Tilburg University

A review on mental imagery in fear conditioning research 100 years since the 'Little Albert' study

Mertens, Gaetan; Krypotos, Angelos-Miltiadis; Engelhard, Iris M.

Published in:
Behaviour Research and Therapy

DOI:
10.1016/j.brat.2020.103556

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

Behaviour Research and Therapy 126 (2020) 103556

Contents lists available at ScienceDirect

Behaviour Research and Therapy

journal homepage: www.elsevier.com/locate/brat

A review on mental imagery in fear conditioning research 100 years since the 'Little Albert' study

Gaëtan Mertens[a,*], Angelos-Miltiadis Krypotos[a,b], Iris M. Engelhard[a]

[a] Department of Clinical Psychology, Utrecht University, Utrecht, the Netherlands
[b] Health Psychology Research Group, KU Leuven, Leuven, Belgium

ARTICLE INFO

Keywords:
Imagery
Fear
Conditioning
Mental imagery
Intrusive memories

ABSTRACT

Since the seminal 'Little Albert' study by Watson and Rayner (1920), fear conditioning has become one of the most commonly used paradigms for studying the etiology of anxiety-related disorders. In a fear conditioning procedure, a (neutral) conditioned stimulus (CS) is paired with an aversive unconditioned stimulus (US), resulting in fear-related conditioned responses (CRs) to the CS. Whereas fear conditioning research initially focused on observable elements in the environment (i.e., CSs, USs, and their contingency) and their effects (i.e., CRs), subsequent research indicated that attention should also be given to unobservable mental events (e.g., intrusive memories of aversive outcomes) to more fully account for the symptomatology of anxiety disorders. In this paper, we review the research relating to four major research questions on the relationship between mental imagery and fear conditioning: (1) Can mental imagery substitute for actual stimulus administration? (2) Can mental imagery inflate CRs? (3) Can fear conditioning result in the installment of mental images as CRs (i.e., intrusions)? (4) Can mental imagery-based interventions reduce CRs? For all these research questions, tentative confirmatory evidence has been found and these findings corroborate contemporary conditioning theories. Nonetheless, we point to several open questions and methodological issues that require further research.

1. Introduction

Since the publication of Watson and Rayner's seminal 'Little Albert' study (Watson & Rayner, 1920), fear conditioning has become one of the most widely used paradigms to study the acquisition, extinction, and return of fear (Mineka & Zinbarg, 2006; Vervliet, Craske, & Hermans, 2013). The core procedural elements of the fear conditioning paradigm are the pairing of an initially neutral stimulus, called the conditioned stimulus (CS), with an aversive unconditioned stimulus (US), resulting in the establishment of conditioned responses (CRs) to the CS, even in absence of the US. Though certain aspects of Watson and Rayner's original study were criticized (see Fridlund, Beck, Goldie, & Irons, 2012; Hermans, Boddez, & Vervliet, 2019), many subsequent studies have demonstrated that fear conditioning can install behavioral, cognitive, and physiological responses related to fear. To date, fear conditioning is one of the dominant paradigms for studying the etiology of fear and anxiety-related disorders (Beckers, Krypotos, Boddez, Effting, & Kindt, 2013; Field, 2006; Mineka & Zinbarg, 2006).

The 'Little Albert' study also pioneered the new psychological territory of behaviorism (Skinner, 1963; Watson, 1913). Behaviorism focuses on analyzing behavior in terms of observable environmental elements (such as CSs and USs) and their effects (observable CRs), without needing to look into the 'black box' of mental events. In Watson's well-known paper 'Psychology as the behaviorist views it' (Watson, 1913), he wrote that: "*we can write a psychology […] [and] never use the terms consciousness, mental states, mind, content, introspectively verifiable, imagery, and the like*" (p. 166). However, behaviorism became criticized from the 1950–1960s onwards for several reasons, including that it failed to account for subjective experiences (Graham, 2019). For example, fear conditioning seems to optimally model posttraumatic stress disorder (PTSD; i.e., persistent anxiety-related responses due to the direct experience with a traumatic event, particularly when presented with associated cues), but core PTSD symptoms are the distressing and vivid re-experiencing of the traumatic event. Such intrusive images of aversive experiences in the past or anticipated in the future are also common in other anxiety-related disorders (Brewin, Gregory, Lipton, & Burgess, 2010; Engelhard, van den Hout, Janssen, & van der Beek, 2010; Holmes & Mathews, 2010),

* Corresponding author. Department of Clinical Psychology, Heidelberglaan 1, 3584CS, Utrecht University, Utrecht, the Netherlands.
E-mail address: mertensgaetan@gmail.com (G. Mertens).

https://doi.org/10.1016/j.brat.2020.103556
Received 30 August 2019; Received in revised form 9 January 2020; Accepted 14 January 2020
Available online 22 January 2020

but they fall outside of the scope of behaviorism as defined by Watson.[1]

Most likely due to these historical roots, mental imagery, and more generally emotional episodic memory (Dunsmoor & Kroes, 2019), has received little attention within fear conditioning research, despite its clinical relevance. Fear conditioning research could, nevertheless, profit from more attention for mental imagery and images. To illustrate, concerns have been raised that fear conditioning is too focused on simple stimuli (e.g., geometric shapes and electric shock; Mertens, Wagensveld, & Engelhard, 2019; Scheveneels, Boddez, Vervliet, & Hermans, 2016), and neglects clinically relevant behaviors (e.g., avoidance behaviors; Krypotos, Vervliet, & Engelhard, 2018) and phenomena (e.g., intrusions; Wegerer, Blechert, Kerschbaum, & Wilhelm, 2013). Studying mental images and memories could help fear conditioning research to become more clinically relevant and provide important insights into the etiology, maintenance, and treatment of anxiety-related disorders. For instance, in recent years, research on mental imagery and how it is involved in psychopathology has been steadily expanding (for reviews see Holmes & Mathews, 2010; Ji, Heyes, MacLeod, & Holmes, 2016), and it has shown that therapeutic interventions that make use of mental imagery are promising for the treatment of anxiety-related disorders (Engelhard, McNally, & van Schie, 2019; Morina, Lancee, & Arntz, 2017). Translation of these insights to conditioning procedures could help to better understand the underlying mechanisms of such interventions.

Given these considerations, we think a systematic review of the available research regarding mental imagery in the context of fear conditioning is warranted. Therefore, we first introduce contemporary definitions and measures of mental imagery. Next, we briefly review the available studies on mental imagery in fear conditioning that have been previously reviewed in the seminal paper by Dadds, Bovbjerg, Redd, and Cutmore (1997), before moving on to our updated review on this topic. We conclude this paper with an integration of this research into contemporary models of fear conditioning and provide an outline of open questions and avenues for future research.

1.1. Definition, measurement, and control conditions of mental imagery

1.1.1. Definition

Imagery is typically defined as the mental simulation of stimuli or situation in the absence of physical stimulation and can involve multiple sensory modalities (Kosslyn, Thompson, & Ganis, 2006). It is also often referred to as “seeing with the mind's eye” or “hearing with the mind's ear” (Holmes & Mathews, 2010; Kosslyn, Ganis, & Thompson, 2001). Several theorists have proposed that there is overlap between processes involved in mental imagery and actual perception (Farah, 1989; Kosslyn et al., 2001; Holmes & Mathews, 2010). In support of such theories, neuroimaging studies have indicated that engaging in mental imagery of stimuli activates many of the same brain areas as those involved in actually perceiving stimuli (Ganis, Thompson, & Kosslyn, 2004). However, it may be noted that there is ongoing debate about whether mental imagery reflects ‘mental pictures in the brain’ (pictographic theories) or propositional knowledge about the world (Kosslyn et al., 2006; Pylyshyn, 2003; Thomas, 2019).

1.1.2. Measurement

Mental imagery is typically measured with self-reports, but these can be sensitive to spurious factors, such as demand characteristics and socially desirable responding (e.g., Allbutt, Ling, Heffernan, & Shafiullah, 2008; Intons-Peterson, 1983). Therefore, other ways to measure mental imagery have been used, such as behavioral tasks, psychophysiological measures, and functional neuroimaging. We will briefly introduce these measures (for a more detailed overview and review of imagery measures see D. G. Pearson, Deeprose, Wallace-Hadrill, Heyes, & Holmes, 2013).

1.1.2.1. Self-report measures

1.1.2.1.1. Measures of imagery about specific objects or situations. When participants are instructed to imagine a specific object or situation, they can be asked to rate its vividness on Likert scales or Visual Analogue Scales (e.g., “How clear did you find the image of the memory that you just recalled?“; Mertens et al., 2018b). Likewise, other dimensions of mental images can be assessed such as emotionality, distress, valence, fear, and arousal (e.g., Dibbets, Lemmens, & Voncken, 2018; Kearns & Engelhard, 2015; Mueller, Sperl, & Panitz, 2019).

Another way to probe mental imagery is to ask participants to complete a structured diary at home or to press a computer key whenever an image comes to mind in the laboratory (Berntsen, 2009; Lau-Zhu, Holmes, & Porcheret, 2018). Such an approach has been used in the context of involuntary memory of past and future mental events (e.g., Cole, Staugaard, & Berntsen, 2016; Schlagman & Kvavilashvili, 2008; Wegerer et al., 2013).

1.1.2.1.2. Measures of trait imagery ability. Mental imagery is also often considered to be a stable inter-individual trait that can be assessed using questionnaires. Relevant questionnaires include the Questionnaire Upon Mental Imagery (QUMI; Sheehan, 1967), Vividness of Visual Imagery Questionnaire-2 (VVIQ-2; Marks, 1995), Spontaneous Use of Imagery Scale (SUIS; Reisberg, Pearson, & Kosslyn, 2003), and the Plymouth Sensory Imagery Questionnaire (Psi-Q; Andrade, May, Deeprose, Baugh, & Ganis, 2014). Little information about the reliability and validity of these questionnaires is available (D. G. Pearson et al., 2013). In a recent validation study, the Psi-Q questionnaire showed good internal (.96) and test-retest (.71) reliability (Andrade et al., 2014) and significant correlations with two other questionnaires (with VVIQ: $r = 0.67$; with SUIS: $r = 0.40$). However, these questionnaires tend to focus on different aspects of mental imagery. Some focus on visual mental imagery specifically, whereas others also focus on imagery in other sensory modalities (see D. G. Pearson et al., 2013).

1.1.2.2. Behavioral tasks

The study of mental imagery has been advanced by its linkage to working memory (WM) models (Andrade, Kavanagh, & Baddeley, 1997; Baddeley & Andrade, 2000). According to WM models, mental operations are executed by a limited pool of mental resources. Often, two different subcomponents of WM are distinguished (next to an overarching central executive): the visuo-spatial sketchpad and the phonological loop (Baddeley, 2012). Visual mental imagery has been coupled to the visuo-spatial sketchpad (Baddeley & Andrade, 2000). Due to the limited capacity of the WM systems, their involvement can be assessed by loading subcomponents of WM by having participants conduct concurrent WM tasks. Indeed, research has shown that concurrent visuo-spatial tasks disrupts visual mental imagery, and vice versa (i.e., engaging in visual mental imagery interferes with the execution of visuo-spatial tasks) (Baddeley & Andrade, 2000; Lau-Zhu, Holmes, Butterfield, & Holmes, 2017).[2] Hence, decreased performance on visuo-spatial WM tasks may be

[1] Watson's behaviorism is sometimes referred to as ‘methodological behaviorism’, focusing on observable procedures and behaviors, and it explicitly rejected the study of unobservable events such as mental imagery (see quotes above). Radical behaviorism advocated by B. F. Skinner, however, does include analysis of events that are only observable for the organism itself, including mental imagery (Anderson, Hawkins, Freeman, & Scotti, 2000). Nonetheless, mental imagery has only received minimal attention in the behavior-analytic tradition (Thomas, 2019).

[2] However, visual mental imagery also affects concurrent tasks with other modalities (auditory, tactile), presumably due to general load effects (see van den Hout & Engelhard, 2012). The extent to which WM resources are modality-specific or nonspecific is a debated issue (Camos, 2017).

used to establish the involvement of mental imagery. Conversely, visuospatial WM tasks can also be used as an intervention to interfere with mental imagery (e.g., Baddeley & Andrade, 2000; Leer, Engelhard, Altink, & van den Hout, 2013; van den Hout & Engelhard, 2012).

1.1.2.3. Psychophysiological correlates

1.1.2.3.1. Defensive responses elicited by mental imagery. According to the bio-informational model of mental imagery (Lang, 1979), mental imagery of emotional stimuli elicits physiological responses that are comparable to direct experience with the imagined stimuli. In support of this theory, experiments probing different sorts of mental imagery have demonstrated that it can elicit physiological responses that correspond to the instructed content of the imagery (Cuthbert et al., 2003; Vrana & Lang, 1990). As such, physiological responses related to fear and negative affect can be used as a manipulation check to ensure that participants engage in aversive mental imagery (Ji et al., 2016), or as outcome measure to assess the emotional evocative power of mental images (e.g., Kearns & Engelhard, 2015). These include increased skin conductance responses, heart rate acceleration, potentiation of the startle reflex, and pupil dilatation (Cuthbert et al., 2003; Mueller et al., 2019; Vrana & Lang, 1990).

1.1.2.3.2. Functional neuroimaging of mental imagery. Involvement of mental imagery can also be established using functional neuroimaging, given that mental imagery activates brain regions that correspond with actual perception of the imagined stimuli (Ganis et al., 2004). In fact, brain activation in these regions appear to correlate directly with rated vividness of mental imagery (Cui, Jeter, Yang, Montague, & Eagleman, 2007). As such, fMRI brain activation in areas previously related to mental imagery can be used as a measure for the involvement of mental imagery (e.g., Reddan, Wager, & Schiller, 2018).

1.1.2.4. Conclusion about mental imagery measures. The involvement of mental imagery can be assessed with a heterogenous set of methods. Prior research indicates that there is a degree of correspondence between self-report measures, behavioral measures, and psychophysiological measures of mental imagery (e.g., Cui et al., 2007; Miller et al., 1987). These sources of information point to a construct that is reliable (i.e., stable inter-individual difference and measurable within laboratory tasks) and valid (i.e., convergence across measures and linked to symptoms in psychological disorders; for evidence regarding the latter point see Muse, McManus, Hackmann, Williams, & Williams, 2010). However, it should be noted that a number of other studies have raised some concerns about inconsistencies in the factor structure of mental imagery questionnaires (e.g., Andrade et al., 2014; Campos & Pérez-Fabello, 2005) and the reliability of the correlations between different measures of mental imagery (e.g., Laor et al., 1999). Therefore, the correspondence between different imagery measures and the structure of the latent construct require further research. We revisit this issue in the Discussion.

1.1.3. Control conditions for mental imagery

Besides the operationalization and measurement of mental imagery, experimental studies investigating mental imagery (such as the ones included in this review) require appropriate control conditions. In the next paragraphs, we briefly introduce five different control conditions that are often used to investigate mental imagery within fear conditioning research.

1.1.3.1. No imagery instructions. One possible control condition is to give participants no specific instructions about mental imagery in the control condition (e.g., ask participants to imagine one stimulus, but not another; see Grégoire & Greening, 2019). An advantage of this approach is that participants are not attended in the control condition to the fact that mental imagery is investigated, thereby reducing demand bias (Orne, 1962) and the possibility that participants nonetheless engage in visual imagery. However, a drawback is that there is little direction for participants on what they should do. This may be particularly problematic when participants are exposed to vivid stimuli material. Under such conditions, it is possible that they will spontaneously engage in mentally rehearsing this information (i.e., have involuntary thoughts) (Ball & Brewin, 2012; James et al., 2016), potentially reducing differences between this control condition and the experimental condition.

1.1.3.2. Recall only or imaginal exposure. Another control condition is to ask participants to recall their memory of a certain stimulus or situation. This condition is typically used to control for the effects of imaginal exposure in studies in which emotional memories need to be reprocessed in a certain way such as, for instance, when using lab models of imagery rescripting or Eye Movement Desensitization and Reprocessing (EMDR) therapy (see below). Prolonged imaginal exposure is an effective imagery-based procedure for reduction of fear (e.g., Foa & Rothbaum, 1998), and merely thinking about an emotional memory in the lab can reduce the emotional distress prompted by subsequent recollection (e.g., van Veen, van Schie, van de Schoot, van den Hout, & Engelhard, 2019). Alternatively, thinking about an aversive memory may also lead to fear inflation (see below). As such, 'recall only' is not a passive control condition. Furthermore, it is worthwhile to note that 'recall only' is a term used in the literature for this type of manipulation, but does not necessarily imply the recall of a long-term memory. Therefore, it could also be referred to as imaginal exposure or mental rehearsal. However, to maintain consistency with the reviewed papers, we will refer to this control condition as 'recall only'.

1.1.3.3. Verbal processing. A third control condition for visual mental imagery is to ask participants to engage in verbally based processing. This approach has been used in studies by Holmes and colleagues (for a review see Holmes & Mathews, 2010), which showed that visual mental imagery elicits stronger emotional responses compared to verbal processing. However, it remains unclear whether this is also the case for mental imagery in other sensory modalities (i.e., auditory, tactile, olfactory, etc.). Moreover, there is evidence that verbal information (without instructions to engage in mental imagery) can also strongly elicit emotional reactions (Costa, Bradley, & Lang, 2015; Mertens, Boddez, Sevenster, Engelhard, & De Houwer, 2018) and that (visual) mental images are related to, rather than independent of, (verbal) expectations and likelihood estimations (Carroll, 1978; Muse et al., 2010).

1.1.3.4. Irrelevant visual imagery. Another approach is to ask participants to engage in irrelevant mental imagery, such as imaging a cat meowing (Jones & Davey, 1990) or a car ride (Arabian, 1982). An advantage of this approach is that it controls for the general effects of engaging mental imagery and reduces the chances of spontaneous imagery of the relevant materials. A drawback is that it is an 'active' control condition that may produce certain effects (e.g., engaging in irrelevant positive imagery may reduce fear; Zbozinek, Holmes, & Craske, 2015), which can complicate the interpretation of effects relative to the experimental (relevant imagery) condition.

1.1.3.5. Actual stimulus administration. Finally, participants can be exposed to the actual stimulus they are asked to imagine in the experimental condition (e.g., Grégoire & Greening, 2019). A potential drawback is that the effects of mental imagery may generally be weaker than those of actual stimulus administration (Dadds et al., 1997). Hence, weaker effects in the mental imagery condition compared to the actual stimulus administration condition are expected. However, this does not necessarily imply that mental imagery had no effects. Therefore, it may be recommended to supplement this control condition with one of the other control conditions mentioned previously to establish whether mental imagery had any effects at all.

1.1.3.6. Conclusion regarding the control conditions for mental imagery. The choice of an appropriate control for mental imagery depends both on theoretical considerations (e.g., whether or not visual mental imagery is independent of verbal processing) and the potential interfering factors that one wants to control for (e.g., spontaneous mental imagery; experimental demand effects; habituation). A useful approach is to use multiple control conditions (e.g., no imagery and actual stimulus administration) to establish the robustness and generalizability of the effects of mental imagery across different conditions.

1.2. Previous work reviewed by Dadds et al. (1997) and introduction of the current review

Early research on the role of imagery in classical conditioning has been reviewed and integrated by Dadds et al. (1997). Of the reviewed studies, only four have focused specifically on fear conditioning (the others focused on conditioned nausea in chemotherapy, vestibular conditioning, and the habituation of orienting reflexes to novel stimuli). We have summarized the main findings of these four studies in Table 1. Based on the reviewed studies, Dadds et al. (1997) concluded that: "*The evidence suggests that mental imagery can facilitate or diminish the outcome of classical conditioning in humans and, more tentatively, that mental images can substitute for actual US and CS in autonomic conditioning*" (p. 89). However, of the available studies for fear conditioning, one did not include an appropriate control condition to assess the effect of visual mental imagery (Drummond, White, & Ashton, 1978), and another one did not include any measure of mental imagery (Yaremko & Werner, 1974) (see Table 1). As such, with addition of the study by Holzman and Levis (1991), the results of these initial studies can be considered to provide preliminary, but not conclusive, support for the idea that mental imagery can serve as a replacement for the actual administration of the CS and US. Additionally, the study of Jones and Davey (1990) provides initial support for the idea that mental imagery during an extinction procedure can maintain conditioned responses (as measured with skin conductance responses). Since the initial review of Dadds et al. (1997), more mental imagery studies have been published in which a fear conditioning procedure was used.

In the following sections, we provide an overview and updated review of the studies in which mental imagery was investigated within fear conditioning research since the review by Dadds et al. (1997). It is important to clarify that, within the context of clinical psychology and psychopathology, the focus of mental imagery is typically on *visual* mental imagery. This is most likely because the visual sensory modality is generally regarded as the most important sensory modality for humans (e.g., Ripley & Politzer, 2010). As such, nearly all of the studies we will review have focused on visual mental imagery (though some have also focused on tactile mental imagery; i.e., imagining an electric shock). However, imagery in other modalities (e.g., auditory, tactile, olfactory) can also be implicated in PTSD and other anxiety-related disorders (Engelhard, van den Hout, Arntz, & McNally, 2002; Hackmann, Ehlers, Speckens, & Clark, 2004).

2. Methods

To identify relevant studies, we conducted a systematic bibliographical search. Due to the heterogeneity in the methods, measures, and research questions (see below), we decided to refrain from quantitative analyses (e.g., a meta-analysis) and to provide a systematic review instead. PRISMA-guidelines were followed for the screening, selection, and presentation of relevant studies (Moher et al., 2015).

Table 1
Studies investigating the impact of mental imagery on fear conditioning reviewed by Dadds et al. (1997).

Reference	Imagery instructions	Control condition(s)	Mental imagery measure(s)	Main findings	Sample size
Drummond et al. (1978)	After an instructed (i.e., unreinforced) conditioning phase, participants were asked to imagine a shock whenever they heard a tone	NA	QUMI	Slower SCR habituation for participants with vivid imagery	14
Holzman and Levis (1991)	Half of the participants were asked to imagine a CS prior to the presentation of a shock (US): "*When I tell you to imagine one of the slides, I would like you to close your eyes and imagine that slide appearing.*"	Half of the participants saw actual visual CSs. The two groups (imagery, actual CSs) were further divided in unpaired and unreinforced groups	GTVI QUMI	A mentally imagined CS can become conditioned, though CRs were less strong compared to actual visual CSs. No correlation between imagery ability and imagery conditioning.	88
Jones and Davey (1990)	Participants were asked to think about a loud tone (imagine the tone and their reaction to it) from a first conditioning phase whenever the word 'think' was presented on the screen	Irrelevant (neutral) imagery: "*Think of a cat meowing when the word 'think' is presented.*" Irrelevant (aversive) imagery: "*Think of someone trying to stick a needle into your eye.*"	Post-experimental questionnaire about participants' hunches about the experiment and difficulty of the imagery task	Retention of conditioned SCRs in a test phase for the experimental group, but not for the neutral imagery or aversive imagery control conditions	24
Yaremko and Werner (1974)	After a delay or trace conditioning procedure (with a tone and a shock), half of the participants were asked to imagine the tone being immediately followed by the shock whenever the experimenter said the words 'tone … shock'	In two control conditions (one for delay and one for trace conditioning) participants were asked to separately imagine the tone and shock (i.e., no emphasis on their contiguity) whenever the experimenter mention the word 'tone' and 'shock' respectively	NA	Stronger SCRs to the tones in a test phase for the groups that were asked to imagine contiguous pairings of the tone and shock compared to the groups that were asked to imagine the tone and shock separately	40

Abbreviations: QUMI = Questionnaire Upon Mental Imagery; GTVI = Gordon Test of Visual Imagery; SCR = Skin Conductance Response; CR = Conditioned Response.

2.1. Search strategy

Three digital databases (PsycINFO, Pubmed, Embase) were used to search for relevant articles published between January 1st' 1995 and June 14th, 2019. The keywords selected for the search were split into two categories: Imagery and Conditioning. These subcategory keywords were connected with the boolean operator "OR", and the two subcategory search terms were merged with the boolean operator "AND". Keywords used for the search engines Embase, Pubmed, and PsycINFO were: image*, mental image*, mental representation*, cognitive representation*, imagery rescripting, intrusive image*, future thinking, counterfactual thinking, image processing, conditioning, classical conditioning, Pavlovian conditioning, respondent conditioning, associative learning, and association learning (truncation applied to include variations on image and representation such as imagery, images, and representations).[3] Additional relevant studies were identified through the reference list of relevant publications and by a prior search conducted by students on 13th April 2018 (using the same search terms, but including Thesaurus Map Terms in the PsycINFO database [imagery and conditioning] and Medical Subject Headings for PubMed [imagery, conditioning, classical conditioning, and association learning]). One additional relevant study was identified by a reviewer during the review process of this article. Fig. 1 provides an overview of the search strategy.

2.2. Screening process and study exclusion criteria

The identified studies were screened by the first author and a research assistant on the basis of their title and abstract to determine their potential relevance for our systematic review. Screening was done independently (using an online tool: https://rayyan.qcri.org/) and conflicts in identification were resolved through discussion. The full texts of 33 identified publications were further screened for final inclusion. Inclusions criteria were: (1) the use of a fear conditioning procedure; and (2) the use of an imagery manipulation or measure. An additional 13 publications were further excluded based on these criteria, resulting in a final selection of 20 publications (reporting 25 separate studies).

2.3. Data extraction and bias assessment

Data extraction focused on the posed research question, population, instructions for introducing mental imagery, control condition(s), mental imagery measures, type of CS and US, outcome measures, and sample size (based on the Population, Intervention, Comparator, and Outcome, or PICO framework; Huang, Lin, & Demner-Fushman, 2006). Data extraction was conducted by the first author (GM) and independently checked by the second author (AMK). Bias assessment focused on whether the studies included adequate control conditions and manipulation checks for the involvement of mental imagery (see Table 2 and the table in the Supplementary Materials).

3. Results

As discussed previously, the studies reviewed by Dadds et al. (1997) mostly focused on whether imagined stimuli can act as replacements for the actual administration of CSs and USs (with the exception of the study by Jones & Davey, 1990). In addition to this first research question, we identified three other thematic research questions in the selected studies: (1) Whether mental imagery can lead to fear inflation (derived from the fear incubation theory; see Eysenck, 1968); (2) Whether CSs can evoke visual mental images as conditioned responses; and (3) Whether conditioned fear responses can be reduced though mental imagery-based interventions. We will discuss the studies in relation to these four research questions. To illustrate the clustering of these research questions, we created a graphical network (using the "visNetwork" R package; Almende, Benoit, & Robert, 2019) of the cross-referencing of the included articles and 4 central theoretical papers relating to each of the research questions (see Fig. 2). This graph shows distinct clusters relating to the different research questions, with a central position for research on mental-imagery based interventions to reduce conditioned fear. Please note that this figure is not meant as a network analysis of this research area, but merely as a graphical illustration of the clusters of research on these four distinct research questions. Furthermore, Table 2 provides an overview of the included studies and their key procedural characteristics. A more detailed table can be found in the Supplementary Materials.

3.1. Mental images as replacement for actual stimuli

Similar to the main theme of the Dadds et al. (1997) review, many of the studies we identified examined whether mental imagery can substitute the actual administration of the CS, US, or CS-US contingency.[4] Regarding whether mental imagery of the CS can substitute the actual administration of the CS, four studies were identified. Particularly, Reddan et al. (2018) asked participants to imagine the CS+ and CS- to the best of their ability when they were cued following a fear conditioning phase with tones. No US was administered during this imagery phase. In two control conditions, participants were shown either actual unreinforced presentations of the CS+ and CS- or were asked to engage in irrelevant mental imagery when cued (i.e., imagine birds singing and rain falling). The authors observed comparable fear extinction (measured by skin conductance) in the imagery condition and the actual administration condition, but not in the irrelevant imagery condition. Furthermore, extinction in the relevant imagery and actual presentations conditions was predicted by activation in similar brain regions centered on the ventromedial prefrontal cortex, amygdala, and auditory cortex. However, nucleus accumbens activation exclusively predicted extinction success in the relevant imagery group. Similarly, Agren, Björkstrand, and Fredrikson (2017) and Grégoire and Greening (2019) found that mental imagery can induce extinction and interfere with memory reconsolidation, comparable to actual stimulus administration. Finally, in a study by Meulders, Harvie, Lorimer Moseley, and Vlaeyen (2015), participants saw pictures of hand movements (i.e., open hand or fist). They were asked to make left-right judgements of the hands, which requires motor imagery. Following the left-right judgement, one of the hand movements was paired with a mild electric shock. Meulders et al. (2015) observed conditioned fear and fear generalization to similar hand movements as indicated by subjective ratings, suggesting that mental motor imagery resulted in the acquisition of movement-related fear. However, due to the omission of an appropriate control condition in this study (e.g., no left-right judgement task), no firm conclusions about mental imagery can be drawn. An alternative explanation could be that the pictures rather than imagery of the hand movements became conditioned. These four studies

[3] PubMed search script: ((((((((((((("Image*") OR "Mental image*") OR "Mental representation*") OR "Cognitive representation*") OR "Intrusive image*") OR "Future thinking") OR "Counterfactual thinking") OR "Image processing")) AND ((((("Association learning") OR "Associative learning") OR "Respondent conditioning") OR "Pavlovian conditioning") OR "Classical conditioning") OR "Conditioning"))) Sort by: Best Match Filters: Publication date from 1995/01/01; Humans.

[4] Note though that some of these studies we describe in this section were motivated by the fear incubation theory rather than focused on investigating whether mental imagery can substitute for physical stimulus presentation (see Fig. 2). Nonetheless, we think that those studies are also relevant for the latter research question and therefore we already introduce these studies already here. A more detailed description of the fear incubation theory and the relevant research is provided in section 3.2.

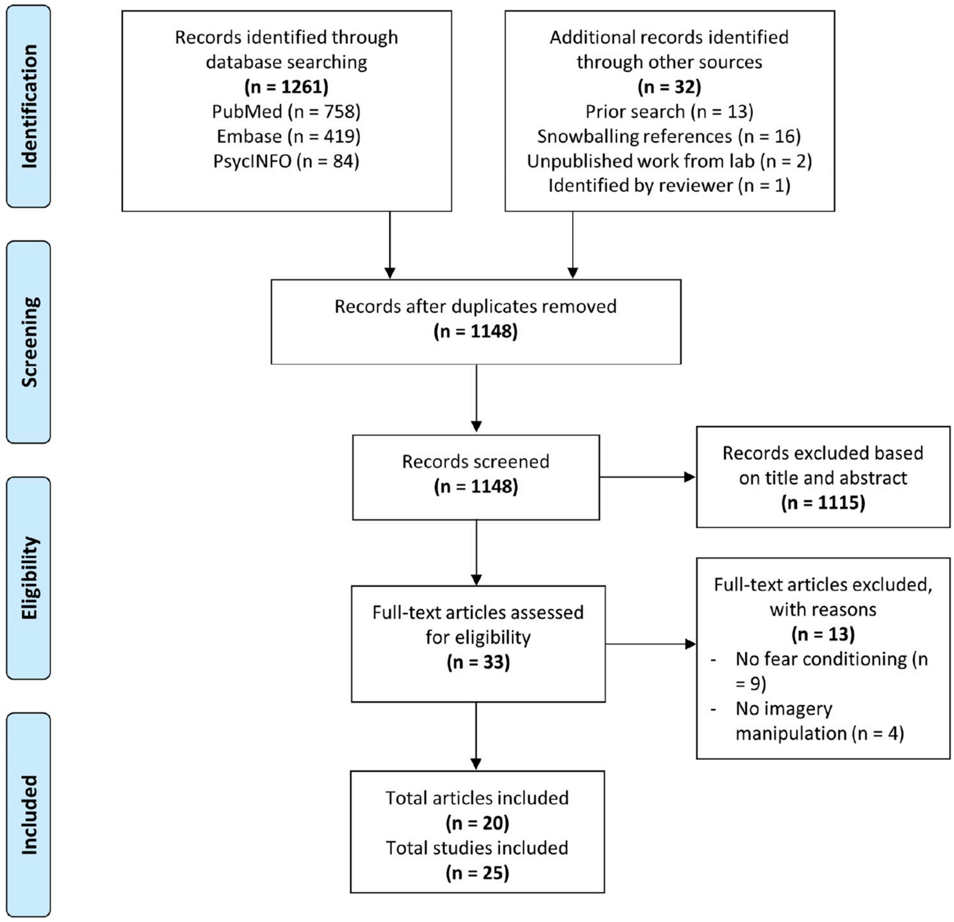

Fig. 1. Flowchart for the literature search.

thus provide some evidence that, following an acquisition phase with actual pairings of the CS and the US, mental imagery can substitute for actual CS administration in subsequent experimental phases (for related evidence in the context of evaluative conditioning, see Lewis, O'Reilly, Khuu, & Pearson, 2013).

Other studies have focused on imagination of the US. For instance, in the study of Mueller et al. (2019) participants were trained to imagine stepping on a thumbtack whenever they saw a particular geometric shape. This shape was subsequently paired with a neutral face as the CS. Their results indicated that the imagery cue elicited physiological defensive responding (i.e., skin conductance responses, increased heart rate), which suggests that participants did indeed engage in mental imagery of the US. Furthermore, conditioning by pairing CSs with the cues for mental imagery was observed using aversiveness ratings of the CS and heart rate acceleration, though not with skin conductance responses. They replicated the findings in a second study using different imagery instructions (i.e., imagine a shock). Similar findings that US imagery can replace actual US administration were found by Arntz, Spit, and Merckelbach (1997), Davey and Matchett (1994), and Krypotos, Mertens, Leer, and Engelhard (2019; Experiment 2).

Finally, two studies focused on the effects of mental imagery of the CS-US contingency (Joos, Vansteenwegen, & Hermans, 2012; Krypotos et al., 2019). In the study by Joos et al. (2012), participants first completed a conditioning phase with faces (CSs) and a loud noise and scream (USs), and then they were probed three times a day for a week to "*think back to the picture, the [scream/noise] and the relationship between them*" through text messages. They found that fear ratings were higher for the contingency that was mentally rehearsed, compared to the contingency (using the other US) that was not rehearsed, but only when the rehearsed US was a scream (and not the loud noise). Likewise, in a study from our lab (Krypotos et al., 2019; Experiment 1), participants were asked to imagine that a previously shown neutral CS (i.e., a blue square) was followed by a shock. Compared to a control condition (between-subjects) in which participants were asked to imagine the CS and a neutral tone, the experimental condition resulted in higher avoidance responses (i.e., pressing the spacebar to cancel US administration) in a subsequent test phase. The results of these studies suggest that mental imagery of the CS-US contingency can result in the installation (Krypotos et al., 2019) and preservation (Joos et al., 2012) of conditioned avoidance and fear responses.

3.2. Mental imagery and fear inflation

Some of the selected studies have been inspired by the fear incubation theory (Eysenck, 1968, 1979; McAllister & McAllister, 1967). According to the fear-incubation theory, offline processing of traumatic experiences may contribute to the development of pathological fear and anxiety, resulting in strengthened conditioned responses over time. Such offline processing may consist of repeatedly reactivating the memory of the US, the CS-US contingency, and/or the CS-CR contingency.

Several studies have examined these predictions using a fear conditioning paradigm. Particularly, the studies by Arntz et al. (1997), Davey and Matchett (1994), and Joos et al. (2012; described in the previous section) were inspired by the fear incubation theory. In the study by Arntz et al. (1997), participants were asked to engage in cue-induced mental imagery (i.e., "Every time when this mark is on the screen, you have to think of the stimulations you have just experienced and of how painful they were") following a conditioning phase with mild electric shocks as CS and a more intense electric shock as US. In

Table 2
Overview of the included studies and their procedural details.

Reference	CS type	US type	Type of imagery	Control condition (s)	Imagery measures	Outcome measure (s)	Main findings	Sample size
Agren et al. (2017)	Colored lamps	Shock	Imagine CS	AS	N/A	SCRs	Fear extinction & interference with fear memory reconsolidation	86
Arntz et al. (1997)	Mild electric stimulation	Painful shock	Imagine US	NI II AS	Custom ratings	SCRs	Slower SCR habituation.	72
Davey and Matchett (1994) Exp. 1	Geometric shapes	Loud noise	Imagine US	II	Custom ratings	SCRs	Stronger SCRs in the imagery group compared to controls.	40
Davey and Matchett (1994) Exp. 2	Geometric shapes	Loud noise	Imagine US	II	Custom ratings	SCRs	Stronger SCRs in the Imagine US group compared to controls.	42
Dibbets et al. (2012)	Pictures of vehicles	Picture of injured child	Rescript US	NI II	QUMI	SCRs US expectancy	Reduced return of fear with US expectancy in the Rescript US group compared to controls.	70
Dibbets et al. (2018)	Pictures of kitchen utilities	Aversive video	Rescript US	AS EM intervention	Custom ratings	SCRs US expectancy	Changed US representation in rescripting group but no between group differences.	105
Grégoire and Greening (2019)	Gabor patches	Shock	Imagine CS	NI	Custom ratings	SCR Fear ratings	Retrieval-induced facilitated extinction for the CS that was imagined.	19
Joos et al. (2012)	Faces	Loud tone Scream	Imagine CS-US contingency	II	Custom ratings	US expectancy Fear ratings	More persistent fear ratings in the imagery compared to control condition in terms of fear ratings.	33
Krypotos et al. (submitted) Exp. 1	Colored squares	Shock	Imagine the CS, the US, and the CS-US contingency	II	QUMI	Avoidance responses Expectancy ratings, Fear ratings	Avoidance responses for CS paired with imagery. Similar results for US expectancies.	66
Krypotos et al. (submitted) Exp. 2	Colored squares	Shock	Imagine US	II	QUMI Custom ratings	Avoidance responses US expectancies Fear ratings	No significant effects across all measures.	60
Kunze et al. (2019) Exp. 1	Faces	Aversive video	Rescript US	RO	Custom ratings	SCR FPS Distress rating	No effect on reinstatement on any measure.	61
Kunze et al. (2019) Exp. 2	Faces	Aversive video	Rescript US	NI Imagery inflation	Custom ratings	SCR FPS Distress rating Valence ratings	Reduced subjective CRs in the Rescript US group (but not for other measures).	66
Kunze et al. (2019) Exp. 3	Faces	Aversive video	Rescript US	NI RO	Custom ratings	FPS Distress rating Heart rate	Reduced differential FPS (but not other measures) in the Rescript US group compared to NI.	74
Landkroon et al. (2019)	Colored lamps	Aversive video	EM intervention	NI RO	Custom ratings	SCR FPS US expectancy	No significant differences in fear renewal for any measure.	75
Leer, Engelhard, Altink, et al. (2013)	Tones	Disgusting video	EM intervention	RO	Custom ratings	SCR Fear ratings	EM intervention reduced conditioned fear ratings. No differences for SCR.	63
Leer, Engelhard, Dibbets, et al. (2013)	Geometric shapes	Aversive IAPS picture	EM intervention	RO	Custom ratings	SCR FPS US expectancy	Reduced renewal of US expectancy in EM condition. No between group differences in FPS.	80
Meulders et al. (2015)	Hand movement	Shock	Imagine CS	N/A	N/A	FPS Attentional bias US expectancy Fear ratings	Generalization gradients for unpaired GSs with fear and US expectancy ratings.	50
Mueller et al. (2019) Exp. 1	Faces	Stepping on thumbtack	Imagine US	NI II	Defensive physiological responses	SCR CS ratings Heart rate	Differential conditioning for ratings and heart rate. No effects for SCR.	45
Mueller et al. (2019) Exp. 2	Faces	Shock	Imagine US	NI II	Defensive physiological responses	FPS CS ratings Heart rate	Differential conditioning for ratings and FPS; no effect for heart rate.	41

(*continued on next page*)

Table 2 (*continued*)

Reference	CS type	US type	Type of imagery	Control condition (s)	Imagery measures	Outcome measure (s)	Main findings	Sample size
Rattel et al. (2019)	Neutral sounds	Aversive films	Intrusive memories	CS unpaired with US	Custom ratings IMQ	SCR CS ratings Number of intrusions	Intrusions elicited by CS + presentations, especially for female participants.	122
Reddan et al. (2018)	Tones	Shock	Imagine CS	AS II	fMRI activation	SCRs fMRI activation	Extinction of conditioned SCRs due to CS imagery.	68
Streb et al. (2017)	Neutral sounds	Aversive film	Intrusive memories	CS unpaired with US	PANAS Physiological arousal IMQ	SCL Heart rate Number of intrusions	Conditioned intrusions after conditioning and one week later.	48
Toumbelekis et al. (2018)	Colored squares	Shock	Imagine attachment figure	II	VVIQ Custom ratings	FPS US expectancy	Less differential FPS in the experimental group compared to the control group. No differences for US expectancy.	61
Wegerer et al. (2013)	Neutral sounds	Aversive film	Intrusive memories	CS unpaired with US	IMQ	SCRs Number of intrusions	Conditioned intrusive mental images during a 1-week follow-up.	66
Zbozinek et al. (2015)	Facial images	Scream Shock	Positive mental visual imagery	VI	PANAS Custom ratings	FPS Fear ratings	More positive affect and less startle and fear ratings in the positive mental imagery group.	94

List of abbreviations: CS = conditioned stimulus; US = unconditioned stimulus; NI = no imagery; II = irrelevant imagery; AS = actual stimulus; RO = recall only; VI = verbal imagery; SCR = skin conductance response; FPS = fear potentiated startle; IAPS = international affective picture system; QUMI = Questionnaire Upon Mental Imagery; VVIQ = Vividness of Visual Imagery Questionnaire; IMQ = Intrusion Memory Questionnaire; PANAS = positive and negative affect scale.

several conditions, participants either received actual US administrations, had to engage in irrelevant pain imagery, or did not receive any intervention. In a subsequent extinction phase, the US imagery group demonstrated heightened SCRs compared to the actual US administration group and the no intervention group (but not compared to the irrelevant mental imagery group). Similarly, in the studies by Davey and Matchett (1994), participants were asked to imagine the US following a conditioning phase with a loud tone (115 dB) as the US and neutral picture as the CSs (i.e., "whenever you see the word *think* on the screen you must try and imagine the loud tone presented in Stage 1 and your reactions to it as vividly as you can"). In a control condition, participants were asked to engage in irrelevant mental imagery (i.e., "think about a cat meowing and reactions to it"). In a subsequent test phase, participants who had to mentally rehearse the US showed stronger SCRs to the CS + compared to participants in the control condition, but this effect was specific for participants high in trait anxiety. This result was confirmed in a second experiment in which the effect of mental US rehearsal was obtained only for participants who had underwent a somatic worrying induction. Overall, these results partially support the fear incubation theory. However, no clear evidence has been obtained so far that the effect is specific to mental imagery of the US rather than unpleasant imagery generally (see Arntz et al., 1997) and the effects of the mental imagery intervention seem to dissipate quickly with subsequent unreinforced CS exposures (see Davey & Matchett, 1994). These latter findings fit less well with predictions of fear incubation theory.

3.3. Visual mental images as conditioned responses

According to the 'warning signal hypothesis' (Ehlers & Clark, 2000; Ehlers et al., 2002), intrusive memories are concerned with stimuli (e.g., sounds, odors) that were present immediately before or during a traumatic event and signal impeding danger, which results in a sense of current threat. This hypothesis indicates that intrusive memories are a reflection of an associative learning experience (i.e., the pairing of neutral cues and a traumatic experience) and may thus be expected to also occur as a result of a fear conditioning procedure. So far, three studies have investigated this hypothesis. In an innovative fear conditioning study, Wegerer et al. (2013) induced involuntary memory of a US. Participants were exposed to a violent video clip (US) while they heard an auditory CS (i.e., a clock ticking or a typewriter) in the background. In a subsequent memory triggering task, participants heard either the CS+, CS-, or no CS while they listened to neutral background soundscapes (e.g., shopping mall). Assessments using an intrusion memory questionnaire indicated that participants reported more, longer, and more distressing mental images (i.e., intrusions) related to the US when they were exposed to the soundscape including the CS + than when they were exposed to the soundscape with either the CS- or no CS.

Two recent studies (Rattel et al., 2019; Streb, Conway, & Michael, 2017) extended these findings by Wegerer et al. (2013) using a similar paradigm. Streb et al. (2017) found that a CS (clock ticking or train passing by) paired with a traumatic film tended to elicit intrusive memories even up to one week after the acquisition phase. Rattel et al. (2019), using the same paradigm as Wegerer et al. (2013; partly overlapping sample), found that women, compared to men, displayed a higher frequency and more distressing intrusions in response to the presentation of the CS paired with the film clips, both immediately after the acquisition phase and during an ambulatory assessment. These sex differences were mediated by stronger responses to the traumatic films, stronger evaluative conditioning, delayed extinction, and larger state anxiety increases in women. These three studies indicate that a fear conditioning procedure can install distressing and persistent mental images (i.e., intrusive memories), particularly in women.

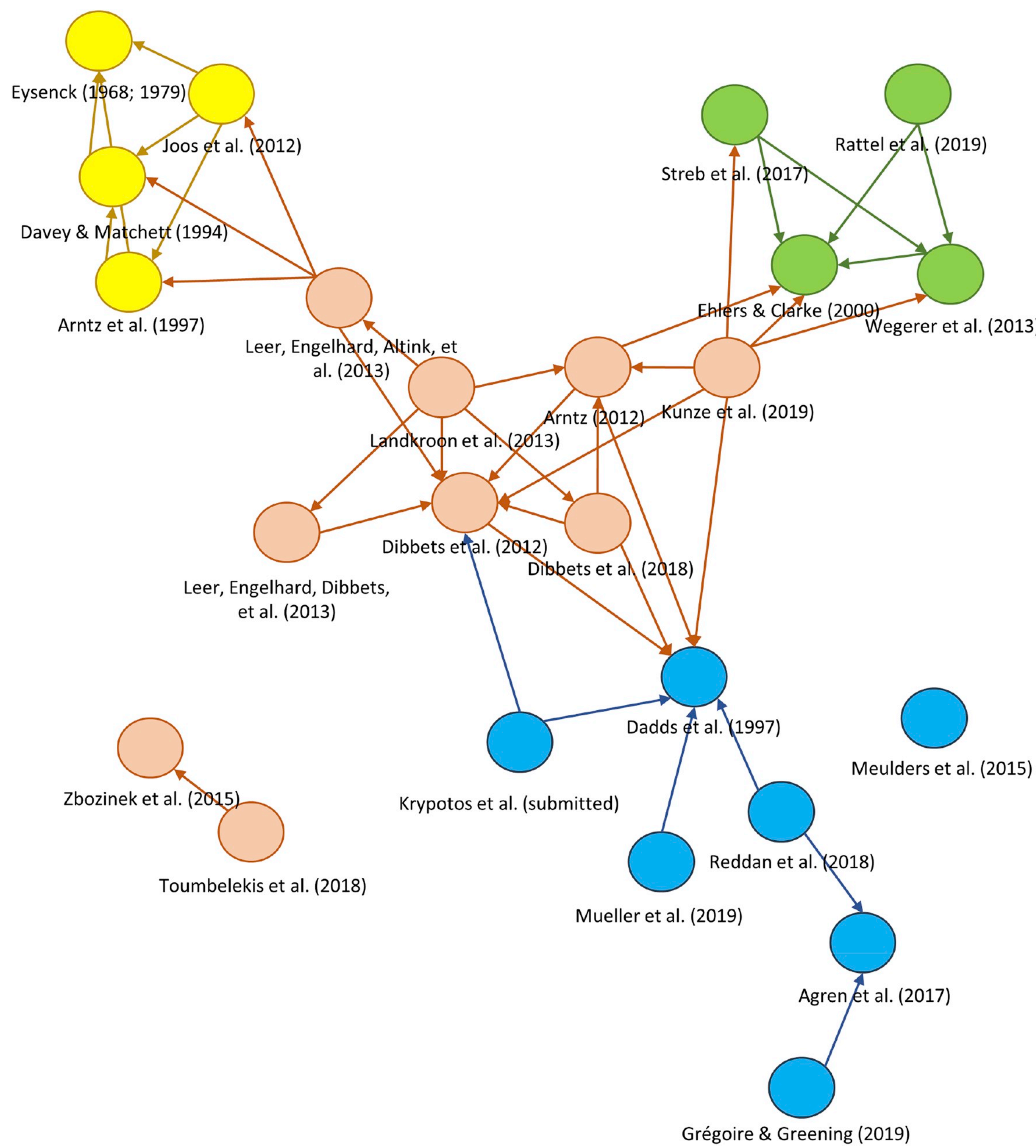

Fig. 2. Network graph of the articles included in this review and four central theoretical papers (i.e., Arntz, 2012; Dadds et al., 1997; Ehlers & Clark, 2000; Eysenck, 1968; 1979). Colors refer to the main research question we identified (blue: mental images as replacement for actual stimuli; green: visual mental images as conditioned responses; red: reduction of conditioned responses through mental imagery-based interventions; yellow: mental imagery and fear inflation). Articles (nodes) at the beginning of each arrow (edge) included the article at the end of the arrow in its reference list. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.4. Reduction of conditioned responses through mental imagery-based interventions

Several lab studies have addressed whether mental imagery can reduce conditioned fear responses. A first approach used a laboratory model of the imagery rescripting intervention (Arntz, 2012; Morina et al., 2017). Particularly, in a study by Dibbets, Poort, and Arntz (2012), participants saw a picture of an injured child as the US and of vehicles as the CSs, and they were told before conditioning to imagine that the child got injured in an accident with one of the CSs. During the rescripting intervention, participants were asked to imagine that the child got saved and recovered after the accident. Dibbets et al. (2012) found that this intervention reduced return of fear after successful extinction, as measured with US expectancy ratings (compared to a no-intervention group and an irrelevant imagery group). Similarly, in Dibbets et al. (2018), participants were exposed to a video clip in which a woman gets visibly burned in the face during a kitchen accident. This video clip (US) was paired with kitchen utensils as CSs. In the imagery rescripting intervention, participants were asked to imagine that they were able to help the woman and that she recovered from her burns after treatment in the hospital. This intervention was compared with an extinction intervention (i.e., unreinforced CS trials) and an eye-movement intervention (see below). All three interventions were successful at reducing US representation ratings (i.e., the amount of details and vividness, evoked tension and averseness, and experienced negativity). However, the extinction intervention was the most effective of the different conditions to reduce conditioned skin conductance responses and US expectancy ratings. Finally, in a series of three studies by Kunze, Arntz, and Kindt (2019), participants were asked to rescript the content of a visual US (clips from the film 'Salo', or the 12 Days of Sodom') used in a prior conditioning phase in which the face of the main character served as the CS. Specifically, participants were asked to imagine a more satisfying storyline for the US (e.g., image that the scene was merely a fake movie) freely (Experiment 1) or using a standardized rescripting intervention (Experiments 2–3). The effects of this intervention were compared to a condition in which participants merely had to imagine the US (Experiments 1 and 3) or against an imagery inflation intervention (Experiment 2). Some aspects of the results of Kunze et al. (2019) indeed indicated that the interventions could reduce the intensity of the US memory and subjective distress to the CS. However, the authors note that further steps need to be taken to make the rescripting intervention more powerful and to assess its effects against suitable control conditions.

Another approach to reduce conditioned responses using an imagery-based intervention makes use of a lab model of the eye movement component of EMDR therapy (Shapiro & Forrest, 2016). Particularly, in a series of studies by Leer and colleagues (Leer, Engelhard, Altink, et al., 2013; Leer, Engelhard, Dibbets, & van den Hout, 2013) and Landkroon, Mertens, and Engelhard (2019), participants were asked to recall the memory of a visual US while they made lateral eye-movements after a conditioning phase with the visual US (i.e., an unpleasant IAPS picture or an unpleasant film clip). There is a considerable amount of research suggesting that such an intervention can reduce the vividness and emotional intensity of emotional memories (Engelhard et al., 2019; Lee & Cuijpers, 2013), and therefore it was expected that this intervention would reduce the intensity of the US memory and, consequently, reduce CRs. No consistent effects were found for psychophysiological measures of fear, but this intervention did indeed attenuate the US memory (Landkroon et al., 2019; Leer, Engelhard, Altink, et al., 2013), and reduced conditioned subjective ratings (Leer, Engelhard, Altink, et al., 2013) and the return of fear after a context switch (Leer, Engelhard, Altink, et al., 2013). However, return of fear one day later was not significantly reduced in the study of Landkroon et al. (2019). So, there is evidence that the eye-movements approach may be used to reduce conditioned fear (assessed with subjective measures) at least temporarily, but more studies with long-term follow-up tests are needed.

A third approach using a mental imagery intervention to reduce conditioned fear responses was reported by Toumbelekis, Liddell, and Bryant (2018). Particularly, in their procedure, participants were asked to think of an attachment figure prior to a fear conditioning phase with colored squares as CSs and an electric shock as the US. Compared to a control condition in which participants had to think about a hypothetical situation that would make them feel happy (only involving themselves), thinking of an attachment figure resulted in reduced differential fear potentiated startle responses (but not US expectancy ratings), and this difference between the conditions was maintained in a 48h follow-up test. Hence, this study provides preliminary support for the idea that thinking of an attachment figure can reduce the acquisition of conditioned startle responses.

Finally, in a study by Zbozinek et al. (2015) a mental imagery mood induction was used with the aim of reducing return of fear. This hypothesis was based on the idea that lingering negative valence after an extinction intervention facilitates the return of fear (Dirikx, Hermans, Vansteenwegen, Baeyens, & Eelen, 2004). In the intervention, participants were asked to imagine positive scenarios (e.g., "*It's your birthday, and your partner reaches over to you with a present. You open it and feel incredibly happy*"). Compared to a positive verbal training condition, positive imagery training resulted in more positive affect, reduced negative CS + evaluation, and reduced the return of fear as measured by startle responses and fear ratings. This study indicates that a mental imagery mood induction may be used to reduce conditioned fear responses and counter the return of fear.

4. Discussion

The current systematic review provided an update of studies on mental imagery in human fear conditioning since the publication of the review by Dadds et al. (1997). Based on a systematic search, 20 articles (reporting 25 studies) were identified that focused on the role of mental imagery within fear conditioning. These studies were centered around four thematic research questions: (1) Whether mental imagery can replace the actual administration of CSs and USs; (2) Whether mental imagery can lead to conditioned fear inflation; (3) Whether CSs can evoke visual mental images; and (4) Whether conditioned fear responses can be reduced through mental imagery-based interventions.

For each of these questions, some confirmatory evidence has been found. However, there is substantial heterogeneity in the procedures, measures of mental imagery, and control conditions (see Table 2 and the Supplementary Materials), complicating any direct comparison between the studies. Furthermore, the available evidence for each of the 4 different research questions is currently based on a limited number of available studies and for some of them relevant control conditions and manipulation checks are missing (see Table 2). In the next few paragraphs, we will discuss several theoretical models, methodological considerations, and open questions that could guide the further development of research in this field.

4.1. Integration with theoretical models

The results of the reviewed studies validate the view that looking at the mental level of analysis can yield additional insights compared to restricting oneself to the observable elements of the procedure. That is, mental images can be part of the conditioned response, and can be a replacement for the actual administration of the CS, US, and CS-US contingencies. Furthermore, considering the potential implication of mental images in the incubation and preservation of fear, and its promising role in therapeutic interventions, we argue that mental imagery should be considered as an indispensable level of analysis in fear conditioning research. This, however, does not imply that the goals of the behaviorists to focus on observable, and therefore verifiable, behaviors need to be given up. That is, the functional approach of behaviorists to link elements in the environment to behavior and the cognitive approach of studying mental processes that mediate such behavioral effects are complementary and mutually informative (De Houwer, 2011). Therefore, they can be studied simultaneously as long as researchers distinguish between the procedure and effects on the one hand (what needs to be explained) and the hypothesized cognitive processes (which provide the explanation) on the other hand (De Houwer, 2011; Hermans et al., 2018).

Speculating on the function of mental imagery in fear conditioning, mental images can be seen, just as other commonly observed conditioned fear responses, as preparatory reactions to an upcoming aversive stimulus. That is, mentally imagining an upcoming US or an intrusive memory of an earlier aversive event may indicate impending danger and help in taking appropriate action in dealing with the US. Thus, mental imaging may serve an important anticipatory function (as a 'warning signal'; Ehlers et al., 2002), just like other conditioned responses (e.g., sexual arousal; salivation) have been argued to prepare for upcoming USs (e.g., sexual intercourse; food intake) (see Domjan, 2005). In fact, other commonly observed conditioned responses in the context of fear conditioning (e.g., skin conductance responses, potentiated startle responses, accelerated heart rate) may be seen as the consequence of this anticipation of the US (Davey, 1992; Fanselow & Pennington, 2017; Lovibond, 2011). Such models with a central mediating role of the mental US representation are central to contemporary models of classical conditioning (Hosoba, Iwanaga, & Seiwa, 2001; Rescorla, 1988).

However, the function of mental imagery in fear conditioning may extend beyond mere anticipation of and preparation for the US.

Specifically, mental imagery is proposed to be a constructive process for developing mental representations of possible future scenarios based on previous (conditioning) experiences (Schacter, Addis, & Buckner, 2007; Schacter et al., 2012). This feature of mental imagery has clear evolutionary advantages because it allows us to prepare for possible future situations beyond those previously encountered. This idea is supported by some of the studies included in this review. Particularly, several studies demonstrated that mental imagery can install fear responses even when no physical stimuli have been directly paired (Krypotos et al., 2019; Lewis et al., 2013; Mueller et al., 2019). Furthermore, several studies showed that mental revaluation of the US can result in the spontaneous inflation of conditioned responses (Davey & Matchett, 1994; Gazendam & Kindt, 2012; Joos et al., 2012). Hence, in the absence of any direct experience, mental imagery can both instill and strengthen CRs.

Taken together, mental imagery within fear conditioning seems to be related to the anticipation of and preparation for the occurrence of the US, and allows us to extend conditioned responses to stimuli, situations, and contexts that have not been previously experienced. This fits well with theories of classical conditioning according to which conditioned responses are the result of the generation of expectations about an upcoming US (Davey, 1992; Lovibond, 2011; Mertens, Boddez, et al., 2018; Reiss, 1980). A similar conclusion was recently reached by Ji et al. (2016) in their review on mental imagery: "*These contemporary accounts view mental imagery as a core component of the "prospective brain," which enables the simulation of hypothetical future events based on prior knowledge and memories of past experience for the purposes of prediction and planning*" (p. 703). This conclusion also fits nicely with Bayesian models of learning and predictive coding theory, according to which individuals form predictions about the outside world, based on their prior experiences (Bubic, von Cramon, & Schubots, 2010; Kruschke, 2008) and which have recently been used to develop computational models to understand the symptoms of mental disorders (Adams, Huys, & Roiser, 2015).

4.2. Limitations, open questions and future directions

A first main limitation of our systematic review is that only 25 studies fitted our inclusion criteria, addressing the four different research questions. Due to this limited number and the lack of methodological standardization, we restricted ourselves to a qualitative assessment of the available studies, rather than using a quantitative approach (e.g., using meta-analytical tools). A second limitation is that we largely limited ourselves to giving a descriptive overview of these studies. A thorough quality assessment was not possible as there are currently no generally accepted methodological standards on how to optimally manipulate and control for mental imagery in conditioning studies (though a lack of any control condition or mental imagery measure was noted for the reviewed studies and is indicated in Table 2). A third limitation is that the protocol of our review was not registered on a public repository (e.g., Prospero). Therefore, it is possible that our conclusions are unintentionally biased. However, this risk was partly mitigated by having the literature selection and data extraction independently checked.

Despite the low number of selected studies, our review shows that for each of the four questions, tentative confirmatory evidence has been found. The studies strongly suggest that integrating the research areas of mental imagery and fear conditioning can advance our understanding of the etiology and treatment of anxiety-related disorders. Therefore, it seems critical that more research will be conducted that brings these fields together. Given the methodological heterogeneity of the reviewed studies, more research will have to clarify what optimal control conditions for mental imagery are and what measures of imagery are optimal as a manipulation check. It also remains unclear whether mental imagery constitutes a unitary construct, and it is difficult to compare studies utilizing different control conditions and mental imagery measures. Large scale initiatives are needed to provide insights in the differences between the various control conditions for imagery and how inter-individual differences in mental imagery are related to subjective, behavioral, psychophysiological, and neural aspects of fear conditioning.

Another direction for future research is to pinpoint the learning principles underlying the reported effects. To illustrate, some of the imagery effects could be explained by fear generalization (i.e., the spread-out of CRs from a CS + to similar stimuli; Dymond, Dunsmoor, Vervliet, Roche, & Hermans, 2015), second-order conditioning (i.e., the conditioning of a CS through its pairing with another CS that has been previously paired with the US; Davey & Arulampalam, 1982) or effects of verbal instructions (i.e., installation of CRs via mere verbal information about CS-US contingencies; Mertens, Boddez, et al., 2018). For example, in the study by Joos et al. (2012) in which participants were probed to think back about the relationship between the CS and the US, mentally rehearsing the CS may have allowed for an easier generalization (possibly due to a better maintained representation of the CS) of learned fear from the first day to the testing session a week later. Likewise, in the studies by Mueller et al. (2019), where participants had to imagine an aversive image (e.g., stepping on a thumbtack) after being presented a shape and then that shape was paired with a neutral face, the observed fear responses for the face could be explained by second order conditioning of the face with the, now aversive, shape. These potential alternative explanations of the reported effects show that plenty of work needs to be done before we reach a theoretical consensus on mental imagery in fear conditioning. Further investigation is also needed for the prediction that specifically sensory-perceptual mental imagery elicits strong emotional reactions compared to verbal processing, a prediction that has been made by several researchers (Holmes & Mathews, 2010; Lang, 1979; J.; Pearson, Naselaris, Holmes, & Kosslyn, 2015). Within the fear conditioning literature on mental imagery, this hypothesis has not received much attention. Only one study has investigated this hypothesis using an appropriate control condition (i.e., verbal imagery) (Zbozinek et al., 2015) and another study demonstrated that verbal-based worrying (rather than mental imagery) can lead to the strengthening of conditioned fear responses (Gazendam & Kindt, 2012).

Another important direction for future studies is testing whether mental imagery ability is a stable inter-individual trait (Andrade et al., 2014; D. G.; Pearson et al., 2013) that predicts the development and maintenance of conditioned fear or intrusions in the lab. According to contemporary fear conditioning models, the intensity of learned fear is not just determined by threat expectancy but also by threat intensity. That is, a CS that signals low probability and intense threat can still elicit strong fear (e.g., the fear that a plane will crash) (Vervliet et al., 2013). Perhaps individuals with high mental imagery ability develop US representations that elicit more fear or could more easily imagine a (low probability) CS-US contingency. Likewise, mental imagery ability could predict the effectiveness of mental imagery interventions to reduce acquired fear. Of the reviewed studies here, only four included measures of trait imagery (see Table 2). Of these, only Dibbets et al. (2012) included trait imagery as a factor in the statistical models. They found no differences regarding effects of the imagery rescripting intervention among participants scoring 'good', 'moderate', or 'poor' on their trait mental imagery ability. Given that these are the results of a single study, the hypothesis that trait mental imagery ability matters for imagery-based interventions requires additional empirical evaluation.

Last but not least, a substantial minority of patients with anxiety-related disorders benefit insufficiently from exposure-based therapy and it remains unclear whether mental imagery-based interventions can enhance treatment effects. For instance, recent studies have found that patients who show reduced fear extinction in a fear conditioning task before treatment benefit less from exposure-based therapy (e.g., Geller et al., 2019). An important area for future lab research would be to test whether mental imagery based interventions promote approach behavior that is needed for exposure therapy and whether individuals who show reduced extinction learning benefit from interventions that target the emotionality of threat memories by pharmacological methods (Elsey, Van Ast, & Kindt, 2018) or by using mental imagery interventions, such as imagery rescripting or EMDR. Such studies may provide insights that help in the development of more individualized and more successful therapy strategies for individuals with anxiety-related disorders.

5. Conclusions

In this systematic review, we evaluated research addressing the role of mental imagery and mental images in human fear conditioning. Overall, the results of these studies fit with earlier conditioning research pointing towards the importance of the anticipation of future threat events and the mental representations thereof. In contrast to the strict behaviorist approach advocated by John Watson, and of which the Little Albert study was a case example, we conclude that it is important to consider the role of unobservable phenomena, such as mental imagery, to come to a full understanding of the processes involved in the fear conditioning procedure and to further expand the potency of this paradigm to understand the development, maintenance, and treatment of fear.

Declaration of competing interest

The authors declare no conflict of interest. The funder did not have any involvement in the planning, execution, or write-up of this review.

Acknowledgements

This work was supported by a VICI grant (453-15-005) awarded to Iris Engelhard by the Netherlands Organization for Scientific Research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2020.103556.

References

Articles included in the review.

Adams, R. A., Huys, Q. J. M., & Roiser, J. P. (2015). Computational psychiatry: Towards a mathematically informed understanding of mental illness. *Journal of Neurology, Neurosurgery & Psychiatry, 87*(1), https://doi.org/10.1136/jnnp-2015-310737 jnnp-2015-310737.

*Agren, T., Björkstrand, J., & Fredrikson, M. (2017). Disruption of human fear reconsolidation using imaginal and in vivo extinction. *Behavioural Brain Research, 319*, 9–15. https://doi.org/10.1016/j.bbr.2016.11.014.

Allbutt, J., Ling, J., Heffernan, T. M., & Shafiullah, M. (2008). Self-report imagery questionnaire scores and subtypes of social-desirable responding. *Journal of Individual Differences, 29*(4), 181–188. https://doi.org/10.1027/1614-0001.29.4.181.

Almende, B. V., Benoit, T., & Robert, T. (2019). *visNetwork: Network Visualization using "vis.js" Library.* Retrieved from http://datastorm-open.github.io/visNetwork/.

Anderson, C. M., Hawkins, R. P., Freeman, K. A., & Scotti, J. R. (2000). Private events: Do they belong in a science of human behavior? *The Behavior Analyst, 23*(1), 1–10. https://doi.org/10.1007/BF03391995.

Andrade, J., Kavanagh, D., & Baddeley, A. (1997). Eye-movements and visual imagery: A working memory approach to the treatment of post-traumatic stress disorder. *British Journal of Clinical Psychology, 36*(2), 209–223. https://doi.org/10.1111/j.2044-8260.1997.tb01408.x.

Andrade, J., May, J., Deeprose, C., Baugh, S.-J., & Ganis, G. (2014). Assessing vividness of mental imagery: The Plymouth sensory imagery questionnaire. *British Journal of Psychology, 105*(4), 547–563. https://doi.org/10.1111/bjop.12050.

Arabian, J. M. (1982). Imagery and pavlovian heart rate decelerative conditioning. *Psychophysiology, 19*(3), 286–293. https://doi.org/10.1111/j.1469-8986.1982.tb02565.x.

Arntz, A. (2012). Imagery rescripting as a therapeutic technique: Review of clinical trials, basic studies, and research agenda. *Journal of Experimental Psychopathology, 3*(2), https://doi.org/10.5127/jep.024211 jep.024211.

*Arntz, A., Spit, S., & Merckelbach, H. (1997). Cued UCS rehearsal and the impact of painful conditioned stimuli: UCS rehearsal increases SCRs but reduces experienced pain. *Behaviour Research and Therapy, 35*(7), 591–605. https://doi.org/10.1016/S0005-7967(97)00020-X.

Baddeley, A. D. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology, 63*(1), 1–29. https://doi.org/10.1146/annurev-psych-120710-100422.

Baddeley, A. D., & Andrade, J. (2000). Working memory and the vividness of imagery. *Journal of Experimental Psychology: General, 129*(1), 126–145. https://doi.org/10.1037/0096-3445.129.1.126.

Ball, S. C., & Brewin, C. R. (2012). The effect of rumination on intrusive images and mood: An experimental investigation using the trauma film paradigm. *Journal of Experimental Psychopathology, 3*(2), 297–309. https://doi.org/10.5127/jep.019511.

Beckers, T., Krypotos, A.-M., Boddez, Y., Effting, M., & Kindt, M. (2013). What's wrong with fear conditioning? *Biological Psychology, 92*(1), 90–96. https://doi.org/10.1016/j.biopsycho.2011.12.015.

Berntsen, D. (2009). *Involuntary autobiographical memories: An introduction to the unbidden past.* Cambridge, England: Cambridge University Press.

Brewin, C. R., Gregory, J. D., Lipton, M., & Burgess, N. (2010). Intrusive images in psychological disorders: Characteristics, neural mechanisms, and treatment implications. *Psychological Review, 117*(1), 210–232. https://doi.org/10.1037/a0018113.

Bubic, A., von Cramon, Y. D., & Schubots, R. I. (2010). Prediction, cognition and the brain. *Frontiers in Human Neuroscience, 4*(March), 1–15. https://doi.org/10.3389/fnhum.2010.00025.

Camos, V. (2017). Domain-specific versus domain-general maintenance in working memory. *Progress in brain research: Vol.232*, (pp. 135–171). Elsevier Ltd. https://doi.org/10.1016/bs.plm.2017.03.005.

Campos, A., & Pérez-Fabello, M. J. (2005). The Spanish version of betts' questionnaire upon mental imagery. *Psychological Reports, 96*(1), 51–56. https://doi.org/10.2466/pr0.96.1.51-56.

Carroll, J. S. (1978). The effect of imagining an event on expectations for the event: An interpretation in terms of the availability heuristic. *Journal of Experimental Social Psychology, 14*(1), 88–96. https://doi.org/10.1016/0022-1031(78)90062-8.

Cole, S. N., Staugaard, S. R., & Berntsen, D. (2016). Inducing involuntary and voluntary mental time travel using a laboratory paradigm. *Memory & Cognition, 44*(3), 376–389. https://doi.org/10.3758/s13421-015-0564-9.

Costa, V. D., Bradley, M. M., & Lang, P. J. (2015). From threat to safety: Instructed reversal of defensive reactions. *Psychophysiology, 52*(3), 325–332. https://doi.org/10.1111/psyp.12359.

Cui, X., Jeter, C. B., Yang, D., Montague, P. R., & Eagleman, D. M. (2007). Vividness of mental imagery: Individual variability can be measured objectively. *Vision Research, 47*(4), 474–478. https://doi.org/10.1016/j.visres.2006.11.013.

Cuthbert, B. N., Lang, P. J., Strauss, C., Drobes, D., Patrick, C. J., & Bradley, M. M. (2003). The psychophysiology of anxiety disorder: Fear memory imagery. *Psychophysiology, 40*(3), 407–422. https://doi.org/10.1111/1469-8986.00043.

Dadds, M. R., Bovbjerg, D. H., Redd, W. H., & Cutmore, T. R. H. (1997). Imagery in human classical conditioning. *Psychological Bulletin, 122*(1), 89–103. https://doi.org/10.1037/0033-2909.122.1.89.

Davey, G. C. L. (1992). An expectancy model of laboratory preparedness effects. *Journal of Experimental Psychology: General, 121*(1), 24–40. https://doi.org/10.1037/0096-3445.121.1.24.

Davey, G. C. L., & Arulampalam, T. (1982). Second-order 'fear' conditioning in humans: Persistence of CR2 following extinction of CR1. *Behaviour Research and Therapy, 20*(4), 391–396. https://doi.org/10.1016/0005-7967(82)90099-7.

*Davey, G. C. L., & Matchett, G. (1994). Unconditioned stimulus rehearsal and the retention and enhancement of differential "fear" conditioning: Effects of trait and state anxiety. *Journal of Abnormal Psychology, 103*(4), 708–718. https://doi.org/10.1037/0021-843X.103.4.708.

De Houwer, J. (2011). Why the cognitive approach in psychology would profit from a functional approach and vice versa. *Perspectives on Psychological Science, 6*(2), 202–209. https://doi.org/10.1177/1745691611400238.

*Dibbets, P., Lemmens, A., & Voncken, M. (2018). Turning negative memories around: Contingency versus devaluation techniques. *Journal of Behavior Therapy and Experimental Psychiatry, 60*(December 2017), 5–12. https://doi.org/10.1016/j.jbtep.2018.02.001.

*Dibbets, P., Poort, H., & Arntz, A. (2012). Adding imagery rescripting during extinction leads to less ABA renewal. *Journal of Behavior Therapy and Experimental Psychiatry, 43*(1), 614–624. https://doi.org/10.1016/j.jbtep.2011.08.006.

Dirikx, T., Hermans, D., Vansteenwegen, D., Baeyens, F., & Eelen, P. (2004). Reinstatement of extinguished conditioned responses and negative stimulus valence as a pathway to return of fear in humans. *Learning & Memory, 11*(5), 549–554. https://doi.org/10.1101/lm.78004.

Domjan, M. (2005). Pavlovian conditioning: A functional perspective. *Annual Review of Psychology, 56*(1), 179–206. https://doi.org/10.1146/annurev.psych.55.090902.141409.

Drummond, P., White, K., & Ashton, R. (1978). Imagery vividness affects habituation rate. *Psychophysiology, 15*(3), 193–195. https://doi.org/10.1111/j.1469-8986.1978.tb01362.x.

Dunsmoor, J. E., & Kroes, M. C. (2019). Episodic memory and pavlovian conditioning: Ships passing in the night. *Current Opinion in Behavioral Sciences, 26*, 32–39. https://doi.org/10.1016/j.cobeha.2018.09.019.

Dymond, S., Dunsmoor, J. E., Vervliet, B., Roche, B., & Hermans, D. (2015). Fear generalization in humans: Systematic review and implications for anxiety disorder research. *Behavior Therapy, 46*(5), 561–582. https://doi.org/10.1016/j.beth.2014.10.001.

Ehlers, A., & Clark, D. M. (2000). A cognitive model of posttraumatic stress disorder. *Behaviour Research and Therapy, 38*(4), 319–345. https://doi.org/10.1016/S0005-7967(99)00123-0.

Ehlers, A., Hackmann, A., Steil, R., Clohessy, S., Wenninger, K., & Winter, H. (2002). The nature of intrusive memories after trauma: The warning signal hypothesis. *Behaviour Research and Therapy, 40*(9), 995–1002. https://doi.org/10.1016/S0005-7967(01)00077-8.

Elsey, J. W. B., Van Ast, V. A., & Kindt, M. (2018). Human memory reconsolidation: A guiding framework and critical review of the evidence. *Psychological Bulletin, 144*(8), 797–848. https://doi.org/10.1037/bul0000152.

Engelhard, I. M., McNally, R. J., & van Schie, K. (2019). Retrieving and modifying traumatic memories: Recent research relevant to three controversies. *Current Directions in Psychological Science, 28*(1), 91–96. https://doi.org/10.1177/0963721418807728.

Engelhard, I. M., van den Hout, M. A., Arntz, A., & McNally, R. J. (2002). A longitudinal study of "intrusion-based reasoning" and posttraumatic stress disorder after exposure to a train disaster. *Behaviour Research and Therapy, 40*(12), 1415–1424. https://doi.org/10.1016/S0005-7967(02)00018-9.

Engelhard, I. M., van den Hout, M. A., Janssen, W. C., & van der Beek, J. (2010). Eye movements reduce vividness and emotionality of "flashforwards. *Behaviour Research and Therapy, 48*(5), 442–447. https://doi.org/10.1016/j.brat.2010.01.003.

Eysenck, H. J. (1968). A theory of the incubation of anxiety/fear responses. *Behaviour Research and Therapy, 6*(3), 309–321. https://doi.org/10.1016/0005-7967(68)90064-8.

Eysenck, H. J. (1979). The conditioning model of neurosis. *Behavioral and Brain Sciences, 2*(2), 155–166. https://doi.org/10.1017/S0140525X00061653.

Fanselow, M. S., & Pennington, Z. T. (2017). The danger of LeDoux and pine's two-system framework for fear. *American Journal of Psychiatry, 174*(11), 1120–1121. https://doi.org/10.1176/appi.ajp.2017.17070818.

Farah, M. J. (1989). The neural basis of mental imagery. *Trends in Neurosciences, 12*(10), 395–399. https://doi.org/10.1016/0166-2236(89)90079-9.

Field, A. P. (2006). Is conditioning a useful framework for understanding the development and treatment of phobias? *Clinical Psychology Review, 26*(7), 857–875. https://doi.org/10.1016/j.cpr.2005.05.010.

Foa, E. B., & Rothbaum, B. O. (1998). *Treating the trauma of rape: Cognitive-behavior therapy for PTSD.* New York: Guilford Press.

Fridlund, A. J., Beck, H. P., Goldie, W. D., & Irons, G. (2012). Little Albert: A neurologically impaired child. *History of Psychology, 15*(4), 302–327. https://doi.org/10.1037/a0026720.

Ganis, G., Thompson, W. L., & Kosslyn, S. M. (2004). Brain areas underlying visual mental imagery and visual perception: An fMRI study. *Cognitive Brain Research, 20*(2), 226–241. https://doi.org/10.1016/j.cogbrainres.2004.02.012.

Gazendam, F. J., & Kindt, M. (2012). Worrying affects associative fear learning: A startle fear conditioning study. *PloS One, 7*(4), e34882. https://doi.org/10.1371/journal.pone.0034882.

Geller, D. A., McGuire, J. F., Orr, S. P., Small, B. J., Murphy, T. K., Trainor, K., et al. (2019). Fear extinction learning as a predictor of response to cognitive behavioral therapy for pediatric obsessive compulsive disorder. *Journal of Anxiety Disorders, 64*, 1–8. https://doi.org/10.1016/j.janxdis.2019.02.005 June 2018.

Graham, G. (2019). Behaviorism. In E. N. Zalta (Ed.). *The stanford encyclopedia of philosophy*Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/spr2019/entries/behaviorism/.

*Grégoire, L., & Greening, S. G. (2019). Opening the reconsolidation window using the mind's eye: Extinction training during reconsolidation disrupts fear memory expression following mental imagery reactivation. *Cognition, 183*, 277–281. https://doi.org/10.1016/j.cognition.2018.12.001.

Hackmann, A., Ehlers, A., Speckens, A., & Clark, D. M. (2004). Characteristics and content of intrusive memories in PTSD and their changes with treatment. *Journal of Traumatic Stress, 17*(3), 231–240. https://doi.org/10.1023/B:JOTS.0000029266.88369.fd.

Hermans, D., Baeyens, F., Beckers, T., Crombez, G., De Houwer, J., Moors, A., et al. (2018). Paul eelen: Reflections on life and work. *Psychologica Belgica, 58*(1), 212–221. https://doi.org/10.5334/pb.468.

Hermans, D., Boddez, Y., & Vervliet, B. (2019). The experimental study of mental health problems – building on Watson & rayner (1920). *Classical studies in clinical psychology*. Thousand Oaks: SAGE Publishing.

Holmes, E. A., & Mathews, A. (2010). Mental imagery in emotion and emotional disorders. *Clinical Psychology Review, 30*(3), 349–362. https://doi.org/10.1016/j.cpr.2010.01.001.

Holzman, A. D., & Levis, D. J. (1991). Differential aversive conditioning of an external (visual) and internal (imaginal) CS: Effects of transfer between and within CS modalities. *Journal of Mental Imagery, 15*(3–4), 77–90. Retrieved from https://psycnet.apa.org/record/1992-18638-001.

Hosoba, T., Iwanaga, M., & Seiwa, H. (2001). The effect of UCS inflation and deflation procedures on 'fear' conditioning. *Behaviour Research and Therapy, 39*(4), 465–475. https://doi.org/10.1016/S0005-7967(00)00025-5.

van den Hout, M. A., & Engelhard, I. (2012). How does EMDR work? *Journal of Experimental Psychopathology, 3*(5), 724–738. https://doi.org/10.5127/jep.028212.

Huang, X., Lin, J., & Demner-Fushman, D. (2006). Evaluation of PICO as a knowledge representation for clinical questions. *AMIA annual symposium proceedings archive* (pp. 359–363). . Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17238363%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC1839740.

Intons-Peterson, M. J. (1983). Imagery paradigms: How vulnerable are they to experimenters' expectations? *Journal of Experimental Psychology: Human Perception and Performance, 9*(3), 394–412. https://doi.org/10.1037/0096-1523.9.3.394.

James, E. L., Lau-Zhu, A., Clark, I. A., Visser, R. M., Hagenaars, M. A., & Holmes, E. A. (2016). The trauma film paradigm as an experimental psychopathology model of psychological trauma: Intrusive memories and beyond. *Clinical Psychology Review, 47*, 106–142. https://doi.org/10.1016/j.cpr.2016.04.010.

Ji, J. L., Heyes, S. B., MacLeod, C., & Holmes, E. A. (2016). Emotional mental imagery as simulation of reality: Fear and beyond—a tribute to peter Lang. *Behavior Therapy, 47*(5), 702–719. https://doi.org/10.1016/j.beth.2015.11.004.

Jones, T., & Davey, G. C. L. (1990). The effects of cued UCS rehearsal on the retention of differential 'fear' conditioning: An experimental analogue of the 'worry' process. *Behaviour Research and Therapy, 28*(2), 159–164. https://doi.org/10.1016/0005-7967(90)90028-H.

*Joos, E., Vansteenwegen, D., & Hermans, D. (2012). Post-acquisition repetitive thought in fear conditioning: An experimental investigation of the effect of CS-US-rehearsal. *Journal of Behavior Therapy and Experimental Psychiatry, 43*(2), 737–744. https://doi.org/10.1016/j.jbtep.2011.10.011.

Kearns, M., & Engelhard, I. M. (2015). Psychophysiological responsivity to script-driven imagery: An exploratory study of the effects of eye movements on public speaking flashforwards. *Frontiers in Psychiatry, 6*(AUG), 1–9. https://doi.org/10.3389/fpsyt.2015.00115.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews Neuroscience, 2*(9), 635–642. https://doi.org/10.1038/35090055.

Kosslyn, S. M., Thompson, W. L., & Ganis, G. (2006). *The case for mental imagery.* New York: Oxford University Press.

Kruschke, J. K. (2008). Bayesian approaches to associative learning: From passive to active learning. *Learning & Behavior, 36*(3), 210–226. https://doi.org/10.3758/LB.36.3.210.

*Krypotos, A.-M., Mertens, G., Leer, A., & Engelhard, I. M. (2019). Imagine avoidance: Induction of conditioned avoidance via mental imagery. https://doi.org/10.31234/osf.io/ad2gf.

Krypotos, A.-M., Vervliet, B., & Engelhard, I. M. (2018). The validity of human avoidance paradigms. *Behaviour Research and Therapy, 111*(October), 99–105. https://doi.org/10.1016/j.brat.2018.10.011.

*Kunze, A. E., Arntz, A., & Kindt, M. (2019). Investigating the effects of imagery rescripting on emotional memory: A series of analogue studies. *Journal of Experimental Psychopathology, 10*(2), https://doi.org/10.1177/2043808719850733 204380871985073.

*Landkroon, E., Mertens, G., & Engelhard, I. M. (2019). Devaluation of threat memory using a dual-task intervention does not reduce context renewal of fear. *Behaviour Research and Therapy*. https://doi.org/10.1016/j.brat.2019.103480 103480.

Lang, P. J. (1979). A bio-informational theory of emotional imagery. *Psychophysiology, 16*(6), 495–512. https://doi.org/10.1111/j.1469-8986.1979.tb01511.x.

Laor, N., Wolmer, L., Wiener, Z., Sharon, O., Weizman, R., Toren, P., et al. (1999). Image vividness as a psychophysiological regulator in posttraumatic stress disorder. *Journal of Clinical and Experimental Neuropsychology, 21*(1), 39–48. https://doi.org/10.1076/jcen.21.1.39.946.

Lau-Zhu, A., Holmes, E. A., Butterfield, S., & Holmes, J. (2017). Selective association between tetris game play and visuospatial working memory: A preliminary investigation. *Applied Cognitive Psychology, 31*(4), 438–445. https://doi.org/10.1002/acp.3339.

Lau-Zhu, A., Holmes, E. A., & Porcheret, K. (2018). Intrusive memories of trauma in the laboratory: Methodological developments and future directions. *Current Behavioral Neuroscience Reports, 5*(1), 61–71. https://doi.org/10.1007/s40473-018-0141-1.

Lee, C. W., & Cuijpers, P. (2013). A meta-analysis of the contribution of eye movements in processing emotional memories. *Journal of Behavior Therapy and Experimental Psychiatry, 44*(2), 231–239. https://doi.org/10.1016/j.jbtep.2012.11.001.

*Leer, A., Engelhard, I. M., Altink, A., & van den Hout, M. A. (2013). Eye movements during recall of aversive memory decreases conditioned fear. *Behaviour Research and Therapy, 51*(10), 633–640. https://doi.org/10.1016/j.brat.2013.07.004.

*Leer, A., Engelhard, I. M., Dibbets, P., & van den Hout, M. A. (2013). Dual-tasking attenuates the return of fear after extinction. *Journal of Experimental Psychopathology, 4*(4), 325–340. https://doi.org/10.5127/jep.029412.

Lewis, D. E., O'Reilly, M. J., Khuu, S. K., & Pearson, J. (2013). Conditioning the mind's eye. *Clinical Psychological Science, 1*(4), 390–400. https://doi.org/10.1177/2167702613484716.

Lovibond, P. F. (2011). Learning and anxiety: A cognitive perspective. In T. R. Schachtman, & S. Reilly (Eds.). *Associative learning and conditioning: Human and non-human applications* (pp. 104–120). New York: Oxford University Press.

Marks, D. F. (1995). New directions for mental imagery research. *Journal of Mental Imagery, 19*, 153–167.

McAllister, D. E., & McAllister, W. R. (1967). Incubation of fear: An examination of the concept. *Journal of Experimental Research in Personality, 2*(3), 180–190.

Mertens, G., Boddez, Y., Sevenster, D., Engelhard, I. M., & De Houwer, J. (2018a). A review on the effects of verbal instructions in human fear conditioning: Empirical findings, theoretical considerations, and future directions. *Biological Psychology, 137*, 49–64. https://doi.org/10.1016/j.biopsycho.2018.07.002.

Mertens, G., Krypotos, A.-M., van Logtestijn, A., Landkroon, E., Veen, S. C. V., & Engelhard, I. M. (2018b). Changing negative autobiographical memories in the lab: A comparison of three eye-movement tasks. *Memory*. https://doi.org/10.1080/09658211.2018.1507041.

Mertens, G., Wagensveld, P., & Engelhard, I. M. (2019). Cue conditioning using a virtual spider discriminates between high and low spider fearful individuals. *Computers in Human Behavior, 91*(October 2018), 192–200. https://doi.org/10.1016/j.chb.2018.10.006.

Meulders, A., Harvie, D. S., Lorimer Moseley, G., & Vlaeyen, J. W. S. (2015). Generalization of pain-related fear using a left–right hand judgment conditioning task. *Behavior Therapy, 46*(5), 699–716. https://doi.org/10.1016/j.beth.2015.02.004.

Miller, G. A., Levin, D. N., Kozak, M. J., Cook, E. W., McLean, A., & Lang, P. J. (1987). Individual differences in imagery and the psychophysiology of emotion. *Cognition & Emotion, 1*(4), 367–390. https://doi.org/10.1080/02699938708408058.

Mineka, S., & Zinbarg, R. (2006). A contemporary learning theory perspective on the etiology of anxiety disorders: It's not what you thought it was. *American Psychologist, 61*(1), 10–26. https://doi.org/10.1037/0003-066X.61.1.10.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., et al. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews, 1–9*. https://doi.org/10.1186/2046-4053-4-1.

Morina, N., Lancee, J., & Arntz, A. (2017). Imagery rescripting as a clinical intervention for aversive memories: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 55*, 6–15. https://doi.org/10.1016/j.jbtep.2016.11.003.

*Mueller, E. M., Sperl, M. F. J., & Panitz, C. (2019). Aversive imagery causes de novo fear conditioning. *Psychological Science*095679761984226. https://doi.org/10.1177/0956797619842261.

Muse, K., McManus, F., Hackmann, A., Williams, M., & Williams, M. (2010). Intrusive imagery in severe health anxiety: Prevalence, nature and links with memories and maintenance cycles. *Behaviour Research and Therapy, 48*(8), 792–798. https://doi.org/10.1016/j.brat.2010.05.008.

Orne, M. T. (1962). On the social psychology of the psychological experiment: With particular reference to demand characteristics and their implications. *American Psychologist, 17*(11), 776–783. https://doi.org/10.1037/h0043424.

Pearson, D. G., Deeprose, C., Wallace-Hadrill, S. M. A., Heyes, S. B., & Holmes, E. A. (2013). Assessing mental imagery in clinical psychology: A review of imagery measures and a guiding framework. *Clinical Psychology Review, 33*(1), 1–23. https://doi.org/10.1016/j.cpr.2012.09.001.

Pearson, J., Naselaris, T., Holmes, E. A., & Kosslyn, S. M. (2015). Mental imagery: Functional mechanisms and clinical applications. *Trends in Cognitive Sciences, 19*(10), 590–602. https://doi.org/10.1016/j.tics.2015.08.003.

Pylyshyn, Z. (2003). Return of the mental image: Are there really pictures in the brain? *Trends in Cognitive Sciences, 7*(3), 113–118. https://doi.org/10.1016/S1364-6613(03)00003-2.

*Rattel, J. A., Wegerer, M., Miedl, S. F., Blechert, J., Grünberger, L. M., Craske, M. G., et al. (2019). Peritraumatic unconditioned and conditioned responding explains sex differences in intrusions after analogue trauma. *Behaviour Research and Therapy, 116*(February), 19–29. https://doi.org/10.1016/j.brat.2019.01.009.

*Reddan, M. C., Wager, T. D., & Schiller, D. (2018). Attenuating neural threat expression with imagination. *Neuron, 100*(4), 994–1005. https://doi.org/10.1016/j.neuron.2018.10.047 e4.

Reisberg, D., Pearson, D. G., & Kosslyn, S. M. (2003). Intuitions and introspections about imagery: The role of imagery experience in shaping an investigator's theoretical views. *Applied Cognitive Psychology, 17*(2), 147–160. https://doi.org/10.1002/acp.858.

Reiss, S. (1980). Pavlovian conditioning and human fear: An expectancy model. *Behavior Therapy, 11*(3), 380–396. https://doi.org/10.1016/S0005-7894(80)80054-2.

Rescorla, R. A. (1988). Pavlovian conditioning: It's not what you think it is. *American Psychologist, 43*(3), 151–160. https://doi.org/10.1037/0003-066X.43.3.151.

Ripley, D. L., & Politzer, T. (2010). Vision disturbance after TBI. *NeuroRehabilitation, 27*, 215–216. https://doi.org/10.3233/NRE-2010-0599.

Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: The prospective brain. *Nature Reviews Neuroscience, 8*(9), 657–661. https://doi.org/10.1038/nrn2213.

Schacter, D. L., Addis, D. R., Hassabis, D., Martin, V. C., Spreng, R. N., & Szpunar, K. K. (2012). The future of memory: Remembering, imagining, and the brain. *Neuron, 76*(4), 677–694. https://doi.org/10.1016/j.neuron.2012.11.001.

Scheveneels, S., Boddez, Y., Vervliet, B., & Hermans, D. (2016). The validity of laboratory-based treatment research: Bridging the gap between fear extinction and exposure treatment. *Behaviour Research and Therapy, 86*, 87–94. https://doi.org/10.1016/j.brat.2016.08.015.

Schlagman, S., & Kvavilashvili, L. (2008). Involuntary autobiographical memories in and outside the laboratory: How different are they from voluntary autobiographical memories? *Memory & Cognition, 36*(5), 920–932. https://doi.org/10.3758/MC.36.5.920.

Shapiro, F., & Forrest, M. (2016). *Emdr: The breakthrough therapy for overcoming anxiety, stress, and trauma.* New York: Basic Books.

Sheehan, P. W. (1967). A shortened form of Betts' questionnaire upon mental imagery. *Journal of Clinical Psychology, 23*(3), 386–389. https://doi.org/10.1002/1097-4679(196707)23:3<386::AID-JCLP2270230328>3.0.CO;2-S.

Skinner, B. F. (1963). Behaviorism at fifty. *Science, 140*(3570), 951–958. Retrieved from https://www.jstor.org/stable/1711326%0A.

*Streb, M., Conway, M. A., & Michael, T. (2017). Conditioned responses to trauma reminders: How durable are they over time and does memory integration reduce them? *Journal of Behavior Therapy and Experimental Psychiatry, 57*, 88–95. https://doi.org/10.1016/j.jbtep.2017.04.005.

Thomas, N. J. T. (2019). Mental imagery. In E. N. Zalta (Ed.). *The stanford encyclopedia of philosophy*Metaphysics Research Lab, Stanford University. Retrieved from https://plato.stanford.edu/archives/sum2019/entries/mental-imagery/.

*Toumbelekis, M., Liddell, B. J., & Bryant, R. A. (2018). Thinking of attachment figures blocks differential fear conditioning. *Social Cognitive and Affective Neuroscience, 13*(9), 989–994. https://doi.org/10.1093/scan/nsy065.

van Veen, S. C., van Schie, K., van de Schoot, R., van den Hout, M. A., & Engelhard, I. M. (2019). Making eye movements during imaginal exposure leads to short-lived memory effects compared to imaginal exposure alone. *Journal of Behavior Therapy and Experimental Psychiatry,* (January), 1–8. https://doi.org/10.1016/j.jbtep.2019.03.001.

Vervliet, B., Craske, M. G., & Hermans, D. (2013). Fear extinction and relapse: State of the art. *Annual Review of Clinical Psychology, 9*(1), 215–248. https://doi.org/10.1146/annurev-clinpsy-050212-185542.

Vrana, S. R., & Lang, P. J. (1990). Fear imagery and the startle-probe reflex. *Journal of Abnormal Psychology, 99*(2), 189–197. https://doi.org/10.1037/0021-843X.99.2.189.

Watson, J. B. (1913). Psychology as the behaviorist views it. *Psychological Review, 20*(2), 158–177. https://doi.org/10.1037/h0074428.

Watson, J. B., & Rayner, R. (1920). Conditioned emotional reactions. *Journal of Experimental Psychology, 3*(1), 1–14. https://doi.org/10.1037/h0069608.

*Wegerer, M., Blechert, J., Kerschbaum, H., & Wilhelm, F. H. (2013). Relationship between fear conditionality and aversive memories: Evidence from a novel conditioned-intrusion paradigm. *PloS One, 8*(11), https://doi.org/10.1371/journal.pone.0079025.

Yaremko, R. M., & Werner, M. (1974). Cognitive conditioning: Imagined stimulus contiguity and the third interval conditional GSR. *Pavlovian Journal of Biological Science, 9*(4), 215–221. https://doi.org/10.1007/BF03001505.

*Zbozinek, T. D., Holmes, E. A., & Craske, M. G. (2015). The effect of positive mood induction on reducing reinstatement fear: Relevance for long term outcomes of exposure therapy. *Behaviour Research and Therapy, 71*, 65–75. https://doi.org/10.1016/j.brat.2015.05.016.