Effectiveness of Emotion Regulation Strategies in Dealing With Weak and Strong Negative Emotion: Self-report, Heart Rate Variability, and Electromyography Data

Dorota Kobylińska (dorotak@psych.uw.edu.pl)
University of Warsaw
Karol Lewczuk
Cardinal Stefan Wyszyński University in Warsaw
Magdalena Wizła
Cardinal Stefan Wyszyński University in Warsaw
Przemysław Marcowski
University of Social Sciences and Humanities
Christophe Blaison
University of Paris
Till Kastendieck
Humboldt-Universität zu Berlin
Ursula Hess
Humboldt-Universität zu Berlin

Research Article

Keywords: emotion regulation, emotion, flexible emotion regulation, self-control, heart rate variability, electromyography, corrugator supercilii

Posted Date: February 25th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1376540/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Scientific Reports on April 17th, 2023. See the published version at https://doi.org/10.1038/s41598-023-33032-2.

Abstract

We investigated how emotion regulation (ER) effectiveness – both on a level of self-reported rating as well as emotional expression (*corrugator supercilii* muscle activity) – is affected by the characteristics of the situation (low *vs.* high negativity), the strategy used (reappraisal, distraction, suppression, no regulation control condition) and individual dispositions (low *vs.* high baseline Heart Rate Variability) as well as their interaction. For this 69 adult women participated in a laboratory study. All the included factors significantly influenced both corrugator activity and appraisals of pictures' negativity (in specific experimental conditions). For example, for high HRV participants, (1) distraction, suppression and reappraisal significantly decreased corrugator activity compared to the control condition, and (2) distraction as well as reappraisal decreased appraised picture negativity for high negativity photos. For low HRV participants, distraction and suppression were most effective in decreasing corrugator responses, while suppression was more effective than reappraisal in decreasing perceived picture negativity in the low negativity condition. Subjectively reported effort and success in applying ER strategies were also dependent on manipulated and dispositional factors. Overall, our results lend support to the flexible emotion regulation framework, showing that emotion regulation effectiveness relies on situational context as well as individual dispositions and their interaction.

1. Introduction

Emotion regulation (ER) is critically important for psychological health, particularly when stress is high. Emotion regulation (ER) deficits are associated with psychiatric symptoms[3,10], whereas success in ER has many adaptive outcomes and correlates. These include better psychological health, increased well-being, better social functioning, more effective coping with stressful life events, and even better performance at school or in one's job[11–13]. For this reason, research on the effectiveness of particular ER strategies has gathered significant attention by researchers, practitioners and the general public alike.

1.1. Flexible Emotion Regulation

In recent years, it has been argued that the effectiveness of ER depends not only on the type of strategy applied but also on the interaction of the features of a situation and the individual characteristics of a person who regulates their emotions[2, 14–17]. Although dynamic models have been proposed in which adaptive ER is based on dispositional as well as situational factors, most studies have relied on the assumption that specific ER strategies can be characterized as adaptive or maladaptive (irrespective of the context); this conviction has been referred to as the fallacy of uniform efficacy[18].

In general, it is psychological flexibility that accounts for adaptive reactions[19,20]. In the domain of ER "[...] flexibility refers to the ability to implement ER strategies that are synchronized with contextual demands"[2]. In line with this proposition, better ER may result from using different strategies depending on contextual factors and individual characteristics, while psychological dysfunction may be characterized by deficits in flexibility[18,21,22]. Thus, research should focus on finding the best situation-

strategy-fit patterns, showing which strategy may be most effective in a given situational context[9,14,18,23,24]. Research should also focus on the interaction of contextual and dispositional variables in predicting ER strategies' effectiveness.

1.2. Importance of Situational and Dispositional Characteristics

Even though the flexible ER framework holds a lot of promise, only a limited amount of research has focused on the interplay between contextual and individual factors[17]. Yet, the lack of consistency in the effectiveness of coping strategies in different situations and for different emotion intensity levels, suggests that strategies are sensitive to contextual factors[25,26]. Indeed, some studies explicitly demonstrated the contextual determinants of ER strategies' effectiveness. For example, the controllability of stressors[9], socioeconomic status[27] or current goals[24,28] were shown to influence ER success. Other studies demonstrated the situational influences on the choice of ER strategies[25]: when the negativity of stimuli was low, cognitive demand was low, and when long-term goals were activated, participants preferred to choose reappraisal, whereas when the negativity of stimuli was high, cognitive demand was high, and when short-term goals were activated, participants preferred to choose distraction. However, in these studies, ER effectiveness was not measured and ER strategies were not manipulated. In a more recent study, the interaction of strategy and stimuli negativity predicted prefrontal brain region reactivity[29].

The notion of incorporating individual differences into research on ER strategy effectiveness has also gained some attention. For example, the use and efficiency of specific strategies were linked to attachment styles[30], emotional intelligence[31], dispositional sensitivity to emotional cues (especially prevalent in affective disorders)[18,32], action orientation[33] or cognitive control abilities[34,35].

There is growing consensus that flexible ER is crucial for the identification, prevention and treatment of affective disturbances that are present in many affective disorders[2,5,18,20]. Greater ER flexibility seems to be associated with better quality of life[23] and functioning among individuals suffering from mental disorders[36,37].

Despite initial evidence for the benefits of ER flexibility discussed above, we still lack knowledge about the circumstances under which a specific strategy is most effective. We lack studies that systematically include both contextual and individual factors, that test more (than two) ER strategies in the same study, and incorporate non-declarative (apart from self-report) measures (e.g., behavioral, physiological) to investigate complex interactions between these factors, which jointly predict ER effectiveness.

1.3. Present Study

General aim: we designed a laboratory experiment that attempts to fill this gap in the ER research. We aimed at investigating how features of the emotional situation (low *vs.* high negativity), the strategy used

(reappraisal, distraction, suppression, no regulation-control condition), and individual differences as well as their interaction influence ER effectiveness.

Heart rate variability: In our study we took into account an interindividual psychophysiological factor – heart rate variability (HRV), which, as shown in previous studies, can contribute to ER efficiency. It is argued that emotion regulation dysfunctions might be explained by autonomic nervous system (ANS) dysregulation whose functioning can be indexed by HRV. The Neurovisceral Integration Model[38] assumes that lower variability between heartbeats is associated with emotion regulation difficulties and this baseline variability was proposed as an objective marker of interindividual emotional capacity[39,40]. Specifically, lower resting HRV was initially linked to lower emotional flexibility suggesting that individuals with lower HRV do not adequately modulate their emotional responses in relation to situational demands[41]. Further, a link between low baseline HRV and self-reported general emotion regulation difficulties[42,43] as well as a positive relationship between baseline HRV and emotion regulation effectiveness[39, 44–48] has been observed. Higher HRV also predicts better cognitive flexibility – better attentional avoidance and cognitive switching – which may contribute to more effective ER[49,50].

Electromyography: To avoid sole reliance on self-report data to assess ER efficiency, we incorporated electromyographical (EMG) measurements into the experiment. EMG is widely used to investigate the behavioral level of emotional responsiveness – it provides us with information about the level of activity of particular facial muscles that are engaged in the emotional expression of certain emotions[51,52]. Specifically, *corrugator supercillii* facial muscle activity measured with EMG is sensitive to the effects of the regulation of emotion via reappraisal and suppression[53,54]. Additionally, we measured self-reported success and effortfulness when employing each ER strategy/experimental instruction during the study.

We predicted that: (H1) we would obtain different patterns of the effectiveness of applied ER strategies for dealing with low and high negativity stimuli – ER will be more effective for low negativity; (H2) the effectiveness of using ER strategies will be influenced by the interaction between situational factors (the strength of negativity) and dispositional factors (heart rate variability); (H3) reappraisal and distraction will be effective for the evaluation of the subjective experience (declared emotional picture appraisal), whereas suppression will be more effective for downregulating emotional expression (EMG response); (H4) higher HRV will be linked to higher ER effectiveness (both on a subjective level and expressive behavior level; (H5) All ER strategies will be appraised as requiring significantly more effort than no regulation in the control condition.

To the best of our knowledge, our study is the first experimental attempt to combine the investigation of individual (HRV), contextual factors (and an interaction of both) to show their influence on the effectiveness of several different ER strategies (reappraisal, distraction, suppression).

2. Method

2.1. Participants

A total of 69 adult female participants (aged between 18 and 61 years old: M = 31.12; SD = 11.45) took part in the study. They were recruited via the PESA system at Humboldt University. Following some other researchers[55], we chose to include only women so as to avoid gender-related factors that might influence emotional responding[56,57] including HRV[58] and emotion regulation[59,60]. Based on their preferences, participants received either course credits or financial gratification (10 euros) for participation in the study.

2.2. Procedure

After participants arrived at the lab, they were welcomed and given the written description of the study ("Information for participants") as well as the participant agreement – all participants were asked to read them carefully before proceeding and sign the consent form if they agreed to participate. Next, participants filled out self-reported measures that are not a part of the current analysis. In the next step, participants were prepared for the experiment, including EKG and EMG recordings.

Before proceeding with the experiment, participants were once again reminded that data acquired from them would stay anonymous and that they could resign any time during the experiment. In case of resignation, participants were informed that they would still receive full payment for participation in the experiment. After the preparation stage was completed, the experimental procedure was run using the E-prime software (Psychology Software Tools, 2016) – the procedure can be divided into three phases, following similar procedures employed during previous studies on ER effectiveness[61–63]. These three phases were: (1) Baseline, (2) Training, and (3) Experiment.

Baseline phase was employed to level participants' emotional experience as well as measure baseline HRV, which was used in our analysis. During this phase, participants watched 30 neutral pictures, each exposed for 10 seconds (the pictures were the same for each participant). **Training phase**: during the training phase participants received written instructions for 3 ER strategies: reappraisal, suppression, and distraction. Following the presentation of each instruction, participants were exposed to three training pictures and they were asked to discuss in detail with the person conducting the experiment, how they employed each of the instructions (e.g., they talked aloud about what reinterpretations of the negative stimuli they came up with when applying reappraisal). When participants had additional questions, needed clarification, or encountered problems, an experimenter gave further instruction, including possible examples of strategy application. This training procedure was based on the available literature and has been applied in many prior studies[25]. **Experimental phase**: after completing the training, participants began the actual experimental phase. During this phase, participants watched 8 blocks of negative pictures (4 blocks of high negativity pictures and 4 blocks of low negativity pictures). Before each block they were instructed to use a specific emotion regulation strategy: reappraisal, suppression, distraction, and no regulation control condition). Each of the strategies appeared twice (once for high- and once for low-negativity pictures). In each block, participants viewed a set of 10 negative pictures and 2 neutral pictures (neutral pictures were used to avoid expectancy effect) in a randomized order. After each of the blocks, participants answered questions about the subjective appraisal of the valence of the

pictures (used in our analysis as an indicator of ER effectiveness): *How negative were the pictures in the last series?* Answer scale between 0 (*No negative at all*) to 7 (*Extremely negative*). Participants were also asked additional questions about the subjective level of implementing each experimental instruction: "*How successful was the instructed strategy ([Name of the strategy]) in reducing your negative feelings*?", with an answer scale between *0* ("*Not at all*") to *7* ("*Very much*"). Lastly, we also asked participants about the subjective effortfulness of applying each experimental instruction. *How effortful was following the instructions?* Answer scale between *0* (Not at all) to 7 (Very much). Answer scale between 0 ("*Not effortful at all*") to 7 ("*Extremely effortful*"). The questions were based on previous research on ER effectiveness[62].

A single **experimental trial** consisted of a fixation point (appearing for 1 second), 7-second picture exposure, which was then followed by a blank screen exposed for 2 seconds. Pictures were displayed across the entire screen of a computer monitor. Figure 1 below shows a scheme of an experimental trial.

Experimental stimuli: pictures from the International Affective Picture System (IAPS)[64] were used for affect elicitation. The set of pictures was used based on numerous previous studies on ER effectiveness[25,55,63, 65–67]. IAPS pictures for high *vs.* low negativity conditions were used based on their valence rating obtained during the validation of the set[64]. We chose pictures similar in arousal ratings but differing in valance. The chosen pictures were grouped into 8 sets, 4 sets for high negativity and 4 sets for low negativity (10 negative and 2 neutral pictures in each set). We made sure the sets were balanced for the content of the photos, for example: 1 war scene in each set, one picture of a child, etc. During the experimental phase, the sets were randomly paired with experimental instructions/strategies and presented to participants. The sequence of pictures in each set was random for each participant as well. IAPS numbers of all pictures used in the current experiment are listed in the supplementary materials (Tables S1-S3).

Experimental instructions. When giving participants instructions to follow in each experimental condition, we used instructions similar to those adopted in a wide range of previous research[59,62]. When using reappraisal, participants were instructed to interpret the situations presented in the pictures so that they had as neutral meaning and caused as few emotions as possible. When using distraction, participants had to concentrate their attention or think about something other than the content of the picture. For suppression, participants were instructed to focus on not showing what they felt or thought during the pictures' presentation. They were instructed to adopt a neutral facial expression and make as few expressions as possible. In the no regulation control condition participants were instructed to just watch the content of the picture without attempting to control their emotions[26,59,62]. The full text of instructions for each experimental condition is available in the supplementary materials.

Lastly, after the experimental phase had been completed, 10 positive IAPS photos were presented (for 7 seconds each), to reduce the negative emotional state of participants possibly induced by the experimental photos and repair potential negative mood. At this stage the procedure ended, participants were thanked for taking part in the study, debriefed, and rewarded for participation. Of note, during the

study, electrodermal activity data were also gathered. Results of the analysis of this type of data is not a part of the current work – it was a part of a Bachelor's thesis available online in full and in English here: [blinded link].

2.2.1. Ethics

The study procedures were carried out in accordance with the Declaration of Helsinki. The study protocol (including measures and procedure) was approved by the Ethics Committee of the Faculty of Psychology, University of Warsaw. All participants were properly informed about the purpose and procedure of the study and signed an informed consent form before participation.

2.2.2. Signal Acquisition and Data Pre-Processing

EMG was measured with 4mm EasyCap GmbH Ag/AgCl miniature surface electrodes filled with Signa gel (Parker Laboratories, Inc.). The skin was cleansed with lemon prep peeling and 70% alcohol, impedances were kept below 30 kΩ wherever possible. Raw EMG data were sampled using a MindWare 8-Slot BioNex bioamplifier (MindWare Technologies, Ltd.) with a 50 Hz notch filter at 1000 Hz. The signals were band-pass filtered between 30 and 300 Hz.

2.3. General Analysis Plan

All analytical procedures were performed in the R statistical environment[68]. The analysis plan consisted of two phases. For each phase, linear mixed-effects models were estimated (with subject-level random intercepts) to determine if behavioral responses or *corrugator supercilii* activity differed depending on the emotional regulation condition, stimuli negativity, and baseline HRV level. The design was as follows: 2 (affect: low or high; within-subjects) x 4 (emotional regulation condition: reappraisal, suppression, distraction, and control; within-subjects) x 2 (HRV group: low or high; between-subjects). In phase 1, we investigated the differences in experienced stimuli negativity as evidenced by declarative and *corrugator* responses. To this end, separate models with the abovementioned specification were fitted to declarative and psychophysiological data. In phase 2 we investigated the differences in perceived effectiveness and effortfulness of the different emotion regulation strategies. Similar to phase 1, in phase 2 separate models were fitted to explain effectiveness and effortfulness appraisals.

Prior to estimating the models, all numeric variables, i.e., effectiveness, effortfulness, and negativity rating responses, as well as the *corrugator supercilii* response, were rescaled to a range between 0 and 1. Subsequently, to investigate the relevant differences—and to increase model estimates' accuracy and stability due to the relatively limited sample size—estimated models were bootstrapped (with 10 000 resamples) to obtain medians and contrasts, along with their 89% Credible Intervals (89% CI). We opted to use 89% CI to characterize estimate uncertainty due to their greater stability, compared to the 95% CI[69]. A contrast is considered significant if its respective 89% CI does not include zero (and nonsignificant if zero is included). An approximation of the Dunnett multiplicity adjustment was applied to the calculation of the intervals, as implemented in the *emmeans* package. To maintain readability, detailed reports of the

obtained results, i.e., marginal estimates and contrasts for *corrugator* activity as well as behavioral responses, are available in the supplementary materials.

3. Results

To investigate our hypotheses, linear mixed-effects models were estimated (with subject-level random intercepts) to determine if *corrugator supercilii* activity (Model 1), perceived picture negativity (Model 2), subjective effectiveness (Model 3) and effortfulness (Model 4) in applying experimental instructions differed depending on the emotional regulation condition, stimulus negativity, and baseline HRV level. The design for each of the models was as follows: 2 (affect: low or high; within-subjects) x 4 (emotional regulation condition: reappraisal, suppression, distraction, and control; within-subjects) x 2 (HRV group: low or high; between-subjects). Marginal means as well as detailed results of statistical comparisons are provided below, as well as in the supplementary information (Tables S1-S3).

3.1. *Corrugator Supercilii* Activity

Illustrated in Fig. 2 is the *corrugator supercilii* activity (Panel A), recorded in response to low or high negativity stimuli for each emotion regulation condition, along with the corresponding contrasts between experimental conditions (Panel B), high vs. weak emotional stimuli (Panel C) and high vs. low baseline HRV groups (Panel D) depending on other factors.

Comparing emotion regulation conditions. The effectiveness ER strategies in regulating emotion expressions interacted with the intensity of the stimuli and baseline HRV (Fig. 2, panel B). Specifically, low HRV participants showed less corrugator supercilii responses in the distraction condition, compared to reappraisal, suppression, as well as control conditions. Similarly, in this group, for high negativity stimuli, the *corrugator* supercilia response was lower for the distraction and suppression strategy, compared to the control condition. In high HRV participants, the *corrugator* response was lower in the distraction, reappraisal, and suppression strategy, compared to no regulation in the control condition, for both low and high negativity stimuli. Also, in response to high negativity stimuli, the response was lower for distraction and suppression rather than reappraisal.

Low vs. high negativity stimuli. Pairwise comparisons between low vs. high negativity stimuli showed that in both low and high HRV participants, more corrugator supercilia activity was shown in response to high negativity stimuli. This effect interacted with baseline HRV and ER strategy. High HRV participants were less successful in regulating their expression in the reappraisal condition, whereas low HRV participants were less successful in the distraction condition (Fig. 2, Panel C).

Low vs. high baseline HRV. Lastly, pairwise comparisons for low vs. high baseline HRV groups showed that after viewing high negativity photos, high HRV participants showed more corrugator activity when not regulating their responses (i.e., in the control condition). No other comparisons were significant (Fig. 2, Panel D).

3.2. Perceived Picture Negativity

In the next step, we conducted a corresponding analysis for our second main dependent variable – subjective evaluation of stimuli negativity. Figure 3 depicts median results for perceived picture negativity in response to low or high negativity stimuli (panels A) along with the corresponding pairwise comparisons: between emotion regulation conditions (Panel B), high vs. low negativity stimuli (Panel C) and high vs. low baseline HRV participant groups (Panel D).

Comparing emotion regulation conditions. Emotion regulation strategies interacted with stimulus negativity and baseline HRV (Fig. 3, panel B). High HRV participants perceived the high negativity stimuli as less negative in the distraction and reappraisal conditions, compared to the no regulation control condition. By contrast, low HRV participants rated the high negativity stimuli to be more negative in the reappraisal than in the suppression condition. No other between-condition comparisons were significant (Fig. 3, Panel B).

Low vs. high negativity stimuli. High negativity stimuli were perceived as more negative regardless of the HRV group or emotional regulation condition (Fig. 3, panel C).

Low vs. high baseline HRV. Participants with high baseline HRV (as compared to low baseline HRV participants) perceived high negativity stimuli as less negative when using reappraisal, and low negativity stimuli as less negative when using a distraction (Fig. 3, Panel D).

3.3. Additional Analyses 1: Subjective Effectiveness of ER Strategies

Participants' assessments of their effectiveness in using the ER strategies as instructed are illustrated in Fig. 3. The results follow a similar pattern as described above.

Comparing emotion regulation conditions. Perceived effectiveness of the ER strategies varied with both baseline HRV and stimulus negativity (Fig. 4, panel B). Specifically, for both low and high negativity stimuli, low HRV participants perceived themselves as more effective using the suppression strategy than distraction. For high negativity stimuli only, they also considered themselves as more effective using suppression compared to reappraisal. For low negativity stimuli, low HRV participants rated themselves as more effective in following instructions in the control than distraction condition. For high negativity stimuli, high HRV participants considered themselves more effective in following instructions for the control condition (no regulation) compared to distraction, reappraisal and suppression instructions. High HRV subjects also rated themselves as more effective using suppression compared to reappraisal for high negativity stimuli.

Low vs. high negativity stimuli. As shown in panel C of Fig. 4, low HRV participants overall considered themselves more effective in following ER instructions in response to low compared to high negativity stimuli. For high HRV participants this difference was significant only for reappraisal and suppression.

Low vs. high baseline HRV. High HRV participants perceived their effectiveness in following ER instructions in the control condition in response to high negativity stimuli as higher than low HRV participants did. No other pairwise comparisons reached significance (Fig. 3, Panel D).

3.4. Additional Analyses 2: Perceived Effort Associated with Employing Emotion Regulation Strategies

Participants' assessment of effort involved in emotion regulation depending on experimental condition, negativity, as well as low vs. high baseline HRV, are depicted in Fig. 4.

Comparing emotion regulation conditions. Pairwise comparisons of the effortfulness across emotional regulation conditions indicated that high HRV participants found the distraction, reappraisal, and suppression strategy in response to high negativity stimuli more effortful than the control task (no regulation). They also found reappraisal more effortful than suppression. Similarly, in response to high negativity stimuli, low HRV participants found the distraction, suppression and reappraisal more effortful than the control task, as well as reappraisal and distraction more effortful than suppression (Fig. 4, Panel B). Moreover, in the control condition for low negativity stimuli low HRV participants found reappraisal and suppression to be more effortful than no regulation.

Low vs. high negativity stimuli. Low HRV participants assessed distraction and reappraisal as more effortful following stimuli higher in negativity (vs. low negativity stimuli). For high HRV participants, distraction, reappraisal, and suppression were perceived as more effortful following high negativity stimuli (Fig. 4, panel C).

Low vs. high baseline HRV There were no significant pairwise differences for the effortfulness of emotion regulation strategies between high vs. low baseline HRV groups (Fig. 5, Panel D).

4. Discussion

The main aim of the current study was to investigate if and how ER efficiency on the level of (1) subjective report and (2) emotional expression is affected by the characteristics of a situation in which ER is taking place (low *vs.* high emotional negativity), individual differences (low *vs.* high baseline HRV level) and the emotion regulation strategy (reappraisal, suppression, distraction, and no regulation control condition). Subjective effectiveness and perceived effort of applying the experimental instructions were also investigated. The results suggest that there are, indeed, substantial differences in ER effectiveness depending on these factors. As such, the data provides partial support to the flexible ER framework. However, a subset of the results (e.g., mixed effects of comparisons between emotion regulation strategies for perceived picture negativity) are also, somewhat contrary to our predictions, and merit further discussion in the context of flexible emotion regulation literature.

4.1. Comparisons between Emotion Regulation Conditions

Comparisons between emotion regulation strategies revealed that for high HRV participants distraction, suppression and reappraisal all significantly decreased corrugator activity compared to the control condition for both high and low stimulus negativity. That is, these participants shown an effective regulation of their emotional expression. Additionally, only for highly negative photos did distraction and suppression downregulate emotional expression better than reappraisal. This suggests that although all the strategies were effective, distraction and suppression worked better to reduce expression. For low HRV participants distraction was most effective in decreasing corrugator responses in the low negativity condition, whereas distraction and suppression decreased emotional expression more than reappraisal and the control condition for high negativity stimuli. This pattern of results suggests, firstly, that only high HRV participants were able to effectively use reappraisal for downregulating emotional expressions. This is consistent with the notion that baseline HRV reflects general emotion regulation capacity[39,40], as reappraisal is the most complex of the analyzed strategies and likely required the highest regulation abilities and resources[16,26,70,71]. In most cases, distraction and suppression led to better reduction in emotional expression. Distraction offers a simple means to disengage from the unpleasant stimuli whereas the stimulus has to be actively processed when using reappraisal. Suppression, in turn, was the only strategy that directly targeted emotional expression and not emotional experience, so it is not surprising that it significantly affected expression. This is also consistent with literature indicating that suppression is especially effective in regulating behavioral aspects of emotion and can be more effective than reappraisal at achieving this goal[16,26].

Yet, even though all strategies could be shown to be effective to some degree, the pattern described above shows that the relative effectiveness depends on both baseline HRV and stimulus negativity.

Thus, reappraisal as a more complex strategy was most effective when used by participants who have a higher capacity to regulate their emotional responses (high baseline HRV)[61,72]. By contrast, low HRV participants were less able to use reappraisal as effectively, suggesting that reappraisal does not seem to be uniformly effective. This is in line with research pointing to contextual predictors of reappraisal success[73], but contrary to claims suggesting general reappraisal benefits[16,74].

Further, when instructed to simply watch the emotional material and show their emotions naturally high HRV participants were more emotionally expressive than low HRV participants, but when instructed to influence their internal states with ER strategies, high HRV participants did this overall more effectively than low HRV ones. This suggests that high HRV participants could regulate their emotions more flexibly and had less trouble engaging and disengaging from emotion regulation. This is in line with previous research that showed the connection between HRV level and emotion regulation flexibility[41,49,50]. However, as noted the differences between high and low HRV groups was not evident for suppression as this is a relatively simple ER strategy (as compared to strategies like reappraisal) and thus required less resources to implement effectively[26,39,40,75]. This notion is also supported by the self-reports on effectiveness and effortfulness of the strategies reported below.

The effect of emotion regulation on the perceived negativity of the stimuli also varied with both stimulus negativity and baseline HRV, yet to a much lesser degree. Across all experimental conditions the difference in perceived negativity between high and low negativity stimuli remained significant. However, the way the question was asked participants may have reported more on their appraisal of the nature of the stimulus (a cognitive task) and less on how negative the stimulus made them feel. Only the latter aspect should be amenable to emotion regulation.

Both stimulus negativity and baseline HRV affected the perceived effectiveness and effortfulness of emotion regulation in expected ways. Overall, regulating responses to highly intense stimuli was perceived to be overall more effortful and less effective, but less so for individuals with high baseline HRV. Also, using reappraisal or distraction was considered more effortful and less effective, but less so for low negativity stimuli and by individuals with high HRV. Yet, exceptions form this general pattern were also found.

Notably, for low and high HRV participants, reappraisal was deemed as especially hard to implement successfully when negativity was high. This is consistent with research indicating when offered a choice of ER strategy for high negativity material, participants prefer other strategies over reappraisal, which is not the case for weakly stimulating material[76].

Interestingly, in the high negativity condition, high HRV participants perceived their effectiveness in applying experimental instruction for no regulation control condition as higher than low HRV participants. Previously, we discussed that under those circumstances, high HRV participants in fact showed higher emotional expression than low HRV participants. This is consistent with the notion that the ability to express one's emotion when one is instructed to simply watch the negatively stimulating material, can also be a signal of flexible emotion regulation, as not only effective engagement, but also disengagement from self-regulation processes is a signal of regulatory flexibility[18,41,50,77].

It is notable that participants overall considered, suppression as less effortful than reappraisal. This stands in opposition to research that indicate that suppression may be the most cognitively demanding of ER strategies[78], but supports our results for subjectively reported ER success, in which reappraisal was deemed harder to be implemented successfully than suppression as well as some new results showing that suppression is less subjectively effortful than distancing[79].

4.2. Implications for Theory and Practice

The present results have implications both for research and practice. Emotion regulation training should accommodate the fact that the effectiveness of ER strategies is not always the same. Instead, tools used to regulate emotion should be adopted on a case by case basis, accounting for changing circumstances, ER goals and should also be dependent on intraindividual characteristics of a person who controls their emotions. For future studies, researchers should focus more on dispositional and contextual factors in investigating the effectiveness of ER strategies[14,17]. Specifically, it may be the case (both for training of ER skills, as well as research) that low HRV participants require more training for complex ER strategies.

4.3. Limitations and Future Directions

The current study had some limitations. As noted above, we did not directly ask about the level of felt emotions, but rather asked for the perceived valence the stimuli. The results suggest that this question does not capture potential changes in feeling state. Moreover, only women participated in this study – future studies should expand our findings to men. Additionally, whenever possible, future studies should also incorporate more ecological ways of evoking and studying ER flexibility (for example using ecological momentary assessment data) – this would allow for gathering information about ER that is happening in daily life, not only in a laboratory setting.

To obtain a fuller picture of ER flexibility, subsequent studies should expand the current findings by (1) including also additional ER strategies such as acceptance[80], as well as (2) use a wider range of dependent variables (including neurophysiological and neuroimaging methods, which were not a part of the current study) and (3) expanding the analysis to positive emotion.

Declarations

Data availability

Dataset and accompanying code for the current paper is available in the Open Science Framework repository:

https://osf.io/v8ngw/?view_only=94de4f9cc4504040bdd76acfb2285535.

Acknowledgements

Funding: The preparation of this manuscript was supported by the Preludium Grant awarded to Karol Lewczuk by National Science Centre, Poland (nr. 2016/21/N/HS6/02678).

Author contributions

Conception and Design: DK, KL

Acquisition of Data: DK, KL, ChB, TK, UH

Analysis and Interpretation of Data: KL, PM, DK, MW

Drafting the Article: DK, KL, MW, PM, ChB TK, UH

Final Approval of the Completed Article: DK, KL, MW, PM, ChB, TK, UH

Additional information

Competing interest declaration

We have no competing interests to declare.

References

1. Aldao, A., Nolen-Hoeksema, S. & Schweizer, S. Emotion-regulation strategies across psychopathology: A meta-analytic review. *Clin. Psychol. Rev.* **30**, 217–237 (2010).
2. Aldao, A., Sheppes, G. & Gross, J. J. Emotion Regulation Flexibility. *Cogn. Ther. Res.* **39**, 263–278 (2015).
3. DeSteno, D., Gross, J. J. & Kubzansky, L. Affective science and health: The importance of emotion and emotion regulation. *Health Psychol.* **32**, 474–486 (2013).
4. Gross, J. J. & John, O. P. Individual Differences in Two Emotion Regulation Processes: Implications for Affect, Relationships, and Well-Being. *J. Pers. Soc. Psychol.* **85**, 348–362 (2003).
5. Koole, S. L., Schwager, S. & Rothermund, K. Resilience is more about being flexible than about staying positive. *Behav. Brain Sci.* **38**, E109 (2015).
6. Luhmann, M., Hofmann, W., Eid, M. & Lucas, R. E. Subjective well-being and adaptation to life events: A meta-analysis. *J. Pers. Soc. Psychol.* **102**, 592–615 (2012).
7. Schwager, S. & Rothermund, K. On the dynamics of implicit emotion regulation: Counter-regulation after remembering events of high but not of low emotional intensity. *Cogn. Emot.* **28**, 971–992 (2014).
8. Troy, A. S., Wilhelm, F. H., Shallcross, A. J. & Mauss, I. B. Seeing the Silver Lining: Cognitive Reappraisal Ability Moderates the Relationship Between Stress and Depressive Symptoms. *Emotion* **10**, 783–795 (2010).
9. Troy, A. S., Shallcross, A. J. & Mauss, I. B. A Person-by-Situation Approach to Emotion Regulation: Cognitive Reappraisal Can Either Help or Hurt, Depending on the Context. *Psychol. Sci.* **24**, 2505–2514 (2013).
10. Werner, K. & Gross, J. J. Emotion regulation and psychopathology: A conceptual framework. in *Emotion regulation and psychopathology: A transdiagnostic approach to etiology and treatment* (eds. Kring, A. M. & Sloan, D. M.) 13–37 (The Guilford Press, 2010).
11. Gross, J. J. The Extended Process Model of Emotion Regulation: Elaborations, Applications, and Future Directions. *Psychol. Inq.* **26**, 130–137 (2015).
12. Gross, J. J. Emotion Regulation: Current Status and Future Prospects. *Psychol. Inq.* **26**, 1–26 (2015).
13. Salovey, P., Detweiler-Bedell, B. T., Detweiler-Bedell, J. B. & Mayer, D. Emotional intelligence. in *Handbook of emotions* (eds. Lewis, M., Haviland-Jones, J. M. & Feldman Barret, L.) 533–547 (Guilford Press, 2010).
14. Doré, B. P., Silvers, J. A. & Ochsner, K. N. Toward a Personalized Science of Emotion Regulation. *Soc. Personal. Psychol. Compass* **10**, 171–187 (2016).
15. Kobylińska, D. & Kusev, P. Flexible emotion regulation: How situational demands and individual differences influence the effectiveness of regulatory strategies. *Front. Psychol.* 10:72 (2019)

doi:10.3389/fpsyg.2019.00072.

16. McRae, K. & Gross, J. J. Emotion regulation. *Emotion* **20**, 1–11 (2020).
17. Sanchez-Lopez, A. How Flexible are we in Regulating our Emotions? A Discussion on Current Conceptual Frameworks of Emotion Regulation Flexibility, Requirements for Future Research and Potential Practical Implications. *Span. J. Psychol.* **24**, E31 (2021).
18. Bonanno, G. A. & Burton, C. L. Regulatory Flexibility: An Individual Differences Perspective on Coping and Emotion Regulation. *Perspect. Psychol. Sci.* **8**, 591–612 (2013).
19. Cheng, C., Lau, H. P. B. & Chan, M. P. S. ally. Coping flexibility and psychological adjustment to stressful life changes: a meta-analytic review. *Psychol. Bull.* **140**, 1582–1607 (2014).
20. Kashdan, T. B. & Rottenberg, J. Psychological flexibility as a fundamental aspect of health. *Clin. Psychol. Rev.* **30**, 865–878 (2010).
21. Koch, S. B. J., Mars, R. B., Toni, I. & Roelofs, K. Emotional control, reappraised. *Neurosci. Biobehav. Rev.* **95**, 528–534 (2018).
22. Rottenberg, J., Gross, J. J. & Gotlib, I. H. Emotion context insensitivity in major depressive disorder. *J. Abnorm. Psychol.* **114**, 627–639 (2005).
23. Haines, S. J. *et al.* The Wisdom to Know the Difference: Strategy-Situation Fit in Emotion Regulation in Daily Life Is Associated With Well-Being. *Psychol. Sci.* **27**, 1651–1659 (2016).
24. Millgram, Y., Sheppes, G., Kalokerinos, E. K., Kuppens, P. & Tamir, M. Do the ends dictate the means in emotion regulation? *J. Exp. Psychol. Gen.* **148**, 80–96 (2019).
25. Sheppes, G. *et al.* Emotion regulation choice: A conceptual framework and supporting evidence. *J. Exp. Psychol. Gen.* **143**, 163–181 (2014).
26. Webb, T. L., Miles, E. & Sheeran, P. Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. *Psychol. Bull.* **138**, 775–808 (2012).
27. Troy, A. S., Ford, B. Q., McRae, K., Zarolia, P. & Mauss, I. B. Change the things you can: Emotion regulation is more beneficial for people from lower than from higher socioeconomic status. *Emotion* **17**, 141–154 (2017).
28. Tamir, M. Why Do People Regulate Their Emotions? A Taxonomy of Motives in Emotion Regulation. *Personal. Soc. Psychol. Rev.* **20**, 199–222 (2016).
29. Moodie, C. A. *et al.* The neural bases of cognitive emotion regulation: The roles of strategy and intensity. *Cogn. Affect. Behav. Neurosci.* **20**, 387–407 (2020).
30. *Handbook of Emotion Regulation.* (Guilford Publications, 2008).
31. Peña-Sarrionandia, A., Mikolajczak, M. & Gross, J. J. Corrigendum: Integrating emotion regulation and emotional intelligence traditions: a meta-analysis. *Front. Psychol.* 10:2610 (2019) doi:10.3389/fpsyg.2019.02610.
32. Chen, S. & Bonanno, G. A. Components of Emotion Regulation Flexibility: Linking Latent Profiles to Depressive and Anxious Symptoms. *Clin. Psychol. Sci.* **9**, 236–251 (2021).

33. Kobylińska, D. & Marchlewska, M. Orientacja na działanie a regulacja emocji. *Psychol.-Etol.-Genet.* **34**, 25–42 (2016).
34. Pruessner, L., Barnow, S., Holt, D. V., Joormann, J. & Schulze, K. A cognitive control framework for understanding emotion regulation flexibility. *Emotion* **20**, 21–29 (2020).
35. Sanchez-Lopez, A., De Raedt, R., van Put, J. & Koster, E. H. W. A novel process-based approach to improve resilience: Effects of computerized mouse-based (gaze)contingent attention training (MCAT)on reappraisal and rumination. *Behav. Res. Ther.* **118**, 110–120 (2019).
36. Coifman, K. G. & Summers, C. B. Understanding emotion inflexibility in risk for affective disease: Integrating current research and finding a path forward. *Front. Psychol.* 20:392 (2019) doi:10.3389/fpsyg.2019.00392.
37. Conroy, K. *et al.* Emotion Regulation Flexibility in Generalized Anxiety Disorder. *J. Psychopathol. Behav. Assess.* **42**, 93–100 (2020).
38. Thayer, J. F. & Lane, R. D. Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration. *Neurosci. Biobehav. Rev.* **33**, 81–88 (2009).
39. Appelhans, B. M. & Luecken, L. J. Heart rate variability as an index of regulated emotional responding. *Rev. Gen. Psychol.* **10**, 229–240 (2006).
40. Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J. & Wager, T. D. A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neurosci. Biobehav. Rev.* **36**, 747–756 (2012).
41. Fujimura, T. & Okanoya, K. Heart Rate Variability Predicts Emotional Flexibility in Response to Positive Stimuli. *Psychology* **3**, 578–582 (2012).
42. Visted, E. *et al.* The association between self-reported difficulties in emotion regulation and heart rate variability: The salient role of not accepting negative emotions. *Front. Psychol.* **8:328**, 8:328 (2017).
43. Williams, D. W. P. *et al.* Resting heart rate variability predicts self-reported difficulties in emotion regulation: A focus on different facets of emotion regulation. *Front. Psychol.* 6:261 (2015) doi:10.3389/fpsyg.2015.00261.
44. Camm, A. J. *et al.* Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. *Eur. Heart J.* (1996) doi:10.1093/oxfordjournals.eurheartj.a014868.
45. Christou-Champi, S., Farrow, T. F. D. & Webb, T. L. Automatic control of negative emotions: Evidence that structured practice increases the efficiency of emotion regulation. *Cogn. Emot.* **29**, 319–331 (2015).
46. Kreibig, S. D., Wilhelm, F. H., Roth, W. T. & Gross, J. J. Cardiovascular, electrodermal, and respiratory response patterns to fear- and sadness-inducing films. *Psychophysiology* **44**, 787–806 (2007).
47. Mauss, I. B., McCarter, L., Levenson, R. W., Wilhelm, F. H. & Gross, J. J. The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion* **5**, 175–190 (2005).
48. Mauss, I. B. & Robinson, M. D. Measures of emotion: A review. *Cogn. Emot.* **23**, 209–237 (2009).

49. Colzato, L. S., Jongkees, B. J., de Wit, M., van der Molen, M. J. W. & Steenbergen, L. Variable heart rate and a flexible mind: Higher resting-state heart rate variability predicts better task-switching. *Cogn. Affect. Behav. Neurosci.* **18**, 730–738 (2018).
50. Grol, M. & De Raedt, R. The link between resting heart rate variability and affective flexibility. *Cogn. Affect. Behav. Neurosci.* **20**, 746–756 (2020).
51. Fridlund, A. J. & Cacioppo, J. T. Guidelines for Human Electromyographic Research. *Psychophysiology* **23**, 567–589 (1986).
52. Hess, U. *et al.* Reliability of surface facial electromyography. *Psychophysiology* **54**, 12–23 (2017).
53. Ray, K. K. *et al.* Statins and all-cause mortality in high-risk primary prevention: A meta-analysis of 11 randomized controlled trials involving 65 229 participants. *Arch. Intern. Med.* **170**, 1024–1031 (2010).
54. Witvliet, C. van O., DeYoung, N. J., Hofelich, A. J. & DeYoung, P. A. Compassionate reappraisal and emotion suppression as alternatives to offense-focused rumination: Implications for forgiveness and psychophysiological well-being. *J. Posit. Psychol.* **6**, 286–299 (2011).
55. Dan-Glauser, E. S. & Gross, J. J. The temporal dynamics of emotional acceptance: Experience, expression, and physiology. *Biol. Psychol.* **108**, 1–12 (2015).
56. Bradley, M. M., Codispoti, M., Sabatinelli, D. & Lang, P. J. Emotion and Motivation II: Sex Differences in Picture Processing. *Emotion* **3**, 300–319 (2001).
57. Wrase, J. *et al.* Gender differences in the processing of standardized emotional visual stimuli in humans: A functional magnetic resonance imaging study. *Neurosci. Lett.* **348**, 41–45 (2003).
58. Koenig, J. & Thayer, J. F. Sex differences in healthy human heart rate variability: A meta-analysis. *Neurosci. Biobehav. Rev.* **64**, 288–310 (2016).
59. McRae, K., Ochsner, K. N., Mauss, I. B., Gabrieli, J. J. D. & Gross, J. J. Gender differences in emotion regulation: An fMRI study of cognitive reappraisal. *Group Process. Intergroup Relat.* **11**, 143–162 (2008).
60. Rusting, C. L. Personality, Mood, and Cognitive Processing of Emotional Information: Three Conceptual Frameworks. *Psychol. Bull.* **124**, 165–196 (1998).
61. Denson, T. F., Grisham, J. R. & Moulds, M. L. Cognitive reappraisal increases heart rate variability in response to an anger provocation. *Motiv. Emot.* **35**, 14–22 (2011).
62. McRae, K. *et al.* The neural bases of distraction and reappraisal. *J. Cogn. Neurosci.* **22**, 248–262 (2010).
63. McRae, K., Ciesielski, B. & Gross, J. J. Unpacking cognitive reappraisal: goals, tactics, and outcomes. *Emotion* **12**, 250–255 (2012).
64. Lang, P. J., Bradley, M. & Cuthbert, B. International Affective Picture System (IAPS): Digitized Photographs, Instruction Manual and Affective Ratings. Technical Report A-6. (2005).
65. Bernat, E. M., Cadwallader, M., Seo, D., Vizueta, N. & Patrick, C. J. Effects of instructed emotion regulation on valence, arousal, and attentional measures of affective processing. *Dev. Neuropsychol.*

36, 493–518 (2011).

66. Dan-Glauser, E. S. & Gross, J. J. The temporal dynamics of two response-focused forms of emotion regulation: Experiential, expressive, and autonomic consequences. *Psychophysiology* **48**, 1309–1322 (2011).
67. Sheppes, G., Scheibe, S., Suri, G. & Gross, J. J. Emotion-regulation choice. *Psychol. Sci.* **22**, 1391–1396 (2011).
68. R Core Team. R: A language and environment for statistical computing. *R Foundation for Statistical Computing* (2019).
69. Kruschke, J. K. *Doing Bayesian data analysis: A tutorial with R, JAGS, and Stan, second edition*. *Doing Bayesian Data Analysis: A Tutorial with R, JAGS, and Stan, Second Edition* (2014). doi:10.1016/B978-0-12-405888-0.09999-2.
70. Waugh, C. E. *et al.* Emotion regulation changes the duration of the BOLD response to emotional stimuli. *Soc. Cogn. Affect. Neurosci.* (2016) doi:10.1093/scan/nsw067.
71. Raio, C. M., Orederu, T. A., Palazzolo, L., Shurick, A. A. & Phelps, E. A. Cognitive emotion regulation fails the stress test. *Proc. Natl. Acad. Sci. U. S. A.* **110**, 151139–15144 (2013).
72. Groß, D. & Kohlmann, C. W. Predicting self-control capacity – Taking into account working memory capacity, motivation, and heart rate variability. *Acta Psychol. (Amst.)* (2020) doi:10.1016/j.actpsy.2020.103131.
73. Troy, A. S., Shallcross, A. J. & Mauss, I. B. Corrigendum to A Person-by-Situation Approach to Emotion Regulation: Cognitive Reappraisal Can Either Help or Hurt, Depending on the Context (Psychological Science, (2013), 24, 2505-2514, DOI 10.1177/0956797613496434). *Psychol. Sci.* **27**, 428–431 (2016).
74. John, O. P. & Gross, J. J. Healthy and unhealthy emotion regulation: Personality processes, individual differences, and life span development. *J. Pers.* **72**, 1301–1334 (2004).
75. Li, P., Zhu, C., Leng, Y. & Luo, W. Distraction and expressive suppression strategies in down-regulation of high- and low-intensity positive emotions. *Int. J. Psychophysiol.* (2020) doi:10.1016/j.ijpsycho.2020.09.010.
76. Milyavsky, M. *et al.* To Reappraise or Not to Reappraise? Emotion Regulation Choice and Cognitive Energetics. *Emotion* **19**, 964–981 (2018).
77. Burton, C. L. & Bonanno, G. A. Regulatory flexibility and its role in adaptation to aversive events throughout the lifespan. in *Emotion, aging, and health.* (2016). doi:10.1037/14857-005.
78. Gross, J. J. Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology* (2002) doi:10.1017/S0048577201393198.
79. Scheffel, C. *et al.* Effort beats effectiveness in emotion regulation choice: Differences between suppression and distancing in subjective and physiological measures. *Psychophysiology* **58**, e13908 (2021).

80. Wojnarowska, A., Kobylinska, D. & Lewczuk, K. Acceptance as an Emotion Regulation Strategy in Experimental Psychological Research: What We Know and How We Can Improve That Knowledge. *Front. Psychol.* 11:242 (2020) doi:10.3389/fpsyg.2020.00242.

Figures

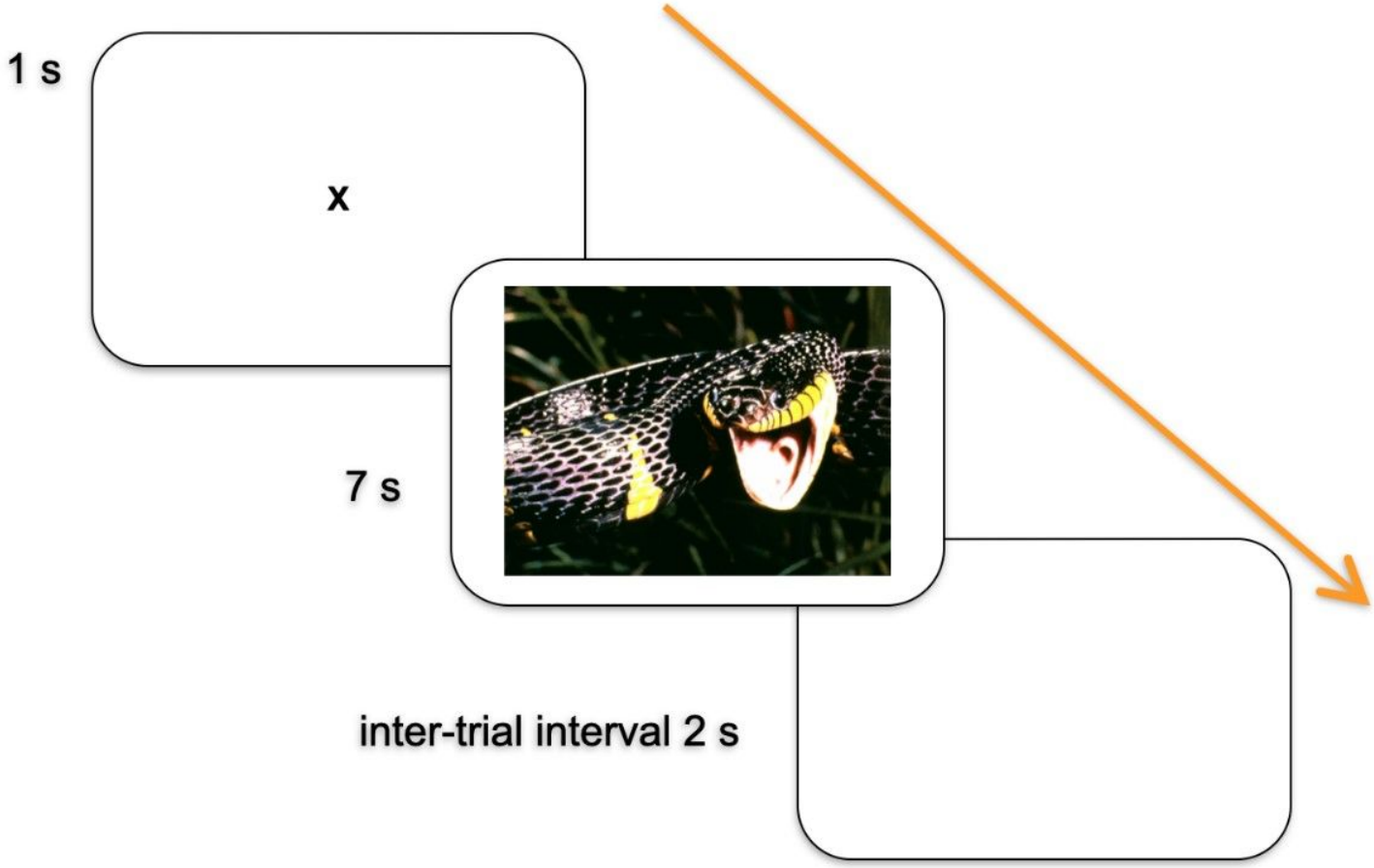

Figure 1

Example of a single experimental trial.

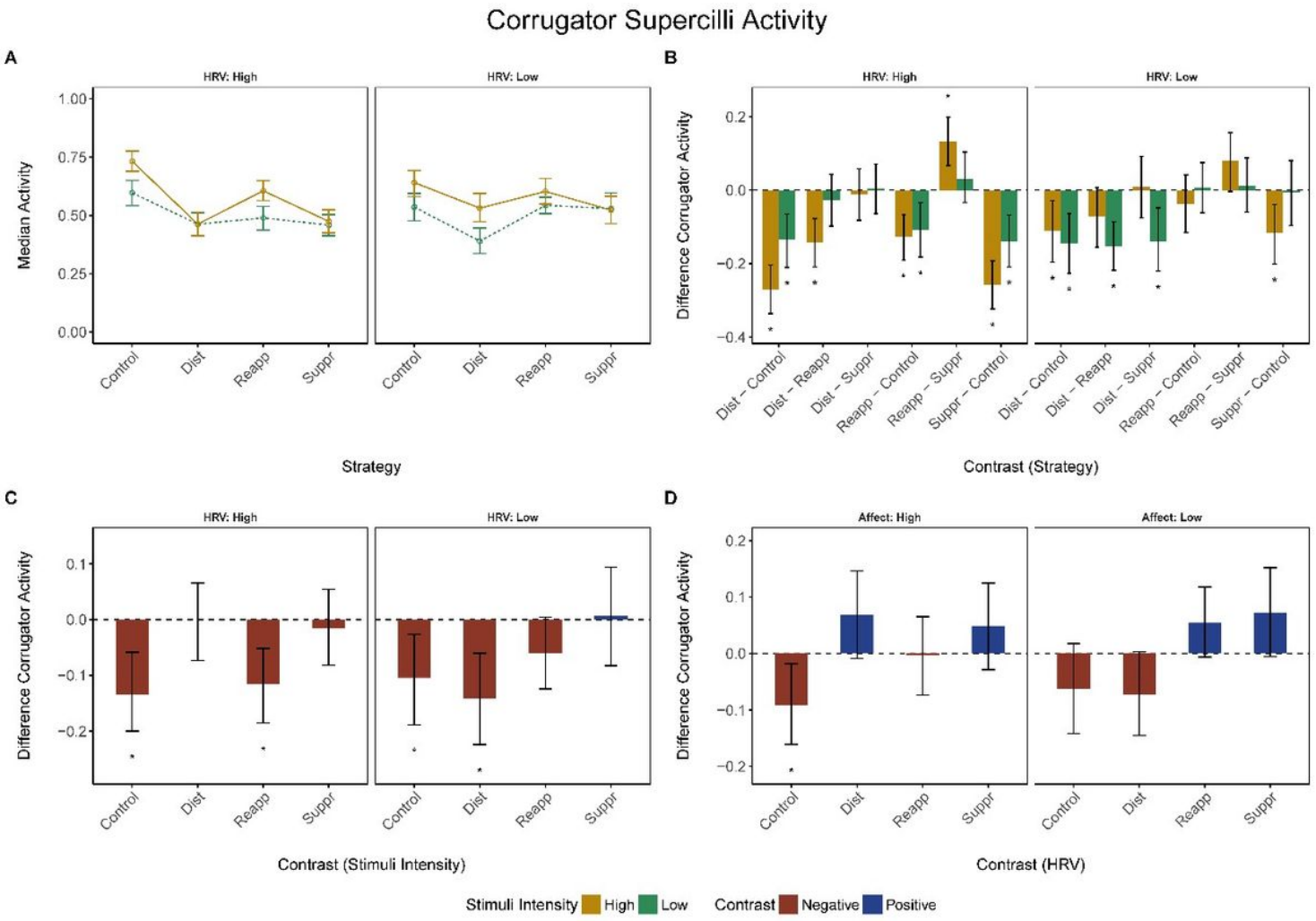

Figure 2

***Corrugator supercilii* activity.** (**a**) *Corrugator supercilii* response (median) corresponding to low or high negativity stimuli in different emotion regulation conditions and low or high baseline HRV groups. (**b**) Pairwise contrasts of the *corrugator supercilii* response between emotional regulation conditions corresponding to low or high negativity stimuli in the low or high HRV group. (**c**) Contrasts of the *corrugator supercilii* response between low and high negativity stimuli across emotional regulation conditions in the low or high HRV group. (**d**) Contrasts of the *corrugator supercilii* response between low vs. high baseline HRV groups. Error bars represent 89% CI of the corresponding estimate. *, significant contrast.

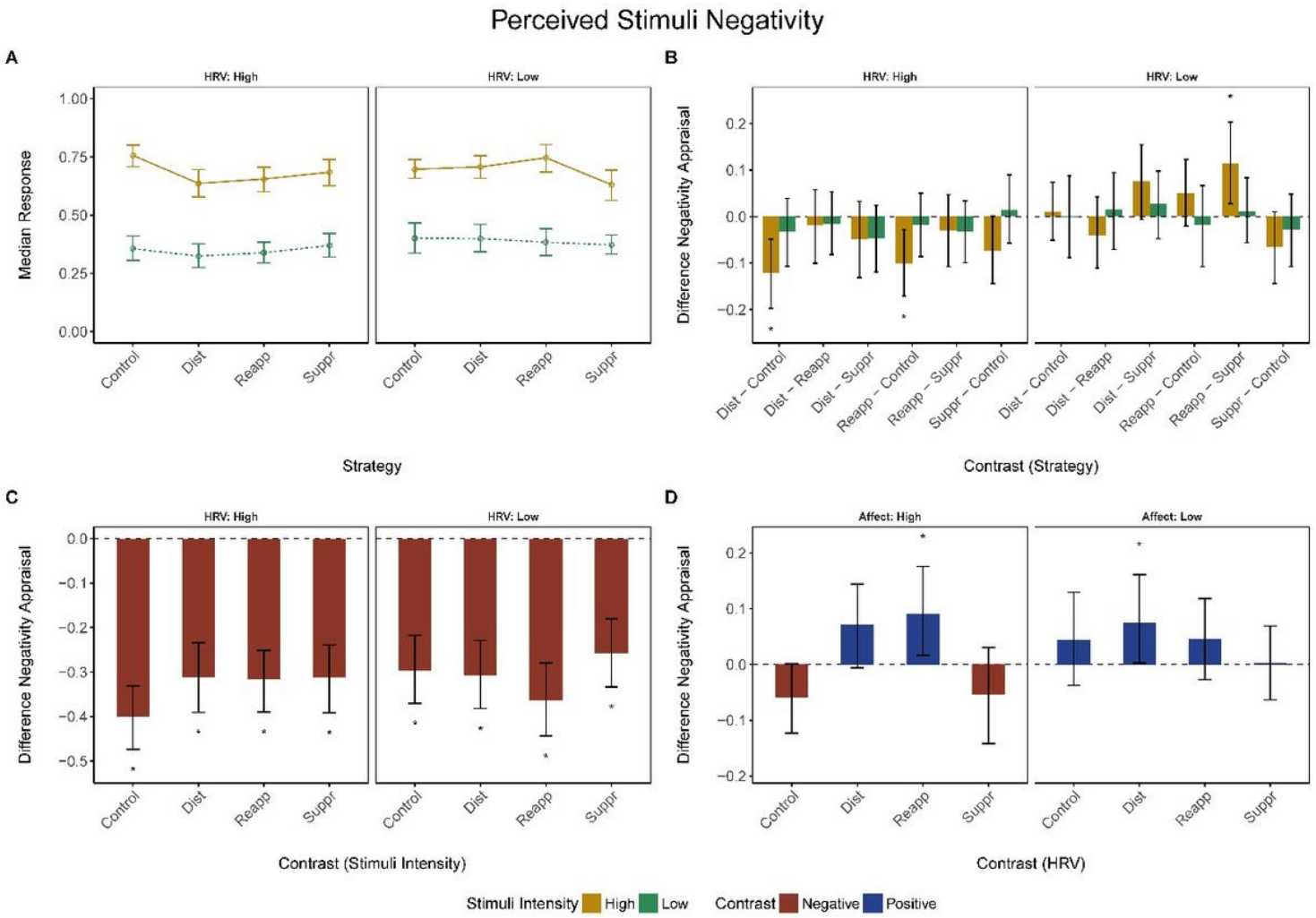

Figure 3

Perceived picture negativity. (**a**) *Perceived picture negativity* (median) corresponding to low or high negativity stimuli in different emotion regulation conditions and low or high baseline HRV groups. (**b**) Pairwise contrasts of the *perceived picture negativity* between emotional regulation conditions corresponding to low or high negativity stimuli in the low or high HRV group. (**c**) Contrasts of the *perceived picture negativity* between low and high negativity stimuli across emotional regulation conditions in the low or high HRV group. (**d**) Contrasts of the *perceived picture negativity scores* between low vs. high baseline HRV groups. Error bars represent 89% CI of the corresponding estimate. *, significant contrast.

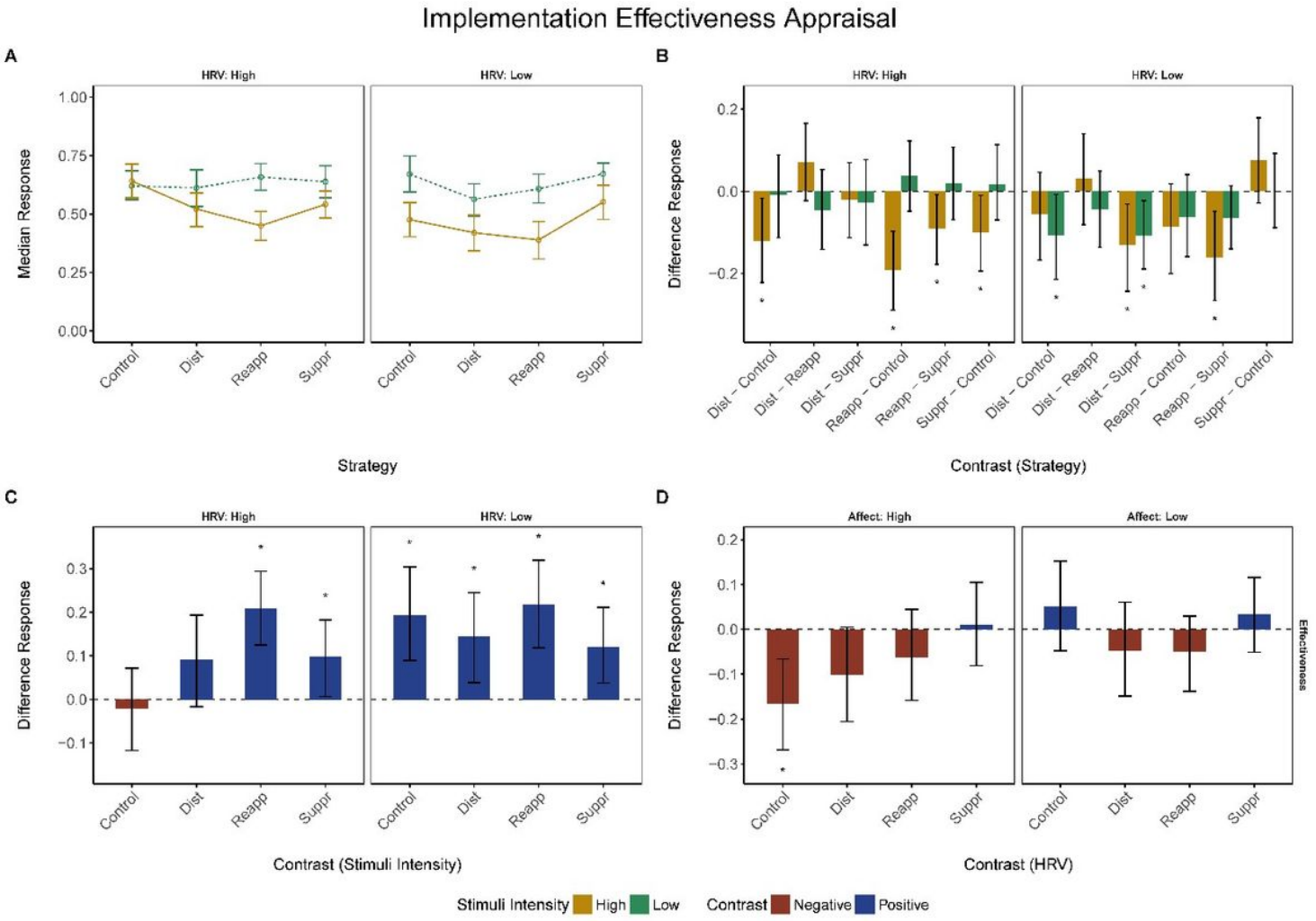

Figure 4

Perceived effectiveness in applying experimental instructions. (**a**) *Perceived effectiveness in applying experimental instructions* (median) corresponding to low or high negativity stimuli in different experimental conditions and low or high baseline HRV groups. (**b**) Pairwise contrasts of the *Perceived effectiveness in applying experimental instructions* between emotional regulation conditions corresponding to low or high negativity stimuli in the low or high HRV group. (**c**) Contrasts of the *Perceived effectiveness in applying experimental instructions* between low and high negativity stimuli across emotional regulation conditions in the low or high HRV group. (**d**) Contrasts of the *Perceived effectiveness in applying experimental instructions* between low vs. high baseline HRV groups. Error bars represent 89% CI of the corresponding estimate. *, significant contrast.

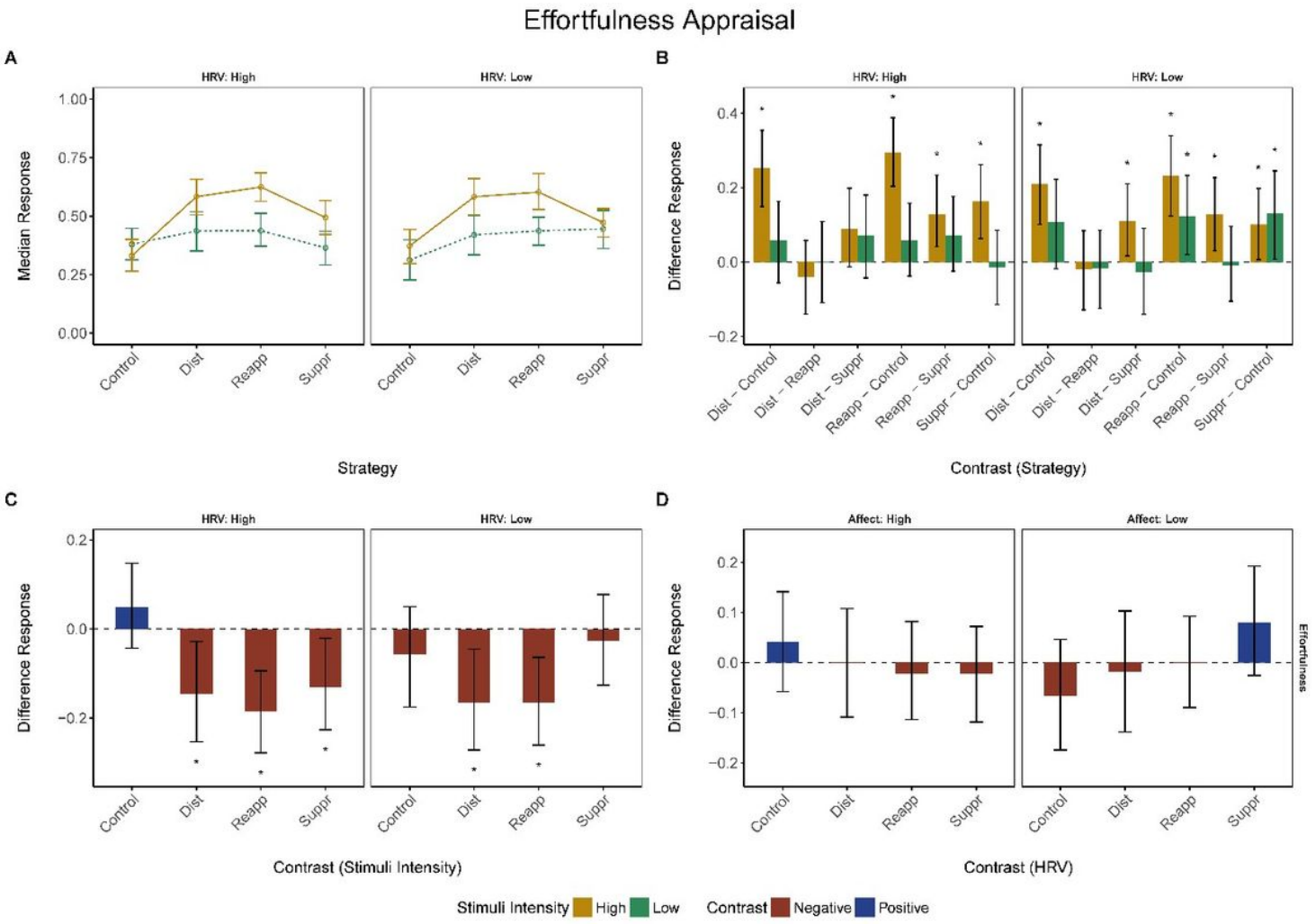

Figure 5

Perceived effortfulness. (**a**) *Perceived effortfulness scores* (median) corresponding to low or high negativity stimuli in different experimental conditions and low or high baseline HRV groups. (**b**) Pairwise contrasts of the *Perceived effortfulness* between emotional regulation conditions corresponding to low or high negativity stimuli in the low or high HRV group. (**c**) Contrasts of the *Perceived effortfulness* between low and high negativity stimuli across emotional regulation conditions in the low or high HRV group. (**d**) Contrasts of the *Perceived effortfulness* between low vs. high baseline HRV groups. Error bars represent 89% CI of the corresponding estimate. *, significant contrast.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- supplementarymaterial.docx