasing task demands or load), or neutral mood dominates with low cognitive control (gray pivot). A bias towards inward attention or narrowing of attention is observed under negative mood, especially when cognitive control is high or exacerbated (red pivot). In this model, not only mood, but also cognitive control shape attention control mechanisms and more specifically the allocation of resources towards internal or external stimuli. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

### 5.4. Specificity of broadening of attention to positive mood?

The new conceptual framework that we put forward might also potentially contribute to a better understanding of how negative mood can change the attentional scope. While the focus of the present review is clearly on effects of positive mood on spatial attention, a concise comparison with negative mood effects is warranted to appraise their specificity (for reviews on negative affect and attention, see Bar-Haim et al., 2007; Eysenck et al., 2007; Vuilleumier, 2005). In our view, the attentional narrowing typically associated with negative mood could also tentatively be conceived as a dynamic change in the trade-off between resources employed for internal versus external attention processes, albeit with an opposite outcome compared to effects brought about by positive mood.

Several studies discussed above also encompassed a negative mood induction, finding evidence for a narrowing of attention in this mood state (Dhinakaran et al., 2013; Huttermann and Memmert, 2015; Schmitz et al., 2009), or no effect (Kuhbandner et al., 2011; Uddenberg and Shim, 2014). However, drawing definite conclusions from this research is complicated by the use of different MIPs, inducing different negative moods, characterized by distinct physiological reactions, action-tendencies and mental processes. While positive affective states such as joy and happiness are generally low in approach motivation and never associated with the tendency to avoid, the differentiation of negative moods depends more heavily on this affective dimension. For example, whereas anger is associated with the inclination to approach, sadness seems less characterized by a strong behavioral tendency, while the urge to withdraw is typical for anxiety. These motivational proclivities might play an important role in broadening or narrowing of attention (e.g., Susskind et al., 2008), as suggested by different effects on the attentional breadth by different positive emotions (see Gable and Harmon-Jones, 2010a,b). Moreover, affective influence on attentional breadth might be subject to specific temporal characteristics, such as an initial attentional broadening followed by attentional narrowing when a threat is detected (Eysenck, 1992). Even within one mood class, processing of external stimuli can be defined by the precise source of the affective state. For instance, anxiety due to bodily threat elicits different effects in the attention domain compared to anxiety related to psychosocial threat, even at early levels of processing (Rossi and Pourtois, 2014).

By and large, the effects of negative mood on attentional breadth can be divided into two categories: either a narrowing of attention, as found in the studies reported here (Dhinakaran et al., 2013; Huttermann and Memmert, 2015; Schmitz et al., 2009), or a "broadening" of attention in the form of hypervigilance. For example, deviant tones have been shown to elicit enhanced auditory ERP's when participants were watching negative compared to positive pictures (Sugimoto et al., 2007). Sensory hypervigilance for threatening information is also found very early on in the stream of information processing in anticipatory anxiety due to bodily threat (Rossi and Pourtois, 2014) and in spider phobics (Weymar et al., 2013). However, the priority given to swift bottom-up attentional capture of (negative) information is often associated with impairments in goal-related attentional processing (e.g., Rossi and Pourtois, 2014). When goal-focused processing and behavior is safeguarded on the other hand, negative mood is rather associated with a narrowing of the attentional scope both in space (Moriya and Nittono, 2011; Rossi and Pourtois, 2014; Schmitz et al., 2009) and/or specific features (Wegbreit et al., 2015). In sum, negative mood seems to be characterized by reduced processing of certain (external) information due to an increased or prioritized processing of other (internal) information, indicating dynamic alterations in attentional control (Ainsworth and Garner, 2013; Eysenck et al., 2007; De Raedt and Koster, 2010; Shackman et al., 2011). Moreover, when confronted with a task placing heavy demands on cognitive control, performance seems to decline even more in individuals experiencing negative mood (Berggren and Derakshan, 2013; Desseilles et al., 2009; Sadeh and Bredemeier, 2011), in line with the finding that negative affective states (anxiety) can mimic the effects of load on spatial attention (Rossi and Pourtois, 2013).

Regardless of a narrowing or broadening of attention in negative mood, this mood seems to trigger a deployment of resources to one specific domain of attention (e.g., foveal or periphery) at the expense of processing other stimuli, compared to positive mood showing a general boost of external information processing. In the preceding sections, we have proposed that positive mood might yield such effect by employing available resources for processing external stimuli when engaged in perceptual or attentional tasks. Analogously, negative mood effects on attention might be associated with processes reflecting a focus on internal information, even when a focus on the external environment is potentially more beneficial or rewarding in a given context, such as enhanced interoception (Paulus and Stein, 2010; Vanden Bogaerde et al., 2011) and increased self-consciousness (Boehme et al., 2015). In addition, deficiencies in the attentional domain in depressive affective states might be due to a high consumption of attentional resources by internal information processing, such as when engaged in rumination, a major component of depressive feelings (Nolen-Hoeksema, 2000; Whitmer and Gotlib, 2012). Along the same lines, it has been shown that depressive moods can be alleviated by decentered thinking cultivated through mindfulness practice (Garland et al., 2015; Teasdale et al., 2002) or by distracting information (Joormann et al., 2007; Van Dillen and Koole, 2007), or in other words, by tipping the balance towards external information (see Fig. 2).

### 5.5. *Possible neuro-anatomical underpinnings*

Positive mood might sensitize specific neural networks for external information processing and thereby induce openness and interest towards the outside world under certain conditions. However, the underlying neuro-anatomical mechanisms accounting for such modulations are still poorly understood. As discussed above, both bottom-up and top-down processes can be enhanced by positive mood, depending on the specific task context. Distributed and non-overlapping fronto-parietal networks underlie the guidance of these attention processes (Buschman and Miller, 2007; Corbetta and Shulman, 2002). Additionally, prefrontal regions are also involved in cognitive control (Braver and Cohen, 2000). On the other hand, positive mood is thought to depend on the integrity of numerous brain structures in widespread neural networks. Kringelbach and Berridge (2010) proposed that pleasure, as a precursor of positive mood, is represented at two distinct levels in the brain. At a subcortical level, the nucleus accumbens, ventral pallidum, and brainstem were pinpointed as possible “hedonic hotspots”. At the cortical level, these authors listed orbitofrontal, cingulate, medial prefrontal and insular cortices as candidate areas. Likewise, an fMRI study showed activation of the nucleus accumbens and the medial PFC, and a correlated activation of these structures with the amygdala, during imagination of pleasant scenes (Costa et al., 2010), in line with a previous study showing amygdala involvement in positive mood (Habel et al., 2005).

A candidate brain area involved in the dynamic interaction between positive mood, cognitive control and attention, is the anterior (ACC) and posterior (PCC) cingulate cortex (see also Shackman et al., 2011). The rostral part of the ACC has connections with, among others, the nucleus accumbens and the orbitofrontal cortex, two of the pleasure hotspots identified by Kringelbach and Berridge (2010), as well as with the amygdala, involved in affective processes (Anderson et al., 2011; Pessoa and Adolphs, 2010; Pourtois et al., 2013) and remote modulation of the primary visual cortex (Amaral et al., 2003). The dorsal, “cognitive” part of the ACC on the other hand is involved in executive attention (Posner and Petersen, 1990) and allocation of control (Banich et al., 2000). Moreover, this part is thought to modulate sensory processing and response selection and to monitor or regulate competition (see Bush et al., 2000). Additionally, the ACC is also involved in the anticipation of challenging tasks and the evaluation of task performance, and is thought to detect conflicts or worse than expected events; hence, it occupies an ideal position to signal the need for enhanced cognitive control in difficult task contexts (Botvinick et al., 1999; Carter et al., 1999).

The PCC on the other hand is mainly known for its link with internal attention within the default mode network (DMN; Raichle et al., 2001), activated when recalling emotional autobiographical memories (Bado et al., 2014). The PCC has also widespread connections with cortical and subcortical regions and is thought of as a core node where information from several brain regions converges (Leech et al., 2012). Evidence also points to a role of the PCC in attention allocation (Leech et al., 2011; Small et al., 2003), top-down attention control (Hopfinger et al., 2000), and cognitive control (Leech et al., 2011). In their “arousal, balance and breadth of attention” model, Leech and Sharp (2014) synthesized these findings in the proposition that the PCC and other paralimbic regions connect internal and external information (Mesulam, 1998). They proposed that the PCC plays a major role in monitoring the balance between internally and externally focused attention, which is particularly interesting in the light of a mobilization of resources for the processing of external information in specific task contexts in positive mood. Specifically for a broad external focus, they predicted an increased functional connectivity between the dorsal PCC and a fronto-parietal control network, constituting a plausible neural mechanism through which positive mood could exert its influence on the breadth of attention. Interestingly, Berridge and Kringelbach (2011) noticed that the DMN encompasses, besides the PCC, also some of the hedonic hotspots they identified, such as the orbitofrontal and cingulate cortices. Indeed, as a network involved in self-related processes and generally deactivated in tasks requiring focused external attention, the DMN might play a role in the relationship between positive mood and attentional broadening. Furthermore, dysregulations of the DMN are observed in depression (Marchetti et al., 2012; Sheline et al., 2009), a mood disorder characterized by impaired experience of pleasure.

Nevertheless, while it is thought-provoking to speculate about the brain areas and networks involved in positive mood effects on specific attention processes and how they interrelate, we are still only starting to unravel the complex and widespread interactions between these processes. Hence, a gap in the literature exists when it comes to neuroanatomical models enabling to generate clear predictions regarding effects of positive mood on attention.

### 5.6. *Summary of the proposed mechanisms*

Based on the reviewed studies, we conclude here that the description of positive mood effects on perception and attention as a broadening of attention cannot satisfactorily account for several key findings. More precisely, it cannot explain improved processing of already attended information, why some studies find a broadening and others fail to, and how the attentional effects of positive mood can lead to both beneficial and detrimental effects on performance. Here, based on the observation that positive mood can enhance processing regardless of task-relevance of information, we propose that positive mood triggers a mobilization of processing resources towards external information when engaged in a perceptual task. This tipping of balance might be controlled by higher-order cognitive control processes, depending on task difficulty. In tasks in which extra processing of (relevant or irrelevant) information does not threaten task performance, positive mood triggers setting new priorities (i.e., exploration and external attention), and accordingly alters monitoring of attentional mechanisms. However, when task demands increase (e.g., when a primary task becomes more challenging), attentional resources are reoriented towards internal processes, such as (proactive) cognitive control (Chun et al., 2011), and effects of positive mood on (external) attention vanish. Hence, in this framework, cognitive control is involved in the positive mood effects on perception and attention at two levels. At the broadest level, control processes ensure in a proactive way that task demands do not exceed available resources. In the condition that such control is not required and thus positive mood can impact perception and attention, reactive control takes the lead, perhaps to compensate for lowered proactive control, resulting in increased processing of all stimuli (i.e., diffuse processing and lowered selectivity). At the neuroanatomical level, the ACC and PCC likely provide key brain areas involved in positive mood influences on attention control mechanisms.

## 6. Functional meaning of changes in perception and attention by positive mood

While scientific methodology can help in gaining insights about *how* positive mood influences perception and attention, the question *why* positive mood has these effects is more challenging to address. Nevertheless, answers to this question would undoubtedly advance our understanding of mood-attention interactions, and therefore we present some hypotheses about their adaptive value here below.

An interesting approach to conceptualize the changes in visual perception and attention with (positive) mood, is provided by signal detection theory (Lynn et al., 2012). Here, perceiving or not perceiving a stimulus can be conceived as responses, and the influence of positive mood on perception as a biased threshold. In this context, Nettle and Bateson (2012) proposed that moods can be conceptualized as "detectors", aimed at assisting the organism in defining the threshold for detection. The optimal threshold depends on a trade-off between the probability to encounter a certain event and the relative costs of responding. Positive moods might signal that the environment is safe, implying little costs for false alarms and optimism about the occurrence of desired events, thereby lowering the threshold for detecting information. Anxious mood, on the other hand, is also characterized by a low detection threshold, because false negatives are more costly than false positives and the occurrence of negative events is deemed likely. Compared with positive mood, enhanced processing of peripheral stimuli in early visual cortex is also evidenced in anxiety (Rossi and Pourtois, 2014; Weymar et al., 2013). At first sight, it might seem confusing that feelings of happiness and anxiety both elicit similar boosted processing of peripheral stimuli, or in other words, a state of "hypervigilance". However, the key to disentangle the effects of positive and anxious states might be the extent to which the task at fixation is shielded from detrimental effects of changed peripheral stimulus processing. Task shielding seems less efficient in individuals experiencing fear or distress (e.g., for physical unpleasant stimuli, see Rossi and Pourtois, 2014), while generally no loss in task performance at fixation is observed with a broadening of attention in positive mood (Grol and De Raedt, 2014; Grol et al., 2014; Schmitz et al., 2009; Uddenberg and Shim, 2014; Vanlessen et al., 2013, 2014). As already argued above (Section 5.2.), this effect could be explained by a stronger representation of the external environment compared to internal information in positive mood if we assume that this affective state biases attentional resources allocation between external and internal attention (Chun et al., 2011).

One possible – and speculative – interpretation of such lowered perception threshold is that mood alters the subjective saliency of stimuli. The saliency inherent to both emotional (Markovic et al., 2014) and arousing stimuli (Mather and Sutherland, 2011) boosts attentional capture, selection, and processing in visual cortex (Pourtois et al., 2013). Some examples show that internal processes can influence processing, presumably by altering the subjective saliency attributed to the objectively unchanged stimulus. For instance, the learned value of (non-informative) stimuli might bias attention competition by increasing the subjective saliency of stimuli that were previously associated with reward (see Anderson, 2013). Another example is found in the affective devaluation of to-be inhibited stimuli: people dislike stimuli more when they have to inhibit attention towards them, hypothetically because they lower the affective saliency of the distractors and thus reduce the distractors' ability to capture attention of the perceiver (Fenske and Raymond, 2006). Hence, it is possible that in a positive mood, neutral information is treated in a similar way as emotional information because the inner state of the perceiver "spills over" to the environment and "contaminates" stimuli, making them temporarily more salient to that person. For instance, positive affect can increase the subjective vividness of (neutral) stimuli, paired with a higher activation of the visual cortex (To et al., 2012). Speculatively, positive mood might increase baseline activation of the visual cortex, diminishing the extent to which stimuli have to elicit cortical activation in order to surpass the threshold for selection and further processing by the visual system.

The adaptive function of positive emotions might further help to understand specific perceptual changes occurring with positive mood (Stefanucci et al., 2011; Shiota et al., 2014). Interesting to mention here is the notion that perception in itself is rewarding, and that learning and curiosity are inherently pleasant for humans (Biederman and Vessel, 2006; Kashdan and Steger, 2007; Perlovsky et al., 2010; Yue et al., 2007) and activate reward-related brain areas (Kang et al., 2009). People engage in seeking information when the environment is safe (Biederman and Vessel, 2006), as possibly signaled by positive mood. Based on the studies reviewed here above, this openness for information may be characterized by higher readiness to perceive stimuli, albeit processed in a less detailed or selective fashion. Interestingly, this would only occur when no other motivations prevail (Biederman and Vessel, 2006), suggesting that positive mood effects on peripheral stimulus processing are limited to situations that are not overly demanding. This is in line with the previously proposed implication of cognitive control processes in regulating positive mood effects on perception and attention, in such a way that they protect the pursuit of primary goals when the task becomes too demanding. Other mechanisms that might be involved in such process is that difficult and demanding tasks can induce stress, diminish the rewarding value of pleasant events (Ivanov et al., 2012), or otherwise counteract positive experiences during task performance.

Together, hedonic based responses to stimuli can be "gated" by sensory processing (Fitzgerald, 2013), while positive mood states might facilitate this gating by enhancing perceptual processing. In accordance, broadening observed under mild to moderate task load might serve as an exploration-based mechanism, scanning the environment for possibly interesting information. Such explorative attention mode heightens the chances to encounter opportunities, which in turn might reward positive mood and support continuation of such broad attentional scope. This is in line with a bias towards rewarding information (e.g., Tamir and Robinson, 2007) and perceptual dominance of happy compared to neutral faces presented to one eye when neutral stimuli are presented to the other eye (i.e., a binocular rivalry task) when experiencing positive mood (Anderson et al., 2011). If detecting information and acquiring knowledge is indeed inherently rewarding, then the affective value of perceiving stimuli is also congruent with positive mood. On the other hand, people might be more open to the external environment when experiencing positive mood because of alertness towards negative signals, prompting them to search for information of the opposite valence in order to regulate their mood (Schwager and Rothermund, 2013a, 2013b) or to allocate attention to other areas where more processing resources are needed because unexpected opportunities appeared (Carver, 2003). Hence, altered attentional processes in the peripheral visual field might indeed serve adaptive goals: to increase the probability to encounter information that is either rewarding or important for survival (cf. abrupt onsets), enabling the system to decide if positive affect and a broad cognitive style are adaptive, or should rather be dampened.

## 7. General conclusions

While the experience of positive mood is usually assumed to give rise to broadened attention, mediating various benefits in mental and physical health, the scientific community has only recently started to put this assumption to the test on a larger scale. Here, we reviewed the existing literature on this topic to establish whether the putative broadening of attention following induction of positive mood is a reliable finding, when it is explored at the behavioral and neurobiological levels. The included studies show a substantial heterogeneity of approaches, using various mood induction procedures, experimental paradigms and operationalizations of broadened attention. This fragmentation of the literature signals the need for a unifying framework supporting the formulation of more precise and verifiable hypotheses. It also emphasizes the necessity to adopt strict methodological criteria to explore the boundaries of this phenomenon. Despite this diversity, results consistently showed that positive mood can dynamically change attentional mechanisms, in such a way that they either broaden attention or boost coarse processing of attended stimuli, albeit with beneficial or detrimental effects at the behavioral level. Moreover, the studies indicate a strong context-dependency of the results. In sum, the review supports the notion that positive mood changes selective attention processes, a mechanism proposed to mediate widespread beneficial effects on mental and physical well-being and health (see Burton and King, 2009; Cohn et al., 2009; Isen, 2000; Tice et al., 2007; Tugade et al., 2004).

Based on these findings, we put forward the novel proposition that positive mood changes the mobilization of resources towards internal (or external) information, depending on task demands, instead of triggering a generic attentional broadening. Moreover, we considered the involvement of cognitive control mechanisms in enabling flexible changes in attentional focus as a function of task context and mood, and in mediating the strength of this relationship. We additionally propose that the ACC and PCC regions may play an important role in this interaction given their role in several crucially involved processes, such as the regulation of internal vs. external attention, affective evaluation, and cognitive control. Although this framework is necessarily preliminary and awaits direct empirical validation, we hope that it will serve to inspire research on this still poorly understood phenomenon (albeit having clear beneficial effects on health and well-being) and eventually allow for the formulation of more precise hypotheses. Moreover, our propositions can potentially reconcile contradicting findings in the literature and provide mechanisms explaining how positive mood can influence disparate processes, such as early visual perception as well as various “internal” processes like creativity and problem solving. Additionally, they allow the generation of novel hypotheses concerning the emphasis on external vs. internal attention in mood effects, the involvement and the role of specific brain structures, the comparison between contexts demanding a weak or strong engagement of cognitive control, and the respective roles of proactive and reactive control. More specifically, future studies could for instance include measures or manipulations of cognitive control to investigate its possible role as a mediator in mood-attention interactions. At the functional level, we do not conceive the changes in perception and attention with positive mood as epiphenomena, but as the expression of an adaptive mechanism fostering the exploration of potentially interesting information in the environment, or, due to its inherent rewarding nature, visual perception per se.

## Acknowledgements

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## Appendix A. : PRISMA checklist

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| TITLE | | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | Title page |
| Abstract | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | 3 |
| Introduction | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 4–6 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reffference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 5 |
| Methods | | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | / |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 17–18 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 17 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | 17 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the *meta*-analysis). | 17–18; Fig. 1 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | n/a |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 17–18 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | n/a |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | n/a |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | n/a |

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | n/a |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | n/a |
| Results | | | |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | 18; Fig. 1 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | n/a |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | n/a |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | n/a |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | n/a |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | n/a |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | n/a |
| Discussion | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | n/a |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 32 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 36–38; 45–48 |
| Funding | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | 50 |

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. http://dx.doi.org/10.1371/journal.pmed1000097

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