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The Undoing Effect of Positive Emotions: A Meta-Analytic Review

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Abstract

The undoing hypothesis proposes that positive emotions serve to undo sympathetic arousal related to negative emotions and stress. However, a recent qualitative review challenged the undoing effect by presenting conflicting results. To address this issue quantitatively, we conducted a meta-analytic review of 16 studies ($N = 1{,}220$; 72 effect sizes) measuring sympathetic recovery during elicited positive emotions and neutral conditions. Findings indicated that in most cases, positive emotions did not speed sympathetic recovery compared to neutral conditions. However, when a composite index of cardiovascular reactivity was used, undoing effects were evident. Our findings suggest the need for further work on the functions of positive emotions.

Keywords
undoing effect, positive emotions, positive affect, cardiovascular recovery

Advocates of functional perspectives on emotion have long struggled to say what functions positive emotions might serve, if any. Whereas it seems easy to specify candidate functions for negative emotions such as fear, disgust, or anger, it has seemed less obvious what functions positive emotions might serve. One promising candidate was offered by Levenson (1988) when he suggested that positive emotions might serve to "undo" negative emotions by facilitating recovery from the high-activation states often associated with negative emotion.

Since this undoing hypothesis was first proposed, dozens of studies have sought to test this hypothesis, but findings to date have been mixed (Cavanagh & Larkin, 2018). In the present review, we employ a meta-analytic technique to quantitatively synthesize the literature on the undoing effect of positive emotions, examining the relationship between positive emotions and autonomic nervous system (ANS) recovery from negative emotions and stress.

The Undoing Hypothesis

In the late nineteen eighties, Levenson (1988) proposed that one function of positive emotions (e.g., happiness) might be to undo the physiological arousal related to negative emotions. To test this "undoing" hypothesis, Fredrickson and Levenson examined whether positive emotions quiet the sympathetic arousal associated with negative emotions and facilitate recovery from distress – the restoration of homeostasis (Fredrickson & Levenson, 1998).

Sixty female students viewed a fear-eliciting film clip and then were randomly assigned to view a second film (eliciting

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contentment, amusement, sadness, or a neutral state). Cardiovascular recovery was measured using a composite index of cardiovascular responding consisting of heart period, finger pulse amplitude, and pulse transit times to ear and finger (Fredrickson & Levenson, 1998). The recovery was operationalized as the amount of time it took participants to return to their initial baseline level after responding to a fear-eliciting film clip. Fredrickson and Levenson (1998) found that participants in contentment and amusement conditions recovered faster than participants in neutral and sad conditions. In a conceptual replication of this initial study, Fredrickson and Levenson (1988) showed participants a sadness-eliciting film clip and measured the number of smiles during film viewing. Participants who smiled at least once during the sad film clip recovered about 20 s faster than non-smilers, suggesting that positive emotion was associated with accelerated cardiovascular recovery.

Taken together, these studies provided initial support for the undoing effect of positive emotions. Since this foundational paper was published, the undoing effect has been replicated using a variety of negative stimuli (Fredrickson et al., 2000; Kaczmarek et al., 2019; Tugade & Fredricksn, 2004; Yuan et al., 2010). However, other studies have not found support for the undoing hypothesis, and a recent qualitative review concluded that findings were mixed and that there was substantial methodological variability between studies examining the undoing effect (Cavanagh & Larkin, 2018).

Broader Perspectives on the Undoing Hypothesis

Emotions and ANS Reactivity

The undoing hypothesis stems from an initial observation that, in contrast to negative emotions, "positive emotions such as happiness, amusement, and contentment did not seem to move autonomic levels away from their baseline states" (Levenson, 1999, p. 494). It is important to note that this observation – which motivates the undoing hypothesis – is agnostic as to whether different negative emotions or groups of emotions elicit unique ANS reactivity (for reviews, see Kreibig, 2010, p. 2014; Mendes, 2016, Siegel et al., 2018). The only requirement would seem to be that negative emotions share a tendency to move autonomic levels away from baseline states.

Although our meta-analysis does not address whether different emotions elicit different patterns of ANS reactivity, current perspectives on how different emotions influence the ANS suggest different expectations regarding the undoing effect. Some theorists have argued for specificity of ANS reactivity in discrete emotions (Ekman & Cordaro, 2011; Stemmler, 2004), and some have argued for more generality (Barrett, 2013, 2017; Cacioppo et al., 2000; Quigley & Barrett, 2014; Siegel et al., 2018) (for a full discussion, see Mendes, 2016). If emotions evolved to deal with fundamental life tasks (e.g., restoring homeostasis), they might involve specific ANS reactivity necessary for optimal responding (Ekman & Cordaro, 2011; Tooby & Cosmides, 1990). This perspective suggests the possibility of an undoing effect in which some discrete positive emotions should decrease sympathetic activity caused by negative emotions.

On the other hand, findings from two large-scale meta-analyses on ANS reactivity to emotions revealed that emotions might be best thought of as highly variable categories constructed within individuals and lacking specific patterns of ANS reactivity (Behnke et al., 2022; Siegel et al., 2018). These findings are consistent with views of constructionists, which hold that ANS responses to emotion are specific to the demands of the particular situation in which emotion occurs, rather than the emotion itself. In its strong form, this perspective might mean that whether or not a given negative or positive emotion moved autonomic levels away from baseline states would depend upon the context, meaning that affective scientists would not be able to detect global undoing effects of any specific emotion or class of positive emotions.

To address this debate, previous reviews focused on the specificity and consistency of ANS responses (Quigley & Barrett, 2014; Siegel et al., 2018). Meta-analyses showed that at least some categories of emotions display different autonomic responses (Behnke et al., 2022; Cacioppo et al., 2000; Lench et al., 2011; Siegel et al., 2018). Meta-analyses that tested the consistency of responses within specific emotion categories showed moderate to high heterogeneity of effect sizes within emotion categories (low consistency). This suggests that the association between emotions and ANS activity might be moderated by additional factors, e.g., situations (Cacioppo et al., 2000; Lench et al., 2011; Siegel et al., 2018). However, tests of expected moderators failed (Behnke et al., 2022; Siegel et al., 2018), leaving neither side supported.

Positive Emotions and Stress

The undoing hypothesis fits into the broader literature linking positive emotions with health and fitness. Theorists suggest that positive emotions evolved to facilitate the pursuit and acquisition of psychosocial resources (material, social, and informational) and promote health and fitness (Folkman, 2008; Fredrickson, 2013; Shiota et al., 2017). Research has shown that positive emotions are related to improved cardiovascular health (Boehm & Kubzansky, 2012; Pressman et al., 2019; Steptoe, 2019), healthier hormonal responses (Miller et al., 2016; Sin et al., 2017), reduced inflammation (Jones & Graham-Engeland, 2021), and lower morbidity (Pressman & Cohen, 2005).

Positive emotions have been proposed to buffer against adverse health outcomes of stress and negative emotions (van Steenbergen et al., 2021). For instance, positive emotions protect from experiencing intense psychological stress symptoms (Zander-Schellenberg et al., 2020), sadness (Brummett et al., 2009), anxiety, and anger (Demorest, 2020). Furthermore, trait and state positive emotions reduce physiological reactivity to different physical stressors, including pain (Ong et al., 2015), inflammation (Steptoe et al., 2008), as well as to stressful social situations (Ong & Isen, 2010). Positive emotions also tend to lessen negative emotions in response to chronic stressors and everyday life events (Ong et al., 2006; Zautra et al., 2005).

Interventions that effectively promote positive emotions support health and well-being (Lyubomirsky & Layous, 2013; Moskowitz et al., 2021). It is proposed that positive emotions trigger upward spiral dynamics that might counter the downward spiral dynamics of negativity observed in emotion dysfunctions and deficits in psychopathology (Fredrickson, 2013; Garland et al., 2010). For instance, the cultivation of positive emotions through interventions helps individuals with cancer (Bränström et al., 2010), heart disease (Huffman et al., 2016), and diabetes (Cohn et al., 2014). Furthermore, positive emotions contribute to undertaking behavioral health-related interventions (Shiota et al., 2021). When people associate positive emotions with health behaviors, they are more likely to engage in the interventions (Kiviniemi & Duangdao, 2009; Rhodes & Kates, 2015).

In sum, the presented research suggests that positive emotions help with the detrimental effects of stress. With this project, we aimed to test whether undoing the sympathetic activity related to stress might be one of the possible pathways linking positive emotions and health.

Moderators of Undoing Effect of Positive Emotions

A recent qualitative review presented mixed support for the undoing effect of positive emotions (Cavanagh & Larkin, 2018). The mixed effects suggest the possibility that there might be moderators of the undoing effect. Candidate moderators include differences between studies among: positive emotions induced, operationalizations of recovery, physiological measures, emotion-elicitation methods of positive positive emotions, emotion-elicitation methods of stress and negative emotions, sampled individuals age, sampled individuals sex, and year of publication. In addition, several other methodological characteristics were considered, as noted below.

Differences among Positive Emotions

Over the years, affective scientists have become increasingly interested in differences among positive emotions. For instance, models that focus on motivational tendencies propose differences between high-approach and low-approach positive emotions in terms of ANS reactivity (Gable & Harmon-Jones, 2010; Harmon-Jones et al., 2013). Some positive emotions, such as excitement or enthusiasm, are characterized by strong goal-attainment, approach tendencies, and increases in sympathetically mediated arousal across cardiac, vascular, and electrodermal systems (Kreibig et al., 2010; Shiota et al., 2017). In contrast, other positive emotions, such as awe or contentment, are characterized by preparation for stillness and withdrawal of sympathetic influence on the heart (Kreibig, 2010). These findings indicate that there may be differences among discrete positive emotions that could influence their impact on physiological recovery from negative states. Indeed, in their initial paper on the undoing effect, Fredrickson and Levenson (1988) proposed (but did not test) the idea that discrete positive emotions might not all show the undoing effect (Fredrickson & Levenson, 1998).

Different Ways of Operationalizing Recovery

Physiological recovery is operationalized and analyzed in the literature in two dominant ways, namely the change score approach and the continuous measurement approach (Gruber et al., 2011). The change score approach uses the difference between two static time points (e.g., watching a sad film clip and the recovery). Change scores are computed by subtracting physiological recovery levels from the reactivity or baseline level, with lower numbers indicating greater recovery. Furthermore, based on the two static time points, some researchers calculated residual change scores, in which the recovery score is regressed on its baseline and/or reactivity levels and saved as regression residuals (Kaczmarek et al., 2019). Residualized change scores inform whether individuals recovered faster or slower than based on expectations from their baseline and/or reactivity.

The continuous measurement approach uses the time needed to return to or stay at the baseline level. The "time to baseline" index of recovery is calculated for each participant using physiological baseline level (mean of baseline period plus and minus one standard deviation) and the time needed to return to the individual physiological baseline level and remain at that level for at least five of six consecutive seconds (Fredrickson & Levenson, 1998). The "time in baseline" index uses the total number of seconds each participant remained at the baseline level during the emotional manipulation (Gilbert et al., 2016). In contrast to the "time to baseline," the "time in baseline" accounts for the possibility that individuals may re-exit the baseline level and never fully recover once recovery is reached. The continuous and fixed-point methods have not previously been used in a single study, making it difficult to infer their complementarity. The use of either method might be a reason for mixed effects in the literature.

Different Physiological Measures

Initial studies of the undoing effect used a composite index of cardiovascular recovery constructed from multiple measures, including heart period, finger pulse amplitude, pulse transit times to ear and finger, and systolic and diastolic blood pressure (Fredrickson & Levenson, 1998; Fredrickson et al., 2000). The motivation for using a broad-band composite index of cardiovascular recovery was that it provides a larger window onto sympathetic activation than does any single index (Fredrickson & Levenson, 1998; Fredrickson et al., 2000). However, more recent studies have used separate measures (Kaczmarek et al., 2019; Quin et al., 2019). These differences in physiological assessment strategy might play a role in mixed findings. Furthermore, there might be differences between the studies that has been focused on pre-ejection period, electrodermal activity, total peripheral resistance, finger pulse amplitude, and pulse transit time, all measures thought to have primarily sympathetic drivers (Boucsein, 2012; Giassi et al., 2013; Shiota & Danvers, 2014; Zou et al., 2004), rather than heart period and blood pressure, which are the result of a combination of sympathetic and parasympathetic influences (Shiota & Danvers, 2014).

Different Elicitation Methods of Positive Emotions

Among studies of the undoing effect, the two most common means of inducing positive emotions are pictures (Cavanagh, 2016; Kaczmarek, 2009; Kaczmarek et al., 2019) and film clips (Fredrickson & Levenson, 1998; Fredrickson et al., 2000; Gilbert et al., 2016; Hannesdóttir, 2007). A recent meta-analysis suggests that the most effective methods to elicit positive emotions are watching film clips, reading stories, and watching pictures of facial expressions (Joseph et al., 2020). However, other meta-analyses suggest no differences among elicitation methods regarding ANS reactivity (Behnke et al., 2022; Lench et al., 2011; Siegel et al., 2018). Differences in elicitation methods between studies could influence the strength of the undoing effect of positive emotions.

Different Elicitation Methods of Negative Emotions or Stress

Researchers have also used multiple methods to elicit negative emotions and stress, including speech-preparation tasks (Fredrickson et al., 2000; Hannesdóttir, 2007; Kaczmarek et al., 2019), film clips (fear, Fredrickson & Levenson, 1998; sad, Fredrickson & Levenson, 1998), pictures (Sokhadze, 2007); arithmetic tasks (Cavanagh, 2016; Kaczmarek, 2009; Medvedev et al., 2015), and writing about sad experience (Soenke, 2014). These differences in elicitation methods of negative emotions or stress might play a role in mixed findings.

Differences in Participants' Age

Younger individuals are expected to experience more intense emotions than older individuals (Charles & Carstensen, 2008; Steenhaut et al., 2018). However, a meta-analysis did not support this view (Behnke et al., 2022; Lench et al., 2011). Thus, it is not clear whether participant age moderates the undoing effects.

Differences in Participants' Sex

Sex is an individual characteristic that is viewed as a potential moderator of ANS recovery related to positive emotions. Women are generally viewed as being more emotionally reactive than men (Bradley et al., 2001). Yet, recent meta-analyses do not support this notion, showing no differences between men and women in response to positive emotions (Behnke et al., 2022; Joseph et al., 2020; Siegel et al., 2018). Therefore, it is not clear whether participants' sex moderates the undoing effects of positive emotion on recovery from negative emotion.

Differences in the Year of Publication

The "decline effect" (Schooler, 2011) or the "law of initial results" (Ioannidis, 2005) proposes that the strength of the effect sizes within a specific paradigm declines over time. This trend can be explained by the increasing number of rigorous studies with larger samples, leading to regression to the mean over time. The significant influence of the publication year can also be interpreted as an indicator of bias in the existing literature.

Differences in Other Methodological Characteristics

In addition to the eight candidate moderators noted above, five other methodological characteristics of studies were considered as possible moderators. These include: emotion elicitation duration for positive emotions, emotion elicitation duration for stress or negative emotions, number of reported ANS measures, sample size, and study quality (e.g., presence of manipulation checks). However, the previously tested variables did not consistently influence the size of the mean ANS reactivity to emotions (Behnke et al., 2022; Siegel et al., 2018). It is therefore not clear whether methodological characteristics moderate the undoing effects.

Overview of the Present Investigation

The goal of the present study was to synthesize and evaluate findings from past research, in which experimentally induced positive or neutral emotional states followed experimentally induced negative emotions or stress, and physiological measures were obtained. Experimental manipulation of emotions was important to ascertain causality from positive emotion to physiological recovery. Experimental manipulation of negative emotions or stress was important to ascertain that sympathetic arousal was produced and that there was potential for recovery. Inclusion of neutral condition was important to ascertain that the function of quieting the sympathetic arousal was related to the onset of positive emotions rather than the termination of negative emotions. Measuring physiology was important to enable objective assessment of the undoing effect of positive emotions.

We focused on the significance and consistency of the mean effect size and possible moderators of ANS recovery from negative emotions in response to positive emotions. First, we tested the consistency with which positive emotions accelerate the physiological recovery from negative emotions and stress. We calculated pooled mean effect sizes for the difference between the effect of positive emotions and neutral conditions on the recovery measure. Second, we tested 13 potential moderators - i.e., differences among positive emotions (e.g., amusement vs. contentment), different ways of operationalizing recovery (e.g., time to baseline vs. change score), different physiological measures (e.g., composite index of cardiovascular recovery vs. heart rate), different elicitation methods of positive emotions (e.g., pictures vs. film clips), different elicitation methods of stress or negative emotions (e.g., speech-preparation tasks vs. film clips), differences in participants' age (e.g., whether the effect is stronger in youth-dominated studies), differences in participants' sex (e.g., whether the effect is stronger in female-dominated studies), differences in the year of publication (whether the strength of the effect decline over the time), and whether the size of the mean effect is related to other methodological characteristics (e.g., whether the effect is stronger in studies with longer positive elicitation periods, or whether the effect is stronger in studies with longer stress or negative emotions elicitation periods, or whether the effect is stronger in studies with longer emotion elicitation periods or lower number of reported ANS measures, or larger sample sizes, or higher study quality). These variables might explain whether and why positive emotions do not facilitate physiological recovery in some contexts or under specific circumstances.

Based on the theoretical model (Fredrickson & Levenson, 1998; Fredrickson et al., 2000), we expected that positive emotions would facilitate the physiological recovery from negative emotions and stress compared to neutral conditions. In light of recent studies (Kaczmarek et al., 2019; Qin et al., 2019), we expected to find differences among discrete positive emotions in ANS recovery, e.g., high-approach positive emotions (e.g., excitement or enthusiasm) versus low-approach positive emotions (e.g., amusement or contentment). We expected that positive emotions characterized by a strong approach tendency would slow down the recovery compared to positive emotions characterized by a weak approach tendency. Examining these effects quantitatively is essential for clarifying the empirical status of the undoing hypothesis and for more clearly specifying boundary conditions and moderators of this effect.

Methods

Selection of Studies

We performed a systematic literature search using EBSCO, PsycINFO, PubMed, ProQuest, Google Scholar, and Open Access Theses and Dissertations, covering the period from January 1872 to September 2021. We used the following terms: ["undoing hypothesis" OR "undoing effect" OR "physiological down-regulation "OR "cardiovascular recovery "AND "positive emotions" OR "positive affect"]. We also cross-checked the references in the studies that we retrieved. We contacted 22 authors who had published articles or dissertations on the undoing effect and asked for any unpublished material. Of nine authors who responded to the request (41%), none reported any unpublished material. We also posted the call for data among members of the Society for Affective Science and the International Society for Research on Emotion.

We selected potentially eligible studies in two phases. First, four research team members (MB, MP, PC, and EW) screened the titles and abstracts. Next, we screened the full text of the articles with a relevant title and/or abstract. All of the identified studies as potentially eligible during the first selection phase were then reassessed in the second selection phase.

The inclusion criteria for eligible studies were: 1) experimentally induced positive emotions or neutral emotional states following experimentally induced negative emotions or stress; 2) non-clinical participants; and 3) ANS recovery was measured during elicitation of positive emotions and during the neutral conditions. The exclusion criteria were: 1) emotion regulation rather than spontaneous responses to positive stimuli; 2) additional manipulations that affected physiological or emotional responses (e.g., exercising before emotion manipulation or priming during a cognitive task); or 3) available data did not allow us to calculate effect sizes. The inter-rater agreement on which studies met the eligibility criteria and could thus be included was high (Krippendorff's $\alpha = .90$). Any disagreement between the coders were resolved through discussion. Figure 1 summarizes the search procedure. Table S1 presents the studies included in this meta-analysis with study characteristics.

Data Extraction

Coding. Based on methodological considerations (Levenson, 2014) and results from previous meta-analyses on ANS reactivity and emotions (Behnke et al., 2022; Lench et al., 2011; Siegel et al., 2018), the following potential moderators were coded: 1) the positive emotion that was studied; 2) recovery calculation methods (e.g., time to baseline, change score from stress; residual change score); 3) type of physiological measure; 4-5) type of experimental manipulation methods for positive emotions or neutral conditions, and negative emotion or stress elicitation (i.e., autobiographical recall, behavioral manipulation, film, memory recall, music, picture presentation, reading text); 6) mean age of the sampled participants (in years); 7) sex of the sampled participants (percentage of females); and 8) publication year. We also coded the studies for several additional characteristics: 9-10) positive emotions or neutral conditions, and negative emotion or stress elicitation

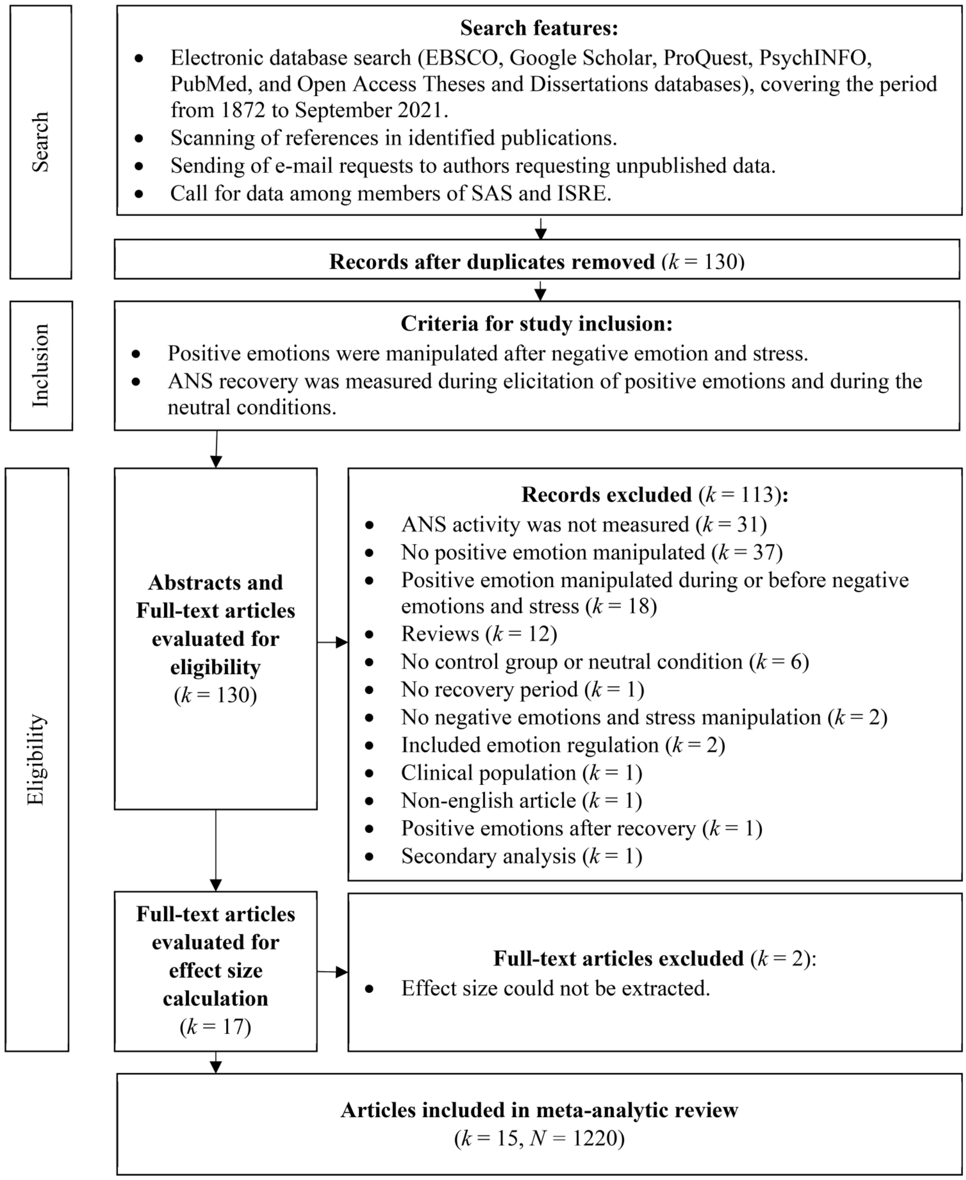

Figure 1. Flow diagram of the search procedure.
Note. SAS = Society of Affective Science, ISRE = International Society for Research on Emotion, ANS = autonomic nervous system.

duration (in seconds); 11) number of ANS measures used in analysis in a given study; 12) sample size; 13) study quality (0–5). The study quality index comprises scores from six criteria: a) provision of exclusion criteria related to physiological activity, e.g., BMI, physical health, drug use (yes = 1, no = 0); b) report on artifacts, outliers, and missing data (yes = 1, no = 0); c) the presence of a manipulation check for positive emotion (e.g., an increase of positive valence or behavioral indexes of positive affect; yes = 1, no = 0); d) the presence of a manipulation check for neutral conditions (e.g., no difference from baseline; yes = 1, no = 0); e) the presence of a manipulation check for self-reported negative emotion and stress (e.g., an increase of negative valence; yes = 1, no = 0); and f) the presence of a manipulation check for physiological activity related to negative emotion and stress (e.g., an increase of HR; yes = 1, no = 0). The inter-rater agreement for codes was acceptable and ranged from Krippendorff's $\alpha = .72$ to Krippendorff's $\alpha = .88$. Any disagreement between the coders was resolved through discussion.

When coding for the positive emotion, we compared the emotion label designated by the primary study authors with the list of discrete positive emotions described in the literature (e.g., Cowen & Keltner, 2017). In 13 cases (48%), we relabeled the original names according to information in the Methods section of the primary study. The reason for relabeling was that 1) the stimulus was assigned a broad category (e.g., pictures eliciting high-approach positive affect) although a specific positive emotion was elicited (e.g., pictures of delicious food to craving; Qin et al., 2019), or 2) the stimulus was not assigned to any emotion (e.g., the sound of the ocean).

When coding for ANS measures, we included indicators of sympathetic activity related to negative emotions and stress. The following measures were included: heart rate (HR), a composite index of cardiovascular reactivity (CVR), pre-ejection period (PEP), stroke volume (SV), cardiac output (CO), finger pulse amplitude (FPA), diastolic blood pressure (DBP), systolic blood pressure (SBP), total peripheral resistance (TPR), skin conductance level (SCL), skin conductance response (SCR), and skin temperature. A detailed description of included ANS measures can be found in reviews focusing on ANS reactivity to emotions (e.g., Behnke et al., 2022; Berntson et al., 1991; Cacioppo et al., 2000; Larsen et al., 2008; Siegel et al., 2018). Finally, because increased sympathetic activation is associated with shortened PEP values, we multiplied the effects of PEP by −1.

Effect size extraction. To calculate effect sizes, we computed the difference in recovery between the neutral condition and positive emotions. For most studies, the authors reported means and standard deviations of the ANS levels during neutral conditions and emotion elicitation. For studies reporting other metrics (e.g., adjusted/partial correlations or regression coefficients), we sent requests to the authors to provide us with the means of the relevant periods. Of the seven authors we contacted, three responded to our inquiry (43%), and of these, all sent us the requested data (100%). No authors denied us access to the requested data. We used Cohen's d as the common effect size measure. We used Cohen's d_s for the between-subject study design, whereas for the within-subject study design, we used Cohen's $d_{av.}$ (Lakens, 2013). We used Cohen's $d_{av,}$ because the primary articles did provide enough data to calculate the Cohen's d_z or Cohen's d_{rm}. We interpreted the magnitude of the effect sizes using conventional standards (small, $d = 0.20$; medium, $d = 0.50$; large, $d = 0.80$; Cohen, 1992).

Meta-Analytic Procedures

We ran meta-analytic procedures, using *R* (R Core Team, 2017) with the *metafor* package (Viechtbauer, 2010) following meta-analysis recommendations (Assink & Wibbelink, 2016; Harrer et al., 2021; Viechtbauer, 2010). Expecting high heterogeneity of the effects (Siegel et al., 2018), we used the random-effects model. Several theorists have argued in favor of adopting random-effects models for meta-analysis as these models are optimal in terms of allowing the generalization of corrected effect sizes to the population (Field & Gillett, 2010; Hunter & Schmidt, 2000; Schmidt & Hunter, 2014). Furthermore, the simulation studies show that applying separate three-level models for a different type of outcome is the only approach that consistently gives adequate standard error estimates (Fernández-Castilla et al., 2021a). We used restricted maximum likelihood estimation to estimate the pooled mean effect sizes.

Most of the included studies ($k = 13$) provided multiple effect sizes of ANS recovery for one or more positive emotions. Thus, we used a three-level meta-analytic approach to account for dependency between effect sizes (Assink & Wibbelink, 2016; Viechtbauer, 2010). Three-level meta-analytic models consider three sources of variance: variance in effect sizes extracted from different studies (i.e., between-study variance) at level three of the model, variance in effect sizes extracted from the same study (i.e., a within-study variance that used two ANS measures) at level two of the model, and sampling variance of the extracted effect sizes at level one of the model (Cheung, 2014; Hox, 2002; Van den Noortgate et al., 2013, 2014).

Magnitude and consistency of the undoing effect. We aimed to examine a pooled mean effect size of the undoing effect of positive emotion versus neutral. We ran a meta-analysis for all ANS measures together because we focused our analysis on the factors (e.g., elicitation method) that may explain variability in the undoing effect (all measures) of positive emotions rather than the variability of specific ANS measures (e.g., HR). We interpret the results considering two parameters, namely, ANS recovery magnitude (significant vs. non-significant) and its consistency (no/low heterogeneity vs. high heterogeneity). Heterogeneous effect sizes may indicate that: a) the average ANS recovery is not consistent for positive emotions in the population; b) the average ANS recovery is moderated by different types of characteristics (e.g., elicitation method); or c) the size of the effect reflects real, contextual changes in ANS recovery.

We tested whether the calculated mean effect sizes were homogeneous (consistent) using I^2-statistic. The rejection of the null hypothesis indicates the presence of possible methodological or population differences that may lead to variation between studies. Furthermore, we used the I^2-statistic, which can be compared across meta-analyses (Higgins et al., 2003). The I^2 - statistic allows for examining the amount of variance in effect sizes extracted from the same study (meta-analytic model's level two) and variance between studies (level three). The sum of the I^2-statistics at levels two and three indicates the amount of variability with the value of 0% indicating an absence of dispersion, and larger values indicating the following levels of heterogeneity: 0–40% = might not be important; 30–60% = may represent moderate heterogeneity; 50–90% = may represent substantial heterogeneity; 75–100% = represents considerable heterogeneity (Higgins et al., 2019). We examined the significance of the variance at levels two and three by calculating two separate one-tailed log-likelihood-ratio tests. In these tests, the deviance of the full model was compared to the deviance of the model, excluding one of the variance parameters.

Publication bias. We performed several publication bias analyses to investigate whether null or weak results were likely to be systematically suppressed from publication (Schmidt & Hunter, 2014). Assessing potential bias in the effect sizes that are synthesized is vital because studies with non-significant or negative results are less likely to be published in peer-reviewed journals (Borenstein et al., 2011). Our bias assessment strategy comprised five methods, including a visual inspection of the funnel plot, a rank correlation test, Egger's regression test (Egger et al., 1997), the trim-and-fill analysis (Duval & Tweedie, 2000), and a moderator test in which the publication year of studies is tested as a moderator of the overall effect (see, for instance, Assink et al., 2018, 2019 for similar bias assessment strategies). In our strategy, we used standard methods for two-level meta-analysis because no techniques have been developed and tested yet for detecting bias in 3-level meta-analyses (Fernández-Castilla et al., 2021b).

First, we visually inspected a funnel plot in which effect sizes are plotted against their standard error around an estimated summary effect (Egger et al., 1997). In contrast to large studies, studies using small samples tend to produce effect sizes of different magnitude due to increased variability in their sampling errors. Thus, effect sizes from smaller studies are expected to scatter widely at the bottom of the funnel plot, whereas effect sizes from larger studies are expected to be more concentrated at the top of the plot. As null or weak results are likely to be systematically suppressed from publication, an asymmetric distribution of effect sizes may be expected in the sense that effect sizes may be missing at the (bottom) left of the estimated summary effect in the funnel plot. In contrast, a symmetric effect size distribution with effect sizes equally distributed to the left and right of a summary effect would suggest the absence of bias.

Second and third, we assessed publication bias using an adapted version of the Egger's regression test and the Begg and Mazumdar's rank-order correlation test (Assink et al., 2018; Assink et al., 2019; Begg & Mazumdar, 1994; Egger et al., 1997; Sterne et al., 2000). In the adapted Egger's regression test, we regressed the effect sizes on their standard errors in a three-level meta-analytic model. Contrary to the classical Egger's test, this adapted test accounted for effect size dependency stemming from the fact that multiple effect sizes were extracted from individual primary studies. For Egger's test, the significance of the slope is indicative for bias, whereas for the Begg and Mazumdar's rank-order test the significance of the rank association is indicative for bias (Begg & Mazumdar, 1994; Egger et al., 1997; Sterne et al., 2000).

Fourth, we examined bias-corrected effect sizes with the trim-and-fill method (Duval & Tweedie, 2000). If funnel plot asymmetry is detected, the trim-and-fill method imputes effect size estimates from "missing" studies and restores the funnel plot symmetry. Fifth, we tested whether the magnitude of the effect sizes declines over time by regressing the summary effect on publication year of primary studies. The tendency for positive results to get smaller over time may indicate a "decline effect" (Schooler, 2011) which is referred to as "law of initial results" by Ioannidis (2005).

Moderator analyses. Finally, to examine potential moderators that may influence the undoing effects of positive emotions, we ran 13 separate moderator analyses. We determined whether the undoing effect differentiates within (categories of) the factor by interpreting the results of an omnibus test, in which a significant F value indicates differences in undoing effect within (categories of) the factor (moderator). To account for Type I error for multiple comparisons (e.g., testing 13 different moderators on the same dataset) that is frequent in meta-analyses (Cafri et al., 2010), we adjusted probability values using the false discovery rate (FDR) formula (Benjamini & Hochberg, 1995). This resulted in adjusting p-values to balance Type I and Type II errors. Next, we considered the undoing effect as significant in one sub-group (e.g., ANS recovery to amusement) when confidence intervals of the mean effect size in a given moderator sub-group did not include zero. We interpreted the mean effect of the moderator category when there were at least three studies per category.

Results

Descriptive Analyses

We included 15 articles with 16 studies and 27 elicited emotions, presenting 72 effect sizes obtained from 1,220 participants with ages ranging from 16 to 60 years ($M = 22.03$ years, $SD = 3.13$) (Figure 1). Most participants (74%) were female. The included studies were published between 1998 to 2019, with the median publication year of 2012. The mean duration of physiological recording for positive emotions was 186.39 ($SD = 137.71$) seconds and for negative emotions and stress 149.46 ($SD = 101.22$) seconds.

The most frequently studied positive emotion was contentment ($n = 10$ cases; 37.0%), followed by amusement (8; 29.6%), mix of positive emotions (5; 18.5%), craving (1; 3.7%), joy (1; 3.7%), mix of high-approach positive emotions (1; 3.7%), and mix of low-approach positive emotions (1; 3.7%). The most frequent method of positive emotion elicitation was presenting film clips to participants ($n = 11$ cases; 40.7%), followed by picture presentation (8; 29.6%), music (6, 22.2%), autobiographical recall (1; 3.7%), and reading a text (1; 3.7%). The most frequent method of negative emotion and stress elicitation was speech preparation ($n = 11$ cases; 40.7%), followed by arithmetic task (6; 22.2%), autobiographical recall (3; 11.1%), film clips (2, 7.4%), Stroop task (2, 7.4%), reward sensitivity task (2, 7.4%), and picture presentation (1, 4.7%). The most frequent method of recovery calculation was time to baseline ($n = 11$ cases; 40.7%), followed by mean change from stress (7, 25.9%), mean change from baseline (5; 18.5%), residual change score (2, 7.4%), and time in baseline (2; 7.4%). The most frequent physiological measure was HR ($n = 20$ effect sizes; 27.8%), followed by DBP (11; 15.3%), SBP (11; 15.3%), a composite index of cardiovascular reactivity (6; 8.3%), SCL (5; 8.3%), CO (4; 5.6%), PEP (4; 5.6%), TPR (4; 5.6%), SV(2; 2.8%), skin temperature (2; 2.8%), FPA (2; 2.8%), and SCR (1; 1.4%).

The Undoing Effect of Positive Emotions

Overall, we found that positive emotions did not facilitate autonomic nervous system recovery relative to neutral condition, $d = 0.05$, 95% CI [-0.11, 0.21], $p = .51$, $k = 72$ (Figure 2). Furthermore, as for heterogeneity in effect sizes in the model, we found significant within-study variance (level 2) $\chi 2$ (1) = 13.55, p < .001, but not between-study (level 3) variance $\chi 2$ (1) = 2.77, $p = .10$. A breakdown of the total variance into the variance distributed at the three levels of the model revealed that 37.53% could be attributed to sampling variance, 50.46% to within-study variance, and 12.00% to between-study variance. Thus, we rejected the null hypothesis of effect size homogeneity and found that the true effect size was moderately heterogeneous and was likely to vary within the studies from effect size to effect size. This indicates that the effect sizes should not be treated as estimates of one common effect size, and thus, moderator analyses are justified to search for variables that can explain the heterogeneity of the overall undoing effect of positive emotions.

Publication Bias

We investigated outliers by calculating studentized residuals, which identify effect sizes that disproportionately contribute to the overall heterogeneity and the results. No effect size was identified as problematic, with all $Zs < 1.93$ (Figure 3). As for the bias assessment results, we found mixed evidence that the distribution of effect sizes was asymmetrical. The trim-and-fill analysis did not impute any "missing effects". Also, a visual inspection of the funnel plot as well as the results of the rank order correlation test ($\tau = .07$, $p = .35$) did not suggest an asymmetrical distribution of effects. Only the adapted Egger's regression test produced indications for an asymmetrical distribution of effects and specifically publication bias, $\beta = 3.33$, $p = .03$. Further, we found a negative association between publication year and size of the ANS reactivity, $\beta = -.04$, 95% CI [-.06, -.02], $p < .001$, $k = 72$, indicating that the magnitude of effect sizes decreases over time, meaning that more recent studies showed smaller effect sizes. In sum, two out of the five bias assessment methods that were applied provided indications for bias in the studies that were synthesized in this meta-analysis, so the results of the meta-analysis might have been affected by bias.

Moderator Analyses

The moderator analysis showed that under most conditions, positive emotions do not "undo" ANS reactivity more efficiently than neutral states, that is, the undoing effect of positive emotions was not affected by most variables tested as moderators; Table 1 presents the results of the omnibus test of the moderator analyses. We did observe that the undoing effect of positive emotions was moderated by the type of ANS measure used in primary studies to calculate the recovery. We found that only studies using a composite index of cardiovascular recovery showed the undoing effect of positive emotions in comparison to neutral conditions. Furthermore, using a composite index of cardiovascular recovery showed bigger effect sizes than other ANS measures, including HR $\Delta d = 0.79$, 99% *CI* [0.33, 1.25], DBP $\Delta d = 0.71$, 96% *CI* [0.30, 1.11], SBP $\Delta d = 0.72$, 97% *CI* [0.29, 1.14], SCL $\Delta d = 0.77$, 98% *CI* [0.28, 1.25], CO $\Delta d = 0.58$, 95% *CI* [0.16, 1.00], PEP $\Delta d = 0.60$, 96% *CI* [0.15, 1.05], TPR $\Delta d = 0.97$, 99% *CI* [0.39, 1.55].

Discussion

In this project, we used meta-analytic procedures to synthesize findings from past research on the undoing effect of positive emotions. Overall, we did not find support for the undoing effect. We observed a non-significant effect of positive emotions on ANS recovery relative to the neutral condition. However, in the moderator analyses, we found that studies which employed a composite index of cardiovascular reactivity showed significant effects of positive emotions relative to the neutral condition. We also found support for the "decline effect" (Schooler, 2011) or the "law of initial results" (Ioannidis, 2005) in the undoing literature, as the strength of the effect sizes declined over time. Thus, our work supports the conclusions of the previous qualitative systematic review that evidence for improving physiological recovery by positive emotions is insufficient (Cavanagh & Larkin, 2018). However, our findings suggest that there may well be specific conditions under which positive emotions serve to undo sympathetic arousal associated with negative emotions and stress.

Across all studies, we found that positive emotions were not more beneficial than neutral states in their effects on ANS recovery after stress or negative emotions. Nonetheless, positive emotions might still offer respite from stress or negative emotions in other contexts (Lazarus et al., 1980; Monfort et al., 2015) or via other mechanisms (Pressman & Cohen, 2005; Pressman et al., 2019). Before answering complex questions about the link

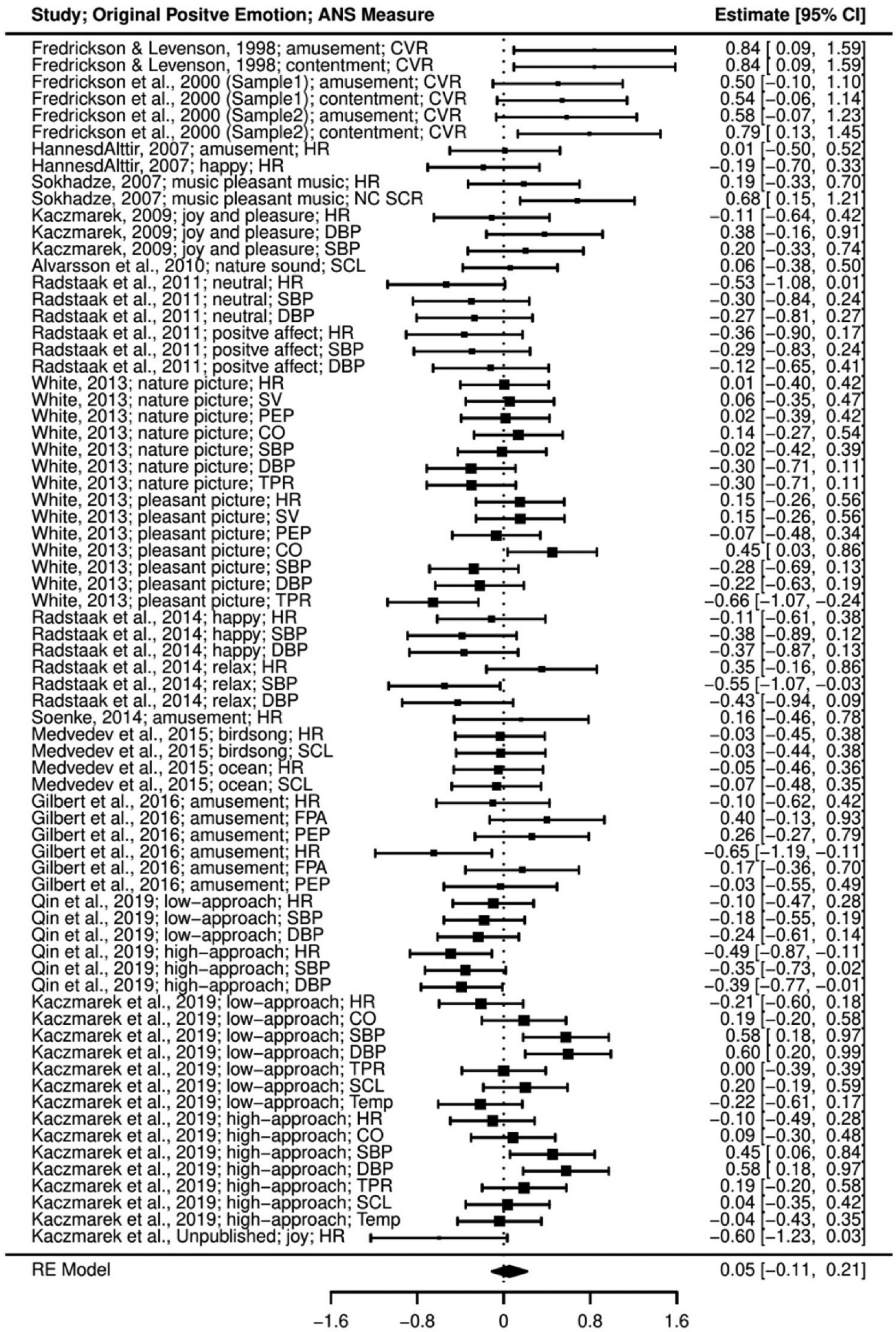

Figure 2. Forrest plot of the effect sizes included in the meta-analysis.

Notes. The square boxes represent Cohen's *d* and sample sizes (the larger the box, larger the sample size, contributed more to the total effect size) in each study. The lines represent 95% confidence intervals. The diamonds represent the pooled effect size and the 95% confidence intervals. HR = heart rate, CVR = composite index of cardiovascular reactivity, PEP = pre-ejection period, CO = cardiac output, FPA = finger pulse amplitude, DBP = diastolic blood pressure, SBP = systolic blood pressure, TPR = total peripheral resistance, SCL = skin conductance level, SCR = skin conductance response, Temp = fingertip skin temperature.

between positive emotions and health, affective scientists might wish to focus on answering more basic questions that still remain, e.g., which affect induction procedure is the most effective, on which ANS measure do positive emotions have the greatest impact, or how ANS changes should be operationalized.

More generally, our findings suggest the need for additional work on the functions of positive emotions. A recent meta-analysis on ANS activity during positive emotions found that the field of psychophysiology of positive emotions has not matured yet and that much needs to be learned (Behnke et al., 2022; Shiota, 2017). Although researchers may believe that the psychophysiological correlates of positive emotions have been established, recent findings in affective science suggest that much remains to be learned about the psychophysiological correlates and functions of positive emotions (if any). Researchers may develop new hypotheses about the psychophysiological functions of some positive emotions or test propositions from existing theoretical frameworks (e.g., Shiota et al., 2017). For instance, it will be important to clarify whether and how enthusiasm might support the fast, active pursuit of tangible resources and how contentment might facilitate physical rest and digestion (Shiota et al., 2017).

Under What Conditions Do Positive Emotions "Undo" ANS Reactivity?

We investigated several variables that we thought might influence the undoing effect. We observed that only studies using the composite index of cardiovascular recovery showed significant differences between positive emotions and neutral conditions (Fredrickson & Levenson, 1998; Fredrickson et al., 2000). This finding is consistent with the idea that this physiological composite provides a broader window onto sympathetic activation and recovery of the cardiovascular system than does any single cardiovascular index (Fredrickson & Levenson, 1998; Fredrickson et al., 2000).

Contrary to our expectations, we did not find that the strength of the undoing effect is influenced by discrete positive emotions or groups of positive emotions. We expected that positive emotions that differ along the dimension of approach motivation would also influence the recovery from stress and negative emotions differently (Gable & Harmon-Jones, 2010; Harmon-Jones et al., 2013) or, even more specifically, that discrete positive emotions would produce specific adaptive changes in physiology (Ekman & Cordaro, 2011; Kreibig, 2010; Levenson, 2011). However, our non-significant result is consistent with findings from previous meta-analyses that challenge the specificity of ANS responses to positive emotions (Behnke et al., 2022; Siegel et al., 2018). The current findings may be interpreted as being consistent with a constructionist view of ANS reactivity on emotion, at least with respect to positive emotions (Barrett, 2013, p. 2017; Quigley & Barrett, 2014). Constructionists view the ANS response to emotions as being a specific response to the demands of the situation in which the emotion occurs rather than the emotion itself. On this view, whether or not a certain positive emotion influences autonomic levels depends upon the context in which the emotion occurs.

Similarly, the recovery operationalization method was not a significant moderator. Further, we did not observe the influence of age, sex proportion, and participant number on physiological recovery. As previous meta-analyses already revealed (Behnke et al., 2022; Lench et al., 2011), we found no support of participants' age effects on the physiological response to emotion. However, this may be due to imbalanced age distribution (with samples skewed to young participants), meaning we did not have sufficient statistical power to detect age differences. A thorough examination of how age influences emotion's effect on recovery from negative emotions and stress requires additional research with older participants. Furthermore, in line with previous meta-analyses, we found no sex differences in the physiological response to positive emotions (Behnke et al., 2022; Joseph et al., 2020; Siegel et al., 2018).

In our bias assessment strategy that comprised five methods for detecting bias, we found mixed indications of bias in the studies that were synthesized. A visual inspection of the funnel plot of effect sizes, the rank order correlation test, and the trim-and-fill analysis did not provide indications for bias. However, the adapted Egger's regression test did reveal that the standard error was a significant and positive predictor of effect sizes, which is indicative for publication bias. As this adapted Egger's test was the only method taking effect size dependency into account, one may argue that more weight should be put on the results of this test relatively to the results of the other techniques that were part of our bias assessment strategy. However, the Egger's test – just like many other available techniques for bias assessment - assumes homogeneity in effect sizes (e.g., Nakagawa & Santos, 2012; Terrin et al., 2003; See also Limitations and Future Directions section) which was violated in the present meta-analysis as we found significant within-study variance in effect sizes pointing towards effect size heterogeneity. This implies that the results of this regression test should be interpreted cautiously as well. Unexpectedly, more effect sizes were published in the literature that opposes the undoing effect than support it. This is puzzling because a potential publication bias would be marked by the overrepresentation of studies supporting the hypothesis. This imbalance may stem from more recent studies presenting multiple effect sizes of ANS recovery (Kaczmarek et al., 2019; Qin et al., 2019), in contrast to early studies which presented a single effect for a physiological composite (Fredrickson & Levenson, 1998; Fredrickson et al., 2000; Hannesdóttir, 2007). Regardless of the results of our bias assessment, this latter finding suggests that the body of published evidence for the undoing effect might be biased in some way.

Finally, we found that the strength of the undoing effect reported in studies declined over time. This might support the publication "decline effect" (Schooler, 2011) or the

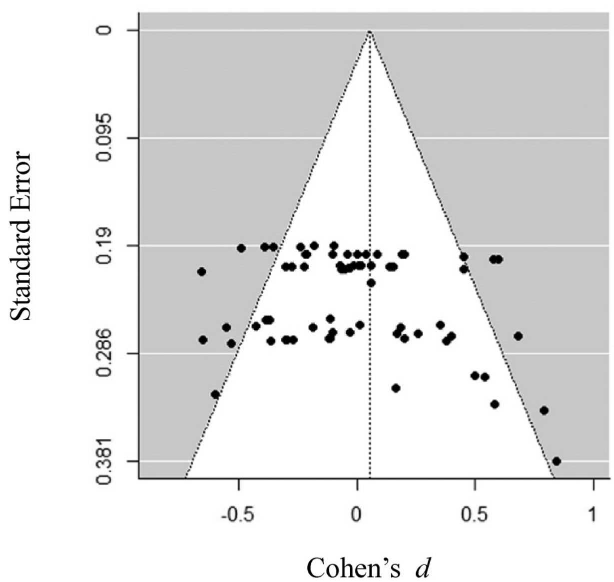

Figure 3. Funnel plot of the effect sizes included in the meta-analysis.

"law of initial results" (Ioannidis, 2005), which is observed in scientific research. This declining trend might be explained by the increasing number of studies with larger samples, leading to regression to the mean over time. A large replication project found that the replicated effects were usually half the size of those reported in the original papers (Open Science Collaboration, 2015). Although the significant influence of publication year can be interpreted as an indicator of bias in the existing literature, we found that studies using the same methodology as original studies (Fredrickson & Levenson, 1998; Fredrickson et al., 2000) supported the undoing effect of positive emotions (Gilbert et al., 2016; Hannesdóttir, 2007). The fact that we found support from direct or close replications (high degree of methodological similarity; Brandt et al., 2014; Simons, 2014) rather than from conceptual or more distant replications (different methodologies; Crandall & Sherman, 2016) suggests the possibility that there may be definable boundary conditions for this effect. Thus, we do not rule out the possibility that the decline observed in our project might result from factors other than the law of initial results.

Limitations and Future Directions

This meta-analytic review has a number of strengths, including its systematic examination of a wide array of candidate moderators. However, this review also has several limitations that bear noting.

First, we found that a relatively small number of studies were eligible for inclusion in this review. Consequently, some comparisons and analyses were based on a small number of effect sizes. It is recommended that at least two studies are needed for meta-analysis (Valentine et al., 2010), with five or more studies recommended to reasonably consistently achieve power from random-effects meta-analyses (Jackson & Turner, 2017). The review of meta-analyses indicates that the median number of studies included in the cardiovascular meta-analyses is four and that ninety percent of cardiovascular meta-analyses included less than 14 studies (Davey et al., 2011). Thus, it is justified to synthesize the literature on the undoing effect of positive emotions with a meta-analytic technique based on the 72 effects sizes from 16 studies.

One puzzle is why we were able to find only 16 studies that examined the undoing effect, as this effect is well known and has been around for decades. This small number of studies resulted from using quite stringent inclusion criteria, which we felt were needed given the previous literature review that found mixed support for the undoing effect (Cavanagh & Larkin, 2018). In our quantitative synthesis of primary research on the undoing effect, we aimed to include studies that were relatively close replications of the original study (Fredrickson & Levenson, 1998). Thus, we only included studies in which experimentally induced positive states followed experimentally induced negative emotions or stress. Experimental manipulation of emotions was important to ascertain causality from positive emotion to physiological recovery. Nonetheless, the relatively small number of included studies limits our ability to draw robust conclusions on specific aspects of the positive emotions' undoing effect, for instance potential moderating variables influencing this effect.

Second, we found that the undoing effect of positive emotions is moderately heterogeneous. The usual way to address effect size heterogeneity is to test variables as potential moderators. Contrary to our expectations, we did not identify many factors significantly influencing the undoing effect. This does not necessarily mean that there are no moderators of the undoing effect, as low statistical power may have driven our non-significant results in our moderator analyses. The posterior power analysis showed that we could detect medium-sized effects at most, with more than 80% power in the sample and distribution of effect sizes that we synthesized (Griffin, 2020). Thus, our moderator analyses may provide an insight into the size of the differences between conditions, but their significance should be interpreted in light of the limited statistical power. Furthermore, we found significant within-study – but not between-study - heterogeneity. This is an encouraging finding because variables that are more likely to vary within versus between studies are the most promising moderators for future researchers to examine. Thus, a future high-powered secondary analysis could examine much of the within-study heterogeneity that we identified in the current review.

Third, we found that primary studies have not sampled broadly across ANS measures and did not sample across multiple discrete positive emotions. This review examined the effects of only four discrete emotions (amusement, contentment, craving, and joy). Recent research has been able to identify 13–17 positive emotions at the subjective level

Table 1. Results of moderator analyses.

	F	*df*	*k*	Mean Effect Size	95% CI
Emotion	0.853	7, 65			
Amusement (RC)			14	0.152	−0.112, 0.417
Contentment			24	0.057	−0.146, 0.260
Craving			3	−0.231	−0.626, 0.164
Joy			1	−0.599	−1.471, 0.274
High-approach Positive Emotions			7	0.169	−0.386, 0.723
Low-approach Positive Emotions			7	0.159	−0.396, 0.713
Mixed Positive Emotions			16	0.040	−0.192, 0.273
Recovery Operationalization	0.891	5, 67			
Mean Change from Baseline (RC)			11	−0.018	−0.377, 0.341
Mean Change from Stress Level			18	−0.073	−0.397, 0.252
Residual Difference Score			14	0.164	−0.432, 0.760
Time in Baseline			3	−0.150	−0.647, 0.347
Time to Baseline			26	0.204	−0.072, 0.479
ANS Measure	**3.076****	12, 60			
CO (RC)			4	0.083	−0.179, 0.345
CVR			6	**0.666*****	0.324, 1.008
DBP			11	−0.039	−0.226, 0.148
Fingertip Temperature			2	−0.392*	−0.737, −0.047
FPA			2	0.340	−0.123, 0.803
HR			20	−0.124	−0.274, 0.027
NS SCR			1	0.600	−0.031, 1.232
PEP			4	0.065	−0.227, 0.356
SBP			11	−0.053	−0.239, 0.134
SCL			5	−0.099	−0.342, 0.145
SV			2	0.129	−0.230, 0.488
TPR			4	−0.302*	−0.565, −0.039
Elicitation Method Positive Emotion	0.605	5, 67			
Article (RC)			1	0.162	−0.745, 1.069
Film			19	0.230	−0.071, 0.530
Memory Recall			1	−0.075	−0.809, 0.661
Music			13	0.023	−0.324, 0.370
Picture			38	−0.076	−0.375, 0.222
Elicitation Method Negative Emotion	0.961	7, 65			
Arithmetic Task (RC)			16	−0.112	−0.436, 0.213
Disgust/Fear Picture			2	0.429	−0.267, 1.124
Fear Film Clip			2	0.840	0.045, 1.635
Recall			15	0.005	−0.474, 0.484
Reward Sensitivity Task			6	0.012	−0.595, 0.618
Speech			27	0.070	−0.207, 0.348
Stroop task			4	−0.045	−0.653, 0.563
Age	1.077	1, 61	63	0.021	−0.019, 0.061
Percentage of Females	0.299	1, 70	72	−0.003	−0.012, 0.007
Publication Year	**12.852*****	1, 70	72	**−0.038*****	−0.059, −0.017
Time Positive Emotion	1.200	1, 69	71	−0.001	−0.002, 0.001
Time Negative Emotion	4.777*	1, 69	71	−0.002	−0.003, 0.000
Number of ANS Measures	0.690	1,70	72	−0.034	−0.117, 0.048
N Participants	2.806	1, 70	72	−0.003	−0.006, 0.001
Study Quality Index	0.067	1, 70	72	0.023	−0.152, 0.197

Note. Bolded = Significant at adjusted *p*-level for FDR. *k* = number of effect sizes; Effect sizes = for continuous moderators, the effect sizes represent meta-regression coefficient, for factor moderators, the effect size represents mean Cohen's *d*. RC = reference category. CO = cardiac output, CVR = a composite index of cardiovascular reactivity, DBP = diastolic blood pressure, FPA = finger pulse amplitude, HR = heart rate, NS SCR = non-specific skin conductance response, PEP = pre-ejection period, SBP = systolic blood pressure, SCL = skin conductance level, SV = stroke volume, TPR = total peripheral resistance. Number of ANS Measures = number of ANS Measures used in analysis in a given study.
$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.

(Cowen & Keltner, 2017; Tong, 2015; Weidman & Tracy, 2020). More studies that include multiple ANS measures and multiple discrete positive emotions with diverse samples are required to strengthen broad inferences about the undoing effect of positive emotions, including positive emotions that have not been explored yet, such as pride, enthusiasm, or love.

Fourth, we used a univariate meta-analytic approach to analyze the difference in ANS recovery between positive emotions and neutral conditions, whereas a multivariate approach might be considered. The multivariate and univariate meta-analytic models produce similar point estimates, but the multivariate approach usually provides more precise estimates (Pustejovsky & Tipton, 2021). The advantages of using multivariate meta-analysis of multiple outcomes are greatest when the magnitude of correlation among outcomes is large, which was not the case for most of our analyses, thus, the benefits of a multivariate meta-analysis would be small (Riley et al., 2017). Furthermore, several factors militated against using a multivariate approach. First, a previous meta-analysis found that multivariate pattern classifiers did not provide strong evidence of a consistent multivariate pattern for any emotion category (Siegel et al., 2018). Second, a multivariate meta-analysis requires a correlation matrix between the ANS measures. This was not possible to obtain because the articles included in our investigation did not report correlations between ANS measures. Along similar lines, two or more ANS measures were never observed jointly in the same study. However, future studies might benefit from collecting multiple physiological measures when studying ANS reactivity to emotions (Cacioppo et al., 2000) to provide data that allows for more robust multivariate analyses.

Fifth, we performed five analyses to examine bias in the effect sizes. However, the major limitation of the presented approach is that we mostly used standard methods for two-level meta-analysis. No techniques have been developed and tested for detecting bias in 3-level meta-analyses (Fernández-Castilla et al., 2021b). The results of simulation studies on publication bias indicate that no method works well across all conditions. Performance depends on the population effect size value and the total variance of 3-level meta-analytic models (Fernández-Castilla et al., 2021b). This might explain why the studies that introduce and explain multilevel meta-analysis omit the recommendations for estimating or correcting selection bias (e.g., Cheung, 2014; Fernández-Castilla et al., 2021a; Van den Noortgate et al., 2013, 2015). Existing techniques assume that mean effect sizes are independent and homogenous (Nakagawa & Santos, 2012; Terrin et al., 2003). These assumptions are often not met in a 3-level meta-analysis. Along similar lines, the asymmetric funnel plots do not necessarily imply a bias resulting from the publication practices. Asymmetry can result from high heterogeneity in the meta-analytic data or a relation between the size of the study and the types of used manipulations (Egger et al., 1997; Ioannidis, 2005; Terrin et al., 2003). In summary, the results of the bias analyses must be interpreted with caution.

Sixth, we compared the effects of positive emotions with neutral states. In all studies, positive emotions procedures elicited more positive emotions or positive affect than neutral states. However, most studies did not test for the neutrality of the control condition. From the studies included in the meta-analysis, only two studies tested for the neutrality of the neutral condition, indicating that the neutral state was slightly negative compared to baseline (Gilbert et al., 2016) or was neutral (Fredrickson et al., 2000). The second group of studies did not test for emotions in a neutral state but presented descriptive data of emotion levels in the neutral state showing its neutrality (Radstaak et al., 2011, 2014; Qin et al., 2019), mild positivity (Fredrickson & Levenson, 1998; Hannesdóttir, 2007; Kaczmarek, 2009; Kaczmarek et al., 2019, unpublished), and mild negativity (White, 2013). The third group did not present data on emotion in a neutral state (Medvedev et al., 2015; Soenke, 2014; Sokhadze, 2007). Our observation supports the complexity of neutral states used in affective research (Gasper, 2018; Gasper et al., 2019). Future studies might address this issue to provide optimal neutral stimuli.

Conclusions

This meta-analytic review addressed whether positive emotions facilitate autonomic nervous system recovery from negative emotions and stress. This review's novelty stems from its being the first quantitative review of the undoing effect of positive emotion. Overall, we found no support for the general undoing effect of positive emotions. However, moderator analyses suggested that undoing effects may, in fact, be evident when broad-band cardiovascular composites are employed. Our findings suggest the value of a meta-analytic approach in directing researchers toward potentially more versus less fruitful lines of enquiry. In the case of the undoing hypothesis, we hope that this review encourages renewed attention to this seminal hypothesis, which remains one of the few attempts to empirically define the physiological functions of positive emotions.

Author Note

The data and the code reported in the manuscript are available as supplementary materials and on the Open Science Framework project website https://osf.io/g7j5t/.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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