



How positive affect buffers stress responses

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Positive affect can help to dampen the impact of adverse life events, facilitating healthy cognitive and emotional functioning after stress. The present review highlights recent findings on the stress buffering effects of these pleasant feeling states, focusing on studies utilizing acute and chronic stress in daily life, stress manipulations in the lab, and examinations of affective and cognitive adaptations during tasks involving difficult or risky events. We review novel findings that neural reward systems dampen activity of brain areas involved in signalling stress and highlight the role of endogenous opioids and other neurochemicals in this buffering effect. We show that across different timescales and physiological systems, positive affect buffers against accumulating stress responses in the body and brain.

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Introduction

Positive affect refers to the pleasant feelings that humans experience across a wide variety of different moods and emotions. Accumulating research from the last three decades has revealed that positive affect plays a key role in living a healthy and meaningful life [1]. Although positive affective states can have direct beneficial health effects, a substantial part of these effects are due to buffering the impact of adverse events in brain and body. Starting in the 1990s, Barbara Fredrickson and co-workers

laid the foundation of work on the so-called ‘undoing effect of positive affect’ [2,3] and subsequent studies have started to reveal the important benefits of stress-buffering effects for a myriad of health outcomes [3–5]. In this review we integrate insights from recent studies on the effects of positive affect on stress and adverse events in general, bridging literature on stress in daily life and lab studies studying the impact of stress.

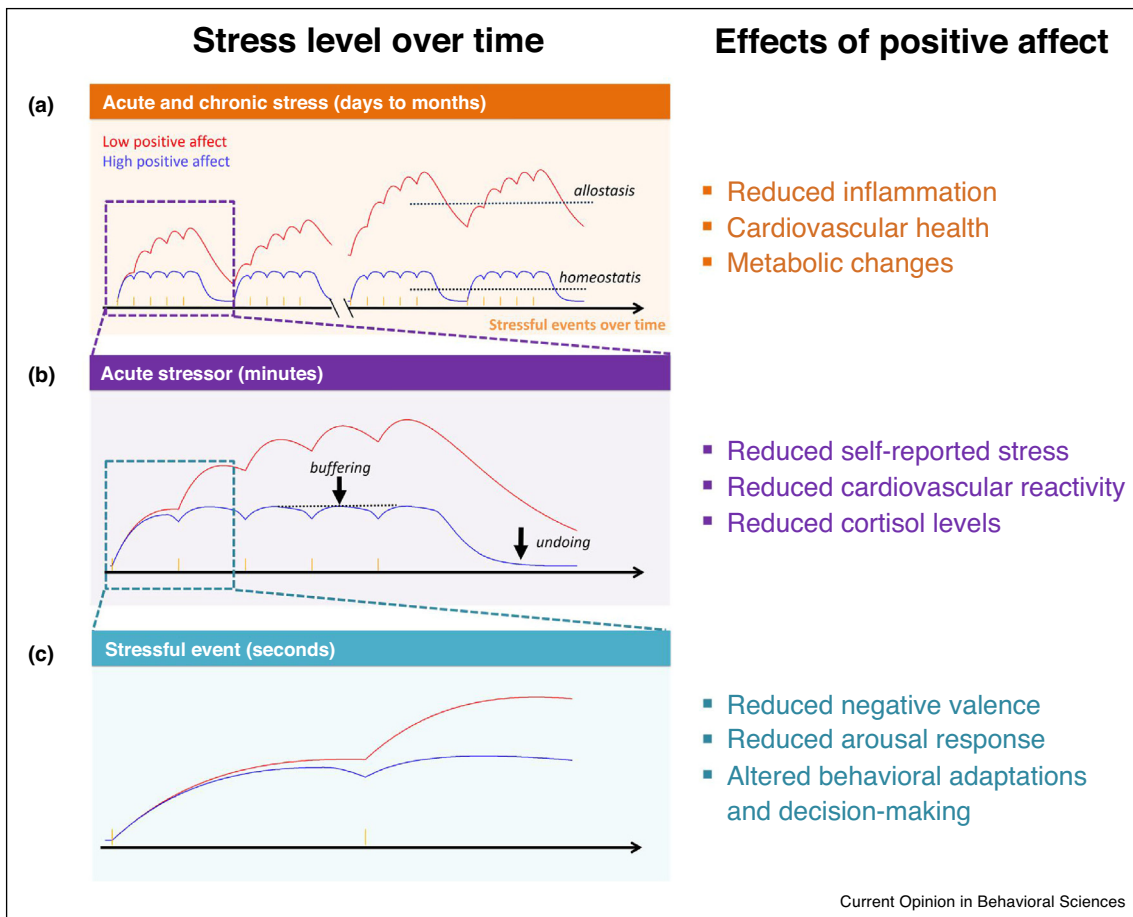
Here we refer to stress as the process of mobilizing resources in response to events of adversity and uncertainty, which can have beneficial (‘eustress’) or detrimental (‘distress’) consequences [6]. In particular, energy mobilization will serve adaptive behaviour when acute and context-appropriate but can become maladaptive when demands exceed resources and/or when this occurs chronically. For example, chronic stressors such as an accumulation of traumatic events can produce wear and tear in the body and brain causing health problems in the long term. However, small unpleasant events such as receiving negative feedback from important others or making errors due to distractions from your primary task causes stress too. In the long-term, the accumulation of such small events might even result in major stressors such as getting divorced or losing your job.

These examples show that to properly understand stress it needs to be investigated at multiple timescales. The present review therefore highlights recent studies that have focused on the effects of positive affect on stress measured at different timescales (see Figure 1). We first review studies investigating chronic and acute stress in daily life. We then discuss studies that have investigated the aftereffects of a short stress manipulation in a lab setting. After that we zoom in on adaptation processes to adverse events that occur at a smaller timescale. In the second part of this review we showcase recent lab studies on the neurobiological mechanisms that might drive these effects. Finally, we discuss opportunities and challenges for future research.

Influence of positive affect on stress Behavior and stress in daily lives

There is a rapidly growing literature suggesting that positive affect has beneficial effects through dampening stress-related phenomenology and related physiological changes. For example, using experience sampling methods, a recent study observed that the frequency of laughter (how often a participant laughs) buffers against

Figure 1



Schematic overview of the reviewed stress-buffering effects of positive affect at multiple timescales. **(a)** At the timescale of days to months, for example, when exposed to acute stress (left) or chronic stress producing allostatic load (right). **(b)** At the timescale of minutes to hours, for example, during and after a stressful task. **(c)** At the timescale of subseconds to seconds, for example, when participants make an error during a stress-inducing cognitive task or when they anticipate making a risky decision. Note that the described stress-buffering effects in the main text might reflect a combination of 'buffering effects' in the strict sense (i.e. that positive dampens stress during the task) and 'undoing effects' of the stress response after the task (i.e. facilitating recovery after stress), although these effects cannot be dissociated in most situations because positive affect is often measured or induced before or during the stressor. Figure retrieved from: <https://doi.org/10.6084/m9.figshare.13341608>.

subsequent self-reported stress symptoms [7^{*}]. At the hormonal level, positive affect traits have been associated with a steeper diurnal cortisol slope [8], and similar cortisol slopes were associated with positive events in a large community-based sample [9]. Relatedly, positive memory recall has been related to lower morning cortisol levels and buffered against the impact of subsequent negative life events on negative self-cognitions and depressive symptoms [10]. Positive affect in daily life also predicted reduced inflammation [11,12], and a growing number of recent studies have started to show that this is due to a stress-buffering effect [13,14].

Whereas acute stress leads to changes in bodily and neural systems aiding homeostasis, prolonged and repeated stress that cannot be resolved leads to so-called allostatic load [15].

In this state, cardiovascular, metabolic and inflammatory stress systems are permanently activated, which over time has detrimental health effects (i.e. 'allostatic overload'). In a recent study by Schenk *et al.* [16] self-reported positive affect was inversely associated with a composite of biomarkers representing allostatic load in a large population-based cohort. Positive affect also influenced health behavior and this relationship may be partly mediated through the stress-buffering effects of positive affect [17^{**}]. Interestingly, in the study by Schenk *et al.* the relationship between positive affect and allostatic load remained significant after correcting for health behavior, suggesting that positive affect can have direct stress-buffering effects, possibly through modulation of the hypothalamic-pituitary-adrenal (HPA) axis and corresponding changes in cortisol levels [for a review, see Ref. 18^{*}].

Effects on stress tasks in the lab

Causal, direct evidence for the buffering effect of positive affect comes from lab studies that have experimentally manipulated stress and positive affect. Many studies have followed-up the work by Fredrickson and Levenson where positive affect induced after the stressor facilitates cardiovascular recovery to negative states [2]. A recent review of this literature shows that although there are several unpublished reports with null-findings, the majority of published studies so far have provided at least partial support for this effect [19]. In addition, similar positive mood effects on cardiovascular responses related to cognitive effort are well documented [20]. However, cardiac recovery from stress occurs quickly and most lab studies did not investigate changes beyond this limited time window, such as those occurring at the hormonal system levels. A recent study by Speer and Delgado [21] changed this situation. Using an experimental manipulation of positive affect in an autobiographical memory recollection task, these authors showed that the cortisol rise after an acute stressor was dampened by positive affect, confirming and extending the results from the observational studies described above. In sum, recent lab studies have provided causal evidence for buffering effects of positive affect on stress, both at a cardiovascular and at a hormonal level.

Adverse events during stressful tasks

Although stress research traditionally focuses on the stress response following the stress-induction, events *within* the task itself might provide important insights into the constituting elements that accumulate into the stress response. Although difficult cognitive tasks are often used as stressors, most studies in the field of stress research have overlooked the affective and cognitive adaptations that occur within these tasks themselves. Interestingly, recent research from the field of cognitive neuroscience has identified many adaptation processes in these tasks, that in turn might predict stress responses in daily life. A key example comes from research on cognitive control processes in Stroop-like conflict tasks. Increasingly, studies have revealed that the uncertainty associated with behavioral responses during difficult incongruent trials triggers negative affect, physiological arousal, cardiovascular activity, and adjustments in performance possibly following an inverted-U shaped function [22^{**},23]. Interestingly, in line with the buffering effects of positive affect, studies have started to use affect induction procedures and found that sustained positive affect consistently modulates behavior adaptation after conflict trials, suggesting that positive affect dampens conflict-related negative arousal [for a review, see Refs. 22^{**},24,25]. In line with this buffering account, a recent study also showed that the comforting feeling of emotional bonding (attachment) with one's romantic partner was associated with reduced conflict-related and error-related adjustments in behavior [26]. On the other hand, recent studies

that utilized electroencephalography (EEG) to examine error responsivity revealed error monitoring *increases* in positive states [27,28], contributing to a very mixed literature that has shown effects in both directions [22^{**}]. The fact that positive affect can increase error monitoring seems to be incompatible with a buffering account and rather suggest that positive affect, at least under some conditions, is associated with increased error processing and/or awareness.

One important direction for future research that might help to resolve this apparent discrepancy is to use online measures of negative affect when participant respond to conflict trials. By measuring activity of facial muscles related to negative affect, such as the frowning muscle, it is possible to determine whether positive affect indeed modulates behavioral adaptation by dampening aversive signals related to conflict and errors. Using this method, we recently showed that participants quickly downregulate the initial negative affective response to errors as measured by frowning muscle activity. Interestingly, this downregulation was accompanied by activation of facial muscles normally involved in smiling [29]. These findings are reminiscent of classical work showing that spontaneous smiling is associated with cardiovascular recovery from negative emotions [2] and highlight the potential to further bridge these literatures in future work. Future studies on error monitoring may also use this method to investigate how induced positive affect changes the affective evaluation of errors and how this relates to the observed increase in error responsivity as measured with EEG.

Effects on risk and uncertainty

Interestingly, dampening signals of stress is not beneficial in all situations. In fact, theories about judgement and decision making have long suggested that positive affect attenuates the negative value of anticipated risks, encouraging risk taking behaviours [30]. In a striking everyday-life illustration, Otto *et al.* [31] showed that on days with unexpected positive events (such as local sport teams performing better than expected), people buy more lottery tickets. Other studies using affect induction in the lab have similarly shown that positive affect causes participants to make more risky decisions [32–35]. Several explanations may be that positive affect influences probability weighting [33], reduces loss-aversion [32], or promotes risk taking by an underweighting of potential loss together with an overweighting of potential gain [34]. Yet, another line of research has revealed that positive mood can increase risk-aversiveness, particularly when decisions involve real losses that could otherwise jeopardize positive mood maintenance [36–38]. Although the literature is slightly in favor of the account that positive affect induces risk taking, the available literature on risk taking reveals mixed findings and it remains a key challenge for future

research to determine the exact factors that can explain these seemingly contradicting results [39].

Positive affect and stress in the brain

The role of the reward system

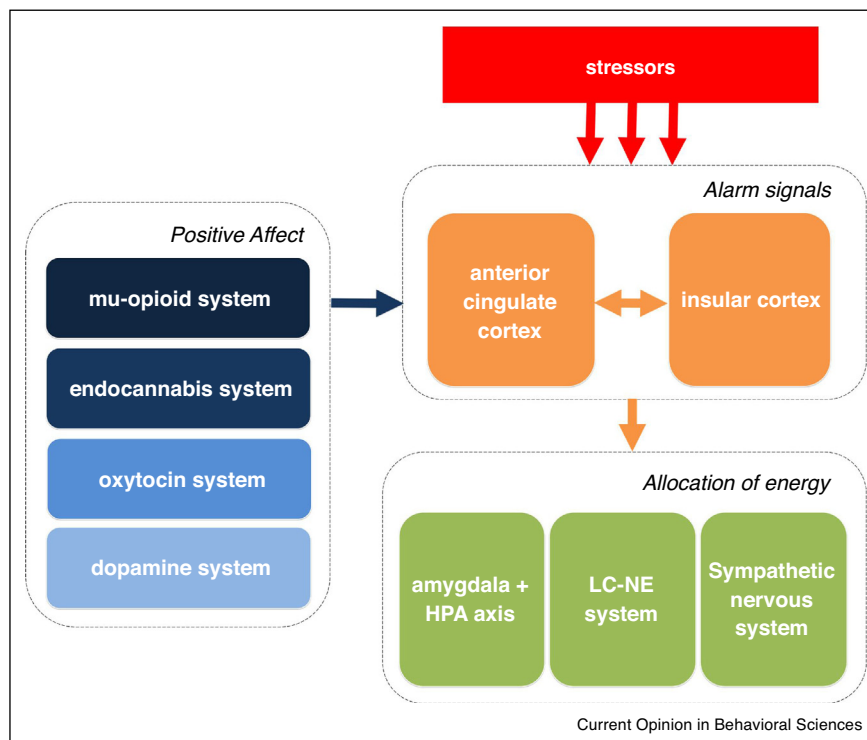
A growing number of neuroimaging studies using functional magnetic resonance imaging (fMRI) suggests that activation of the reward system may play a stress-buffering role. Specifically, reward system activation may help dampen brain activity in areas coding risk, uncertainty and negative affect. For example, it has been suggested that funny cartoons reduce behavioral adjustments after Stroop-like conflict by activating the ventral striatum and ventral pallidum, which in turn dampens conflict-related anterior cingulate activity [25]. Similarly, the earlier described recall of positive events which was associated with dampened cortisol responses to stress, also activates the vmPFC and ventral striatum, confirming a potential role of the reward system in stress buffering [21]. In another study, watching a positive movie did not reduce self-reported stress, but vmPFC activity during the stressor did predict stress relief [40]. Other work has linked social connectedness to reduced stress responses, for example showing that support-giving behaviour is associated with ventral striatum activity in an affiliative task and with reduced anterior cingulate, insula, and,

amygdala activity in a stress task [41]. Finally, in the computational modeling study on risk taking induced by positive feedback, it was shown that positive affect increases activity in vmPFC and was associated with reduced activity in the anterior cingulate and insula which in turn related to the weight of the potential loss parameter [34]. Together with older studies [42], these findings suggest that across different types of adverse and stressful events, neural systems involved in reward processing dampen alarm signals in the anterior cingulate and insulae, which in turn may dampen the stress responses in different physiological systems [cf. Ref. 43] such as the HPA-axis, the locus-coeruleus-norepinephrine (LC-NE) arousal system and the sympathetic nervous system (see Figure 2).

Neurochemical mechanisms

One important limitation of fMRI is that it cannot provide evidence for the neurochemical mechanisms that drive altered brain activity. Positive affect is associated with the release of several neurochemicals that might help dampen stress responses. Recent work from emotion science has charted how different positive emotions have differential functions based on partially separable neurochemical systems [44].

Figure 2



Proposed neurobiological mechanism of how positive affect buffers stress responses. Neurochemical systems involved in positive affect and reward processing dampen alarm signals which in turn reduce the stress responses in different energy-mobilization systems, including the HPA-axis, the LC-NE arousal system and the sympathetic nervous system. Figure retrieved from: <https://doi.org/10.6084/m9.figshare.13341611>.

Table 1

Overview of methods used in the reviewed empirical papers

Reference	Positive affect: induction procedure or measure	Stress: induction procedure or stress-related measure
[2]	Viewing an emotion-eliciting film (contentment, amusement) and spontaneous smiling	Emotion-eliciting film (anxiety, sadness) and cardiovascular reactivity
[7*]	Self-reported laughter	Self-reported stress
[8]	PANAS	Cortisol levels
[9]	Self-reported daily positive events	Self-reported stress and cortisol
[10]	Recall of positive events	Self-reported negative life-events, negative mood and negative self-cognitions
[12]	PANAS	Salivary markers of inflammation
[13]	Self-reported happiness	Perceived Stress Scale and salivary markers of inflammation
[14]	Self-reported daily positive events	Salivary markers of inflammation
[16]	PANAS	Composite of biological markers of allostatic load
[21]	Autobiographical memory recall (positive versus neutral)	Socially evaluated cold-pressor test and cortisol
[24]	Viewing an emotion-eliciting film (amusement)	Conflict in a cognitive-control task
[25]	Viewing funny cartoons	Conflict in a cognitive-control task
[26]	Self-reported levels of attachment to romantic partner	Conflict and errors in a cognitive-control task
[27]	Viewing an emotion-eliciting film (funny/fail videos)	Conflict and errors in a cognitive-control task
[28]	Holding hand of romantic partner	Conflict and errors in a cognitive-control task
[29]	Spontaneous muscle activity related to smiling	Errors in a cognitive-control task
[31]	Better than expected incidental outcomes in the environment (local sport team performance, sunny day)	Lottery purchases
[32]	Listening to self-selected liked or disliked music	Risk decision-making task
[33]	Listening to happy music	Lottery choice task
[34]	Receiving positive feedback in a quiz task	Effort-choice task
[35]	Viewing emotional pictures	Monetary gambling task
[40]	Viewing an emotion-eliciting film	Anagram task
[41]	Self-reported receiving and giving social support	Mental arithmetic under evaluative threat
[55]	Viewing funny cartoons and pictures, reading words with affective content	Conflict in a cognitive-control task
[60*]	Recalling autobiographical memories (happiness, love, compassion)	Recalling autobiographical memories (anxiety)
[61]	Viewing affective pictures (high and low in approach motivation state), Sensation Seeking Scale (approach motivation trait)	Public speaking task and cardiovascular measures of stress

The endogenous mu-opioid system provides a key candidate mechanism in buffering effects. Studies in rodents and humans have implicated this system in the liking, and more recently also wanting, of rewards, and in their role to attach a 'hedonic gloss' to our perception of the world [45,46]. Consistent with a buffering role, opioids alter behavioral adaptations after errors [47] and are known to have more stress-relieving properties in general [48,49*]. However, future studies still have to demonstrate a causal role of the opioid system by combining pharmacological manipulations with affect inductions in the same experimental design.

The endocannabinoid system also plays an important role in positive affect [50]. Given it is unsafe to pharmacologically block this system in humans, most causal evidence comes from rat studies, implicating the endocannabinoid system in social play behavior [51] which in turn can buffer stress responses [52]. The role of oxytocin and dopamine is more complex [42]. For example, the link between positive affect and dopamine is not as strong as previously conceived. Although dopamine plays a role in the incentive salience of rewards [53] and the arousal level of positive emotions such as enthusiasm, and

achievement [44], it is also activated by stress itself, making the interaction difficult to understand [42].

Challenges and opportunities

In this mini-review we outlined research from different fields with the aim to understand the effects of positive affect at different domains, ranging from chronic stress in daily life, to stress and their constituting adverse events in laboratory settings. Together, these findings show that positive affect can help to buffer or undo stress at different timescales. One future challenge is to bridge these domains and to leverage the individual effects of positive affect on adverse events to predict resilient stress responses in daily life, an approach that has already produced promising initial findings [54]. In addition, several lab studies show that under certain circumstances positive affect does not have an effect or actually increases the weighing of negative events allowing individuals to avoid the events if possible [30,55]. These effects may occur when positive affect induced before a stressor is too weak and/or the adverse events are too negative [36,56], possibly turning accommodation effects into contrast effects when this difference is too strong [57]. It is also important that future studies consider the

impact of arousal [58]. To illustrate, many observational studies have used the PANAS (Positive and Negative Affect Schedule) questionnaire [59], which is biased to positive states with high arousal levels. Indeed, the predictive effects of this measure of positive affect is relatively small [16], suggesting that different methods to assess positive valence are required. In addition, recent work has started to show that some discrete positive emotions (such as love and happiness) may be more effective to reduce negative affect than others (such as compassion) [60], and these differences may also relate to additional affective dimensions such as motivational intensity that can produce different effects [61]. These findings echo the call for more research into separate positive affective states and advancing our understanding of how these states map onto different neurochemical systems [44]. Finally, the empirical studies briefly reviewed here used a variety of different positive affect measures and inductions (see Table 1 for an overview). Given that some work has shown that the sustained striatal response to positive pictures is associated with reduced cortisol [62], it is important to also investigate how different timescales of positive states interact with stress.

Conclusion and outlook

This review showed how positive affect has important stress-buffering effects in different contexts through its impact on differential neurobiological systems. Understanding the biological mechanisms that aid these effects is an important goal for future work. Given the beneficial effects of positive affect on stress and negative affect, beneficial effects of positive affect might still work if cognitive regulation itself is compromised by extreme stressors [21,63]. At the same time, when experiencing moderate daily stressors, positive affect can also directly and indirectly facilitate emotion regulation and positive reappraisal processes [64] which are thought to be central stress resilience mechanisms [65]. Other findings show that positive affect has pain-relieving properties [66,67] and can reduce psychopathology [4]. There is also increasing evidence that positive interventions such as engaging in mindfulness, enjoying positive events or doing physical exercise can increase positive affect and reduce stress [17,18,68]. This shows that positive affect is a promising target for interventions fostering stress-resilience, with the ultimate goal to promote human flourishing.

Conflict of interest statement

Nothing declared.

CRedit authorship contribution statement

Henk van Steenbergen: Conceptualization, Visualization, Writing - original draft, Writing - review & editing. **Ellen**

RA de Bruijn: Writing - review & editing. **Anna CK van Duijvenvoorde:** Writing - review & editing. **Anne-Laura van Harmelen:** Writing - review & editing.

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