

Imaginal extinction and the vividness of mental imagery: Exploring the reduction of fear within the mind's eye

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ABSTRACT

Patients are encouraged to produce *vivid* mental imagery during *imaginal exposure*, as it is assumed to promote fear reduction. Nevertheless, the link between fear reduction and imagery vividness is unclear. We investigated the impact of vividness on fear responses using an experimental analogue of imaginal exposure - imaginal extinction - in which conditioned fear, measured with skin conductance, is reduced through exposure to mental imagery of the conditioned stimulus. We examined (1) if task-specific vividness (high vs low) of the conditioned stimulus during imaginal extinction moderated the reduction of fear responses, and (2) if task-specific vividness influenced remaining fear responses 24 h later. Findings suggest that high vividness may be advantageous for fear reduction during imaginal extinction, but it may not influence fear responses in the longer term. A possible clinical implication is that high imagery vividness during imaginal exposure may not be vital for overall treatment outcome. As high vividness is associated with increased levels of distress, a future direction would be to explore whether similar fear reduction can be obtained with less vivid imaginal exposure and thereby make treatment tolerable for more patients

1. Introduction

Imaginal exposure involves bringing to mind mental imagery of fear-provoking objects or events in order to reduce dysfunctional fear. It is a widely used psychological treatment technique for posttraumatic stress disorders (PTSD) and a quintessential mental imagery technique within cognitive behavioural therapy [1]. Mental imagery refers to sensory experiences in the absence of external sensory input [2,3]. Vivid mental imagery can produce life-like experiences of 'seeing', 'hearing', 'tasting', 'smelling', and 'touching' [4]. The vividness of mental imagery has been defined as the "clarity and liveliness" of the image [5], i.e., the more vivid the mental image is, the closer it resembles the *experience* of the actual percept [6]. Imaginal exposure has been suggested to harness an intricate relationship between mental imagery, perception, and emotion, allowing mental imagery to "stand in" for perception and influence emotion [7]. Indeed, emerging findings show that mental imagery and perception employ similar neurocircuitry [8], and that similar brain areas are activated by mental imagery and direct perception of a phobic stimulus (e.g., spider) [9]. However, a question that remains unanswered is to what extent fear reduction in imaginal exposure depends on the vividness of mental imagery, that is, how vividly the

patient imagines the fear-provoking stimulus during the exposure session.

Patients' capacity to produce vivid mental imagery has long been considered vital for the success of imagery-based treatments [7]. Imagery vividness has been suggested to be important for the activation of physiological arousal responses, which in turn has been considered essential for fear reduction [10]. Also, Emotion Processing Theory, the theoretical framework underlying Prolonged Exposure (PE) [11], a gold standard treatment for PTSD, proposes that activation of the trauma memory (i.e., fear structure) is a prerequisite for successful treatment, and considers vividness during exposure to reflect the completeness of activation [12,13]. However, high vividness during imaginal exposure is also associated with higher levels of subjective distress [9,14,13] and may lead to premature dropout from therapy [15,16]. Thus, a better understanding of the role of imagery vividness in imaginal exposure is essential, as it could open new avenues to the development of more effective and acceptable treatments.

Few studies have investigated the relationship between imagery vividness and fear reduction in imaginal exposure, and even less so under controlled conditions. Two clinical treatment studies on imaginal exposure-based treatment protocols (i.e., PE) [11] explored the

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relationship between imagery vividness during imaginal exposure sessions and treatment outcome [13,14]. Results showed that vividness was positively correlated with the reduction of subjective distress within the exposure session. Unexpectedly, in-session imagery vividness was not associated [13], or only partly associated [14] with overall treatment outcome. However, the interpretation of these findings is complicated by the inclusion of other treatment components in PE (e.g., in vivo exposure, cognitive components), making it difficult to isolate the effects specifically associated with imaginal exposure [17]. To further our knowledge about the role of imagery vividness in imaginal exposure, there is a need for controlled studies, pinpointing the mechanisms driving mental imagery-based fear reduction, separate from other treatment components.

Recent years have seen advances in the science of mental imagery for conditioning and extinction (for review see [18]). Specifically, the fear conditioning paradigm has been used to demonstrate that mental imagery alone can create [19,20] and extinguish conditioned fear [21–23] and reactivate a fear memory to disrupt memory re-consolidation [24]. Imaginal extinction is an experimental procedure derived from in vivo fear extinction, designed to study the reduction of fear within the mind's eye, i.e., an experimental analogue of imaginal exposure [21]. In imaginal extinction, conditioned fear is diminished through repeated exposure to mental imagery of the conditioned stimulus (CS+). Thus, imaginal extinction mimics the in vivo extinction procedure, but uses mental imagery of the CS+ instead of direct perception of the stimulus. In line with the standard in vivo extinction procedure, participants undergoing imaginal extinction are not informed that there will be no more presentations of the unconditioned stimulus (US, e.g., electric shocks) and have to discover for themselves that the CS+ no longer predicts the US and update their expectations accordingly. Furthermore, mirroring how imaginal exposure is used in clinical settings, imaginal extinction uses verbal instructions to prompt mental imagery. Corresponding to how in vivo extinction has been widely used as an experimental analogue of in vivo exposure therapy to inform treatment development [25] we suggest that imaginal extinction could be used as an experimental analogue of imaginal exposure to explore the link between imagery vividness and fear reduction. However, using imaginal extinction for this purpose requires taking some issues into consideration.

Fear conditioning and extinction are most often performed using simple geometric figures as stimuli. What if imagery vividness does not matter for such simple stimuli? How vivid can the outline of a square and a circle really be? Hence, it is possible that imagery vividness impacts the emotional response for complex, but not for simple stimuli. In addition, producing imagery of simple geometric figures may be so easy that most participants will report high vividness, creating a ceiling effect. Another consideration concerns the choice of vividness measure, as imagery vividness can be assessed in several ways [26]. Individuals vary substantially in their general capacity to produce mental imagery [27], and vividness can therefore be measured at the trait level [5]. However, vividness also varies considerably within individuals across different tasks [28,29]. Indeed, vividness ratings of the task at hand (task-specific vividness) appear to be a more suitable measure in experimental studies, as ratings of task-specific vividness better predict behavioural and neurophysiological responses than trait measures [26]. Furthermore, a methodological consideration of the imaginal extinction procedure is the use of single versus multiple verbal cues to prompt mental imagery. A previous study showed that imaginal extinction provided similar reductions in conditioned fear as in vivo extinction [21]. In that particular study, imaginal extinction used one verbal cue to prompt mental imagery of the CS+ and one cue for CS-. Using a single verbal cue leaves the possibility that imaginal extinction may not be dependent on mental imagery of the CS+. Instead, it is possible that an association is formed between the verbal cue and the US (i.e., electric shock) by secondary conditioning, making the verbal cue a CS+₂. Thus, extinction may have occurred to the CS+₂ without much involvement of mental imagery. In essence, extinction may have occurred to a specific verbal cue rather

than to mental imagery of the CS+. One way to address this concern would be to use several different verbal cues to prompt mental imagery of the CS+, i.e., varying verbal cues while keeping the content of mental imagery constant. If the imaginal extinction procedure provides fear reduction despite the use of multiple verbal cues, it would strengthen the notion that imaginal extinction depends on the content of mind.

1.1. Aim of the study

The current study aimed to examine the link between mental imagery and the reduction of fear in imaginal extinction, in particular, the effects of imagery vividness. We used imaginal extinction, an experimental analogue of imaginal exposure, to examine if the reduction of conditioned fear was moderated by how vividly participants were able to imagine the CS+. Specifically, participants were divided into a high versus a low vividness group, defined by a median split based on task-specific vividness ratings of the CS+. We also assessed the impact of imagery vividness on fear responses in the longer term by assessing remaining fear responses 24 h after imaginal extinction with a reinstatement procedure (i.e., a test of return of fear). The study took part over three consecutive days, with fear conditioning to visual stimuli on day 1, imaginal extinction on day 2, and a reinstatement procedure, again to visual stimuli, on day 3. Skin conductance (SCR) was used to measure fear responses (on days 1, 2, and 3; primary outcome measure). We hypothesised that participants in the high vividness group would show superior fear reduction during imaginal extinction compared to participants in the low vividness group. However, we did not have a directional hypothesis regarding the relation between vividness and remaining fear responses 24 h later. To explore the potentially different impact of imagery vividness on fear response depending on stimuli complexity, and to defend against a possible ceiling and floor effect on vividness (i.e., stimuli being too easy/hard to visualise vividly), participants were allocated to undergo the entire experiment (day 1–3) with either complex or simple stimuli (Fig. 1). To strengthen the notion that fear reduction provided by imaginal extinction is linked to the exposure to the content of mind (e.g., mental imagery) rather than to a specific external verbal cue, the present study used several different verbal cues to prompt mental imagery of the CS+ and CS-, respectively.

2. Materials and methods

2.1. Participants

Sixty non-clinical individuals (age: $M = 26.0$; $SD = 6.1$ years; 27 women and 33 men) were recruited through advertisements on billboards at university campuses and social media. All participants were residents in Uppsala, Sweden, and were students at Uppsala University ($n = 57$) or had employment ($n = 3$). Exclusion criteria consisted of self-reported current psychiatric disorder, neurological condition, receiving psychological treatment or psychotropic medication within six months, age under 18, and non-fluent in Swedish. For inclusion in analyses, participants had to meet criteria for successful fear acquisition (mean SCR CS+ > mean SCR CS-) and have conducted the imaginal extinction procedure (Fig. 1 shows an overview of the allocation of participants into experimental conditions complex vs simple stimuli and attrition across all experimental phases acquisition, imaginal extinction, and reinstatement). Participants were reimbursed with three cinema tickets (one per completed session), corresponding to ca 300 Swedish kronor for their participation. Ethical approval was granted by the Swedish Ethical Review Authority (2019–00524). All participants provided their written and informed consent. Clinical trial registration can be found at ClinicalTrials.gov (NCT03989518). The data is available in the Open Science Framework (<https://osf.io/r4jac/>).

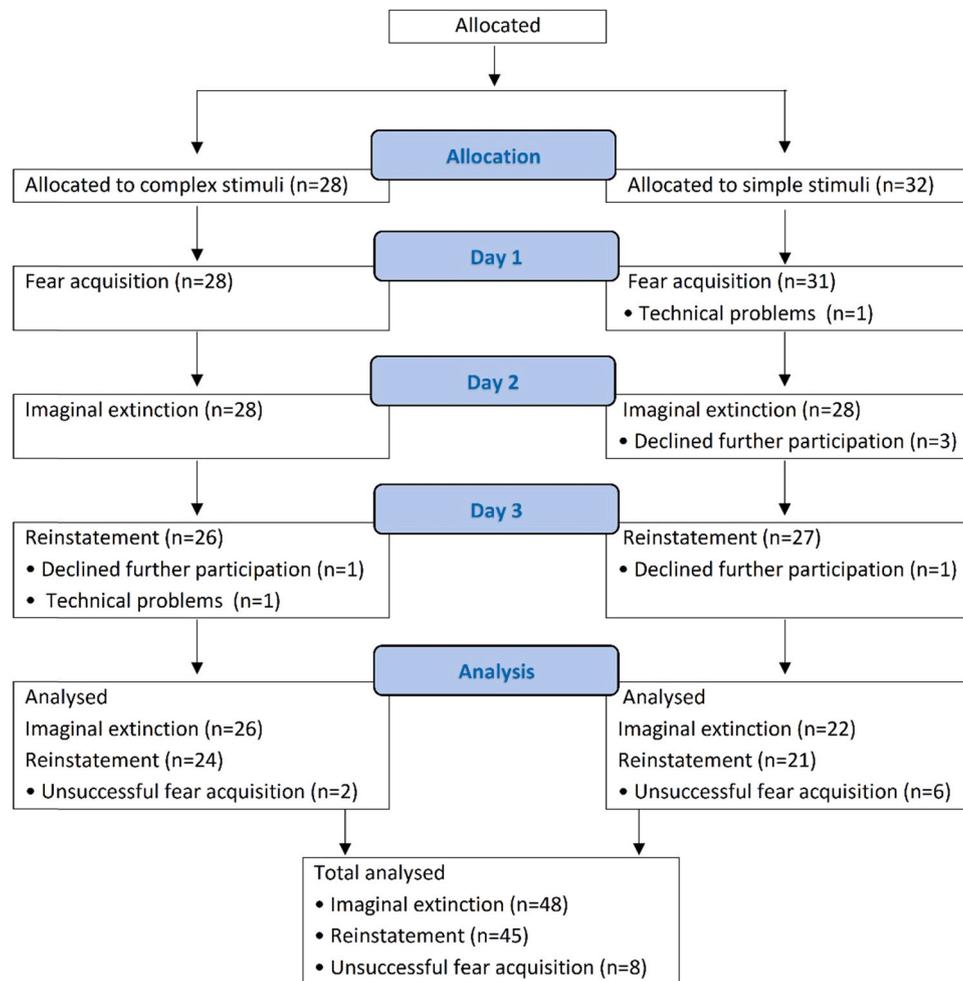


Fig. 1. Participant flowchart for the study. The flowchart shows an overview of the allocation to experimental conditions (complex vs simple stimuli) and attrition across experimental phases (acquisition, imaginal extinction and reinstatement). For inclusion in analyses, participants had to meet the criteria for successful fear acquisition (mean SCR CS+ > mean SCR CS-) and undergo the imaginal extinction procedure.

2.2. Stimuli

Simple stimuli consisted of two different geometrical figures. Complex stimuli consisted of photos of two different stimuli of the same size and shape as simple stimuli but included more complex features, such as colour, depth, heterogeneous patterns, and details (Fig. 2a), in accordance with previous research on stimulus complexity [30,31].

2.3. Procedure

The experimental procedure took part over three consecutive days, with fear acquisition to visual stimuli on day 1, imaginal extinction on day 2, and a reinstatement procedure (i.e., a test of return of fear), again to visual stimuli, on day 3 (Fig. 2b) [21]. A 24-hour gap between experimental phases was set to ensure sufficient time for consolidation of fear and extinction memory, respectively. All experimental phases included one experimental (CS+) and one control stimulus (CS-), presented in a pseudo-randomised order to control for order effects (the same stimulus was presented a maximum of two times in a row). Participants were allocated to undergo all experimental phases (acquisition, imaginal extinction, and reinstatement) to either complex or simple stimuli (see Fig. 2a for an overview of stimuli). Every other participant was allocated to complex or simple stimuli, as they came to the lab. Experimental stimuli were counterbalanced within each condition, such that a specific stimulus was CS+ for half of the participants, and CS- for the other half, and vice versa.

At the start of each experimental phase, participants were instructed to pay attention to the screen, or in the case of imaginal extinction, to the audio instructions. They were also told that ‘electric shocks may be delivered during the procedure’. The experiment was conducted in a dark, soundproof room. Experimental procedures were programmed in E-prime 2.0 (Psychology Software Tools, Pittsburgh, PA).

2.3.1. Day 1 – fear acquisition

Prior to fear acquisition, the strength of the electric shock was determined by the participant. It included a step-wise increase of shock strength until it was experienced as uncomfortable, but endurable. The participant was informed that the same shock strength would be used in all experimental phases. Visual stimuli were presented on a 17" computer screen for 6 s. Inter-trial intervals ranged from 12.5 to 15.5 s, with a mean inter-trial interval of 14 s, during which a crosshair was displayed on the screen. The CS+ was always paired with a shock (100% reinforcement rate), while CS- was never paired. A 2 ms shock was delivered to the dorsal side of the right lower arm, 250 ms before the end of each presentation of the CS+. Fear acquisition included ten trials of each stimulus. Electric shocks were administered using the BIOPAC MP 160 system's STMISOC module (BIOPAC Systems, Goleta, CA) through electrodes (EL500; BIOPAC Systems, Goleta, CA) prepared with electrolyte medium, fastened to the dorsal side of the lower right arm.

2.3.2. Day 2 – imaginal extinction

Before imaginal extinction, participants underwent task-specific

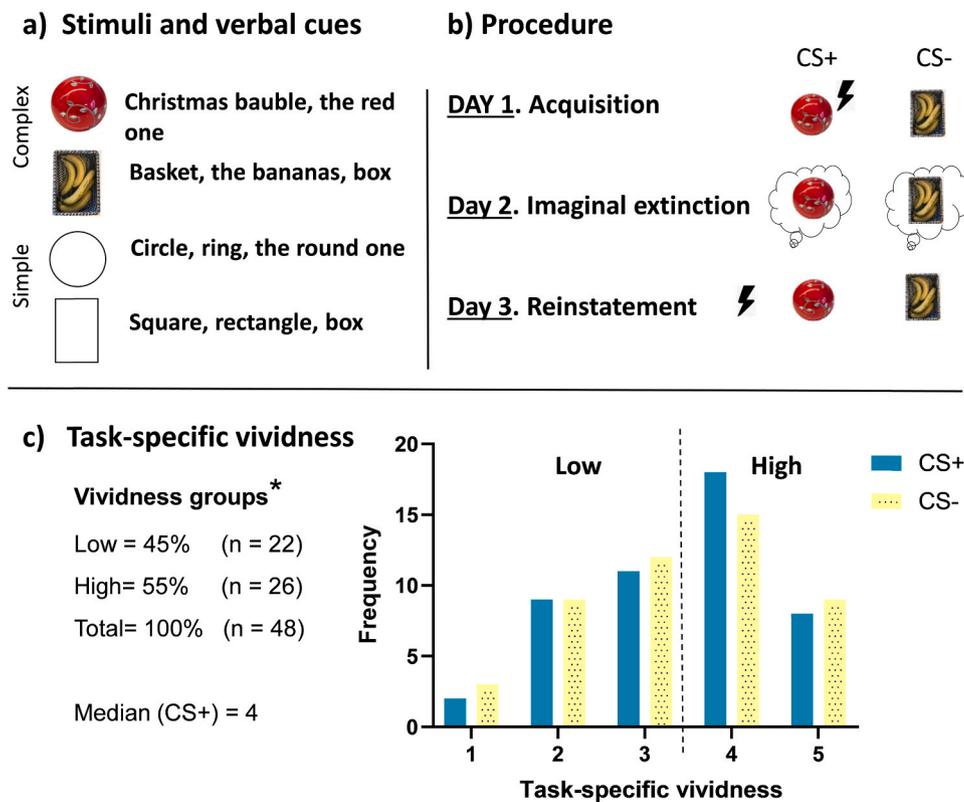


Fig. 2. Overview of stimuli, experimental design and task-specific vividness. Top-left panel (a): Experimental stimuli and corresponding verbal cues used to prompt imagery of each stimulus. The experimental stimuli representing CS+ and CS- within each condition (simple vs complex) were counterbalanced across participants. Top-right panel (b): Overview of the experimental procedure, using complex stimuli as an example. Each experimental phase was performed 24 h after the previous phase. Bottom panel (c): Distribution of ratings of task-specific vividness during imaginal extinction across all participants. *Participants were divided into two groups (high vs low), based on a median split of task-specific vividness ratings of the CS+.

mental imagery training, including learning how to use the vividness scale. See [Supplementary materials](#) for training protocol, vividness scale ([Supplementary Fig. S1](#)), and stimuli used for training ([Supplementary Fig. S2](#)). During imaginal extinction, participants were asked to produce mental imagery of the same stimuli used during fear acquisition (CS+ and CS-; [Fig. 2b](#)). Audio-recorded verbal cues signalled stimulus onset. In our previous study [21], the same verbal cue was used to prompt mental imagery of each stimulus (one cue for CS+ and one for CS-). In this study, three different verbal cues were used to prompt imagery of each stimulus (CS+ and CS-). Thus the verbal cues varied, but the mental imagery was kept constant (see [Fig. 2a](#) for list of verbal cues). The modification was done to control for the possibility that fear reduction was driven by extinction to a specific audio stimulus rather than the internal representation of the CS+. In order to check that participants correctly understood which verbal cues corresponded with each stimulus, and to control for the influence of individual differences in recall [28], experimental stimuli were presented on a computer screen together with corresponding verbal cues for 15 s immediately before the start of the imaginal extinction procedure. Verbal cues were alternated between stimulus presentations in a pseudo-randomised order. Verbal cues (1.2–3.7 s) were followed by 7 s of mental imagery, after which a bell sounded, initiating a period of rest (inter-trial intervals: $M = 14.0$, range 12.5–15.5 s) until the next verbal cue was presented. Imaginal extinction included ten trials of each stimulus. Participants were asked to keep their eyes closed during the whole procedure. No shocks were delivered. Ratings of vividness and subjective fear were collected immediately after the imaginal extinction procedure.

2.3.3. Day 3 – reinstatement

A test of return of fear was conducted 24 h after imaginal extinction to compare remaining fear responses between vividness groups (high vs low). It consisted of a reinstatement procedure where participants were exposed to the same visual stimuli used during fear acquisition (day 1: [Fig. 2b](#)), but preceding the first stimulus, two unsignaled shocks were delivered to reactivate the association between the CS+ and the electric

shock. No further shocks were administered during the presentations of the stimuli (i.e., re-extinction).

2.4. Primary outcome measure – skin conductance responses (days 1–3)

Skin conductance was used to measure physiological fear responses and constituted the primary outcome measure in all three experimental phases. SCRs (fear responses) were used to assesses fear acquisition (day 1), imaginal extinction (day 2), and return of fear (reinstatement, day 3), as well as to explore main effects of task-specific vividness and stimulus complexity, and interactions between fear responses, task-specific vividness, and stimulus complexity.

2.5. Secondary outcome measures

2.5.1. Task-specific vividness ratings

The vividness of mental imagery during imaginal extinction was assessed with a 5-point Likert scale adapted from the Vividness of Visual Imagery Questionnaire (VVIQ-2; day 2) [5,32]. The anchor points ranged from ‘no image at all, you only ‘know’ that you are thinking of an object’, representing a score of 1, to ‘perfectly clear and as vivid as normal vision’, on the other end of the scale, representing a score of 5 (see [Supplementary Fig. S1](#)).

2.5.2. Other secondary outcome measures

Other secondary outcome measures were the VVIQ-2 [5,32] (day 2), *fear ratings* (subjective fear during the experimental procedure on a scale ranging from 0–100; no fear at all–extreme fear), and *expectancy ratings* (the extent participants believed that electric shocks would be delivered during the procedure; 0–100%). Fear ratings and expectancy ratings were collected once at the end of each experimental phase (fear ratings: days 1, 2, and 3; expectancy ratings: days 2 and 3). See [Supplementary Table S1](#) in [Supplementary Materials](#) for details on other measures collected in the study: the trait version of the *Spielberger State-Trait Anxiety Inventory* [33] (day 1), *Difficulties in Emotion Regulation Scale*

[34] (day 1), the *Plymouth Sensory Imagery Questionnaire* [4] (day 2), and the *Spontaneous Use of Imagery Scale* [35] (day 2).

2.5.3. Other pre-specified outcome measures

Task compliance was assessed by asking participants to what extent they followed the instructions during the experimental procedure on a scale ranging from 0% to 100% (days 1, 2, 3).

2.6. Data acquisition, preprocessing and analyses

2.6.1. Skin conductance responses

SCRs were assessed using BIOPAC MP 160 (BIOPAC Systems, Goleta, CA) and two disposable 8-mm Ag/AgCl-electrodes prepared with isotonic electrolyte gel (EL507; BIOPAC Systems, Goleta, CA) attached to the hypothenar eminence of the left hand. The SCR signal passed through a high-pass hardware filter of 0.05 Hz and was analysed with the Ledalab software package using continuous decomposition analysis [36] implemented in Matlab (Mathworks Inc., Natick, MA). SCR was scored using the maximum phasic driver amplitude 1–5.75 s after visual stimuli onset. The end of the interval coincided with the onset of the electrical shock. For SCRs to mental imagery, the interval 1–7 s after the end of verbal cues was used. SCRs were root transformed and range corrected by dividing each response for every individual with the individual’s maximum response across all stimuli and experimental phases [37]. To study fear reduction during extinction, trials were partitioned into three bins (start, mid, end; acquisition and imaginal extinction trials 1–3, 4–7, 8–10; reinstatement: 1–3, 4–5, 6–8).

2.6.2. Statistical analyses

Analyses of variance (ANOVA) were used to assess the effects of task-specific vividness and stimulus complexity on fear responses (SCR) during acquisition, imaginal extinction, and reinstatement, respectively. Stimulus (CS+, CS-) and trial (start, mid, end) were treated as within-subjects variables and task-specific vividness (high vs low) as a between-subjects variable. Participants were partitioned into two groups (high and low) by using a median split of task-specific vividness ratings of the CS+, i.e., the stimulus producing the fear responses to be reduced by imaginal extinction (Fig. 2c). Unexpectedly, vividness ratings did not differ between complex and simple stimuli (CS+: $p = .29$; CS-: $p = .85$; Table 1). Thus, the manipulation of stimulus complexity, which was expected to produce differences in task-specific vividness for complex and simple stimuli, could therefore be considered unsuccessful. Because of the lack of differences in vividness between complex and simple stimuli and the limited power of the study, stimulus complexity was entered as a covariate into the ANOVA:s (rather than a between-subjects variable) in order to focus the analyses on imagery vividness. Results of analyses including both imagery vividness and stimulus complexity as between-subjects variables can be found in the Supplementary Materials (Supplementary Tables S7–S10), but these results should be treated with caution because of the limited power of the study.

In order to examine to what extent results depended on our criteria for successful fear acquisition and transparency of data [38], we also conducted the analyses including participants showing unsuccessful fear acquisition (i.e., ANOVA:s for all experimental phases with stimulus

complexity entered as a covariate).

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 22 (IBM Corp., Armonk, NY). The Greenhouse-Geisser correction was used in all ANOVAs.

3. Results

3.1. Participant characteristics

Forty-eight participants (age: $M = 25.3$; $SD = 5.8$ years; 22 women and 26 men) were included in analyses (Fig. 1). Participant ratings on the VVIQ-2 ($M = 58.4$, $SD = 12.5$) were consistent with levels of trait-vividness of visual mental imagery previously reported in the general population [5].

3.2. Task-specific vividness ratings

Task-specific vividness ratings of experimental stimuli during imaginal extinction are presented in Table 1. Results showed that task-specific vividness ratings did not differ between complex and simple stimuli (CS+: $p = .29$; CS-: $p = .85$; Table 1). Participants were partitioned into two groups (low and high vividness) through a median split using task-specific vividness of CS+ (median CS+ = 4), resulting in the groups: low vividness (N = 22) and high vividness (N = 26).

3.3. Primary outcome measures – skin conductance responses (days 1–3)

3.3.1. Acquisition

Fear acquisition data (SCR) was analysed using a $2 \times 3 \times 2$ mixed ANOVA, with stimulus (CS+, CS) and trial (start, mid, end) as within-subject variables, and task-specific vividness (high vs low) as a between-subjects variable. Because ratings of task-specific vividness for simple and complex stimuli did not differ, and the limited power of the study, stimulus complexity was entered into the model as a covariate, instead of as a between-subject variable (see 2.6.2). In line with successful fear acquisition, results showed a significant stimulus \times trial interaction ($F(1.9, 87.5) = 11.0$, $p < .001$, $\eta_p^2 = 0.20$; Fig. 3a). Main effects were found for both stimulus ($F(1.0, 45.0) = 79.4$, $p < .001$, $\eta_p^2 = 0.64$) and trial ($F(1.4, 64.7) = 7.1$, $p = .004$, $\eta_p^2 = 0.14$). No significant main effects or interactions were observed for task-specific vividness. See Supplementary Table S2 for mean SCRs to CS+ and CS- during acquisition and Supplementary Table S3 for full ANOVA table.

3.3.2. Imaginal extinction

In line with analysis of acquisition, imaginal extinction was examined with a $2 \times 3 \times 2$ mixed ANOVA, with stimulus (CS+, CS-) and trial (start, mid, end) as within-group variables and task-specific vividness (high vs low) as a between-subjects variable and SCRs as dependent variable. Stimulus complexity was entered into the model as a covariate, instead of as a between-subject variable (see 2.6.2). In line with successful fear extinction across the whole sample, results showed a significant stimulus \times trial interaction ($F(1.9, 87.0) = 4.09$, $p = .02$, $\eta_p^2 = 0.08$). Stimulus differentiation (i.e., larger responses to CS+ than CS-) was noted at the start ($t(47) = 3.3$, $p = .002$, $d = 0.47$) and mid part of

Table 1
Task-specific vividness ratings of experimental stimuli (CS+ and CS-).

	All participants		Vividness groups						Stimulus complexity			
			High		Low		Complex		Simple			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
CS+	3.4	1.1	4.3	0.5	2.4	0.9	3.6	0.9	3.2	1.3		
CS-	3.4	1.2	3.8	0.9	2.9	1.3	3.4	0.9	3.3	1.4		

Note: The table shows task-specific vividness ratings of experimental stimuli (CS+ and CS) across all participants and within each vividness group (high and low). Task-specific vividness ratings of CS+ and CS- are also displayed for each level of stimulus complexity (complex and simple).

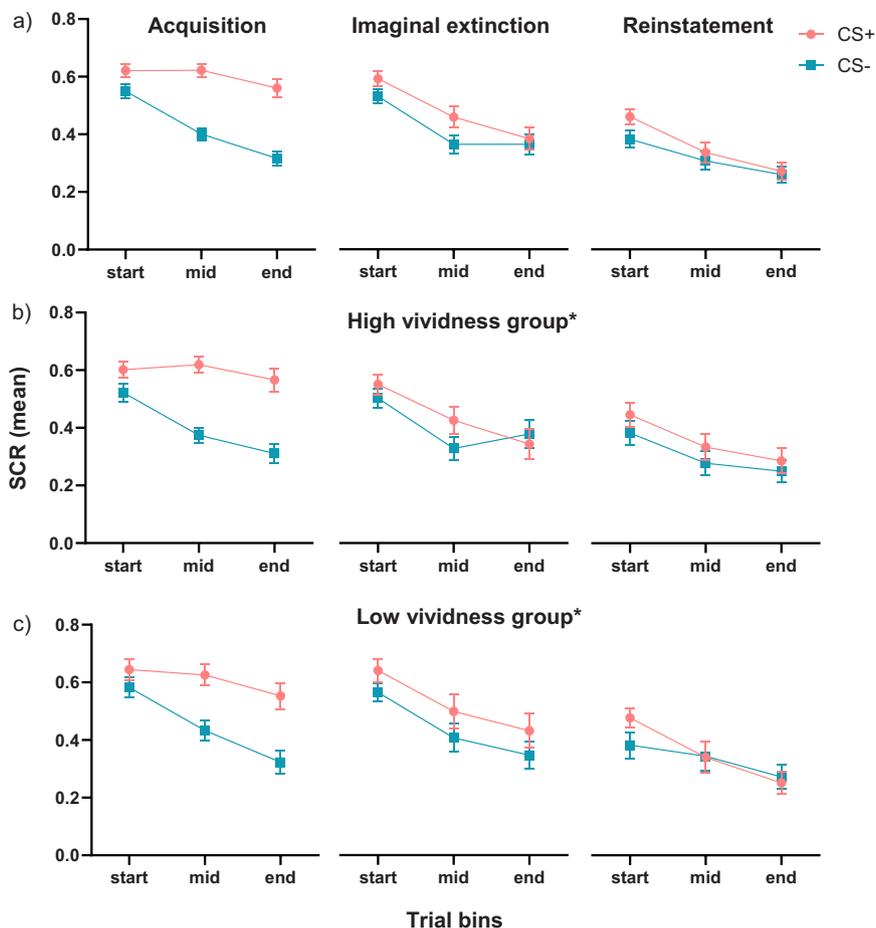


Fig. 3. Skin conductance responses across experimental phases for all participants and within each vividness group. Mean skin conductance responses (SCR) to experimental stimuli (CS+ and CS-) within all experimental phases (start, mid, end). SCRs are displayed for (a) all participants and for (b) high and (c) low vividness group. *Vividness groups are based on task-specific vividness ratings of the CS+. SCRs are root transformed and range corrected. Error bars represent standard error.

extinction ($t(47) = 4.4, p < .001, d = 0.64$), but not at the end ($t(47) = 0.77, p = .45, d = 0.11$; Fig. 3a). Main effects were found for both stimulus ($F(1.0, 45.0) = 7.72, p = .01, \eta_p^2 = 0.15$) and trial ($F(1.6, 70.1) = 14.52, p < .001, \eta_p^2 = 0.24$), reflecting higher mean SCR to CS+ compared to CS- ($t(47) = 3.8, p < .001, d = 0.56$) and attenuation of mean SCR from start to end of extinction ($t(47) = 6.2, p < .001, d = 0.90$). Results also revealed a significant three-way interaction between task-specific vividness \times stimulus \times trial ($F(1.9, 87.0) = 3.73, p = .029, \eta_p^2 = .077$). See [Supplementary Table S4](#) for full ANOVA table. A post hoc 2×3 repeated measures ANOVA was performed for the high and low task-specific vividness groups separately, with stimulus (CS+, CS-) and trial (start, mid, end) as within-group variables. Consistent with successful extinction, the high vividness group showed a significant stimulus \times trial interaction in the imaginal extinction phase ($F(1.7, 43.0) = 8.44, p = .001, \eta_p^2 = 0.25$; Fig. 3b). In contrast, no significant stimulus \times trial interaction was observed in the low vividness group ($F(1.8, 41.1) = 0.09, p = .90, \eta_p^2 = 0.004$, Fig. 3c). ANOVA tables for high and low task-specific vividness groups separately, are presented in [Supplementary Table S5](#). Mean SCRs to CS+ and CS- during imaginal extinction can be found in [Supplementary Table S2](#).

3.3.3. Reinstatement

As for acquisition and extinction (see 3.3.1 and 3.3.2), SCRs during reinstatement were analysed using a $2 \times 3 \times 2$ mixed ANOVA, with stimulus (CS+, CS-) and trial (start, mid, end) as within-group variables and task-specific vividness (high vs low) as a between-subjects variable and stimulus complexity entered into the model as a covariate. Results showed a significant main effect of trial ($F(1.7, 70.1) = 10.17, p < .001,$

$\eta_p^2 = 0.20$), showing attenuation of mean SCR from start to end of the reinstatement procedure ($t(44) = 6.4, p < .001, d = 0.96$; Fig. 3a). Post-hoc analysis showed no significant difference in the reinstatement effect between high and low vividness group, which was measured with an independent t -test of stimulus differentiation (mean SCR for CS+ - mean SCR for CS-) during the first three trials of reinstatement, between high ($M = 0.064, SE = 0.025$) and low ($M = 0.096, SE = 0.040$) vividness groups ($t(43) = 0.71, p = .48$). In addition, there was a significant correlation between the differential response (CS+ - CS-) at the end of imaginal extinction and the differential response at the start of reinstatement ($r = 0.34, p = .022$), suggesting a generalisation of extinction memory from imaginal stimuli to in vivo stimuli, i.e., the extinction memory evoked through imaginal extinction influenced the fear response to in vivo stimuli at reinstatement. See [Supplementary Table S6](#) for full ANOVA table and [Supplementary Table S2](#), for mean SCRs to CS+ and CS- during reinstatement.

3.4. Analyses including participants with unsuccessful fear acquisition

In order to examine to what extent our results depended on our criteria for successful fear acquisition, and for transparency [38] we conducted corresponding analyses including participants with unsuccessful fear acquisition ($n = 8$). The total number of participants included in analyses of acquisition and imaginal extinction were $n = 56$ (high vividness $n = 28$; low vividness $n = 28$), and $n = 53$ in analyses of reinstatement (high vividness $n = 27$; low vividness $n = 26$). For imaginal extinction, a significant three-way interaction between task-specific vividness \times stimulus \times trial ($F(2.0, 104.1) = 3.41,$

$p = .038$ $\eta_p^2 = 0.060$) was observed when including participants with unsuccessful fear acquisition into a $2 \times 3 \times 2$ mixed ANOVA, with stimulus (CS+, CS-) and trial (start, mid, end) as within-group variables and task-specific vividness (high vs low) as a between-subjects variable and stimulus complexity entered as a covariate. Although the stimulus \times trial interaction was not significant in analyses of imaginal extinction when including participants with unsuccessful fear acquisition ($F(2.0, 104.1) = 2.32$ $p = .11$, $\eta_p^2 = 0.042$), there was significant stimulus differentiation at the start ($t(55) = 3.11$ $p = .003$, $d = 0.32$), but not at the end of imaginal extinction ($t(55) = 1.31$, $p = .20$, $d = 0.13$). Full ANOVA tables for analyses including participants with unsuccessful fear acquisition for each experimental phase are presented in the [Supplementary Materials](#) (acquisition: [Table S11](#), imaginal extinction: [Table S12](#), and reinstatement: [Table S13](#)).

3.5. Secondary outcome measures

3.5.1. Subjective fear

Subjective fear ratings, which were assessed once after each session, on a scale from 0 to 100 (no fear - extreme fear), were relatively low throughout all experimental phases (acquisition: $M = 15.3$, $SD = 14.8$; imaginal extinction: $M = 21.3$, $SD = 18.8$; reinstatement: $M = 12.9$, $SD = 13.3$; see [Supplementary Table S14](#) for ratings of subjective fear for high and low vividness groups separately). In order to assess differences in subjective fear between imaginal extinction and reinstatement, we conducted a 2×2 mixed ANOVA, with session (imaginal extinction, reinstatement) as a within-subjects variable and task-specific vividness (high, low) as a between-subject variable. There was a significant main effect of session with a decrease in subjective fear from imaginal extinction to reinstatement ($F(1.0, 43.0) = 24.6$, $p < .001$, $\eta_p^2 = 0.36$). There was no significant main effect of task-specific vividness and no interaction between session and task-specific vividness. During the acquisition phase there was a near-significant difference in subjective fear ratings, with slightly higher subjective fear ratings in the low vividness group ($M = 19.6$, $SD = 15.6$) compared to the high vividness group ($M = 11.6$, $SD = 13.2$; $t(46) = 1.9$ $p = .06$).

3.5.2. Task compliance and expectancy ratings

Mean task compliance with instructions was 93.3% ($SD = 10.0$) for acquisition, 91.9% ($SD = 8.9$) for imaginal extinction, and 91.1% ($SD = 11.1$) for reinstatement. Mean expectancy ratings (of electric shocks) was 94.2% ($SD = 13.0$) for imaginal extinction and 65.6% ($SD = 22.4$) for reinstatement.

4. Discussion

The current study examined the link between mental imagery, in particular imagery vividness, and the reduction of fear in imaginal extinction. Results showed that high task-specific vividness of the CS+ was advantageous for fear reduction during imaginal extinction. However, task-specific vividness did not moderate fear responses in the long term, as remaining fear responses, 24 h later, did not differ significantly between the high and low vividness group. Moreover, the current study also extended previous results showing that conditioned fear can be successfully attenuated through extinction to mental imagery of the CS+, that is, without external sensory input of the actual fear-provoking stimulus [21,23]. The fact that verbal cues were varied (see [Fig. 2a](#) for list of verbal cues), while the object of mental imagery was kept constant, indicates that fear reduction was indeed linked to the internal representation of the CS+ rather than the exposure to a specific external verbal cue. Furthermore, the correlation between the differential response (CS+ - CS-) at the end of imaginal extinction and the differential response at the start of reinstatement, suggests that the extinction memory produced through imaginal extinction (i.e., imaginal stimuli) influenced fear responses to in vivo stimuli at reinstatement.

In line with our hypothesis, the high vividness group showed

successful fear extinction, as reflected by a significant stimulus \times trial interaction ([Fig. 3b](#)), while the low vividness group did not. Instead, in the low vividness group, a general reduction of SCRs to both CS+ and CS- was observed ([Fig. 3c](#); and [Supplementary Table S5](#)). Skin conductance responses to the CS- did not reach zero at the end of extinction, which may reflect that merely the effort of producing the mental imagery in this specific task may have given rise to an arousal response. This apparent floor of SCRs to CS- was not affected by imagery vividness, as there was no difference between high and low vividness groups regarding responses to CS- at the end of extinction ($t(46) = 0.46$, $p = .65$).

Task-specific vividness was not found to moderate fear responses in the longer term (24 h). This result is in line with research indicating that within-session extinction learning is a poor predictor for memory strength [39,40]. Furthermore, in clinical studies, an association between vividness and reduction in subjective distress has been noted within the imaginal exposure session, but not with overall treatment outcome (c.f. long-term fear reduction; [13,14]). The differential influence of task-specific vividness on short- and long-term extinction perhaps reflects that there seem to be different mechanisms involved in within- and between-session fear reduction [13,41]. It is possible that highly vivid mental imagery primarily enhances mechanisms that promote fear reduction during the exposure session. However, lower vividness levels may be sufficient for mechanisms that impact fear reduction between sessions, such as the formation of a memory of extinction learning [41]. Indeed, accumulating evidence, primarily from clinical studies, shows that within-session fear reduction is not necessary to obtain beneficial long-term effects from either in vivo or imaginal exposure [25,41].

4.1. Clinical relevance

Our results, along with findings from clinical studies [13,14], suggest that while high imagery vividness may be advantageous to reduce fear within-session, lower vividness levels may produce comparable long-term effects on fear responses. Patients may only need to surpass a certain threshold of vividness for imaginal exposure to be effective [13]. As previously noted, higher vividness during imaginal exposure is associated with higher levels of subjective distress [9,14,13]. High distress is not well tolerated by some individuals, which can lead to premature dropout from therapy [16]. Previous studies show that emotional responses to mental imagery can be attenuated by reducing imagery vividness [28,42,43]. If the long-term effects of imaginal exposure indeed can be achieved with lower imagery vividness, then perhaps treatment could be made tolerable for more patients by integrating strategies to reduce (rather than boost) vividness to keep down distress levels [42-44] and to calibrate optimal levels. Future studies should evaluate the minimal level of vividness necessary for imaginal exposure to be effective. Exploring optimal/minimal vividness levels could be done in experimental studies by manipulating vividness during exposure, e.g., by including concurrent visuospatial tasks [45].

4.2. Limitations and open questions

Some limitations should be considered when interpreting the current results. The present study used the fear conditioning paradigm to pinpoint the process of fear reduction through exposure to mental imagery, with a high level of experimental control. However, to evaluate the actual clinical implications, our results need to be translated into the clinic. Thus, future studies should extend our finding on conditioned fear to naturally occurring fear (e.g., phobia). Conditioned fear (in the lab) generally evokes relatively low levels of subjective fear, and studies of naturally occurring fear are therefore more suitable for investigating subjective fear. Consistent with this, subjective fear ratings were also low in the current study ([Supplementary Table S4](#)). Still, a reduction in subjective fear ratings was observed between sessions (from imaginal

extinction to reinstatement). Echoing the results on SCR at reinstatement (24 h), reduction in subjective fear was not moderated by vividness (i.e., the high and low vividness groups did not differ in the reduction of subjective fear between sessions). Analysis of within-session reduction in subjective fear was not possible as fear ratings were collected only once per experimental phase. Furthermore, although previous studies indicate that imaginal and in vivo extinction produce similar effects on the extinction of conditioned fear [21,23], a future direction would be to include an in vivo control condition to elucidate further the mechanisms of the reduction of fear within the mind's eye as compared with in vivo extinction.

Other limitations concern the use of static and relatively simple stimuli, compared to imagery targeted in imaginal exposure in the clinic. To explore the potentially different impact of imagery vividness on fear response depending on stimuli complexity, and to defend against a possible ceiling and floor effect on vividness (i.e., stimuli being too easy/hard to visualise vividly), participants were allocated to undergo the entire experiment with either complex or simple stimuli (Fig. 1). However, the stimulus complexity manipulation failed as vividness ratings did not differ between complex and simple stimuli. The use of relatively simple stimuli overall could explain why the vividness of mental imagery did not differ between complex and simple stimuli (both relatively simple), which precluded us from adequately examining the impact of stimulus complexity on the relationship between imagery vividness and fear reduction. Also, this study focused only on *visual* mental imagery. Therefore, future studies should explore the influence of vividness using more ecologically valid stimuli (more complex stimuli) and include other mental imagery modalities (e.g., sound). Lastly, studying non-observable processes within the mind is challenging, including reliance on self-reported ratings of imagery vividness. However, accumulating evidence indicates that people generally have good metacognitive knowledge of their imagery ability as shown by a positive correlation between subjective vividness ratings and non-subjective measures of imagery "strength" (e.g., priming effect of mental imagery on perception; [46,47]). Lastly, the limited samples size should also be considered when interpreting the current findings. Thus, a test of replication of current findings is needed in a well-powered sample size.

4.3. Conclusions

Our findings suggest that while high imagery vividness may be advantageous to reduce fear within-session, lower vividness levels appear to produce comparable long-term effects on fear responses. A clinical implication would be to explore if similar fear reduction can be obtained with less vivid imaginal exposure, which may help lower distress and thereby make treatment tolerable for more patients.

CRedit authorship contribution statement

JMH made substantial contributions to conception and design, acquisition of data, analysis, and interpretation of data, as well as drafting the article. EAH made substantial contributions to conception and design, interpretation of data, revised the manuscript critically for important intellectual content. TA made substantial contributions to conception and design, acquisition of data, analysis, and interpretation of data, revised the manuscript critically for important intellectual content. All authors approved the final version.

Declaration of Conflicting Interests

The authors declare no conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.bbr.2021.113632.

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