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"The Role of Sleep on Enhancing the Efficacy of Psychotherapy"

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When every inch of the world is known, sleep may be the only wilderness that we have left.

Louise Erdric

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Abbreviations

- **AASM** – American Academy of Sleep Medicine
- **AMCQ** – Autobiographical Memory Characteristics Questionnaire
- **ANOVA** – Analysis of Variance
- **ANCOVA** – Analysis of Covariance
- **ASC** – Allgemeine Schlafcharakterisierung
- **BDI-II** – Beck Depression Inventory-II
- **CBT** – Cognitive Behavioral Therapy
- **CDI** – Categorical-Dynamic Index
- **DSS** – Durchschlafstörungen
- **EEG** – Electroencephalography
- **EMDR** – Eye Movement Desensitization and Reprocessing
- **EMG** – Electromyography
- **EOG** – Electrooculography
- **ECG** – Electrocardiography
- **EDA** – Electrodermal Activity
- **ESS** – Einschlafstörungen
- **FFT** – Fast Fourier Transform
- **fMRI** – Functional Magnetic Resonance Imaging
- **FRABO** – FRAgebogen zu Belastenden autobiografischen Erinnerungen
- **FSA** – Fast Spindle Activity
- **GAD** – Generalized Anxiety Disorder
- **GES** – Gefühl des Erholtseins nach dem Schlaf
- **GSD** – Gesamtschlafdauer
- **G*Power** – General Power Analysis Tool

- **HR** – Heart Rate
- **HRV** – Heart Rate Variability
- **IBI** – Inter-beat Interval
- **ICA** – Independent Component Analysis
- **ImR** – Imagery Rehearsal
- **IRASA** – Irregular-Resampling Auto-Spectral Analysis
- **IRRT** – Imagery Rescripting and Reprocessing Therapy
- **LIWC** – Linguistic Inquiry and Word Count
- **MA N1** – Movement Arousals during N1 sleep stage
- **MA N2** – Movement Arousals during N2 sleep stage
- **MA N3** – Movement Arousals during N3 sleep stage
- **MA REM** – Movement Arousals during REM sleep stage
- **MA Total** – Total Movement Arousals during the entire sleep duration
- **MATLAB** – Matrix Laboratory (Computational Software)
- **MEQ** – Memory Experiences Questionnaire
- **MS** – Multiple Sclerosis
- **ND** – Nightmare Disorder
- **NREM** – Non-Rapid Eye Movement
- **OCD** – Obsessive-Compulsive Disorder
- **PE** – Prolonged Exposure
- **PSQI** – Pittsburgh Sleep Quality Index
- **PSS** – Psychosomatische Symptome in der Schlafphase
- **PSYA** – Psychische Ausgeglichenheit vor dem Schlafenlegen
- **PSYE** – Psychisches Erschöpftsein vor dem Schlafenlegen

- **PTSD** – Post-Traumatic Stress Disorder
- **REM** – Rapid Eye Movement
- **RSDI** – Response to Script-Driven Imagery Scale
- **SAD** – Social Anxiety Disorder
- **SE** – Sleep Efficiency
- **SDI** – Script-Driven Imagery
- **SF-A/R** – Schlaffragebögen A
- **SL** – Sleep Latency
- **SPSS** – Statistical Package for the Social Sciences
- **SO** – Slow Oscillations
- **SQ** – Schlafqualität
- **STAI** – State-Trait Anxiety Inventory
- **SUIS** – Spontaneous Use of Imagery Scale
- **SWA** – Slow-Wave Activity
- **SWS** – Slow-Wave Sleep
- **TMR** – Targeted Memory Reactivation
- **TST** – Total Sleep Time
- **VMPFC** – Ventromedial Prefrontal Cortex
- **VR** – Virtual Reality
- **VZA** – Vorzeitiges Erwachen
- **WHO-5** – World Health Organization Five Well-Being Index

Abstract

Memory reconsolidation is a process by which previously stored memories become labile upon retrieval and can be modified before being restabilized. Imagery rescripting and reprocessing therapy is one therapeutic approach that takes advantage of this process by updating aversive autobiographical memories with adaptive, self-empowering imagery. Targeted memory reactivation, a sleep-based technique, has been shown to enhance memory consolidation and reconsolidation by cueing relevant information during sleep. This dissertation explores whether adding targeted memory reactivation into imagery rescripting and reprocessing therapy can enhance its efficacy in modifying emotionally distressing autobiographical memories.

In the study set up, 54 healthy participants underwent imagery rescripting and reprocessing therapy for two of their aversive autobiographical memories. During the modification, a contextual odor was presented to form an association between the positive reappraisal of the memories and a sensory cue. Thereafter, subjects either had a full-night sleep or remained awake for an equivalent duration (retention interval), accompanied by an odor that was either associated with the positive reappraisal (congruent condition) or was unrelated (incongruent condition) using a randomized controlled design. Subjective ratings (such as emotional intensity and vividness), physiological measures (such as heart rate), narrative characteristics (such as positive and negative words), and electroencephalographic data were collected across three time points; before the intervention, immediately after the retention interval, and one week later.

Results demonstrated that targeted memory reactivation during sleep with congruent odor cues significantly enhanced slow-wave activity (0.75-4 Hz) and slow oscillations (0.75-1.5 Hz), while it significantly reduced the fast spindle activity (12-16 Hz) during NREM sleep. Although the therapy intervention itself, irrespective of sleep or wake group and the odor condition, was highly effective in reducing the emotional reactivity over time, these neural changes in response to the targeted memory reactivation were not translated into significant behavioral improvements, or physiological response towards the autobiographical memories across all time points assessed.

These findings suggest that while targeted memory reactivation can modulate sleep-related neural activity, its additive therapeutic effects may be limited in healthy

individuals. This study points to the importance of future research targeting clinical populations and optimizing odor presentation parameters in order to fully demonstrate the potential of targeted memory reactivation as a sleep-based tool in therapeutic contexts.

Zusammenfassung

Die Gedächtnis-Rekonsolidierung ist ein Prozess, bei dem zuvor gespeicherte Erinnerungen nach ihrer Reaktivierung labil werden und vor ihrer erneuten Stabilisierung modifiziert werden können. Die Imagery Rescripting and Reprocessing Therapy ist ein therapeutischer Ansatz, der sich diesen Mechanismus zunutze macht, indem belastende autobiografische Erinnerungen durch adaptive, selbststärkende Vorstellungen aktualisiert werden. Targeted Memory Reactivation, eine schlafbasierte Methode, konnte bereits zeigen, dass durch die gezielte Reaktivierung relevanter Gedächtnisinhalte im Schlaf sowohl die Konsolidierung als auch die Rekonsolidierung von Erinnerungen verbessert werden kann. Diese Dissertation untersucht, ob die Gedächtnisreaktivierung während des Schlafs die Wirksamkeit der Imagery Rescripting and Reprocessing Therapy bei der Bearbeitung emotional belastender autobiografischer Erinnerungen steigern kann.

In dieser Studie erhielten 54 gesunde Teilnehmende im Rahmen eines randomisierten und kontrollierten Studiendesigns eine therapeutische Intervention zur Bearbeitung zweier belastender autobiografischer Erinnerungen. Während der therapeutischen Intervention wurde ein spezifischer Geruch präsentiert, um eine Assoziation zwischen der positiven Neudeutung der Erinnerungen und einem sensorischen Hinweisreiz herzustellen. Anschließend schliefen die Teilnehmenden eine Nacht im Schlaflabor oder durchwachten ein äquivalent langes Zeitintervall am Tag (Retentionsintervall), jeweils begleitet von einem Geruch, der entweder mit der positiven Neudeutung assoziiert (kongruente Bedingung) oder fremd (inkongruente Bedingung) war. Erfasst wurden subjektive Bewertungen wie emotionale Intensität und Lebendigkeit, physiologische Messgrößen wie die Herzfrequenz, narrative Merkmale wie der Gebrauch emotionaler Sprache, sowie EEG-Aktivität. Die Datenerhebung erfolgte an drei Messzeitpunkten: vor der Intervention, unmittelbar nach dem Retentionsintervall sowie eine Woche später.

Die Ergebnisse zeigen, dass die Gedächtnisreaktivierung mit kongruenten Geruchshinweisen während des NREM-Schlafs zu einer signifikanten Erhöhung der langsamen Oszillationen (0.75-1.5 Hz) und der Slow-Wave-Aktivität (0.75-4 Hz) führte, während die Aktivität der schnellen Spindeln (12-15 Hz) verringert wurde. Assoziationen zwischen diesen neuronalen Veränderungen mit stabilen Verhaltensänderungen oder

physiologischen Reaktionen auf die autobiografischen Erinnerungen über die drei Messzeitpunkte hinweg konnten nicht gefunden werden. Zudem zeigte sich, dass die therapeutische Intervention selbst, unabhängig von der Schlaf- oder Wachbedingung sowie des präsentierten Geruchs, über die Zeit hinweg sehr wirksam darin war, die emotionale Reaktivität auf belastende Erinnerungen zu verringern.

Diese Ergebnisse deuten darauf hin, dass die Gedächtnisreaktivierung zwar schlafbezogene Gehirnaktivität beeinflussen kann, ihr zusätzlicher therapeutischer Nutzen bei gesunden Personen, jedoch begrenzt sein könnte. Die Studie unterstreicht die Bedeutung zukünftiger Forschung mit klinischen Zielgruppen sowie die Optimierung der Bedingungen der Geruchsdarbietung, um das volle Potenzial der Gedächtnisreaktivierung als schlafgestützte Methode im therapeutischen Kontext zu erschließen.

1. Chapter 1: Introduction

1.1 Human memory system

1.1.1 Memory processes and memory systems

The constantly changing environment requires continuous adjustment of an organism's behavior. To accomplish this, the organism must be able to form and recall memories of occurrences. According to Squire and Zola (1996), encoding, consolidation, and retrieval are the three main stages of memory formation and processing. During encoding, the stimulus is perceived, resulting in the formation of a new memory trace. This memory trace is labile and prone to alterations and decay. During consolidation, the memory trace is stabilized, strengthened, and integrated into the existing knowledge. Finally, during retrieval, the stabilized memory trace is retrieved and recalled (Squire & Zola, 1996). Recent research has shown that these stabilized memory traces can re-enter a labile state upon reactivation, such as during active retrieval, and must undergo a reconsolidation phase to re-stabilize (Nader & Hardt, 2009).

Considering the complexity of these memory processes, it is essential to take into account the different types of memory that shape how we learn, adapt, and navigate in the world. Memory exists in different forms, but it is mainly divided into two main categories based on the essential role played by the medial temporal lobe areas, especially the hippocampus, in the process of their acquisition (Squire & Zola, 1996). Declarative memories refer to those memories that a person can consciously recall. This may include memories of specific events like parking your car the day before (episodic memory) or could refer to the person’s general knowledge such as explicit and factual information about the capital of Brazil (semantic memory; Squire & Zola, 1996). The acquisition and retrieval of declarative memories depend on the engagement of structures within the medial temporal lobe. Non-declarative memories, however, refer to our memories of skills such as how to ride a bike and are formed independently from the medial temporal lobe areas. Non-declarative memories are further classified into several subcategories such as priming, conditioning, or skills, and habituation (Henke, 2010; Squire & Zola, 1996; Stickgold, 2005).

1.1.1.1 Autobiographical memory

Autobiographical memory refers to the recollection of experiences of the self and its interactions with others, which shapes our identity and sense of purpose in the world. This memory is exclusive to humans and is best understood as a form of declarative memory integrating both episodic and semantic memory types into a coherent self-centered narrative consisting of linked episodes (Fivush, 2011; Tulving, 2002). Autobiographical memory is interconnected within a constantly updated and prediction-driven network (Fivush & Grysman, 2023). On the one hand, it depends on semantic memory, which pertains to self-related knowledge, and, on the other hand, on episodic memory, which involves specific information about past personal experiences (see Figure 1; Tulving, 2002).

Hereby, the episodic memory component is a vital aspect of autobiographical memory, as it allows for the rich and vivid recollections of one's personal and past experiences (Rubin, 2005 as cited in Sheldon et al., 2019). Therefore, autobiographical memories play an important role in how human functions, by adding to individuals' self-perception, their capacity to stay oriented in the world, and their effectiveness in pursuing goals based on prior problem-solving experiences (Williams et al., 2007).

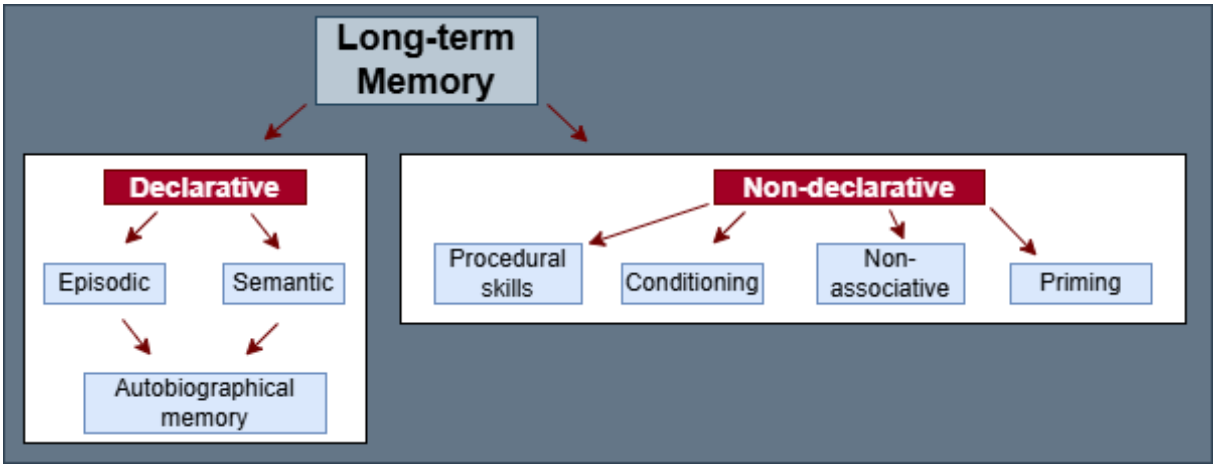

Figure 1. A classification of the long-term memory. Declarative memory includes episodic memory, which stores personal experiences, and semantic memory, which holds general knowledge. Non-declarative memory encompasses procedural skills, conditioning, non-associative learning, priming, and conditioning. The figure was adapted from Henke (2010) and created using https://www.drawio.com/.

1.1.1.2 Emotional Modulation of Memory

For a long time, psychology has tried to understand how memory is influenced by emotions such as in stressful, negative, or traumatic events. Numerous studies have shown that emotional memories are encoded, stored, and recalled differently from neutral memories (e.g., McGaugh, 2004; Kensinger, 2009) such that the memory of emotional information is promoted above neutral information. Even the pattern of eye fixations has been shown to be modulated by whether the subjects are exposed to emotional or neutral scenes or objects (Subramanian et al., 2014). Emotions have been shown to play a role in determining which objects or scenes individuals focus on (Touryan et al., 2007), with enhanced recognition of specific visual details specifically for objects with negative valence (Kensinger et al., 2007). Interestingly, the formation of neutral memories has been shown to be affected by acute stress during encoding (Qin et al., 2012). Furthermore, the recall of emotional memory has also been demonstrated to be different from neutral memory. Several studies have shown that the recall of emotional scenes, specifically negatively aroused ones, was significantly higher than for positive or neutral ones (Bookbinder & Brainerd, 2017; Minor & Herzmann, 2019; Otani et al., 2007; Xu et al., 2011).

The amygdala appears to play a critical role in the observed enhancement of emotional memory. The activation of amygdala during encoding was shown to be the highest for scenes with higher emotional intensity, with this activity predicting the subsequent memory performance only for emotionally intense scenes (Canli et al., 2000). Activation in the amygdala and the perirhinal cortex was also found to be crucial for the recall of memories, suggesting the contribution of these regions to the retrieval of the emotionally enhanced memory content (Ritchey et al., 2019).

1.1.1.3 Autobiographical memory for stressful events

Classic theories such as Freud's theories of repression along with those that evolved from it, suggest that trauma-related memories differ from other memories. They propose that highly intense extreme emotional arousals during an event prevent its complete initial processing, resulting in a fragmented and incoherent memory that is

stored separately (Van der Kolk, 2000). In fact, distressing autobiographical memories characterize most psychiatric disorders, such as post-traumatic stress disorder (PTSD) or affective disorders. PTSD, for instance, is defined as a disorder centered around a representation of a traumatic experience at its core (Ehlers & Clark, 2000). As in patients with PTSD, patients with depression endure elevated levels of distressing visual memories. In both cases, the severity of the disorder is typically related to the frequency of intrusions and the extent of avoidance behavior towards stimuli associated with the initial event (Ehlers & Clark, 2000; Patel et al., 2007). This pattern has also been observed in individuals with SAD, who exhibit symptoms resembling those of PTSD (Seinsche et al., 2023).

Autobiographical memories are not only important for shaping human identity and guiding their behavior, but they are also subject to mechanisms by which memories are stabilized or altered over time. The following section introduces the concepts of memory consolidation and reconsolidation.

1.1.2 Memory consolidation and reconsolidation

1.1.2.1 The concept of consolidation

Memory consolidation is a hypothetical process through which a labile memory trace transforms into its long-lasting form. This concept is typically explored from two interrelated levels: the cellular/synaptic level, known as synaptic consolidation, and the broader level of brain systems, referred to as systems consolidation (Dudai, 2012; Squire et al., 2015). Synaptic consolidation involves the transformation of information into long-term memory at local neural circuit nodes. This process typically concludes within hours after initiation and can be triggered by various stimuli, either perceptual or internally generated, and is observed across all animals (Dudai, 2012). System consolidation, on the other hand, refers to the post-encoding processes in which long-term memory is reorganized through the distributed brain circuits. The process can affect both declarative and non-declarative memory and vary in duration from days to years depending on the memory system and task (Dudai, 2012; Squire et al., 2015).

1.1.2.1.1 Evidence of a consolidation process

Empirical evidence supporting the existence of a consolidation process arises from numerous observations in which recently formed memories demonstrate susceptibility to disruptions within a post-acquisition time frame (McGaugh, 1966). Studies have found that memory recall can be impaired by amnesic treatments, such as electroconvulsive shock soon after learning (Duncan, 1949, as cited in Nader and Hardt, 2009; Raio et al., 2014). In contrast, retention of information can be improved using specific substances like strychnine administered immediately after encoding (McGaugh and Krivanek, 1970 as cited in Nader and Hardt, 2009). The fact that these interventions are only effective when applied immediately after encoding demonstrates that the memory is labile in this phase and, therefore, susceptible to change. After a while, a stable state emerges during which memory becomes insensitive to amnesic interventions and, thus, consolidated by definition (Dudai, 2004).

1.1.2.1.2 The role of sleep on memory consolidation

Several studies across molecular, physiological, or behavioral research have provided evidence supporting the impact of sleep on memory consolidation (see Alger et al., 2015; Stickgold, 2005 for a review). These studies suggest that different sleep stages contribute to memory consolidation processes. Slow-wave-sleep (SWS), for instance, has been found to play a crucial role in memory consolidation as seen in both animal and human studies with <1 Hz slow oscillations (SO) representing the most distinct of these oscillations. For example, Oyanedel et al., (2014) showed that the percentage of SWS during the retention interval in rats was positively correlated with better performance in an object recognition task. In humans, SWS during a nap has been found to enhance the consolidation of paired-association learning tasks (Alger et al., 2012). Other studies have provided causal evidence that by enhancing SO externally, memory performance can be improved. Using closed-loop auditory stimulation during the SO-up states, Ngo et al. (2013) could successfully increase the retention ratio of word-pairs across sleep compared to the sham condition. Meanwhile, rapid eye movement (REM) was demonstrated to improve the discrimination between fear-relevant and neutral stimuli,

resulting in increased fear extinction in human subjects (Menz et al., 2016). Importantly, other studies have focused on the differential but complementary roles of SWS and REM. While SWS was linked to improvements in recall of negative remote memories and reduction in hippocampal activity during recollection, REM sleep was associated with increased connectivity between hippocampal and neocortical areas for negative remote memories (Cairney et al., 2015). Although the beneficial effects of sleep on memory consolidation have been well studied and documented, its underlying mechanisms are still being explored. Two of the main theories that explain how sleep affects memory consolidation are synaptic homeostasis hypothesis and active system consolidation hypothesis.

1.1.2.1.3 Mechanisms of sleep-dependent memory consolidation

1.1.2.1.3.1 Synaptic homeostasis hypothesis

According to the synaptic homeostasis hypothesis, the regulation of synaptic strength in the brain is closely tied to sleep, with SWS playing a crucial role. During wakefulness, humans engage in activities (e.g., learning) that lead to the strengthening of synaptic connections between neurons across various cortical circuits. The degree of synaptic potentiation that occurs during these wakeful periods determines the extent of SWS during subsequent sleep, with slow-wave activity (SWA) mirroring the strength and density of these cortical synapses (Tononi & Cirelli, 2003). SWS is believed to facilitate a process known as synaptic downscaling, which reduces the overall strength of synaptic connections. This reduction is essential for maintaining a balance in synaptic input to neurons, ensuring that neural circuits remain stable and functional. Essentially, non-rapid eye movement (NREM) sleep supports brain plasticity by enhancing the signal-to-noise ratio in neural communications. This ensures that important neural signals are preserved while redundant activity is minimized, leading to the stabilization and optimal functioning of neurons (Tononi & Cirelli, 2003). In this way, sleep not only restores the brain's capacity for learning and memory but also maintains the overall health and stability of neural networks (Alger et al., 2012).

1.1.2.1.3.2 Active system consolidation hypothesis

Based on the active system consolidation model, the newly encoded memory traces in the short-term memory are highly labile and hippocampally dependent (Born & Wilhelm, 2012; Klinzing et al., 2019; Rasch & Born, 2013). During SWS, these new representations are repeatedly reactivated in the hippocampus, triggering reactivations in the associated neural networks and their neocortical components (Born & Wilhelm, 2012). Consequently, these freshly encoded hippocampal representations are gradually redistributed to neocortical networks during sleep for stable, long-term storage. This hypothesis suggests that the reactivation and integration of temporarily stored memories into the long-term buffer involves a qualitative reorganization, or transformation, of these memory representations (Klinzing et al., 2019; Rasch & Born, 2013). This transformation and redistribution of information results in the strengthening of some and the weakening of other synaptic connections. Through this process the brain extracts the relevant from the irrelevant aspects of the newly encoded information, where the irrelevant ones may be eliminated (Born & Wilhelm, 2012; Rasch & Born, 2013). This system consolidation requires stabilization through a synaptic consolidation process, which is believed to occur primarily during NREM sleep periods. Unlike theories that propose sleep merely offers a passive environment for consolidation, this hypothesis asserts that memory consolidation during sleep is an active process (see Figure 2a and b; for review see Born & Wilhelm, 2012; Klinzing et al., 2019; Rasch & Born, 2013).

Several studies have yielded findings consistent with the hypothesis that sleep facilitates memory consolidation through neural reactivation, providing empirical support for its validity. The pioneering study of Wilson and McNaughton (1994) on rats demonstrated that the place cells which were activated during spatial exploration, were reactivated during the post-learning NREM sleep in the same sequence and temporal order. This observation demonstrated potential mechanisms behind memory consolidation. To further test whether supporting the replay of memories in rats during sleep can actively boost memory consolidation, Bendor and Wilson (2012) showed that presenting an external cue linked to prior learning during the post-learning sleep can bias the hippocampal replay, leading to better memory consolidation. More recent findings have confirmed that ripple-reactivation (coordinated reactivation of neural firing patterns) of hippocampus–amygdala

circuits contribute to contextual emotional memory consolidation during sleep (Girardeau et al., 2017). Complementing these findings, Clawson et al. (2021) observed that neurons involved in the fear memory encoding remained active during post-learning sleep which resulted in increased consolidation of these fear memories.

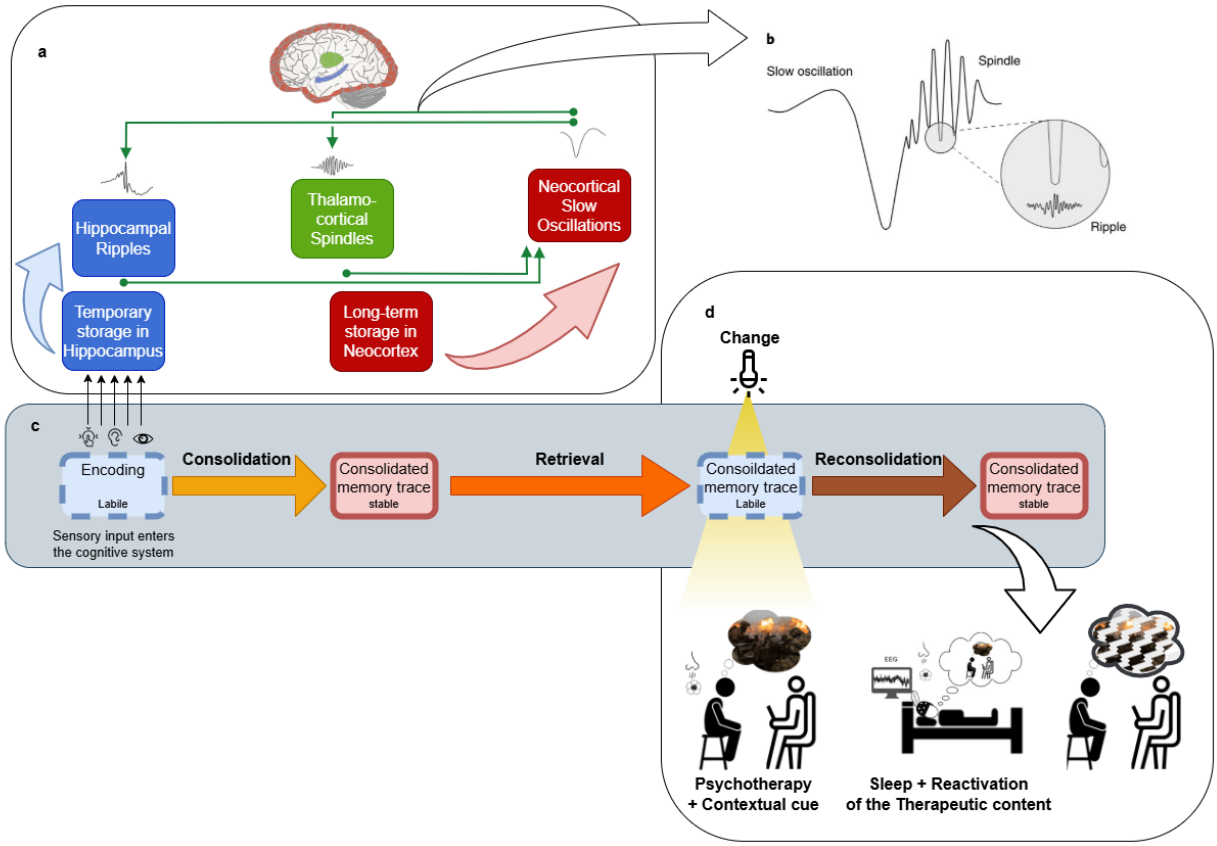

Figure 2. Memory processing and therapeutic reactivation during sleep. a. New information is temporarily stored in the hippocampus, then gradually transferred to the neocortex via coordinated interactions between hippocampal ripples, thalamo-cortical spindles, and neocortical SO during sleep. The conceptual framework of this panel is based on established models of sleep-dependent memory consolidation, specifically Born and Wilhelm (2012). The brain sketch is taken from Klinzing et al. (2019). **b.** Slow oscillations, spindles, and ripples, which facilitate memory consolidation and reconsolidation during sleep. The illustration is taken from Klinzing et al. (2019). **c.** Sensory input is encoded in a labile state, then stabilized into a consolidated memory trace. Upon retrieval, the memory trace becomes labile again and is subject to modification, requiring reconsolidation. **d.** At the time of retrieval, memory is labile and susceptible to change, offering the best period for memory modifications through psychotherapy. In psychotherapy, a contextual cue (e.g., an odor or sound) is paired with positive memory modification. During subsequent sleep, presentation of the same cue can reactivate and strengthen the therapeutic content, potentially leading to memory restructuring, vividness and symptom reduction. Figure created using https://www.drawio.com/.

1.1.2.1.4 Sleep-dependent emotional memory consolidation

Studies have investigated whether and how sleep influences the processing of emotional memories by examining both the emotional responses and recall ratio in post-sleep emotional memory retrieval compared to neutral ones. Results related to changes in the emotional response have shown inconsistencies. For example, Cunningham et al. (2014) reported that one night of sleep reduced the physiological reactivity (i.e., heart rate deceleration and skin conductance response) towards the emotional memory. Other studies such as Ashton et al. (2019) and Baran et al. (2012) suggest perseveration in the emotional response, while a few reported an increase in the perceived negativity of emotional images (e.g., Wagner et al., 2002).

Regarding the consolidation of emotional memories, research highlights that to fully grasp how emotional memories are integrated and consolidated in the brain, it is necessary to consider the role of both encoding-related arousal as well as sleep afterwards. For example, Cunningham and colleagues suggested that stronger emotional reactions or arousal at encoding tags or marks these experiences as important and relevant to the organism. Therefore, these memories are prioritized for the selective and preferential sleep-related consolidation (Cunningham et al., 2014). Consequently, emotional arousal at the time of learning leads to better memory for emotional vs. neutral stimuli as seen in most cases. Research using functional magnetic resonance imaging (fMRI) has shown that during an emotional memory recognition task, the brain relies on more refined and restricted networks of regions including the amygdala, the ventromedial prefrontal cortex (VMPFC) and the cingulate gyrus after sleep compared to wakefulness (Payne & Kensinger, 2011). Additionally, sleep has been shown to strengthen the connectivity between key limbic regions with the amygdala forming a strong connection to both hippocampus and VMPFC (Payne & Kensinger, 2011). Building on this, other research has highlighted the amygdala's crucial role in sleep-dependent consolidation of fear memories. Sleep enhances the recall of fear memories with this recall being related to the activity in the basolateral amygdala as well as the time spent in post-learning REM sleep (Menz et al., 2013).

Moreover, electroencephalography (EEG) data from the study by Denis et al. (2020) demonstrated that stress during encoding, on the one hand, alters the interaction

between SO (0.75– 1.5 Hz) and spindles (12–16 Hz) and, on the other hand, changes the spindle dynamics during sleep. In this study, half of the subjects were exposed to psychosocial stressor (stress group), whereas the other half underwent a non-stressful control task (control group) before encoding emotional and neutral stimuli. Results indicated that the SO-spindle coupling during SWS was negatively correlated with memory performance in the stress group. This relationship was not observed in the control group suggesting that spindle activity may not function effectively in high stress levels (Denis et al., 2020). Furthermore, spindles have been shown to be involved in anxiety regulation in individuals with more severe PTSD symptoms. However, in those with milder symptoms, spindles mostly support memory consolidation, suggesting a dual role for spindles in emotion regulation and memory consolidation in acute stress (Natraj et al., 2023).

Other studies suggest the specific role of REM sleep in processing emotional memory with REM theta power predicting the selective consolidation of these memory traces especially in subjects with higher cortisol levels (Kim et al., 2020). REM theta power, REM duration, and SWA have been found to be negatively correlated with both the number and distress of the intrusions of aversive memories. Additionally, it has been demonstrated that the individuals who entered REM sleep during a nap reported lower number of intrusions and reduced negative mood response to trauma-related cues (Wilhelm et al., 2021). This further indicates the effects of sleep on emotion regulation and processing.

Together, these findings underscore the complex interplay between the emotional arousal of the memory, sleep and the neural mechanisms shaping emotional memory consolidation.

1.1.2.2 The concept of reconsolidation

While the traditional perspective in the consolidation hypothesis initially suggested that consolidation occurs only once for any item, this view was questioned in the late 1960s when researchers reported that presenting a reminder cue could make a seemingly consolidated memory item susceptible to decay. Reactivation re-opens a consolidation-like window, challenging the one-way memory maturation concept, and is called

reconsolidation (McGaugh, 1966; Rodriguez et al., 1993, as cited in Dudai, 2012). Reconsolidation is necessary to stabilize a retrieved memory from long-term storage that has entered an unstable state due to retrieval (Nader & Hardt, 2009). The reconsolidation theory has received significant interest among researchers due to its proposition that memories might be alterable based on experiences or manipulations introduced within a restricted and labile time frame after retrieval (see Figure 2c, Forcato et al., 2011; Nader et al., 2000; Nader & Hardt, 2009; Oyarzún et al., 2012).

This theory presents an encouraging avenue for creating possible therapeutic approaches to tackle mental disorders that result from dysfunctional memories, which are arguably a central element in various mental health conditions. These conditions encompass a range of mental disorders from PTSD, where the memory of a traumatic event becomes so distressing that it interferes with everyday functioning (Brewin, 2001; Elsey & Kindt, 2017; Kim et al., 2021), to addiction, where memories associated with drug consumption exert such significant control over behavior that individuals pursue the drug even at substantial personal and social costs (Milton & Everitt, 2012). Thus, reprocessing or modifying the content of the maladaptive memories has been the focus of several treatment methods such as eye movement desensitization and reprocessing (EMDR; Shapiro, 2002) or Imagery rescripting (ImR) therapy (Morina et al., 2017). In the therapeutic application, reconsolidation can create a mismatch between the initial memory and the new information. It can initiate a destabilization that contradicts the memory's original schema that contributes to psychological distress and dysfunctional behaviors. This represents a shift in understanding and treatment of many maladaptive learning-based conditions that have historically been considered lifelong burdens (Ecker, 2015; Lane, 2024).

1.1.2.2.1 Evidence of reconsolidation processes

Many observations in both rats and humans provide empirical evidence supporting the existence of reconsolidation processes. For instance, Nader et al. (2000) showed that the consolidated fear memory in rats was impaired by administering a protein synthesis inhibitor directly into the amygdala right after memory retrieval. In humans, Walker et al. (2003) demonstrated that the memory of a finger-tapping sequence can be interfered with

retrieving the initial finger-tapping sequence. Such interventions have also been administered in a clinical setting and showed that disrupting reconsolidation led to a decrease in the expression of fear among individuals with phobias. In an experiment by Soeter and Kindt (2015) with spider-phobic participants, a single dose of propranolol disrupted the reconsolidation of fear memory, transforming avoidance behavior into approach behavior. This effect was reported to last at least a year. Another line of research has explored how reconsolidation can be used to therapeutically alter fear-related emotional memories. Building on this idea that reactivating memories can temporarily put them in a labile state and, thus, susceptible to change, Kindt (2018) demonstrated that administering propranolol during this time-limited window following memory reactivation, can effectively reduce fear responses without changing the explicit recall of the original memory. These findings support reconsolidation as a potential paradigm shift in the treatment of emotional memory disorders. Correspondingly, Björkstrand and colleagues (2016) showed that in individuals with lifelong spider fear, disrupting reconsolidation by activating fear memory and exposing them to fear cues after 10 minutes reduces amygdala activity during re-exposure after 24 hours, leading to increased approach behavior. Additionally, interruption of memory reconsolidation reduced PTSD symptoms. In a case study by Kindt and van Emmerik (2016), the trauma memory was reactivated using imaginal exposure and, therefore, destabilized. Afterwards, patients had to take 40 mg propranolol aiming to impair memory stabilization. In all three cases, there was a rapid reduction in fear symptoms after intervention sessions.

In summary, various studies in both animals and humans demonstrate how interrupting reconsolidation can alter long-standing memories and behaviors, providing strong evidence for reconsolidation processes.

1.1.2.2.2 The role of sleep on memory reconsolidation

A crucial aspect of memory reconsolidation is that changes that are made in the reactivated memories are not immediately manifested in behavior. Instead, they gradually emerge after a period of sleep. Some studies suggest that sleep is so crucial that its absence or disruption can impair reconsolidation and prevent memory updates from taking hold (Simon et al., 2020). Directly studying the effects of sleep on memory

reconsolidation, Klinzing et al. (2016) showed that a brief 40-minute period of sleep compared to wakefulness can enhance the reconsolidation of reactivated memories. In contrast, non-reactivated remote memories were less influenced. In a separate study, Jones and colleagues demonstrated that reactivating consolidated memory improved memory retrieval, with sleep, specifically NREM sleep, leading to less memory deterioration than wakefulness (Jones et al., 2022). In another study, Moyano and colleagues studied whether sleep could accelerate the reconsolidation of memories. Their findings demonstrate that sleep can shorten the reconsolidation window with SWS (especially slow-oscillations; SO and delta (1-4 Hz) activity) showing a significant positive correlation with re-stabilization rate in the memory (Moyano et al., 2019). Another recent study examined how sleep, in particular, sleep spindles during NREM support the reconsolidation and modification of memories. Subjects who slept after encoding showed higher memory integration, and this was predicted by spindle density (Bryant et al., 2020).

In sum, these findings suggest that sleep is not a passive state, rather it is where memory reconsolidation actively occurs leading to long term storage of the altered memories.

1.1.3 Enhancing memory consolidation and reconsolidation during sleep

Studying the neuroscience of learning and memory at a fundamental level could offer new perspectives on enhancing consolidation through diverse methods. The use of closed-loop stimulation or targeted memory reactivation (TMR), two techniques with potential applications in clinical interventions, could enable increases in the consolidation of therapy-acquired knowledge and processes, boost the effectiveness of therapy, and enhance the retention of therapeutic progress over time (Lee, 2020; Ngo et al., 2013).

1.1.3.1 Closed-loop stimulation

Synchronized cortical SO are particularly important for memory and learning. Therefore, researchers have used various ways to externally boost this activity with methods such as the closed-loop stimulation. While SO are a primary target due to its role in memory consolidation, closed-loop stimulation has also been used to modulate other

brain oscillations, such as spindles or theta rhythms (4–8 Hz), depending on the process being studied (Navi et al., 2022). In this method, rhythmic electrical pulses, e.g., auditory or transmagnetic stimulations, are used to boost this activity in the brain. Studies such as those by Ngo et al. (2013) and Ngo and Staresina (2022) applied rhythms to the brain in synchrony with the ongoing endogenous oscillatory activity which led to enhancement in the SO during sleep. In the first study, Ngo et al. (2013) showed that in-phase stimulations during NREM sleep on the one hand, increases SO, and on the other hand, enhances memory consolidation. In the subsequent study, Ngo and Staresina (2022) further showed that stimulating during the SO up states, compared to the SO down states, increased the ongoing up state and enhanced spindle power and task performance. Consistent with the findings of these studies, Göldi et al. (2019) demonstrated that combining TMR with closed-loop stimulation enhanced recall performance only when cues were presented during the SO up-state. In contrast, cues presented during the down states did not show a significant improvement. However, Wang et al. (2022) arrived at different conclusions and did not observe any differences between up- and down-state cueing in memory performance.

In sum, closed-loop stimulation of SO has been found to increase memory consolidation. However, the timing of the stimulation application, especially in relation to SO up or down states is still a matter of debate with studies showing mixed results.

1.1.3.2 Targeted memory reactivation

TMR is a technique used to manipulate the processing and consolidation of memories by artificially inducing the same neural replay that naturally happens during sleep (Carbone & Diekelmann 2024). In this method, olfactory, auditory, or tactile contextual cues are presented during the learning phase to form an association between the learning material and the cue. During subsequent sleep, the same sensory cue is presented to support and facilitate sleep-dependent memory consolidation processes leading to stabilization and integration of new information into the network of existing memories (e.g., Hu et al., 2020; Whitmore, et al., 2022b, Carbone & Diekelmann 2024).

One of the first studies that employed this method was conducted by Rasch and colleagues in 2007, where subjects had to learn an object-location memorization task

while a contextual odor cue was presented. During subsequent sleep, the same odor or an odorless control was presented. Thereafter, retrieval was tested upon waking which indicated a significant improvement following odor re-exposure during SWS (Rasch et al., 2007). Since then, numerous studies have demonstrated that TMR can enhance performance in both declarative (e.g., Diekelmann et al., 2012; Schreiner & Rasch, 2015) and non-declarative (e.g., Antony et al., 2012; Schönauer et al., 2014) memory tasks.

More specifically, this method has been successfully implemented in a variety of basic memory tasks such as object-location (e.g., Bar et al., 2020; Cairney et al., 2014; Creery et al., 2015), bimanual motor task (e.g., Nicolas et al., 2022), picture-word association (e.g., Groch et al., 2017; Ngo & Staresina, 2022), creativity task (e.g., Ritter et al., 2012), face-name pairs (e.g., Whitmore, et al., 2022a), conditioning/extinction paradigm (e.g., Ai et al., 2015), fear conditioning paradigm (e.g., He et al., 2015), or vocabulary learning (e.g., Göldi et al., 2019) where either odor or auditory cues were served as the contextual cues.

Studying the effects of TMR on non-declarative memories, Rakowska and colleagues, for instance, conducted two studies using a bimanual serial reaction time task. Their analysis showed that TMR significantly enhanced motor memory performance on the cued sequence after sleep in both studies. They additionally found significant increases in the SO-spindle coupling during cueing (Rakowska et al., 2021, 2022). In another interesting study, subjects learned two melodies with one of them later used as a contextual cue during nap. After the nap, performance was better in the TMR group. Moreover, spindle density during TMR was significantly higher than during periods without stimulation and the spindle count positively predicted memory accuracy (Hopper, 2021).

Recent research further supports the efficacy of TMR in declarative memory. Schechtman and colleagues used a spatial-memory task where subjects learned the locations of images on a 2D circular grid, with each set linked to a distinct sound. During NREM sleep, half of these sounds were replayed. The study compared the benefits of TMR between cued and non-cued items, finding that TMR significantly improved recall for cued items over non-cued ones. TMR additionally increased delta-theta (0–11 Hz) and sigma activity (Schechtman et al., 2021). Similarly, Vidal and colleagues applied TMR in a real-world educational setting with secondary school students during a history lesson. When an odor cue was presented during learning and was represented during the night

at home, students exhibited significant improvements in memory performance for the history class compared to the control condition (Vidal et al., 2022).

Recent research into the neural mechanisms of TMR has provided key insights into memory consolidation during sleep. Research on non-emotional memory tasks has consistently demonstrated the significance of specific neural patterns specifically during NREM sleep. Schreiner and Rasch (2015) used Dutch-German word pairs and found that successful verbal cueing during NREM sleep was associated with pronounced frontal negativity in event-related potentials. This reactivation was further characterized by an increased frequency of frontal slow-waves and a cueing-related rise in right frontal and left parietal oscillatory theta power. In a different study using a word-object task, Groch and colleagues (2017) presented auditory cues linked to the memory task during NREM sleep and observed that stimuli related to prior knowledge induced higher theta and fast spindle activity (FSA). Additionally, Whitmore and colleagues (2022a) used a face-name association paradigm each paired with an auditory cue. During the subsequent NREM sleep, half of the cues were represented. Results showed a positive correlation between memory benefits and the duration of SWS. Additionally, memory benefits were negatively correlated with measures of sleep disruption, emphasizing the importance of uninterrupted deep sleep for memory consolidation. Another recent study applied TMR unilaterally through a specialized mask and observed a general increase in SWA during cueing. Additionally, local TMR increased the phase-amplitude coupling between sleep spindles and SO. However, this activity was negatively correlated with memory performance (Bar et al., 2020).

In addition to NREM sleep, other studies have highlighted the key role of REM in studies with TMR. Hutchison et al. (2021) showed that TMR for picture-sound combinations during REM, but not during SWS, could significantly decrease subjective arousal. Additionally, in the study by Tamminen et al. (2017) although TMR during SWS did not have a significant effect on behavior, findings indicate that TMR influence on lexical integration is mediated by the duration of REM sleep in a way that the memory for the cued words was positively correlated with REM duration. Moreover, recent research by Sifuentes Ortega and colleagues (2023) showed that memory recall improved for words reactivated during NREM sleep followed by REM sleep, compared to those reactivated

during NREM sleep without subsequent REM. These findings highlight the complementary role of REM and NREM sleep in memory consolidation.

Beyond its traditional role in facilitating memory consolidation, TMR has been shown to additionally facilitate selective weakening or intentional forgetting. Schechtman and colleagues (2020) employed a revised item-based directed-forgetting paradigm where participants were assigned to memorize specific image locations on a grid while ignoring others, coupled with auditory cues. During an afternoon nap, those cues instructing participants to avoid memorizing the locations of certain images were presented in NREM sleep. Following sleep, participants exhibited weakened memory recall for the locations of images linked with the presented cues demonstrating intentional suppression using TMR. Similarly, Whitmore & Paller (2023) showed the potential of TMR on weakening memories. This was achieved by presenting TMR cues during sleep that also caused sleep arousals, and consequently disrupted sleep stages. The findings suggest that when TMR coincides with sleep disruption, it can actually lead to a weakening of the reactivated memories and to forgetting.

Taken together, these studies strongly support the powerful effect of TMR on non-declarative as well as declarative memories. Results of these studies have also shown the crucial role of sleep, in particular slow waves, spindles, and theta activity in facilitating the consolidation processes. At the same time, other studies have emphasized the complementary role of NREM and REM sleep suggesting that in order to better understand the sleep mechanisms, TMR studies should be conducted in the context of the whole night sleep rather than targeting specific sleep stages. Moreover, most of these studies have focused on non-emotional tasks. However, emotional memories have been shown to work differently in many ways, especially when they hold personal significance. Emotions are shown to shape how the memories are processed, stored, or recalled. In the next section, we will explore TMR in the context of emotional memories.

1.1.3.2.1 TMR on emotional memories

Efforts to apply TMR for emotional memory have produced conflicting results, likely due to the diversity in methodologies employed (Schouten et al., 2017). While in some studies, TMR facilitated emotional memory consolidation (e.g., Cairney et al., 2014), in

others it had no impact on the strength of the emotional memory trace (e.g., Rihm & Rasch, 2015).

Research utilizing TMR to reactivate arousing picture-location memory has indicated that the reactivation during NREM and in particular SWS, is linked to increased theta and spindle activity leading to better emotional memory performance (Lehmann et al., 2016). Yet, we still observe inconsistencies with research demonstrating that although TMR during NREM led to increases in theta activity, it did not translate to emotional object memory increases (Denis & Payne, 2024). Similarly, other studies such as the one by Pereira and colleagues found no significant differences in memory consolidation or emotional valence between the cued and non-cued items, regardless of their emotional category. However, TMR during REM sleep appeared to modulate the activity of the orbitofrontal cortex, whereas REM sleep itself was found to mediate the cueing effect on the amygdala (Pereira et al., 2022). Consistently, another study used odor cues in a trauma-film paradigm. Participants who napped after watching the trauma film had fewer intrusive memories with their memories being less vivid compared to those who stayed awake. However, TMR during NREM sleep did not significantly enhance these effects (Gvozdanovic et al., 2023) suggesting that additional factors, beyond the type of cueing and memory task, may influence the effectiveness of TMR in emotional memory consolidation. Therefore, the extent to which the TMR effects can be generalized across different types of memories or whether the brain responses to TMR are translated to behavioral results remains uncertain.

TMR has also been shown to change the emotional tone or intensity of memories. Some studies have demonstrated that reactivating negative memories with positive TMR leads to modification of the emotional tone of the memories. Moreover, greater theta power in response to TMR was linked to decreased emotional valence of the aversive stimuli (Groch et al., 2016). Similarly, in a separate context, higher cue-evoked theta power correlated with stronger reduction in negative emotional responses (Xia et al., 2024). This evidence demonstrates the potential of TMR in altering the emotional intensity or tone of aversive memories. A process that closely aligns with the objectives of psychotherapy, which aims to alter negative emotional responses to maladaptive memories and promote adaptive ones instead.

Together, these studies illustrate that although TMR has shown potential effects on emotional memory consolidation and altering their emotional tone or intensity, its effects remain inconsistent across studies. This could be the result of different factors such as the specific time of TMR presentation during sleep or the nature of the memory task. Overall, the potential of using TMR in the clinical context seems promising, as it offers a novel approach to facilitating the consolidation of treatment-induced modifications of emotional memories. However, further research is needed to determine its optimal application methods, especially when reactivating highly personal memories as compared to simpler emotional memory tasks, which differ in both intensity and personal significance.

1.1.3.2.2 Clinical Applications of TMR

Recent research has begun to explore the clinical applications of TMR for various psychological disorders. However, little is known about the optimal timing, type, or duration of TMR application to enhance therapeutic effects in the clinical setting. In certain studies, TMR has supported the positive effects of psychotherapy, leading to observable and measurable behavioral improvements. However, in other cases, this effect was only evident at the neural level and was not translated into observable behavioral changes.

For instance, Rihm and colleagues presented a contextual odor cue while patients suffering from spider phobia verbalized their positive experiences during the successful exposure therapy. In the following 90-minute nap, contextual odor was re-presented to half of the patients. TMR led to increased SWA and FSA suggesting the possible successful reactivation of the therapy-related contents. However, it did not lead to any further reduction in symptoms (Rihm et al., 2016). In accordance with this study, Lee (2020) found that combining TMR and exposure therapy on patients with phobias of spiders, contamination, or enclosed spaces, did not significantly improve the consolidation of extinction learning. Correspondingly, the study conducted by van der Heijden et al. (2024) on PTSD patients found that TMR did not lead to a significant overall reduction in PTSD symptoms when compared to the sham group. However, patients in the TMR group exhibited greater improvements in avoidance symptoms. Likewise, TMR did not yield improvements in the effectiveness of exposure therapy for patients with social anxiety

disorder (SAD). The study conducted by Borghese and colleagues employed a virtual reality (VR) environment where SAD patients engaged in two consecutive exposure therapy sessions, involving delivering a talk in front of a virtual jury. In the TMR group, an auditory contextual cue was played at the end of each session, coinciding with positive feedback from the jury. During the subsequent night, a headband automatically detected the REM sleep and presented the auditory cue during this stage. The results indicated that TMR during REM sleep did not significantly improve the benefits of the therapy in reducing the patients' experience of anxiety. However, those participants in the TMR group, who had longer REM sleep durations and, therefore, more auditory presentations, exhibited reduced anxiety levels (Borghese et al., 2022).

Conversely, other studies have reported beneficial effects of TMR on enhancing the therapy effects. For example, Schwartz and colleagues (2022) explored the potential benefits of combining TMR with imagery rehearsal (ImR) therapy. Researchers used TMR to reactivate the therapy content in patients suffering from nightmare disorders (ND). Using a sound during the therapy session, subjects associated therapy with the auditory cue. Over the following weeks, all participants continued with their evening therapy sessions and received an auditory cue during REM sleep automatically. The results indicated that the TMR group experienced a reduction in the frequency of nightmares compared to the control group. This positive effect was observed after a two-week period and remained present even after three months (Schwartz et al., 2022). Building on these, Recher and colleagues (2024) studied the effects of multiple cuing nights on therapeutic success. Subjects had a session of ImR focused on their aversive autobiographical memories. In the following 2-5 nights of TMR, subjects were presented with words from the ImR updated memory during NREM sleep. Results showed that these memories became less vivid and emotionally charged.

In sum, these findings suggest that further research is needed to refine methodology and establish best parameters for TMR application to optimize its clinical context. Additionally, there is a lack of research examining the impacts of TMR on psychotherapy of maladaptive autobiographical memories, which are known to be one of the fundamental aspects posing challenges in various disorders.

1.2 Psychotherapy as a form of memory modification and learning

One of the main aspects of shaping every individual's unique pattern of behavior, emotions, and thoughts is learning and memory. Among the various forms of learning, implicit emotional learning is primarily responsible for the majority of problems and symptoms that lead individuals to seek psychotherapy. These learnings are normally formed in emotionally intense situations and mostly develop without awareness, which also significantly strengthens their intensity and durability (Ecker, 2015). Therapy, however, is a collaborative process between a client and a therapist. The client seeks guidance for mental health concerns, with the goal of achieving a perspective change and developing emotional learning. This learning is deeply personal, as it involves reflecting on and understanding one's own experiences (Rose et al., 2005). Therapy helps identify and address maladaptive patterns of interpreting events, both conscious and unconscious, that can hinder learning from life's experiences. Ultimately, therapy empowers individuals to be more open to their experiences, allowing them to evaluate these experiences objectively without being limited by past interpretations (Rose et al., 2005). From this view, psychotherapy is not only a process that introduces new experiences, but also a process that fundamentally transforms and reshapes our understanding of past events. This happens through the interaction between different types of memory and emotion (Lane, 2024). Ultimately, psychotherapy offers repetitive counter learning and corrective experiences which overwrite the past maladaptive learning (Ecker, 2015).

1.2.1 Exposure therapy

Exposure therapy is a well-established and highly effective psychological treatment method used for anxiety-related disorders such as obsessive-compulsive disorder (OCD), PTSD, panic disorders, or phobias (Craske et al., 2014; Knowles & Tolin, 2022). This method involves systematic and repeated confrontation with the fear-provoking stimulus in a controlled environment to decrease anxiety and avoidance over time. This method functions on the principles of fear extinction, in which the patient learns that feared stimuli are not inherently dangerous (Craske et al., 2014). This way, exposure therapy helps

create new learning that competes with the original fear-based associations and violates the expectations of danger, such as overestimation of harm leading to reductions in avoidance (Craske et al., 2014; Knowles & Tolin, 2022).

1.2.2 Eye movement desensitization and reprocessing

EMDR is also a well-established psychological treatment primarily for PTSD. This method has been effective in reducing anxiety symptoms in a variety of psychological conditions. In this method, bilateral stimulations (such as eye movements) trigger the orienting reflex of the body which is initially activated to prepare the body for threat (Pagani et al., 2017). However, by quickly shifting this response to relaxation, this process helps with traumatic memory desensitization. With eye movements, the working memory is engaged and competes for cognitive resources which further reduces vividness and emotional intensity of traumatic memories. In summary, this method shifts the traumatic memories from a hyperactive limbic state to a less distressing cognitive state (Pagani et al., 2017).

1.2.3 Imagery Rescripting and Reprocessing Therapy (IRRT)

Therapeutic interventions such as EMDR and ImR aim to reprocess or create an adaptive version of maladaptive memories. In the latter, imagery is used not only to activate stressful memories and trauma-related inhibited emotions, but also to change meanings, reduce distress, and thereby create an adaptive version of the memories through corrective information (Arntz, 2012; Arntz et al., 2007; Hackmann, 2011). In this method, trauma-related beliefs and schemas such as helplessness are corrected during imagination and a more favorable outcome, e.g., having control over the situation, is produced (Arntz et al., 2007).

IRRT, in particular, is an imagery-based cognitive-behavioral therapy (CBT) technique designed specifically for individuals suffering from PTSD, as it facilitates cognitive and emotional processing of traumatic events (Grunert et al., 2007). As a primary goal, IRRT uses cognitive restructuring to convert the mental images of victimization into adaptive images, which enables the trauma survivors to envision themselves as strong

and empowered, rather than feeling helpless and trapped (Smucker, 2005). This method focuses on actively identifying and changing maladaptive thoughts and images linked to the trauma and thereby creates a new mental framework that helps resolve symptoms in PTSD. This treatment primarily consists of three major phases. First, imaginal exposure that involves activating the distressing abuse-related imagery. Second, mastery imagery which aims to replace or rewrite abuse imagery with coping/mastery visualization. Third, self-soothing imagery that involves providing care to the traumatized inner child (Grunert et al., 2007; Smucker, 2005).

Despite extensive research on ImR, studies focusing specifically on IRRT are still scarce. Nonetheless, Grunert and colleagues (2007) studied the effects of IRRT on PTSD patients. This study focused on 23 patients who had PTSD after prolonged exposure (PE) therapy. The researchers added IRRT into PE treatment. The results indicated that 18 out of the 23 patients fully recovered from their PTSD symptoms after just 1-3 sessions of IRRT. In line with this, another study aimed to examine the effectiveness of IRRT in improving emotional processing in patients with Multiple Sclerosis (MS). After 7 IRRT sessions, the results showed significant improvements in emotional processing and significant decreases in emotional distress compared to the control group (Khalili et al., 2023). A recent study using IRRT on Generalized Anxiety Disorder (GAD) patients also demonstrated the effectiveness of IRRT aligning with previous findings on its effectiveness in PTSD or anxiety disorders. In this study, high school teenagers diagnosed with GAD underwent 12 IRRT sessions. Compared to the control group, the IRRT group showed a significant decrease in GAD symptoms as well as in cognitive fusion and avoidance (Soleimani et al., 2024).

1.3 Present study and rationale

Research has consistently shown that sleep is beneficial for both memory consolidation and reconsolidation by facilitating the re-stabilization of updated memories (Azza et al., 2022; Klinzing et al., 2016). Reconsolidation is a key stage of the post-encoding memory modification process, during which retrieved memories are updated and re-encoded. This process offers a perfect opportunity to integrate new and adaptive information into an already existing, maladaptive memory trace while it is retrieved and

labile, and thereafter restabilizing it into existing networks (Lane et al., 2015; Stickgold & Walker, 2007).

Considering the widespread occurrence of disorders linked to maladaptive autobiographical memories and the considerable distress and impairment they cause, advancing therapeutic strategies is urgent. Unlike simple emotional memory paradigms (e.g., emotional picture recall), which are less personal and, thereby, carry lower emotional weight, autobiographical memories are highly personal, intensely emotional, and deeply rooted in an individual's life experience, making them hard or resistant to change. While effective for many, the current therapeutic techniques, including IRRT, still face limitations, demonstrating the need for novel treatment approaches that further augment these well-established interventions. Especially methods that actively support the spontaneous reactivation and reconsolidation of the newly formed memory traces during sleep could significantly improve the efficacy of such treatments. Our partially unexplored but promising approach is TMR. While this method has been extensively studied in the context of declarative memories and fundamental research, its application in the context of autobiographical memories, especially in combination with the therapy techniques that involve memory modifications such as IRRT, is yet to be explored. Since IRRT is a method that involves updating aversive memories by reprocessing and rescripting them, it creates a substantial amount of information that needs to be reconsolidated or updated. Methods like TMR have been shown to enhance the consolidation and reconsolidation rates and may provide valuable support in stabilizing this modified information. If TMR can effectively facilitate the reconsolidation of the modified memories, it could significantly improve the psychotherapy outcomes particularly for maladaptive or trauma-related disorders such as PTSD (see Figure 2d).

In this study, IRRT is used to create and restructure an adaptive version of the individual's aversive memories. By presenting a contextual cue during the re-scripting process and re-presenting the same cue during the subsequent sleep, we aim to strengthen the re-stabilization of the modified memories. Previous research has already demonstrated the effectiveness of TMR in targeting emotional memories. However, the mechanisms behind TMR are not yet fully understood in the clinical setting. Therefore, more research is needed to refine its application, determine optimal conditions, timing and its type. The integration of TMR into clinical practice could offer an accessible,

straightforward method for enhancing psychotherapy with its major advantage being its ease of implementation. Therapists could simply apply it during therapy sessions, and patients could continue the process at home, reinforcing therapeutic progress while they sleep. Aiming to simulate real-life conditions, we employed a whole-night sleep paradigm rather than a more commonly used nap-based design in this research, allowing sufficient time for overnight reconsolidation. This approach could not only enhance the positive effects of traditional therapy but also can also deepen our understanding of the relationship between sleep and psychotherapy.

By further investigating TMR and IRRT as complementary techniques, we hope to advance both theoretical knowledge and practical applications, ultimately bringing us closer to more effective and personalized interventions for disorders related to maladaptive memories. If successful, this study could further mark the power of sleep to reshape aversive memories, promote lasting psychological well-being, and open new doors for innovative therapeutic applications. To test these assumptions, we propose the following hypotheses:

H1. The reduction in emotional distress in response to an individual aversive memory script and its free recall, as measured by continuous recordings of heart rate (HR), subjective ratings of induced emotions and cognitions, and memory free recall characteristics will be greater when a whole-night sleep is accompanied with congruent odor as compared to

a) whole-night sleep with incongruent odor,
b) wake interval with congruent odor,
c) wake interval with incongruent odor

following memory modification.

H2. No significant differences are expected in total sleep time, sleep efficiency, the percentage of time spent in each sleep stage, or the number of epochs containing arousals between nights when a congruent odor is presented and nights when an incongruent odor is presented.

H3. We expect to observe the highest SWA (0.75-4 Hz) during NREM sleep in the ON-periods of nights when a congruent odor is presented, compared to:

a) OFF-periods of nights with a congruent odor,
b) ON-periods of nights with an incongruent odor.

H4. We expect to observe the highest SO (0.75-1.5 Hz) during NREM sleep in the ON-periods of nights when a congruent odor is presented, compared to:

a) OFF-periods of nights with a congruent odor,
b) ON-periods of nights with an incongruent odor.

H5. We expect to observe the highest FSA (12-15 Hz) during NREM sleep in the ON-periods of nights when a congruent odor is presented, compared to:

a) OFF-periods of nights with a congruent odor,
b) ON-periods of nights with an incongruent odor.

H6. We expect to observe the highest Theta activity (4.25 – 8 Hz) during REM sleep in the ON-periods of nights when a congruent odor is presented, compared to:

a) OFF-periods of nights with a congruent odor,
b) ON-periods of nights with an incongruent odor.

By refining these hypotheses and conducting thorough research, we aim to uncover more about the complex interplay between sleep, psychotherapy and TMR, ultimately improving therapeutic interventions specifically for those suffering from disorders related to maladaptive memories.

2. Chapter 2: Methods

Participants, each with two personally emotionally distressing memories were recruited mainly from undergraduate university students at the University of Lübeck. The study was advertised throughout the university using flyers, direct emails to students and posts on social media. Participants first underwent a telephone screening (n = 118) and were screened for their memories, sleep habits, psychological disorders, physical illnesses, and substance use habits using the following criteria:

Inclusion criteria:

1. Participants must have at least 2 personally distressing that are at least 2 years old.
2. Participants should be between 18 and 30 years of age.

Exclusion criteria:

1. Participants whose memories are traumatic requiring treatment.
2. Individuals with psychological disorders who are currently undergoing treatment.
3. Participants who have traveled across 2 or more time zones or have worked in shift schedules within the past 30 days.
4. Individuals who use sleep medications.
5. Participants with sleep disorders.
6. Those with chronic diseases or any conditions that could interfere with polysomnographic recordings, such as brain injuries, epilepsy, etc.
7. Individuals with allergies, including skin allergies, hay fever, or olfactory disorders.
8. Male participants consuming more than 60g and female participants consuming more than 40g of alcohol daily.
9. Individuals who frequently use cannabis or are currently using substances such as cocaine, Ritalin, amphetamines, etc.

The current experiment used a randomized controlled design, in which all participants underwent IRRT therapy in the presence of a contextual odor. Following the treatment, participants were randomly assigned to either sleep or wake group, with each group exposed to either the same odor used during IRRT therapy or a novel one.

Data from 72 healthy participants (M_{age} = 24, SD_{age} = 3.580) were collected for this study. Participants received either course credits or 180 € (wake group) or 210 € (sleep

group). All participants provided written informed consent prior to participation, and the study was approved by the University of Lübeck's local ethics committee. Using G*Power (Faul et al., 2009), a sample size of 60 participants (α = .05, power = 0.95 and estimated effect size = 0.25) was estimated for this study.

16 participants were excluded from the study: 7 had only participated in the first session. In addition, 1 participant took a short nap during the wake interval, and 4 had difficulties falling asleep while wearing the EEG caps. Another because the wrong odor was presented during the first 30 minutes of the retention interval. 1 participant, who scored 26 on the Beck Depression Inventory-II (BDI-II; Beck et al., 1996), was also excluded due to a clinically significant level of depression (defined as a BDI-II score ≥18). Moreover, 2 participants only took part in the first 2 laboratory assessment sessions, so they were not included in the final analysis.

In the end, the sample of 56 participants was included for the behavioral data analysis (sleep group: N = 28 (24 women) age: M = 23.357 ± 3.291 years (M_{woman} = 23.416 ± 3.549, M_{men} = 23 ± .816); wake group: N = 28 (24 women) age: M = 25.035 ± 3.564 years (M_{woman} = 24.708 ± 3.381, M_{men} = 27 ± 4.546). None of them reported current psychological problems. However, 3 participants reported psychological problems (i.e., two of them had an eating disorder, one of them an adjustment disorder) in the past. The mean BDI-II score of the sample was M = 5.100 ± 3.921 and the average State-Trait Anxiety Inventory score (STAI; Spielberger, 1970) was M = 42.533 ± 4.220.

According to the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) all participants reported good subjective sleep quality within two weeks prior to the adaptation night (M = 1.423, SD = 1.132, Min = 0, Max = 5). Moreover, due to technical issues the data from only N = 12 subjects (10 women; age: M = 24.333 ± 3.984 years (M_{woman} = 24.700 ± 4.295, M_{men} = 22.500 ± .707)) from the sleep group were included in the EEG analysis.

2.1 Procedure

In Figure 3, the study design and procedures are summarized. In the first session (T0), participants arrived at the sleep lab and filled out their demographic data as well as PSQI, the World Health Organization Five Well-Being Index (WHO-5; World Health

Organization, 1998), and the Spontaneous Use of Imagery Scale (SUIS; Goergen et al., 2016). The STAI (Spielberger, 1970) and the BDI-II questionnaire were used to assess participants' levels of anxiety and depression. The questionnaires were generated online by the SoSci Survey (Leiner, 2019) and were available via www.soscisurvey.de. Thereafter, participants described 2 emotional and 2 neutral autobiographical memories in detail for later intervention. To select the most neutral odor for the study, participants rated a set of odors with a self-administered questionnaire. Based on these ratings, the therapist chose the 3 most neutral scents from a predefined pool of fragrances. Following this, participants in the sleep group stayed for an adaptation night to become familiar with the sleep lab environment and to sleep while wearing the EEG cap, whereas participants in the wake group were allowed to leave the lab. From this session on, all participants were asked and reminded every morning to complete the Sleep Questionnaire (SF-A/R; Görtelmeyer, 1986) via a customized app until the end of the experiment. All appointments were carried out in the sleep laboratory of the Universitätsklinikum Schleswig-Holstein, Campus Lübeck. After an interval of around 3-7 days, sleep participants returned to the laboratory in the evening around 3 hours before their habitual bedtime, and wake participants returned in the early morning for their experimental session (T1). First, the electrodes were attached for the recording of EEG, electrooculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), and electrodermal activity (EDA). Subsequently, all participants completed the script-driven imagery (SDI) to evaluate both their emotional and neutral target memories at baseline (Pre). It is important to note that the EDA data were recorded but not analyzed for this study.

Once the participant was prepared, a trained psychologist instructed them to recall their emotional autobiographical memory as vividly as possible (IRRT Phase 1) and complete the memory characteristics questionnaire referred to as FRABO (FRAgebogen zu Belastenden autobiografischen Erinnerungen). Afterwards, throughout the intervention from the start of emotional memory modification (IRRT Phase 2) to the end (the self-calming imagery, IRRT Phase 3) an odor was presented.

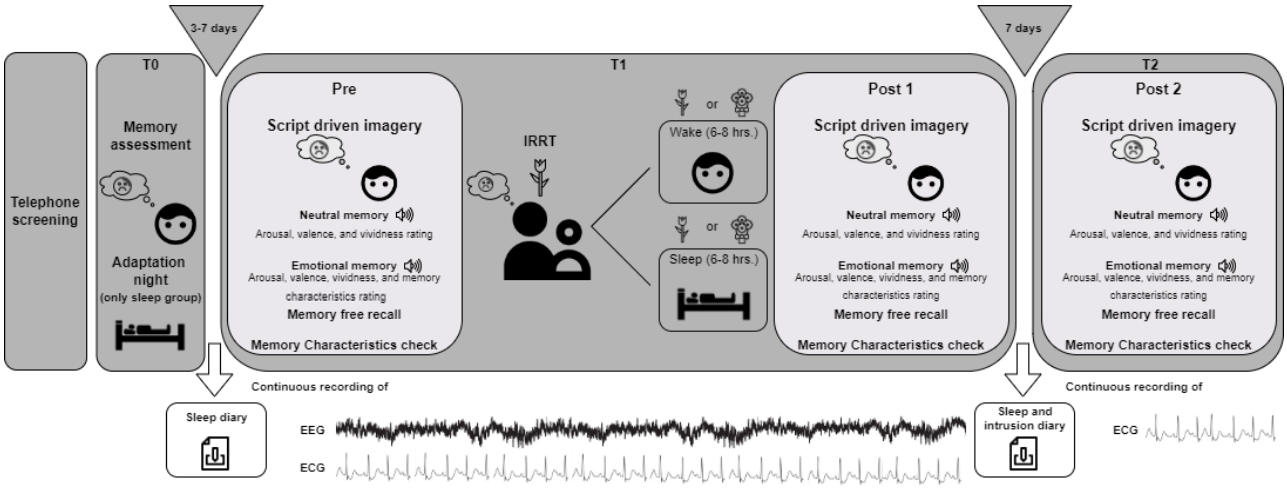

Figure 3. Study design. The study design included a telephone screening and 3 subsequent appointments at the sleep laboratory (T0, T1, and T2). At T0, 2 target memories for the IRRT and 2 neutral memories were evaluated, necessary information for the script preparation was collected, and participants filled out questionnaires. Additionally, those in the sleep group had an adaptation night. The second session (T1) was conducted after 3-7 days, during which the participants filled out a sleep diary each morning using a customized app. T1 included the SDI procedure, memory free recall (IRRT Phase 1), and memory characteristics assessment (all together referred to as "Pre") followed by the IRRT intervention while ECG and EEG were continuously recorded. As soon as the memory modification (IRRT Phase 2) started until the end of IRRT (Phase 3), an odor was presented. Afterward, participants had 6-8 hours of sleep (sleep group), or an equivalent duration of wake interval (wake group) accompanied by either the congruent or the incongruent odor in a randomized order. After the retention interval, another SDI, memory free recall, and memory characteristics assessment took place (Post 1) and was repeated after 7 days at T2 (Post 2). Between T1 and T2, participants filled out sleep and intrusion diaries. T1 and T2 sessions were repeated similarly for the second emotional memory. Figure created using Draw.io (https://www.drawio.com/).

During the next 6-8 hours, those in the sleep group went to sleep while those in the wake group remained awake. In the congruent condition, the same odor as in the IRRT session was presented, while in the incongruent condition, a novel odor was presented during the retention interval in a randomized order. Odor presentation for the sleep group was started manually during NREM sleep, as soon as stable sleep stage 3 was detectable. The Post 1 measurement was taken immediately after the retention interval for the wake group, and approximately 45 minutes after awakening for the sleep group participants to minimize the influence of sleep inertia on recall performance. The third session (T2, Post 2), which followed the same procedure as the Pre and Post 1 sessions, took place approximately 7 days later. During these 7 days, participants completed a sleep diary

each day and an intrusion diary, which inquired about the vividness, emotional distress, and type of any involuntary or triggered intrusions related to the emotional memory. The sessions T1 and T2 were repeated for the second emotional memory.

2.2 Script-driven imagery

SDI is a well-established symptom provocation method developed by Pitman and colleagues in 1987 (Pitman et al., 1987) that is designed to evoke and measure emotional response to memories, especially traumatic or maladaptive experiences. This method involves participants listening and vividly imagining the narrative of the past event (Hopper et al., 2007) and is a useful tool not only in research on PTSD (e.g., Britton et al., 2005; Lindauer et al., 2006) but also on social emotional processing (e.g., Frewen et al., 2011) in healthy individuals or patients with mental disorders (e.g., Kraus et al., 2010). Following their proposed procedure, which includes 30-second script listening and 30-second imagination, the participants' emotional response to their individual memories was assessed over time. The scripts for neutral and aversive memories were created by the therapist based on the detailed narrative obtained during the T0 session. These scripts were then converted into 30-second recorded narratives, describing the scenes in the present tense. The SDI consisted of 4 intervals each 30-second for each memory. First, during the "baseline" phase, participants were instructed to sit quietly and focus on a fixation cross. Then, during the "script listening" phase, participants listened to the recorded audio script of their autobiographical memory. This interval was followed by the "script imagining" phase, during which participants were instructed to vividly imagine the scene. Finally, during the "recovery" phase, participants were asked to relax and mentally disengage from their imagination. Lastly, participants rated the arousal, valence, and vividness of their mental picture (1 = not at all to 10 = extremely). Moreover, to better assess the stressful memory characteristics, participants answered the FRABO questionnaire which was designed based on the adapted version of the Autobiographical Memory Characteristics Questionnaire (AMCQ; Boyacioglu & Akfirat, 2015), Memory Experiences Questionnaire (MEQ; Luchetti & Sutin, 2016), Response to Script-Driven Imagery Scale (RSDI; Hopper et al., 2007) along with 4 additional self-designed items. The complete questionnaire consisted of 13 items each rated on a 7-point Likert scale,

ranging from 1 (not at all) to 7 (completely), of which 8 were used in the final analysis (see Appendix 6.1). To avoid any carryover effects, the neutral script was always presented before the emotional memory script. The SDI and the subsequent questionnaires were presented using the PsychoPy® open-source software (Peirce et al., 2019). Figure 4 illustrates the SDI procedure in more detail.

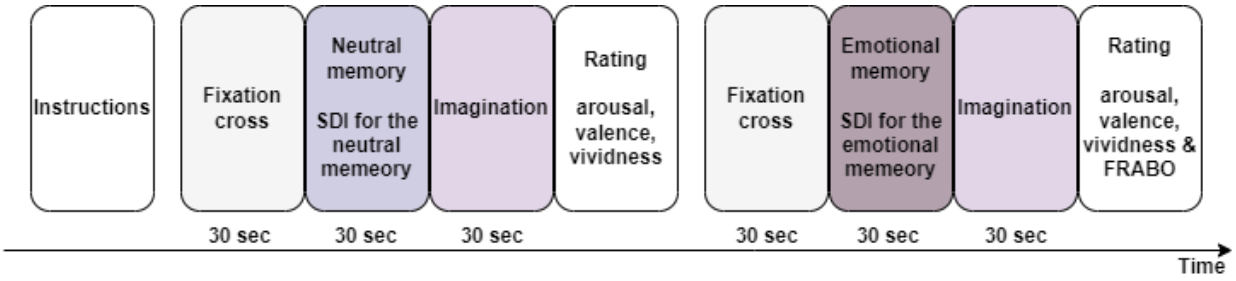

Figure 4. Schematic overview of the experimental framework for the SDI. First, participants received instructions to remain seated and calm, to listen to the scripts, and to answer the questions. This was followed by a 30-second fixation cross. Next, the 30-second audio script of their neutral memory was presented. Participants were then instructed to vividly imagine the scene and its continuation for 30 seconds. Afterward, they rated their arousal, valence, and vividness of the imagined event. The same steps were followed for their emotional memory, with the additional requirement that participants complete the FRABO questionnaire. Figure created using Draw.io (https://www.drawio.com/).

2.3 Imagery rescripting and reprocessing therapy

In the current study, modifying mental images was based on the protocol developed by Schmucker and Köster (2014) and administered by a trained psychologist. Phase 1 of IRRT, “Imaginal Exposure”, consisted of imagining and reliving the memory *in sensu*, describing it, and conveying the details of the scene as vividly as possible. To deepen their imagination, if necessary, subjects were asked to report what they saw, smelled, or heard during recollection. To pinpoint the so-called “hotspot”, which is defined as the most distressing part of the memory, the psychologist repeatedly asked the participants to rate their perceived arousal, valence, and vividness (1 = not at all to 10 = extremely). Lastly, subjects rated the intensity and distress of their emotions as well as the distress and correctness of the cognitions related to each emotion (1 = not at all to 10 = extremely) during the imagination. They then completed 12 FRABO questions, of which 10 were used for the final analysis (see Appendix 6.2). The most distressing emotion and its

corresponding dysfunctional cognition were defined as the “dominant emotion” and the “dominant cognition” by the psychologist. In Phase 2, “Mastery Imagery”, subjects were instructed to imagine themselves as a bystander watching the younger version of themselves in the scene. Participants were then encouraged to develop a conversation with the perpetrator through their imagination until they described the perpetrator as being disempowered. Finally, in Phase 3, “Self-Calming”, there was a direct interaction between the younger and the current self, including explanations and consultations, typically resulting in a sense of emotional relief. As a final step, the participant was asked to visualize a positive image for 30 seconds, which had the most meaning and significance from the entire intervention, to conclude the intervention with a sense of closure.

In each phase of the intervention, EEG, ECG, and EDA were constantly recorded, and arousal, valence, and vividness were repeatedly assessed and rated by the participants.

The follow-up sessions focused solely on Phase 1 of IRRT, and involved rating the arousal, valence, and vividness of the imagination, as well as assessing emotions and cognitions and completing the FRABO questionnaire. ECG and EDA were recorded during the follow-up sessions.

2.4 Odor substances and presentation

To identify the most neutral odors to use as olfactory stimuli in this study, each participant evaluated a set of 7 essential oils (see Appendix 6.3) produced by Gya Labs (https://gyalabs.com/). To assess the hedonic perception of the odors, the scents were presented randomly to participants for 10 seconds each. Following this, participants rated the odors on familiarity, valence, and intensity using a self-administered questionnaire (see Appendix 6.4), with responses ranging from 1 (not at all) to 5 (completely). Additionally, participants were asked to indicate whether each odor was linked to a specific memory. If an odor was linked to a personal memory, rated with a high familiarity and intensity (5), or a low valence (1), it was excluded from the remainder of the study. The experimenter selected 4 different odors for participants in the sleep group and 3 for those in the wake group based on their individual ratings, without the participants’ knowledge. One odor was used for the adaptation night in the sleep group to help participants become

familiar with sleeping in the presence of an odor. Another was used during the IRRT session and its subsequent retention period (referred to as the retention interval with congruent odor). Two additional odors were used during another IRRT session and its subsequent retention period, respectively (referred to as retention interval with incongruent odor). The order of the retention intervals with congruent or incongruent odor was randomized.

The selected odors were presented using the “Ezzence” olfactometer developed by Amores Fernandez (Amores Fernandez, 2020). All scents were prepared ahead of time, with each one comprising 0.1 ml essential oil and 1.9 ml distilled water. During both IRRT sessions and the subsequent retention interval, the olfactometer was located near the participant's head and was secured in a holder. To control the intensity and the frequency of the odor presentation, a mobile phone with a custom-made app developed by Amores Fernandez (Amores Fernandez, 2020) was used. Throughout the IRRT session, odor was continuously presented in 30-millisecond bursts, with a 30-second interval between each presentation. The odor presentation was initiated manually once IRRT Phase 2 began and was stopped at the end of Phase 3. Subsequently, during the retention interval, odor presentation alternated between 4-minute ON- and OFF-periods. In the ON-periods, the odor was administered as a 20-millisecond burst, with a 55-second interstimulus interval. Therefore, in every 4-minute period of odor presentation, 5 odor bursts were delivered. This was followed by 4 minutes of no odor presentation. This pattern repeated throughout the whole retention interval (6-8 hours; see Figure 5 for nighttime odor presentation). To start odor presentation during the retention interval from outside the intervention room, the ApowerMirror® app was used (Apowersoft Ltd., 2022). In both groups, odor presentation started manually. In the wake group, it started during the daytime and as soon as the retention interval started. Participants were checked multiple times by the experimenter to make sure that they were not napping or eating. In the sleep group, odor cueing started as soon as stable N3 sleep stage was visible in the EEG, paused when the participants were awake, and was restarted after ten minutes of stable sleep. Odor presentation was ultimately stopped 30 minutes before the participant was scheduled to wake up in the morning to avoid odor cuing during wakefulness.

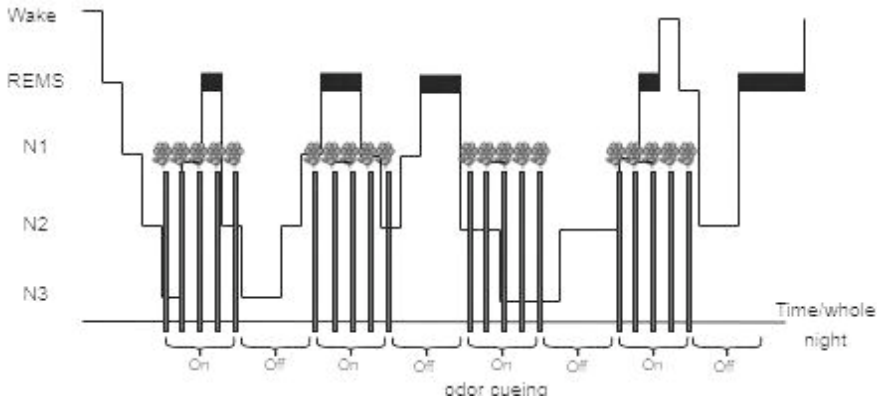

Figure 5. Odor presentation during sleep. A typical polysomnogram displays the proportion of sleep stages throughout the nocturnal retention interval, which includes Wake (W), NREM stages 1–3 (N1–N3), and REM sleep (REM). Lines in the figure indicate the odor cueing during the whole-night sleep on the post-intervention night. The odor was presented using a bimodal stimulation protocol, which involved alternating 4-minute "ON" periods with 4-minute "OFF" periods. During "ON" periods, the odor was presented in 20-millisecond bursts, with a 55-second pause between each presentation. Each line on the graph represents a single odor burst. Figure created using Draw.io (https://www.drawio.com/).

In case of olfactometer malfunction during either the IRRT session (N = 14) or the retention interval in the wake condition (N = 3) or the sleep condition (N = 2), a diffuser delivering a constant odor presentation was used, containing water and the corresponding odor. The data from these participants were included in the behavioral analysis but excluded from EEG analysis.

2.5 Sleep recording and analysis

A 64-channel actiCHamp Plus EEG amplifier (Brain Products GmbH, Gilching, Germany) was used to record polysomnography. EEG was recorded using a customized LC-64-X2 cap with 64 passive electrodes, including a reference electrode. A ground electrode was positioned between Fpz and AFz while the electrodes were referenced online to an electrode placed at the left mastoid (M1). Additionally, the actiCHamp Plus amplifier and auxiliary channels were used to record EOG, EMG, ECG, and EDA, in accordance with the recommendations of the American Academy of Sleep Medicine (AASM; Iber, 2007). To record vertical and horizontal eye movements, 4 external electrodes were placed on the left infraorbital, supraorbital, and on the right and left

temples. Two external electrodes were placed on the chin, and 3 external electrodes were placed below the right clavicle, in the center of the chest, and below the left costal arch to record EMG and ECG respectively. EDA was only recorded for IRRT and follow-up sessions using two additional external electrodes placed on the palm of the non-dominant hand. The EEG data were recorded using BrainVision Recorder 1.23.0001 software (Brain Products GmbH, Gilching, Germany). All channels were sampled at 500 Hz, with no high-pass (DC-mode), and a 140 Hz low-pass filter with a resolution of 0.049 μV/bit. To ensure recording quality, all impedances were kept below 10 kΩ and re-checked after each pause during the study.

EEG data were analyzed using the software BrainVision Analyzer 2.2.0.7383 (Brain Products GmbH, Gilching, Germany, 2017), and MATLAB version R2021b (The MathWorks, 2021). The EEG signals were filtered with a high-pass filter of 0.03 Hz and a low-pass filter of 35 Hz, the EOG signals with a high-pass filter of 0.16 Hz and a low-pass filter of 35 Hz, the EMG signals with a high-pass filter of 1.6 Hz and a low-pass filter of 90 Hz, and lastly the ECG signals with a high-pass filter of 1 Hz and a low-pass filter of 30 Hz. Additionally, all signals were passed through a notch filter of 50 Hz.

2.5.1 Sleep scoring

To prepare EEG data for manual sleep scoring, EEG signals were imported at a sampling rate of 500 Hz into BrainVision Analyzer 2 and reduced to two scalp electrodes (i.e., C3 and C4, which were re-referenced to M2), EOG, and EMG. The scoring was performed offline using SchlafAus 1.0 (Gais, 2013) by two experienced scorers who were blinded to the experimental conditions following the guidelines of the AASM (Iber, 2007). The recordings were visually inspected in 30-second epochs, and channels containing muscle or technical artifacts were excluded.

Sleep architecture analysis involved calculating total sleep time (TST), sleep efficiency (defined as the ratio of TST to time spent in bed), percentage of time in each sleep stage (calculated as time spent in each stage divided by TST), and the number of arousals in each sleep stage.

2.5.2 Spectral and sleep spindle analysis

EEG data preprocessing was performed in MATLAB and included the identification of bad channels, artifacts, and interpolation. Custom MATLAB scripts developed by Hong-Viet V. Ngo using the Fieldtrip toolbox (Oostenveld et al., 2011) were used for whole-night spectral and sleep spindle analysis. For this analysis, only arousal- and artifact-free sleep stages were selected and REM and NREM sleep were analyzed separately. Eye movement artifacts were removed using Independent Component Analysis (ICA).

After this stage, the data were segmented into 4-minute ON- and 4-minute OFF-periods. In separate analyses of NREM and REM periods, the data were further segmented into 8.192-second intervals with 50% overlap using a Hanning window for each period (once across the entire night and once within the 4-minute periods). Artifact-free epochs were then subjected to a Fast Fourier Transform (FFT) to calculate absolute spectral power within the frequency range of 0.125-45 Hz. The resulting spectra were averaged across all intervals. Spectral power was computed for the entire night as well as for ON- and OFF-periods. Spectral analysis additionally incorporates the Irregular-Resampling Auto-Spectral Analysis (IRASA) approach to remove 1/f or aperiodic components (Wen & Liu, 2016). Lastly, spectral band power was calculated by summing across the bins defined by the following frequency ranges: slow wave (0.75-4 Hz), slow oscillation (0.75-1.5 Hz), fast spindle (12-15 Hz) during N2 and N3, and theta (4.25-8 Hz) during REM sleep.

During analysis, it was discovered that the EEG data had been recorded without a high-pass filter. Consequently, slow drifts (e.g., due to high electrode impedances) caused the signal to drift outside the measurable range, resulting in flat-line segments in the EEG recordings. To address this, all 30-second segments of the sleep recordings were manually reviewed, and epochs affected by flat-line artifacts were removed, resulting in the inclusion of 12 participants for the EEG analysis.

2.6 Heart rate recording and analysis

This study used Kubios Heart Rate Variability (HRV) software (version 4.0; Tarvainen et al., 2014) to pre-process and analyze the ECG data. R-waves were

automatically detected by the built-in QRS detector algorithm (based on the Pan–Tompkins' algorithm; Pan & Tompkins, 1985). For preprocessing, the ECG signal was bandpass filtered, the data samples were squared, and a moving average filter was applied. The R-peak intervals were then interpolated at 2000 Hz to ensure high detection resolution. Moreover, noise segments were automatically detected based on the raw ECG and inter-beat interval (IBI) data and were subsequently excluded from the analysis. Threshold-based and automatic corrections were used to correct ectopic beats and artifacts. The automatic noise correction was set to medium, which compared and identified any IBI that deviated by more than 0.25 seconds from the local average. These identified artifacts were then replaced by interpolated values (Tarvainen & Niskanen, 2012).

2.6.1 Heart rate analysis during SDI

HR, HRV, and stress index (calculated using the height of the normalized RR interval histogram and the difference between the highest and the lowest RR interval values; Kubios HRV Analysis Methods, 2023) during SDI were measured at three time points: before the intervention (Pre), immediately after the retention interval (Post 1), and 1 week later (Post 2). For SDI, the following 30-second segments were extracted from the whole recording and used for the later analysis: (1) Fixation cross: start of the intervention, (2) Script listening: neutral memory, (3) Fixation cross: imagination of the neutral memory, (4) Resting phase: neutral memory, (5) Fixation cross, (6) Script listening: emotional memory, (7) Fixation cross: imagination of the emotional memory, (8) Resting phase: emotional memory. To calculate ECG response to the aversive memory script across the 3 sessions (Pre, Post 1, Post 2), ECG change scores were determined by subtracting the neutral memory script values from the emotional memory script values for "script listening" and "script imagining" intervals. ECG data count was reduced due to technical artifacts, missing values, or after outlier detection (N = 45).

2.6.2 Heart rate analysis during IRRT Phase 1

The HR analysis during Phase 1 in IRRT consisted of 3 consecutive 10-second intervals preceding the 3 markers set by the psychologist during the IRRT session: (1) Start of the intervention, (2) Hotspot, (3) Closing image. These segments began 5 seconds after each marker was set, to avoid physiological artifacts caused by the psychologist's instructions. Mean HR, mean HRV, and the stress index were calculated and analyzed for each segment. This analysis was repeated for each of the three sessions (Pre, Post 1, and Post 2) to assess changes in HR responses to memory free recall over time. HR data exceeding 1.5 times the interquartile range of the HR distribution, or affected by technical issues (e.g., incorrect marker placement) were excluded from the analysis, resulting in a final sample size of $N = 40$.

2.7 Narrative analysis

During each Phase 1 session of the IRRT (Pre, Post 1, Post 2), participants were instructed to freely recall the emotional memory as vividly and in as much detail as possible. To calculate the changes in the narratives in these three time-points, the audio recordings were first transcribed using Amberscript Global B.V. software (AmberScript, 2021), which is an automatic speech-to-text tool. Next, narrative segments that did not pertain to the original event (e.g., the psychologist's questions and direct responses to them) were marked by 2 independent raters, then cross-referenced and aligned for comparison. The marked segments were then removed, and the remaining narrative was manually reviewed and matched word-by-word against the original audio for accuracy.

Linguistic features of each narrative were extracted using the Linguistic Inquiry and Word Count (LIWC; Pennebaker et al., 2015) software, in both its German and English versions (Meier et al., 2019). The software analyzes texts based on 87 predefined categories by calculating the number of words from a set of categories, such as positive and negative emotion words, personal pronouns, and social processes, based on an established lexicon. 3 LIWC variables (analytic thinking, positive emotion, and negative emotion) were selected for exploratory analysis. Additionally, 1 last item (narrative architecture) examined the structured process of storytelling of the narratives over the

three time points. While no specific hypotheses were formulated in advance, these selections were guided by plausibility and their conceptual fit with the intervention context and might reflect how individuals process and articulate emotionally significant experiences. Each of these measures represents the percentage of times the specific element occurs in relation to the total number of words in the file (Biggiogera et al., 2021). For the analysis of words, the German version of LIWC was used. For the narrative analysis, the narratives were initially translated into English using ChatGPT 4.0 with the instruction: "translate word by word without adding or deleting anything from the original text." This was necessary because the English version of LIWC was the only one available for analyzing the narratives.

In addition to the linguistic analysis, we conducted a qualitative coding of the narratives to capture structural and memory-related changes over time. Using the recordings from IRRT Phase 1 at Pre, Post 1, and Post 2 time points, we examined 3 key aspects of the participants' narratives: (1) pauses longer than 4 seconds, (2) memory gaps, where participants either could not recall how the story unfolded or explicitly stated they could not remember it, and (3) story alterations, where the narrative at Post 1 or Post 2 differed significantly from the pre-session version, influenced by the psychotherapeutic intervention. These features were chosen since they may reflect narrative disruption, therapeutic processing, and memory integration and may be relevant in trauma therapy contexts. This analysis was conducted independently by 2 individuals who reviewed and rated each recording for these 3 aspects. The results were then compared, and the final dataset was created by averaging the ratings from both reviewers.

These exploratory analyses were conducted exclusively for participants in the sleep group. Given the time-intensive nature of preparing and analyzing the narrative data, this approach was limited to a subset of the sample. The sleep group was selected as it aligns most closely with the core research questions of this project and was, thus, prioritized for this in-depth linguistic investigation.

2.8 Sleep and intrusion diary

For data collection, we used the “Somnio” app, which was developed by Daniel Sabinasz specifically for this study. This custom-made app sent push notifications to

participants every morning, reminding them to complete the sleep diary to report on their previous night's sleep quality. Additionally, participants were instructed to fill out the intrusion diary as soon as they experienced involuntary reminders of their stressful memories, either spontaneously or through a reminder cue (see Appendices 6.5 and 6.6). Diary data collection began after the T0 session to collect baseline data and continued throughout the study until its conclusion. The pre-intervention phase included data from 3 to 7 days, depending on individual scheduling, and took place before the intervention (referred to as the no odor condition). The congruent and incongruent conditions refer to the 7-day period following the IRRT session, during which participants had previously been exposed to either a congruent or an incongruent odor during the intervention. For the statistical analysis, daily entries were averaged across participant for each of the three time points (Pre, Post 1, and Post 2). These mean values were entered into a 2 (group: sleep vs. wake) × 3 (odor condition: congruent, incongruent, no odor) ANCOVA, with age included as a covariate.

2.9 Data reduction and statistical analysis

Statistical analysis was conducted using MATLAB, IBM SPSS Statistics 26.0 (IBM Corp., 2019), and RStudio 2022.07.0-548 (RStudio Team, 2020).

A preliminary analysis revealed a significant age difference between the sleep and wake groups ($F_{(1,59)} = 4.536$, $p = .037$). Therefore, age was included as a covariate in all statistical analyses related to Hypotheses 1 and 2. Prior to conducting the ANCOVAs, model assumptions were checked. Normality was visually inspected using QQ plots and indicated that the data did not violate the normal distribution assumption. However, violations of normality are generally tolerated, especially with sample sizes of 25-30 participants (Ghasemi & Zahediasl, 2012; Rasch & Guiard, 2004).

Levene’s test indicated some violations of homogeneity of variances. However, ANCOVA was still performed, as minor deviations are not uncommon in larger samples and do not substantially impact the robustness of the analysis (Field, 2013).

To ensure the independence of observations, we implemented a careful study design with randomization, where participants were randomly assigned to groups to avoid

any potential dependencies. Additionally, we checked for outliers and verified the homogeneity of regression slopes to ensure the validity of the analysis.

Consequently, 2 x 2 x 3 ANCOVAs were conducted with odor (congruent or incongruent) and time (Pre, Post 1, and Post 2) as within-subject factors, and group (sleep, wake) as a between-subject factor for the analysis of the SDI, IRRT, HR, and diaries. However, the EEG and the narrative analysis were conducted only in the sleep group.

It is important to note that the main analysis used ANCOVA to control the impact of age as a covariate on the dependent variables. However, because the ANCOVA results masked the main effect of time, ANOVA was used as a sensitivity analysis to examine the unadjusted time effects, providing a clearer understanding of the overall effectiveness of psychotherapy.

The significance level for all analyses was set at $\alpha = 0.05$. For all repeated-measures ANCOVAs, Mauchly's test of sphericity was conducted to assess whether the assumption of sphericity was met. When this assumption was violated, degrees of freedom were corrected using either Huynh-Feldt or Greenhouse-Geisser estimates of sphericity, depending on the epsilon value. All reported *F*-values reflect these corrections where applicable.

3. Chapter 3: Results

3.1 Odor-induced reactivation effects on the behavioral level

3.1.1 Emotional reactivity response to the aversive memory during SDI

The first hypothesis of the study (H1) predicted that a whole-night sleep with congruent odor leads to the greatest reduction in emotional distress, as measured by subjective ratings of emotions and cognitions, HR and memory recall characteristics. The following results address each aspect of this hypothesis.

Emotional reactivity during SDI was tested using arousal, valence, and vividness questions (after emotional and neutral memory scripts) and the FRABO questionnaire (after emotional memory script) in addition to the constant recordings of EEG, and ECG. These were tested once before the intervention (Pre), right after the retention interval (Post 1), and one week later (Post 2).

For all SDI items, results are presented as adjusted and unadjusted means with standard errors (see Table G 1–Table G 11). The arousal and valence levels in response to listening to the emotional memory script were determined by subtracting the response to the neutral memory from the emotional memory for each time point.

For arousal, no significant main effects were observed for time ($F_{(2, 104)} = .109$, $p = .897$), nor for odor ($F_{(1, 52)} = 1.766$, $p = .190$), or group ($F_{(1, 52)} = .087$, $p = .769$). Similarly, no significant interaction effects were found for odor × group ($F_{(1, 52)} = .002$, $p = .961$), group × time ($F_{(2, 104)} = .281$, $p = .756$), odor × time ($F_{(1.773, 92.185)} = .061$, $p = .923$), or odor × time × group ($F_{(2, 104)} = .668$, $p = .515$).

In contrast, the ANOVA, performed without adjusting for covariates, showed a significant main effect of time ($F_{(1.870, 99.086)} = 97.575$, $p < .001$, $\eta^2_p = .648$) likely because the covariate absorbed variance shared with time.

For valence, no significant main effects of time ($F_{(2, 98)} = .124$, $p = .884$) or group ($F_{(1, 49)} = .197$, $p = .659$) were observed, but a marginally significant main effect of odor emerged ($F_{(1, 49)} = 3.963$, $p = .052$, $\eta^2_p = .075$). No significant interaction effects were found for odor × group ($F_{(1, 49)} = .347$, $p = .558$), group × time ($F_{(2, 98)} = .352$, $p = .704$), odor × time ($F_{(1.908, 145.299)} = .642$, $p = .522$), or odor × time × group ($F_{(2, 98)} = .027$, $p = .973$).

However, repeated measures ANOVA revealed a significant main effect of time ($F_{(2, 100)}$ = 119.792, p < .001, η^2_p = .706), indicating a reduction in emotional reactivity over time.

For vividness, no significant main effects were observed for time ($F_{(2, 106)}$ = .434, p = .649), odor ($F_{(1, 53)}$ = 2.281, p = .137), or group ($F_{(1, 53)}$ = .371, p = .545). Interaction effects were also not statistically significant: odor × group ($F_{(1, 53)}$ = .358, p = .552), group × time ($F_{(2, 106)}$ = 1.436, p = .243), odor × time ($F_{(1.891, 100.242)}$ = .013, p = .984), and odor × time × group ($F_{(2, 106)}$ = 1.560, p = .215).

For the first FRABO question in SDI ("While I recalled the event, I felt like I was reliving it."), no significant main effects were found for time ($F_{(2, 106)}$ = 1.805, p = .170), odor ($F_{(1, 53)}$ = .056, p = .813), or group ($F_{(1, 53)}$ = .083, p = .775). Likewise, no significant interaction effects emerged: odor × group ($F_{(1, 53)}$ = .323, p = .572), group × time ($F_{(2, 106)}$ = .540, p = .584), odor × time ($F_{(2, 106)}$ = 2.185, p = .118), or odor × time × group ($F_{(2, 106)}$ = .343, p = .710).

For the second FRABO question in SDI ("The retrieval of the memory was easy for me."), no significant main effects were found for time ($F_{(2, 106)}$ = .153, p = .859), odor ($F_{(1, 53)}$ = .246, p = .622), or group ($F_{(1, 53)}$ = .168, p = .684). Similarly, there were no significant interaction effects of odor × group ($F_{(1, 53)}$ = .101, p = .752), group × time ($F_{(2, 106)}$ = .638, p = .530), odor × time ($F_{(2, 106)}$ = .908, p = .407), or odor × time × group ($F_{(2, 106)}$ = 1.200, p = .303).

For the third FRABO question in SDI ("While recalling the event, I experienced many sensory inputs in the form of sounds, smells, tastes, touches, etc.”), no significant main effects were found for time ($F_{(2, 106)}$ = .642, p = .528) or odor ($F_{(1, 53)}$ = .676, p = .415), but a marginal group effect was observed ($F_{(1, 53)}$ = 2.518, p = .089, η^2_p = .054). No significant interactions were detected for odor × group ($F_{(1, 53)}$ = .027, p = .870), group × time ($F_{(2, 106)}$ = .151, p = .860), odor × time ($F_{(2, 106)}$ = .507, p = .604), or odor × time × group ($F_{(2, 106)}$ = .132, p = .877).

For FRABO item 4 in SDI ("In the process of recalling the event, my heart was pounding.”), no significant main effects were found for time ($F_{(1.738, 92.128)}$ = 1.017, p = .357) or group ($F_{(1, 53)}$ = 2.195, p = .144), but a significant main effect of odor was observed ($F_{(1, 53)}$ = 5.050, p = .029, η^2_p = .087). No significant interactions were found for odor × group ($F_{(1, 53)}$ = 1.422, p = .238), odor × time ($F_{(1.901, 100.774)}$ = .260, p = .761), or odor × time ×

group ($F_{(2, 106)} = .030$, $p = .970$). The group × time interaction was marginally significant ($F_{(2, 106)} = 2.655$, $p = .075$, $\eta^2_p = .048$).

For the FRABO item 5 in SDI ("While recalling the event, I had sweaty hands."), there were no significant main effects of time ($F_{(1.244, 65.941)} = .379$, $p = .586$) or group ($F_{(1, 53)} = .194$, $p = .661$), but a significant main effect of odor was found ($F_{(1, 53)} = 4.020$, $p = .050$, $\eta^2_p = .071$). No significant interactions emerged for odor × group ($F_{(1, 53)} = .286$, $p = .595$), group × time ($F_{(2, 106)} = .986$, $p = .377$), odor × time ($F_{(1.910, 101.249)} = 1.364$, $p = .260$), or the three-way interaction ($F_{(2, 106)} = 1.173$, $p = .313$).

For the sixth FRABO question in SDI ("While recalling the event, I was tense."), there were no significant main effects of time ($F_{(1.851, 98.093)} = .545$, $p = .568$), odor ($F_{(1, 53)} = 1.078$, $p = .304$), or group ($F_{(1, 53)} = .975$, $p = .328$), and no significant interaction effects were found for odor × group ($F_{(1, 53)} = .622$, $p = .434$), group × time ($F_{(2, 106)} = .694$, $p = .502$), odor × time ($F_{(1.917, 101.605)} = 1.542$, $p = .220$), or odor × time × group ($F_{(2, 106)} = .219$, $p = .803$).

For FRABO item 7 in SDI ("While recalling the event, I felt burdened."), the main effect of time was marginally significant ($F_{(1.839, 97.470)} = 2.937$, $p = .062$, $\eta^2_p = .053$), while effects of odor ($F_{(1, 53)} = 1.229$, $p = .273$), and group ($F_{(1, 53)} = 1.452$, $p = .234$) were not statistically significant. No significant interaction effects were found for odor × group ($F_{(1, 53)} = .005$, $p = .945$), group × time ($F_{(2, 106)} = 1.988$, $p = .142$), odor × time ($F_{(1.890, 100.169)} = .542$, $p = .573$), or the three-way interaction ($F_{(2, 106)} = .050$, $p = .951$).

For the FRABO item 8 in SDI ("While recalling the event, I felt an emotional distancing from the event."), a marginally significant main effect of time was observed ($F_{(1.928, 102.203)} = 2.567$, $p = .084$, $\eta^2_p = .046$), while effects of odor ($F_{(1, 53)} = .253$, $p = .617$) and group ($F_{(1, 53)} = .573$, $p = .452$) were not significant. No significant interaction effects were found for odor × group ($F_{(1, 53)} = .616$, $p = .436$), group × time ($F_{(2, 106)} = .448$, $p = .640$), odor × time ($F_{(2, 106)} = 1.289$, $p = .280$), or odor × time × group ($F_{(2, 106)} = .175$, $p = .840$).

In summary, the SDI data revealed no significant reduction for participants who slept in the presence of the congruent odor compared to those exposed to the incongruent odor.

3.1.2 Emotional reactivity response to the aversive memory during IRRT

Emotional reactivity during IRRT was evaluated by repeatedly asking participants about arousal, valence, and vividness in relation to the emotional memory. To test the hypotheses, the focus was on the ratings taken during the IRRT hotspot in Phase 1. The analysis also incorporated responses from the FRABO questionnaire and questions on emotions and their associated cognition regarding the emotional memory. Furthermore, EEG and ECG data were recorded throughout the procedure. This process was carried out at 3 points: before the intervention (Pre), after the retention interval (Post 1), and one week later (Post 2).

Across all analyses, the adjusted and unadjusted means and standard errors of the variables during the IRRT hotspot are presented in Table G 12-Table G 28 in the appendix. In addition to the main ANCOVA models (which included age as a covariate), repeated-measures ANOVAs were conducted for key variables to assess time effects without the covariate. These helped clarify effects potentially masked by shared variance between time and age.

For arousal during IRRT hotspot, no significant effects were found for time ($F_{(1.419, 75.233)} = .545$, $p = .523$), odor ($F_{(1, 53)} = .079$, $p = .780$), or group ($F_{(1, 53)} = 15.138$, $p = .186$). No significant interaction effects were found for odor × group ($F_{(1, 53)} = .331$, $p = .568$), group × time ($F_{(2, 106)} = 1.103$, $p = .336$), odor × time ($F_{(1.483, 78.579)} = .021$, $p = .950$), or odor × time × group ($F_{(2, 106)} = .092$, $p = .912$). ANOVA without covariates revealed a significant time effect ($F_{(1.414, 76.337)} = 140.300$, $p < .001$, $\eta^2_p = .722$).

For valence during IRRT hotspot, no significant main effects were observed for time ($F_{(1.596, 84.612)} = .699$, $p = .469$), odor ($F_{(1, 53)} = .969$, $p = .330$), or group ($F_{(1, 53)} = 9.659$, $p = .378$). Similarly, no significant interaction effects of odor × group ($F_{(1, 53)} = .581$, $p = .449$), group × time ($F_{(2, 106)} = .396$, $p = .674$), odor × time ($F_{(1.884, 99.875)} = .222$, $p = .788$) were found. However, a significant three-way interaction was observed ($F_{(2, 106)} = 3.462$, $p = .035$, $\eta^2_p = .061$; see Figure 6). To better understand the significant three-way interaction, a two-way ANCOVA (odor × group) at each level of time and another two-way ANCOVA (odor × time) at each level of group was conducted.

Post hoc two-way ANCOVAs showed that at Post 1, there were no main effects of odor ($F_{(1, 53)} = .225$, $p = .637$), group ($F_{(1, 53)} = .098$, $p = .755$), or odor × group interaction ($F_{(1, 53)} = .036$, $p = .850$).

At Post 2, no main effects of odor ($F_{(1, 53)} = 1.387$, $p = .244$), or group ($F_{(1, 53)} = .710$, $p = .403$) were observed. However, the odor × group interaction was significant ($F_{(1, 53)} = 4.557$, $p = .037$, $\eta^2_p = .079$). For sleep at Post 2, no significant main effects of odor were observed ($F_{(1, 26)} = .862$, $p = .362$). For wake at Post 2, a significant main effect of odor ($F_{(1, 26)} = 5.300$, $p = .030$, $\eta^2_p = .169$) was observed. Moreover, the odor × age interaction was significant ($F_{(1, 26)} = 4.516$, $p = .043$, $\eta^2_p = .148$) indicating that the effect of odor on valence ratings at Post 2 in the wake group varied depending on participants' age. Further analysis is required to clarify the direction of this effect.

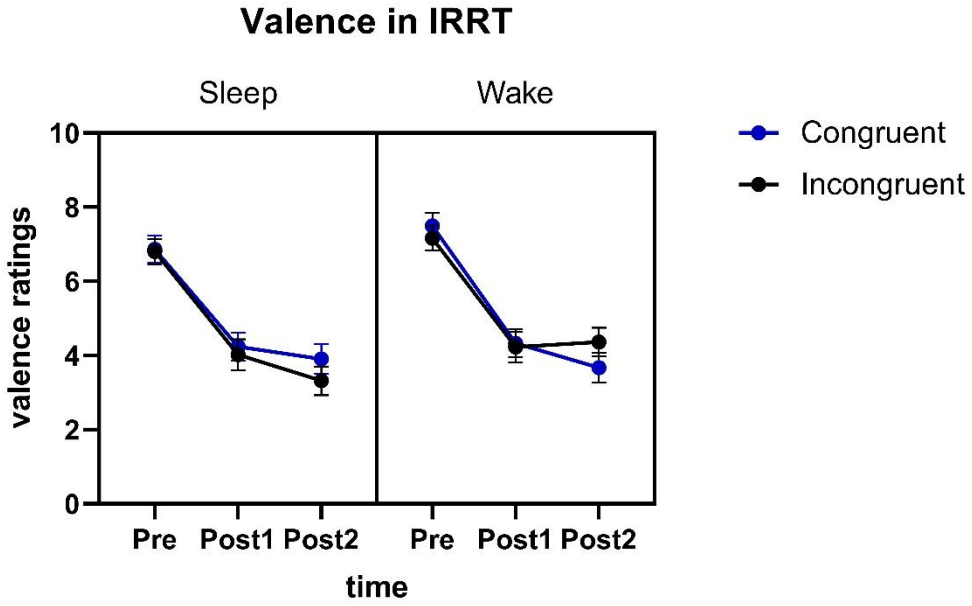

Figure 6. Valence ratings over time during IRRT. Ratings were assessed at three time points: Pre, Post 1, and Post 2. These ratings were analyzed for both the wake and sleep groups, across both odor conditions. The points represent group means, while the vertical lines represent standard errors. The covariate included in the model, age, was set to a value of 24.196. This figure was made using GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts, USA; www.graphpad.com).

In the sleep group, no significant effects were found for odor ($F_{(1, 26)} = .739$, $p = .398$), time ($F_{(1.369, 35.599)} = .025$, $p = .933$), and odor × time ($F_{(1.737, 45.175)} = .161$, $p = .822$).

In wake subjects, a significant main effect of odor was observed ($F_{(1, 26)} = 4.255$, $p = .049$, $\eta^2_p = .141$; see Figure 7). However, no significant main effect of time ($F_{(1.753, 45.587)} = 1.203$, $p = .309$) and no interaction effect of odor × time ($F_{(2, 52)} = .807$, $p = .452$) was found. An additional ANOVA without covariates also revealed a significant time effect ($F_{(1.569, 84.706)} = 166.647$, $p < .001$, $\eta^2_p = .755$).

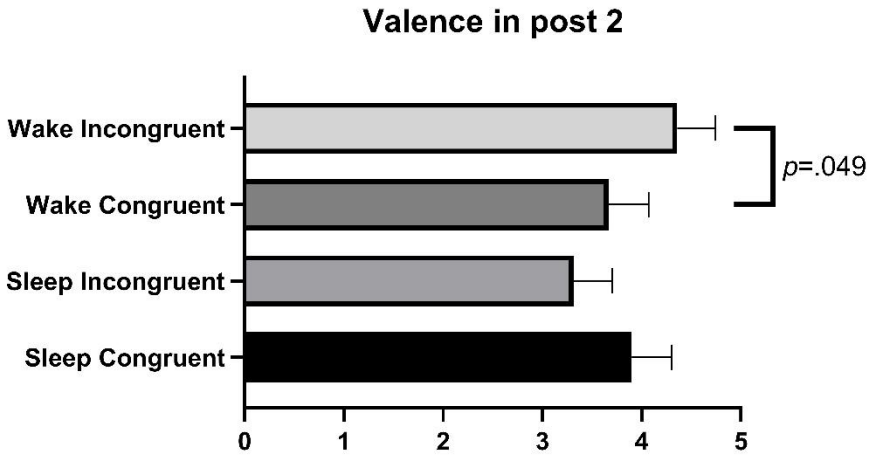

Figure 7. Valence ratings in Post 2. The figure shows the valence ratings at Post 2 (one week after the intervention) for the wake and sleep groups across the two odor conditions. The bars represent group means; error bars indicate standard errors. The covariate included in the model, age, was set to a value of 24.196. This figure was created using GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts, USA; www.graphpad.com).

For vividness during IRRT, no significant effects for time ($F_{(1.884, 99.868)} = 1.694$, $p = .191$), odor ($F_{(1, 53)} = .413$, $p = .523$), or group ($F_{(1, 53)} = .183$, $p = .671$), and no significant interactions for odor × group ($F_{(1, 53)} = .048$, $p = .827$), group × time ($F_{(2, 106)} = 2.054$, $p = .133$), odor × time ($F_{(2, 106)} = .432$, $p = .650$), and odor × time × group ($F_{(2, 106)} = .027$, $p = .973$) were observed. However, in a separate analysis an ANOVA showed a significant time effect ($F_{(1.844, 99.579)} = 31.862$, $p < .001$, $\eta^2_p = .371$).

When examining the intensity of emotions evoked during IRRT, participants showed variability in their primary distressing emotions (sadness: n = 21; powerlessness: n = 6; guilt: n = 11; anger: n = 16; shame: n = 15; loneliness: n = 11; helplessness: n = 22; horror: n = 8). Therefore, for each participant, we identified the most intense distressing emotion and its associated cognition, referred to as the "dominant emotion" and "dominant cognition" for further analysis. In cases where multiple emotions had equal intensity, we compared the levels of distress and selected the dominant emotion with the highest score.

For the intensity of the dominant emotion, no significant effects were found for time ($F_{(1.848, 97.935)} = .793$, $p = .446$) or odor ($F_{(1, 53)} = .271$, $p = .605$), whereas a significant effect of group was observed ($F_{(1, 53)} = 4.855$, $p = .032$, $\eta^2_p = .084$). No significant interactions were found for odor × group ($F_{(1, 53)} = .609$, $p = .439$), group × time ($F_{(2, 106)} = .729$, $p = .485$), odor × time ($F_{(2, 106)} = .278$, $p = .758$), or odor × time × group ($F_{(2, 106)} = .111$, $p = .895$). A repeated-measures ANOVA without covariates showed a significant main effect of time ($F_{(1.759, 94.989)} = 222.471$, $p < .001$, $\eta^2_p = .805$).

For the distress of the dominant emotion, no significant effects were found for time ($F_{(1.711, 90.665)} = 1.352$, $p = .262$), odor ($F_{(1, 53)} = .388$, $p = .536$), or group ($F_{(1, 53)} = 2.649$, $p = .110$), and no significant interactions were found for odor × group ($F_{(1, 53)} = .116$, $p = .735$), group × time ($F_{(2, 106)} = .293$, $p = .746$), odor × time ($F_{(2, 106)} = .439$, $p = .646$), and odor × time × group ($F_{(2, 106)} = .699$, $p = .499$). A separate ANOVA without covariates showed a significant time effect ($F_{(1.686, 91.062)} = 205.422$, $p < .001$, $\eta^2_p = .792$).

For the distress of the dominant cognition, a baseline group difference was observed ($F_{(1, 53)} = 4.129$, $p = .047$, $\eta^2_p = .072$), therefore, ANCOVAs were conducted separately by group. In the sleep group, no significant effects were found for time ($F_{(1.488, 38.693)} = .079$, $p = .872$), odor ($F_{(1, 26)} = .418$, $p = .523$), or their interaction ($F_{(2, 52)} = .063$, $p = .939$). In the wake group, no significant effects were found for time ($F_{(2, 50)} = .831$, $p = .442$) or odor ($F_{(1, 25)} = .101$, $p = .753$). However, a marginal odor × time interaction was observed ($F_{(2, 50)} = 3.092$, $p = .054$, $\eta^2_p = .110$). An additional ANOVA showed a significant time effect ($F_{(1.626, 86.157)} = 221.429$, $p < .001$, $\eta^2_p = .807$).

For the correctness of the dominant cognition, no significant effects were found for time ($F_{(2, 106)} = .283$, $p = .754$), odor ($F_{(1, 53)} = .177$, $p = .676$), or group ($F_{(1, 53)} = 2.520$, $p = .118$). Similarly, no significant interactions were observed for odor × group ($F_{(1, 53)} = .843$, $p = .363$), group × time ($F_{(2, 106)} = .848$, $p = .431$), odor × time ($F_{(1.925, 102.039)} = 1.771$, $p = .175$), or odor × time × group ($F_{(2, 106)} = .158$, $p = .854$). An additional ANOVA revealed a significant main effect of time ($F_{(2, 108)} = 82.330$, $p < .001$, $\eta^2_p = .604$).

For FRABO item 1 ("While I recalled the event, I felt like I was reliving it."), the main effect of time was marginally significant ($F_{(2, 106)} = 2.704$, $p = .072$, $\eta^2_p = .049$), while no significant effects were found for odor ($F_{(1, 53)} = 1.173$, $p = .284$) or group ($F_{(1, 53)} = .312$, $p = .579$). No significant interactions were observed for odor × group ($F_{(1, 53)} = 1.687$, $p = .200$), group × time ($F_{(2, 106)} = .137$, $p = .872$), or odor × time × group ($F_{(2, 106)} = .372$, $p =$

.691). The odor × time interaction was marginally significant ($F_{(2, 106)} = 2.956$, $p = .056$, $\eta^2_p = .053$).

For FRABO item 2 ("The retrieval of the memory was easy for me."), no significant effects were observed for time ($F_{(1.715, 90.892)} = .907$, $p = .394$) or group ($F_{(1, 53)} = .713$, $p = .402$). A marginally significant effect was found for odor ($F_{(1, 53)} = 3.670$, $p = .061$, $\eta^2_p = .065$). No significant interactions were observed for odor × group ($F_{(1, 53)} = 2.562$, $p = .115$), group × time ($F_{(2, 106)} = .461$, $p = .632$), odor × time ($F_{(2, 106)} = .052$, $p = .950$), or odor × time × group ($F_{(2, 106)} = .155$, $p = .857$).

For FRABO item 3 ("My memory has gaps."), no significant main effects were observed for time ($F_{(2, 106)} = .550$, $p = .579$), odor ($F_{(1, 53)} = .129$, $p = .721$), or group ($F_{(1, 53)} = .007$, $p = .932$). Interaction effects were similarly non-significant for odor × group ($F_{(1, 53)} = 2.176$, $p = .146$), group × time ($F_{(2, 106)} = .233$, $p = .792$), odor × time ($F_{(2, 106)} = 1.344$, $p = .265$), and odor × time × group ($F_{(2, 106)} = .068$, $p = .934$).

For FRABO item 4 ("While recalling the event, I experienced many sensory inputs in the form of sounds, smells, tastes, touches, etc."), the effect of time ($F_{(2, 106)} = 2.375$, $p = .098$, $\eta^2_p = .043$), and group ($F_{(1, 53)} = 3.824$, $p = .056$, $\eta^2_p = .067$) were marginally significant, while the main effect of odor was not significant ($F_{(1, 53)} = .253$, $p = .617$). No significant interactions were found for odor × group ($F_{(1, 53)} = .001$, $p = .976$), group × time ($F_{(2, 106)} = .601$, $p = .550$), or odor × time ($F_{(2, 106)} = 1.137$, $p = .325$). However, the three-way interaction of odor × time × group was significant ($F_{(2, 106)} = 3.500$, $p = .034$, $\eta^2_p = .062$; see Figure 8).

Given this interaction, separate 2 × 3 repeated-measures ANCOVAs were conducted for sleep and wake groups.

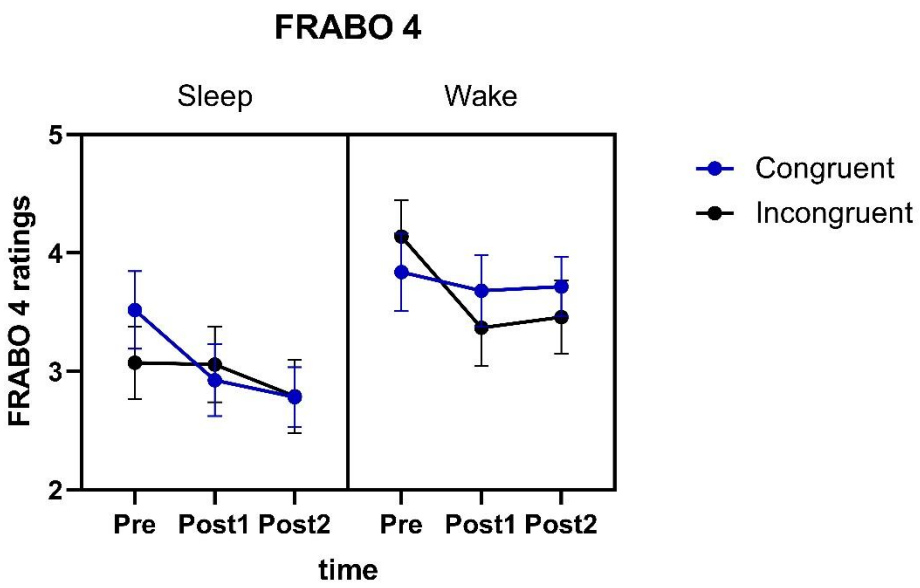

Figure 8. Changes in FRABO 4 ratings over time. The figure shows ratings for FRABO 4 ("While recalling the event, I experienced many sensory inputs in the form of sounds, smells, tastes, touches, etc.") assessed at three time points: Pre, Post 1, and Post 2. The ratings were analyzed for the wake and sleep groups across the two odor conditions. The points represent group means, and the vertical lines represent standard errors. The covariate included in the model, age, was set to 24.196. This figure was made using GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts, USA; www.graphpad.com).

For the sleep group, no significant effects were found for time ($F_{(2, 52)} = 1.219$, $p = .304$), odor ($F_{(1, 26)} = .003$, $p = .960$), or the odor × time interaction ($F_{(1.462, 38.020)} = .023$, $p = .945$). For the wake group, no significant effects were found for time ($F_{(2, 52)} = 1.371$, $p = .263$), odor ($F_{(1, 26)} = .415$, $p = .525$), or the odor × time interaction ($F_{(2, 52)} = 1.482$, $p = .237$). To address baseline differences, change scores were plotted instead of absolute values (see Figure 9 displaying the change scores).

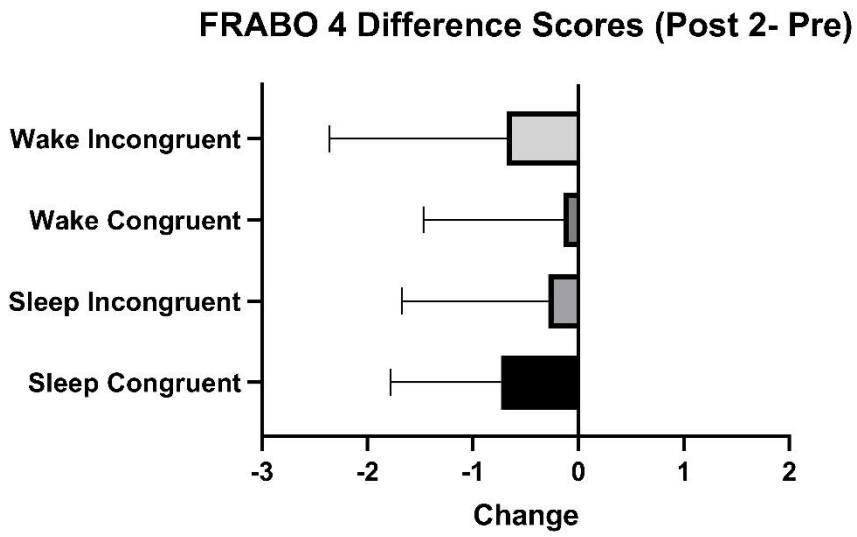

Figure 9. FRABO 4 Difference Scores (Post 2 - Pre). The figure shows the mean difference scores in FRABO 4 ("While recalling the event, I experienced many sensory inputs in the form of sounds, smells, tastes, touches, etc.") ratings from Pre to Post 2 for both the sleep and wake groups across odor conditions. Negative values reflect a reduction in sensory reliving over time. The bars represent group means; error bars indicate standard errors. The covariate included in the model, age, was set to 24.196. This figure was created using GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts, USA; www.graphpad.com).

For FRABO item 5 ("In the process of recalling the event, my heart was pounding."), there was no significant main effect of time ($F_{(1.903,\ 100.863)} = .940$, $p = .390$), however, marginally significant effects were found for odor ($F_{(1,\ 53)} = 3.753$, $p = .058$, $\eta^2_p = .066$) and for group ($F_{(1,\ 53)} = 3.660$, $p = .061$, $\eta^2_p = .065$). No significant interactions were observed for odor × group ($F_{(1,\ 53)} = .363$, $p = .550$), group × time ($F_{(2,\ 106)} = .532$, $p = .589$), odor × time ($F_{(1.451,\ 76.919)} = .457$, $p = .572$), or odor × time × group ($F_{(2,\ 106)} = 1.483$, $p = .232$).

For FRABO item 6 ("While recalling the event, I had sweaty hands."), no significant main effects were found for time ($F_{(1.791,\ 94.913)} = .632$, $p = .517$), or group ($F_{(1,\ 53)} = .658$, $p = .421$), whereas a significant main effect of odor was found ($F_{(1,\ 53)} = 5.287$, $p = .025$, $\eta^2_p = .091$). No significant interactions were observed for odor × group ($F_{(1,\ 53)} = .053$, $p = .819$), group × time ($F_{(2,\ 106)} = .587$, $p = .558$), odor × time ($F_{(2,\ 106)} = .340$, $p = .713$), or odor × time × group ($F_{(2,\ 106)} = .326$, $p = .722$).

For FRABO item 7 ("While recalling the event, I was tense."), no significant main effects were found for time ($F_{(1.887,\ 100.006)} = .468$, $p = .616$), odor ($F_{(1,\ 53)} = .487$, $p = .489$), or group ($F_{(1,\ 53)} = .887$, $p = .350$). Similarly, no significant interaction effects were observed

for odor × group ($F_{(1, 53)} = .194$, $p = .662$), group × time ($F_{(2, 106)} = .055$, $p = .947$), odor × time ($F_{(1.783, 94.476)} = .202$, $p = .792$), or odor × time × group ($F_{(2, 106)} = .377$, $p = .686$).

For FRABO item 8 ("While recalling the event, I felt burdened."), no significant main effects were found for time ($F_{(1.685, 89.324)} = .449$, $p = .606$), odor ($F_{(1, 53)} = .018$, $p = .894$), or group ($F_{(1, 53)} = .167$, $p = .685$). Additionally, no significant interaction effects were observed for odor × group ($F_{(1, 53)} = .056$, $p = .813$), group × time ($F_{(2, 106)} = .286$, $p = .752$), odor × time ($F_{(1.836, 97.287)} = .291$, $p = .730$), or odor × time × group ($F_{(2, 106)} = .495$, $p = .611$).

For FRABO item 9 ("While recalling the event, I felt an emotional distancing from the event."), no significant main effects of time ($F_{(1.738, 92.123)} = .844$, $p = .419$), odor ($F_{(1, 53)} = .225$, $p = .637$), or group ($F_{(1, 53)} = 1.096$, $p = .300$) were found. No significant interactions were observed for odor × group ($F_{(1, 53)} = .000$, $p = .998$), group × time ($F_{(2, 106)} = .243$, $p = .785$), odor × time ($F_{(2, 106)} = 1.436$, $p = .242$), or odor × time × group ($F_{(2, 106)} = .573$, $p = .565$).

For FRABO item 10 ("I bear the primary responsibility for the outcome of the situation."), no significant main effects were found for time ($F_{(1.447, 81.273)} = 1.952$, $p = .147$), odor ($F_{(1, 53)} = .115$, $p = .736$), or group ($F_{(1, 53)} = .218$, $p = .642$). No significant interaction effects were observed for odor × group ($F_{(1, 53)} = .044$, $p = .835$), group × time ($F_{(2, 106)} = .617$, $p = .541$), odor × time ($F_{(1.674, 88.727)} = .772$, $p = .444$), or odor × time × group ($F_{(2, 106)} = .998$, $p = .372$).

In summary, the IRRT data revealed no significant reduction for participants who slept in the presence of a congruent odor compared to those exposed to an incongruent odor.

3.1.3 Electrocardiography responses to the aversive memory

3.1.3.1 During SDI

HR, stress index, and HRV were measured at three time points: (1) before the intervention (Pre), (2) immediately after the retention interval (Post 1), and (3) one week later (Post 2). For SDI, 30-second segments were extracted for different phases of the intervention, including neutral and emotional memory script listening, imagination, and resting phases. The mean HR, stress index, and HRV were calculated for each segment. To assess ECG response to the emotional memory script, change scores were calculated

by subtracting the values during the neutral memory script from those for the emotional memory script for each "script listening" and "script imagining" intervals across the 3 sessions. For each condition, adjusted and unadjusted means and standard errors are reported in the corresponding tables in the appendix (Table G 29-Table G 43).

3.1.3.1.1 Mean HR: during script listening

A significant interaction effect of odor × group was found at baseline ($F_{(1, 47)} = 6.774$, $p = .012$, $\eta^2_p = .126$). Since neither odor nor group showed a main effect at baseline, the ANCOVAs were performed separately for each group to avoid misinterpretations.

For the sleep group, a marginal trend toward a main effect of time was observed ($F_{(2, 42)} = 1.301$, $p = .090$), while no significant main effect of odor ($F_{(1, 21)} = 2.307$, $p = .144$) was found. The interaction effect of odor × time was also not significant ($F_{(2, 42)} = 1.074$, $p = .351$).

For the wake group, no significant main effects of time ($F_{(2, 40)} = .834$, $p = .442$) or odor ($F_{(1, 20)} = .359$, $p = .556$) were observed. Moreover, the interaction effect of odor × time was not significant ($F_{(2, 40)} = .178$, $p = .838$).

3.1.3.1.2 Stress index: during script listening

For stress index during listening, no significant main effects of time ($F_{(2, 78)} = 1.455$, $p = .240$), odor ($F_{(1, 39)} = .010$, $p = .922$), or group ($F_{(1, 39)} = .190$, $p = .665$) were observed. No significant interaction effects were observed for odor × group ($F_{(1, 39)} = .346$, $p = .560$), group × time ($F_{(2, 78)} = .673$, $p = .513$), or odor × time ($F_{(2, 78)} = .303$, $p = .739$). However, the three-way interaction of odor × time × group was marginally significant ($F_{(2, 78)} = 2.979$, $p = .057$, $\eta^2_p = .071$).

3.1.3.1.3 HRV: during script listening

A significant interaction effect of odor × group was observed at baseline ($F_{(1, 48)} = 8.068$, $p = .007$, $\eta^2_p = .144$). Since there were no main effects of odor or group at baseline, ANCOVA was performed separately for each group to avoid misinterpretations.

For the sleep group, no significant main effect of time was found ($F_{(1.686, 37.100)}$ = .006, p = .994), whereas a significant main effect of odor was observed ($F_{(1, 22)}$ = 8.425, p = .008, η^2_p = .277). The interaction effect of odor × time was not significant ($F_{(2, 44)}$ = 1.155, p = .324).

For the wake group, no significant main effects were found for time ($F_{(2, 38)}$ = 1.626, p = .210) or odor ($F_{(1, 19)}$ = .104, p = .750). The interaction effect of odor × time was also not significant ($F_{(1.732, 32.899)}$ = .973, p = .378).

3.1.3.1.4 Mean HR: during script imagining

For mean HR during script imagining, no significant main effects were found for time ($F_{(2, 84)}$ = .754, p = .474), odor ($F_{(1, 42)}$ = .319, p = .579), or group ($F_{(1, 42)}$ = .001, p = .973). No significant interaction effects were observed for odor × group ($F_{(1, 42)}$ = .091, p = .765), group × time ($F_{(2, 84)}$ = 1.303, p = .277), or odor × time ($F_{(2, 84)}$ = .229, p = .795). The three-way interaction of odor × time × group was not significant ($F_{(2, 84)}$ = .596, p = .553).

3.1.3.1.5 Stress index: during script imagining

For the stress index during script imagining, a significant main effect of time was found ($F_{(2, 72)}$ = 4.638, p = .013, η^2_p = .114), while no significant main effects were observed for odor ($F_{(1, 36)}$ = 1.567, p = .219) or group ($F_{(1, 36)}$ = .258, p = .614). No significant interaction effects were found for odor × group ($F_{(1, 36)}$ = 1.023, p = .319) or group × time ($F_{(2, 72)}$ = .904, p = .409). However, the two-way interaction of odor × time was marginally significant ($F_{(2, 72)}$ = 2.862, p = .064, η^2_p = .074). The three-way interaction of odor × time × group was not significant ($F_{(2, 72)}$ = .159, p = .853).

3.1.3.1.6 HRV: during script imagining

For HRV during script imagining, no significant main effects were found for time ($F_{(2, 84)}$ = .901, p = .410), odor ($F_{(1, 42)}$ = .151, p = .699), or group ($F_{(1, 42)}$ = .001, p = .972). No significant interaction effects were observed for odor × group ($F_{(1, 42)}$ = .050, p = .824),

group × time ($F_{(2, 84)} = .918$, $p = .403$), or odor × time ($F_{(2, 84)} = .185$, $p = .832$). The three-way interaction of odor × time × group was not significant ($F_{(2, 84)} = .202$, $p = .818$).

3.1.3.2 During IRRT Phase 1

HR, stress index, and HRV during Phase 1 of IRRT were measured at three time points: once before the intervention (Pre), right after the retention interval (Post 1), and one week later (Post 2). For IRRT Phase 1, the following 10-second segments were extracted from the whole recording using the markers set by the psychologist during IRRT: (1) Start of the intervention (2) Hotspot (3) Closing image. For each of these segments, the Mean HR, stress index and HRV were calculated.

3.1.3.2.1 Mean HR: Start

For mean HR during the start of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 74)} = 2.359$, $p = .102$), odor ($F_{(1, 37)} = 1.161$, $p = .288$), or group ($F_{(1, 37)} = .151$, $p = .700$). No significant interaction effects were observed for odor × group ($F_{(1, 37)} = .100$, $p = .753$), group × time ($F_{(2, 74)} = .423$, $p = .656$), or odor × time ($F_{(1.757, 65.012)} = .701$, $p = .482$). The three-way interaction of odor × time × group was not significant ($F_{(2, 74)} = 1.046$, $p = .356$).

3.1.3.2.2 Mean HR: Hotspot

For mean HR during the hotspot of IRRT Phase 1, a marginally significant main effect of time was found ($F_{(2, 70)} = 2.864$, $p = .064$, $\eta^2_p = .076$), while no significant main effects were observed for odor ($F_{(1, 35)} = 1.676$, $p = .204$) or group ($F_{(1, 35)} = .257$, $p = .615$). No significant interaction effects were observed for odor × group ($F_{(1, 35)} = .728$, $p = .399$), group × time ($F_{(2, 70)} = .358$, $p = .700$), or odor × time ($F_{(2, 70)} = .300$, $p = .741$). The three-way interaction of odor × time × group was not significant ($F_{(2, 70)} = .411$, $p = .665$).

3.1.3.2.3 Mean HR: Closing image

For mean HR during the closing image of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 58)} = 1.642$, $p = .202$), odor ($F_{(1, 29)} = .410$, $p = .527$), or group ($F_{(1, 29)} = .449$, $p = .508$). No significant interaction effects were observed for odor × group ($F_{(1, 29)} = .147$, $p = .704$), group × time ($F_{(2, 58)} = .928$, $p = .401$), or odor × time ($F_{(2, 58)} = .349$, $p = .707$). The three-way interaction of odor × time × group was not significant ($F_{(2, 58)} = .405$, $p = .669$).

3.1.3.2.4 Stress index: Start

For the stress index during the start of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 62)} = .176$, $p = .839$), odor ($F_{(1, 31)} = .682$, $p = .415$), or group ($F_{(1, 31)} = .622$, $p = .436$). No significant interaction effects were observed for odor × group ($F_{(1, 31)} = .842$, $p = .366$), group × time ($F_{(2, 62)} = .307$, $p = .736$), or odor × time ($F_{(1.750, 54.245)} = .773$, $p = .451$). The three-way interaction of odor × time × group was not significant ($F_{(2, 62)} = .679$, $p = .511$).

3.1.3.2.5 Stress index: Hotspot

For the stress index during the hotspot of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 66)} = .189$, $p = .829$), odor ($F_{(1, 33)} = .616$, $p = .438$), or group ($F_{(1, 33)} = .051$, $p = .823$). There were also no significant interaction effects for odor × group ($F_{(1, 33)} = 2.517$, $p = .122$) or group × time ($F_{(2, 66)} = 1.405$, $p = .253$). The odor × time interaction showed a marginal trend ($F_{(2, 66)} = 2.581$, $p = .083$, $\eta^2_p = .073$). The three-way interaction of odor × time × group was not significant ($F_{(2, 66)} = .179$, $p = .836$).

3.1.3.2.6 Stress index: Closing image

For the stress index during the closing image of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 56)} = 1.469$, $p = .239$), or group ($F_{(1, 28)} = .567$, $p = .458$), but a significant effect was observed for odor ($F_{(1, 28)} = 6.321$, $p = .018$, $\eta^2_p = .184$). No

significant interaction effects were found for odor × group ($F_{(1, 28)} = .633$, $p = .433$), group × time ($F_{(2, 56)} = 1.076$, $p = .348$), or odor × time ($F_{(2, 56)} = .536$, $p = .588$). The three-way interaction of odor × time × group was not significant ($F_{(2, 56)} = 1.646$, $p = .202$).

3.1.3.2.7 HRV: Start

For HRV during the start of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 76)} = 2.353$, $p = .102$), odor ($F_{(1, 38)} = 1.519$, $p = .225$), or group ($F_{(1, 38)} = .580$, $p = .451$). No significant interaction effects were observed for odor × group ($F_{(1, 38)} = .005$, $p = .942$), group × time ($F_{(2, 76)} = .506$, $p = .606$), or odor × time ($F_{(1.832, 69.598)} = .539$, $p = .570$). The three-way interaction of odor × time × group was not significant ($F_{(2, 76)} = .784$, $p = .460$).

3.1.3.2.8 HRV: Hotspot

For HRV during the hotspot of IRRT Phase 1, a marginally significant main effect was found for time ($F_{(2, 72)} = 3.046$, $p = .054$, $\eta^2_p = .078$), while no significant effects were observed for odor ($F_{(1, 36)} = .611$, $p = .439$) or group ($F_{(1, 36)} = 1.127$, $p = .295$). No significant interaction effects were found for odor × group ($F_{(1, 36)} = .084$, $p = .773$), odor × time ($F_{(2, 72)} = .254$, $p = .777$), or group × time ($F_{(2, 72)} = .409$, $p = .666$). The three-way interaction of odor × time × group was not significant ($F_{(2, 72)} = .480$, $p = .621$).

3.1.3.2.9 HRV: Closing image

For HRV during the closing image of IRRT Phase 1, no significant main effects were found for time ($F_{(2, 60)} = 1.566$, $p = .217$), odor ($F_{(1, 30)} = 1.058$, $p = .312$), or group ($F_{(1, 30)} = 1.461$, $p = .236$). No significant interaction effects were observed for odor × group ($F_{(1, 30)} = .022$, $p = .883$), group × time ($F_{(2, 60)} = .945$, $p = .394$), or odor × time ($F_{(2, 60)} = .428$, $p = .654$). The three-way interaction of odor × time × group was not significant ($F_{(2, 60)} = .717$, $p = .493$).

In summary, the HR data revealed no significant reduction for participants who slept in the presence of a congruent odor compared to those exposed to an incongruent odor.

3.1.4 Analysis of the narratives

Exploratory analyses of the narratives were conducted for the sleep group to assess linguistic and structural changes across the three IRRT Phase 1 sessions (Pre, Post 1, Post 2). The adjusted and unadjusted means and standard errors of the measured variables are presented in Table G 44 - Table G 49.

3.1.4.1 Analytic thinking

Analytic thinking measures how much language reflects formal and logical thinking. High scores are linked to reasoning skills, while lower scores suggest more intuitive, and personal language. Initially called the Categorical-Dynamic Index (CDI), this dimension captures structured versus intuitive thinking styles (LIWC; Pennebaker et al., 2015).

For analytic thinking during IRRT Phase 1, no significant main effects were found for time ($F_{(1.712, 34.246)} = .730$, $p = .469$) or odor ($F_{(1, 20)} = 1.215$, $p = .284$). The interaction between odor and time was also not significant ($F_{(2, 40)} = .917$, $p = .408$).

3.1.4.2 Positive Emotions

For positive emotions during IRRT Phase 1, no significant main effects were observed for time ($F_{(2, 40)} = 1.241$, $p = .300$) or odor ($F_{(1, 20)} = .038$, $p = .847$). The interaction effect of odor × time was not significant ($F_{(2, 40)} = 1.055$, $p = .358$).

3.1.4.3 Negative Emotions

For negative emotions during IRRT Phase 1, no significant main effect was found for time ($F_{(2, 40)} = .236$, $p = .791$), while the effect of odor was marginally significant ($F_{(1, 20)}$

= 3.793, p = .066, η^2_p = .159). The interaction between odor and time was not significant ($F_{(2, 40)}$ = .081, p = .922).

3.1.4.4 Narrative architecture

This variable refers to the structured process of storytelling. It begins with "Staging," where nouns and their relationships are established, followed by "Plot Progression," where actions and shared understandings drive the story forward. Throughout the narrative, "Cognitive Tension" builds up, often peaking in the middle or later stages, reflecting the conflict and uncertainty in achieving the characters' goals. LIWC-22's Narrative Architecture analysis measures these elements, providing narrativity scores to assess how closely a text aligns with traditional story structures (LIWC; Pennebaker et al., 2015).

For overall narrativity during IRRT Phase 1, no significant main effects were found for time ($F_{(2, 38)}$ = .515, p = .601) or odor ($F_{(1, 19)}$ = .001, p = .972). The interaction between odor and time showed a marginal trend toward significance ($F_{(2, 38)}$ = 2.787, p = .074, η^2_p = .128).

3.1.4.5 Pauses

Given the significant difference in the number of pauses between the odor conditions at baseline ($F_{(1, 20)}$ = 5.537, p = .029), even after controlling for age as a covariate, we calculated the change in the number of pauses from the time point Pre to Post 1 and from the time point Pre to Post 2 for each odor condition separately. These changes were then compared using paired samples t-tests. Results showed no significant differences in the number of pauses between the congruent and incongruent odor conditions for either time period: Post 1 - Pre ($t_{(21)}$ = -1.142, p = .266) and Post 2 - Pre was marginally significant ($t_{(20)}$ = -1.746, p = .096).

3.1.4.6 Memory Gaps

Memory gaps refer to moments when participants were unable to recall how the story continued or clearly said they did not remember certain parts. Given that no gaps were expected at baseline, we calculated the number of gaps at time point Post 1 and Post 2 and conducted a 2 x 2 ANCOVA for two odor conditions and two time points while controlling for age.

For memory gaps, no significant main effect of time ($F_{(1, 19)} = .051$, $p = .824$) was observed. However, we observed a marginally significant effect of odor ($F_{(1, 19)} = 4.276$, $p = .053$, $\eta^2_p = .184$). Also, the interaction between odor and time was not significant ($F_{(1, 19)} = 1.343$, $p = .261$).

3.1.4.7 Story alterations

Story alterations refer to instances where the narrative shared at Post 1 or Post 2 time point changed notably compared to the version told during Pre, likely shaped by the effects of the psychotherapeutic intervention. To analyze this item, we calculated the number of changes at Post 1 and Post 2 and conducted a 2 × 2 ANCOVA for two odor conditions and two time points while controlling for age.

For story alterations, no significant effects of time ($F_{(1, 19)} = 2.423$, $p = .136$) or odor ($F_{(1, 19)} = .202$, $p = .659$) were observed. Moreover, the interaction between odor and time was not significant ($F_{(1, 19)} = 1.343$, $p = .261$).

In summary, the narrative analysis showed no significant reduction across the three time points for participants who slept in the presence of a congruent odor compared to those exposed to an incongruent odor during the retention interval.

3.1.5 Diaries

Participants used a custom app to complete daily sleep and intrusion diaries throughout the study, with entries averaged across three time points (Pre, Post 1, Post 2) and analyzed using a 2 (group) × 3 (odor condition) ANCOVA, controlling for age. The

adjusted and unadjusted means and standard errors of all of the items are presented in Table G 50 - Table G 63 in the appendix.

3.1.5.1 Sleep diary

3.1.5.1.1 Difficulty falling asleep (Einschlafschwierigkeiten; ESS)

For ESS, no significant effects of odor ($F_{(2, 104)} = .738$, $p = .480$) or the odor × group interaction ($F_{(2, 104)} = 1.298$, $p = .277$) were observed. However, a significant main effect of group was found ($F_{(1, 52)} = 4.775$, $p = .033$, $\eta^2_p = .084$).

3.1.5.1.2 Difficulty staying asleep (Durchschlafschwierigkeiten; DSS)

For DSS, no significant main effects were found for odor ($F_{(2, 86)} = .069$, $p = .934$) or group ($F_{(1, 43)} = .027$, $p = .871$). No significant interaction effect of odor × group was observed ($F_{(2, 86)} = .052$, $p = .949$).

3.1.5.1.3 Early awakening (Vorzeitiges Aufwachen; VZA)

For VZA, significant main effects were found for odor ($F_{(2, 104)} = 3.919$, $p = .023$, $\eta^2_p = .070$) and group ($F_{(1, 52)} = 5.185$, $p = .027$, $\eta^2_p = .091$). However, the interaction effect of odor × group showed a marginal trend ($F_{(2, 104)} = 2.454$, $p = .091$, $\eta^2_p = .045$).

3.1.5.1.4 General sleep characteristics (Allgemeine Schlafcharakterisierung; ASC)

For ASC, no significant main effects were observed for odor ($F_{(2, 102)} = 1.089$, $p = .341$) or group ($F_{(1, 51)} = .337$, $p = .564$). The interaction effect of odor and group was also not significant ($F_{(2, 102)} = .731$, $p = .484$).

3.1.5.1.5 General Sleep Duration (in hours; Gesamtschlafdauer; GSD)

For GSD, a significant main effect of group was found ($F_{(1, 52)} = 6.278$, $p = .015$, $\eta^2_p = .108$), while no significant effects were observed for odor ($F_{(2, 104)} = .396$, $p = .674$) or the odor × group interaction ($F_{(2, 104)} = .776$, $p = .463$).

3.1.5.1.6 Sleep Quality (Schlafqualität; SQ)

For SQ, the main effect of odor showed a marginal trend ($F_{(2, 86)} = 2.730$, $p = .071$, $\eta^2_p = .060$), while no significant effect was found for group ($F_{(1, 43)} = .017$, $p = .896$). The interaction effect of odor × group was also marginally significant ($F_{(2, 86)} = 2.711$, $p = .072$, $\eta^2_p = .059$).

3.1.5.1.7 Feeling of being refreshed after sleep (Gefühl des Erholtseins nach dem Schlaf; GES)

A significant group difference was found at baseline ($F_{(2, 57)} = 3.470$, $p = .038$, $\eta^2_p = .109$). Therefore, ANCOVAs were conducted separately for each group to prevent misinterpretation. For the sleep group, no significant effect of odor was observed ($F_{(2, 50)} = .295$, $p = .746$). Similarly, in the wake group, the effect of odor on GES was not significant ($F_{(2, 52)} = .476$, $p = .624$).

3.1.5.1.8 Mental balance before going to sleep (Psychische Ausgeglichenheit vor dem Schlafenlegen; PSYA)

For PSYA, no significant main effects were found for odor ($F_{(2, 104)} = .381$, $p = .684$) or group ($F_{(1, 52)} = .833$, $p = .366$). The interaction effect of odor × group was also not significant ($F_{(2, 104)} = .226$, $p = .798$).

3.1.5.1.9 Mental exhaustion before going to sleep (Psychisches Erschöpftsein vor dem Schlafenlegen; PSYE)

For PSYE, a significant main effect of odor was found ($F_{(2, 104)} = 5.076$, $p = .008$, $\eta^2_p = .089$), while no significant effects were observed for group ($F_{(1, 52)} = 1.219$, $p = .275$) or the odor × group interaction ($F_{(2, 104)} = .269$, $p = .764$).

3.1.5.1.10 Dreams

As part of the sleep diary, we also gathered information on the number of dreams and their emotional tone, comparing the baseline phase (no odor condition) with the congruent and incongruent odor conditions.

3.1.5.1.10.1 Number of dreams

For the number of dreams, no significant main effects were found for odor ($F_{(2, 48)} = .430$, $p = .653$) or group ($F_{(1, 24)} = .012$, $p = .913$). The interaction effect of odor × group was also not significant ($F_{(2, 48)} = .138$, $p = .871$).

3.1.5.1.10.2 Emotional tone of the dreams

The emotional tone of participants' dreams was significantly influenced by odor condition, as reflected by a main effect of odor ($F_{(2, 88)} = 4.103$, $p = .020$, $\eta^2_p = .085$). While no significant differences emerged between groups overall ($F_{(1, 44)} = 2.332$, $p = .134$), a significant interaction between odor and group ($F_{(2, 88)} = 3.327$, $p = .040$, $\eta^2_p = .070$) was found. Also, the odor × age interaction was significant ($F_{(2, 88)} = 4.327$, $p = .016$, $\eta^2_p = .090$) indicating that the relationship between odor condition and the emotional tone of dreams may vary depending on participants' age. Further analyses are required to clarify the direction of this effect.

To better understand the two-way interaction between odor × group, we ran an ANCOVA at each level of group. For participants in the sleep group, no significant effect of odor on the emotional tone of dreams was found ($F_{(2, 46)} = .493$, $p = .614$). In contrast,

a significant main effect of odor was observed in the wake group ($F_{(2, 40)} = 5.091$, $p = .011$, $\eta^2_p = .203$). Also, the odor × age interaction was significant ($F_{(2, 40)} = 4.743$, $p = .014$, $\eta^2_p = .192$). Follow-up paired samples t-tests (Bonferroni-corrected) revealed a significant increase in pleasantness ratings from baseline to the congruent odor condition in the wake group ($t_{(23)} = 2.836$, $p = .009$; see Figure 10).

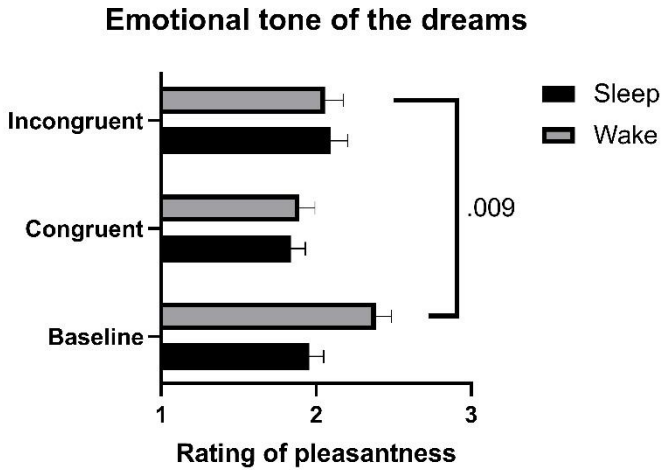

Figure 10. Emotional tone of the dreams. The figure shows the emotions reported in the dreams at baseline and one week after the retention interval, for each odor condition in both the wake and sleep groups. The pleasantness rating scale was as follows: 1 = pleasant, 2 = neutral, 3 = unpleasant. The covariate included in the model, age, was set to a value of 23.702. This figure was made using GraphPad Prism version 10.0.0 for Windows (GraphPad Software, Boston, Massachusetts, USA; www.graphpad.com).

3.1.5.2 Intrusion diary

3.1.5.2.1 Number of intrusions

For the number of intrusions, no significant main effects were found for odor ($F_{(1.645, 87.167)} = 2.237$, $p = .112$) or group ($F_{(1, 53)} = 2.172$, $p = .146$). The interaction between odor and group was not significant ($F_{(2, 106)} = 2.256$, $p = .110$).

3.1.5.2.2 Distress of the intrusions

No significant main effects were found for odor ($F_{(1.840, 97.525)} = .935$, $p = .389$) or group ($F_{(1, 53)} = 1.063$, $p = .307$) on the distress associated with intrusions. The interaction between odor and group was also not significant ($F_{(2, 106)} = .821$, $p = .443$).

3.1.5.2.3 Vividness of the intrusions

No significant main effects were found for odor ($F_{(1.755, 93.040)} = .886$, $p = .404$) or group ($F_{(1, 53)} = .897$, $p = .348$) on the vividness of intrusions. The interaction between odor and group was also not significant ($F_{(2, 106)} = .941$, $p = .393$).

In summary, the data from the sleep and intrusion diaries showed no significant reduction for participants who slept in the presence of a congruent odor compared to those exposed to an incongruent odor.

3.2 Sleep macrostructure

The second hypothesis of the study (H2) predicted that there are no significant differences in the sleep macrostructures between nights when a congruent odor is presented and nights when an incongruent odor is presented. The ANCOVA revealed no significant differences between conditions. The following results explore this hypothesis further through exploratory post-hoc analyses using t-tests

Table 1. Subjective Sleep Parameters. The table shows the results of sleep architecture features for the congruent versus incongruent night. Variables include sleep efficiency (SE), total sleep time in minutes (TST), sleep latency (SL), and movement arousals during specific sleep stages: N1 (MA N1), N2 (MA N2), N3 (MA N3), and REM (MA REM). Additionally, total movement arousals during the entire sleep duration are presented (MA total). Adjustments for multiple comparisons were made using the Sidak method.

Polysomnography data	Congruent	Incongruent	*p*
	M(SE)	M(SE)	
SE	.938 (.009)	.936 (.008)	.778
TST (min)	421.769 (5.976)	427.635 (6.139)	.315
SL	9.198 (1.229)	11.973 (2.087)	.129
MA N1	5.615 (.548)	4.788 (.640)	.119
MA N2	10.827 (.961)	10.442 (1.137)	.571
MA N3	.740 (.131)	1.220 (.177)	**.004***
MA REM	5.580 (.647)	5.660 (.666)	.895
MA total	23.115 (1.603)	22.000 (1.905)	.445
REM duration (%)	21.642 (.798)	21.624 (.985)	.988
N1 duration (%)	4.057 (.391)	3.670 (.326)	.286
N2 duration (%)	56.115 (.986)	55.537 (.795)	.632
N3 duration (%)	14.963 (1.041)	16.164 (1.080)	.218
Wake (%)	2.696 (.415)	2.541 (.431)	.713

In summary, the data from the measures of sleep architecture revealed a significant reduction in the number of movement arousals during the N3 sleep stage for participants who slept with the congruent odor compared to those who were exposed to the incongruent odor during night.

3.3 EEG: odor-induced reactivation effects on spectral activity

The study proposed that the presentation of a congruent odor during sleep would lead to a significant increase in SWA, SO, and FSA during NREM sleep, as well as an

increase in Theta activity during REM sleep, compared to nights when an incongruent odor was presented. The results below address this prediction.

The effects of reactivation were examined across congruent and incongruent conditions by analyzing data in two key phases. First, spectral activity across the following frequency bands was assessed for the entire night: SWA (0.75-4 Hz), SO (0.75-1.5 Hz) and FSA (12-15 Hz) during NREM sleep (N2 and N3 sleep stages), and Theta (4.25-8 Hz) during REM sleep. Second, the spectral activity during the 4-minute ON- and OFF-periods was compared over all the above-mentioned frequency bands.

3.3.1 Effects on SO during NREM sleep

The impact of odor-induced reactivation during NREM sleep on SO is shown in the scalp topography for all cluster-based permutation tests conducted, as presented in Figure 11. The comparison between conditions over the entire night showed no significant differences (see Figure 11A-C). However, comparing the 4-minute ON- and OFF-periods during nights with congruent odor revealed a significant difference (with cluster-level significance at p = .005; see Figure 11D). In the congruent condition, SO during ON-periods were significantly higher than during OFF-periods, with the difference being most pronounced frontally and laterally. No significant differences were found in the incongruent condition or interaction analysis (see Figure 11E and F).

In summary, the data showed a significant increase in SO between the 4-minute ON- and OFF-periods within the congruent condition and, therefore, hypothesis can be accepted.

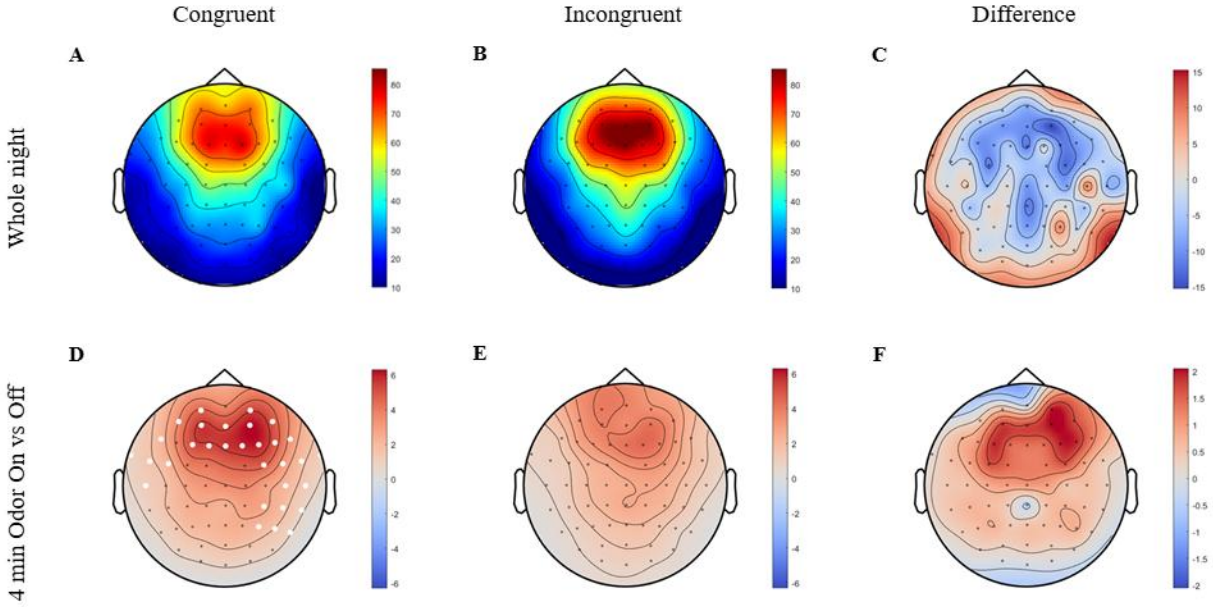

Figure 11. Slow oscillations (0.75-1.5 Hz) during NREM sleep. ON refers to the periods when an odor was presented. OFF indicates the periods without odor presentation. The colors highlight the differences from two-sided cluster-based permutation tests. Significant differences are marked by white points (α = .05). Cluster formation was determined using a neighbor matrix, with each cluster requiring at least two significant electrodes. (A) Whole-night congruent odor presentation, (B) Whole-night incongruent odor presentation, (C) The difference between the whole-night congruent activity and the whole-night incongruent activity, (D) The difference between 4-minute ON- and OFF-periods in congruent nights, (E) The difference between 4-minute ON- and OFF-periods in incongruent nights, (F) Interaction effect (D-E). Cluster-level significance: p = .005. n = 12.

3.3.2 Effects on SWA during NREM sleep

The impact of odor-induced reactivation during NREM sleep on SWA is shown in the scalp topographies for all cluster-based permutation tests conducted, as presented in Figure 12. The comparison between conditions over the entire night showed no significant differences (see Figure 12A-C). However, comparing the 4-minute ON- and OFF-periods during nights with congruent odor revealed a significant difference (with cluster-level significance at p = .005; see Figure 12D). In the congruent condition, SWA during ON-periods was significantly higher than during OFF-periods, with the difference being most pronounced frontally and laterally. No significant differences were found in the incongruent condition or interaction analysis (see Figure 12E-F).

In summary, the data showed a significant increase in SWA between ON- and OFF-periods within the congruent condition. Therefore, the hypothesis can be considered accepted.

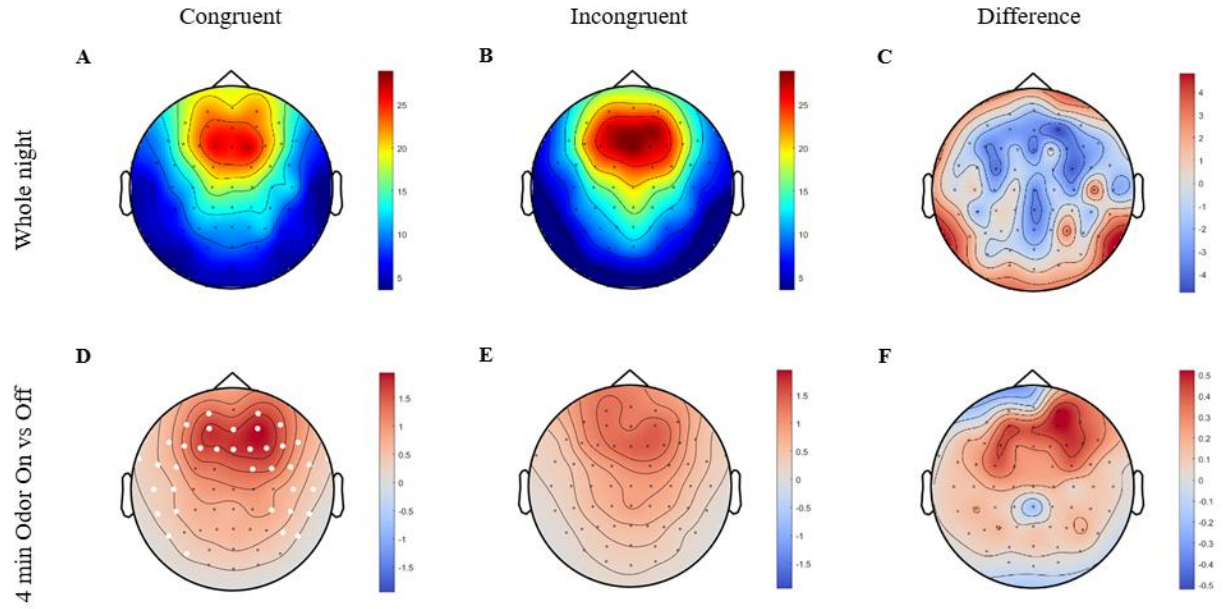

Figure 12. Slow-wave activity (0.75-4 Hz) during NREM sleep. ON refers to the periods when an odor was presented. OFF indicates the periods without odor presentation. The colors highlight the differences from two-sided cluster-based permutation tests. Significant differences are marked by white points (α = .05). Cluster formation was determined using a neighbor matrix, with each cluster requiring at least two significant electrodes. (A) Whole-night congruent odor presentation, (B) Whole-night incongruent odor presentation, (C) The difference between the whole-night congruent activity and the whole-night incongruent activity, (D) The difference between 4-minute ON- and OFF-periods in congruent nights, (E) The difference between 4-minute ON- and OFF-periods in incongruent nights, (F) Interaction effect (D-E). Cluster-level significance: p = .005. n = 12.

3.3.3 Effects on FSA during NREM sleep

The impact of odor-induced reactivation during NREM sleep on FSA is shown in the scalp topographies for all cluster-based permutation tests conducted, as presented in Figure 13. The comparison between conditions over the entire night showed no significant differences (see Figure 13A-C). However, comparing the 4-minute ON- and OFF-periods during nights with congruent odor revealed a significant difference (with cluster-level significance at p = .005; see Figure 13D). In the congruent condition, FSA during ON-

periods was significantly lower than during OFF-periods, with the difference being most pronounced occipitally. No significant differences were found in the incongruent condition or interaction analysis (see Figure 13E-F).

In summary, the data showed a significant decrease in FSA between ON- and OFF-periods during congruent nights. Therefore, the hypothesis was not supported as stated.

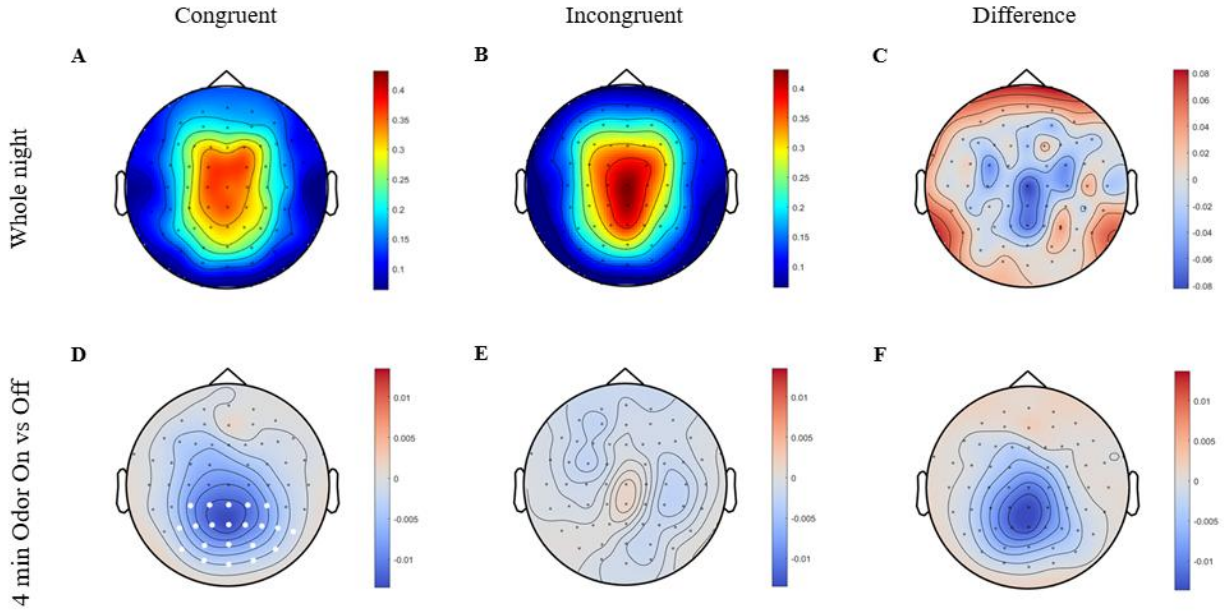

Figure 13. Fast Spindle Activity (12-15 Hz) during NREM sleep. ON refers to the periods when an odor was presented. OFF indicates the periods without odor presentation. The colors highlight the differences from two-sided cluster-based permutation tests. Significant differences are marked by white points (α = .05). Cluster formation was determined using a neighbor matrix, with each cluster requiring at least two significant electrodes. (A) Whole-night congruent odor presentation, (B) Whole-night incongruent odor presentation, (C) The difference between the whole-night congruent activity and the whole-night incongruent activity, (D) The difference between 4-minute ON- and OFF-periods in congruent nights, (E) The difference between 4-minute ON- and OFF-periods in incongruent nights, (F) Interaction effect (D-E). Cluster-level significance: p = .005. n = 12.

3.3.4 Effects on Theta during REM sleep

The impact of odor-induced reactivation during REM sleep on theta power is shown in the scalp topographies for all cluster-based permutation tests conducted, as presented in Figure 14. The comparison between conditions over the entire night and the 4-minute intervals showed no significant differences (see Figure 14A-F).

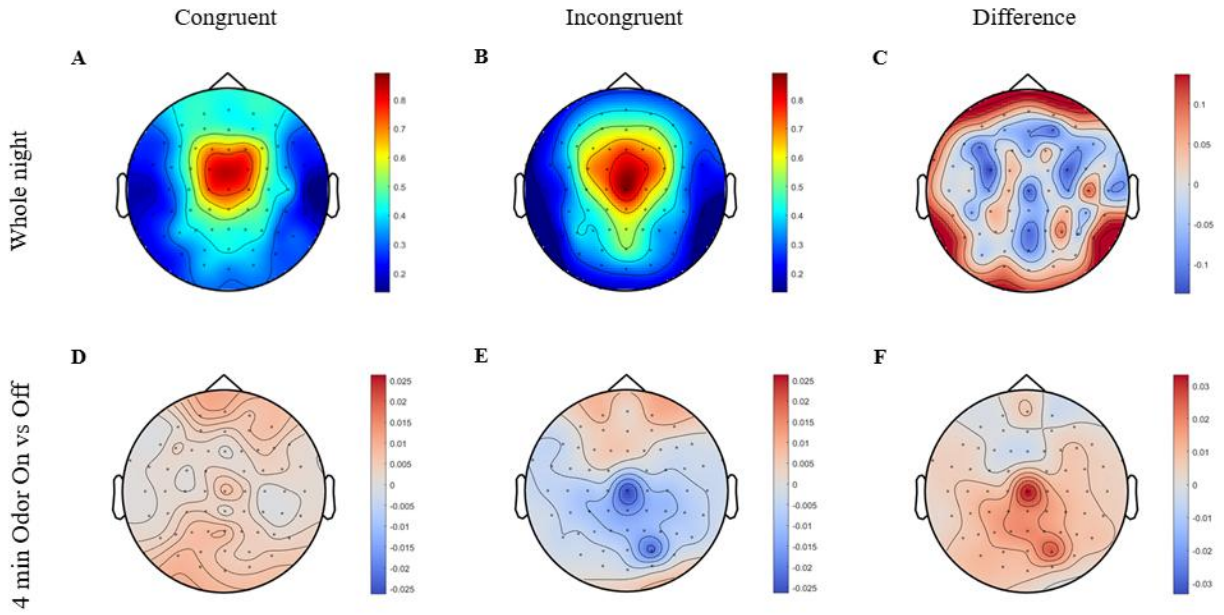

Figure 14. Theta activity (4.25-8 Hz) during REM sleep. ON refers to the periods when an odor was presented. OFF indicates the periods without odor presentation. (A) Whole-night congruent odor presentation, (B) Whole-night incongruent odor presentation, (C) The difference between the whole-night congruent activity and the whole-night incongruent activity, (D) The difference between 4-minute ON- and OFF-periods in congruent nights, (E) The difference between 4-minute ON- and OFF-periods in incongruent nights, (F) Interaction effect (D-E). *n* = 12.

In summary, the data showed no significant differences in theta activity within the odor conditions and during the 4-minute odor-ON-periods for those nights with congruent odor, compared to those with incongruent odor. Therefore, the hypothesis was not supported.

4. Chapter 4: Discussion

This study was conducted to examine whether adding TMR to IRRT enhances its efficacy by facilitating memory reconsolidation processes. To test this, participants with at least 2 distressing autobiographical memories, each at least 2 years old, underwent IRRT. During the therapy, a contextual odor cue was presented at the time when positive changes were introduced into the original memory (IRRT Phase 2 & 3) to form an association. Thereafter, participants were randomly assigned to a sleep or wake group and were again presented with either the same odor cue or a novel one. The memory characteristics were once tested before the intervention, and twice after that. This process was repeated for the second memory in a counter-balanced order; if a congruent odor was used for the first memory, an incongruent odor was used for the second memory, and vice versa. It was hypothesized that participants who experienced sleep in the presence of the congruent odor show significantly higher reductions in stress response elicited by their aversive autobiographical memories compared to those in incongruent conditions and those in the wake group. This was measured by various self-report questionnaires, physiological measures such as HR response, memory characteristics evaluation, etc., during all measurements. Moreover, it was hypothesized that re-exposure to the congruent odor leads to increased SO, SWA, and FSA during NREM, as well as enhanced theta activity during REM sleep, compared to presentation of an incongruent odor.

4.1 Effect of odor-induced reactivation of modified autobiographical memories on slow oscillatory activity (SWA including SO) during NREM sleep

Cluster-based permutation tests revealed significantly higher SWA (0.75-4 Hz) and SO (0.75-1.5 Hz) during the 4-minute odor-on periods compared to the odor-off periods on the nights when the congruent odor was presented. This was consistent with our hypothesis that TMR during NREM sleep increases slow oscillatory activity. Additionally, this finding demonstrates that the reactivation of a modified personal memory, rather than simply odor presentation as demonstrated in the study by Perl et al. (2016), can enhance slow oscillatory activity. No such effect was observed when analyzing the entire night, possibly because by calculating the mean activity over the entire night, the effects have

been averaged out. This can be especially true when the effect is concentrated during a short period of time, in this case, during the odor presentation. This suggests that TMR induced localized oscillations, rather than a general increase in SWA/SO across the night.

SWA is known to be one of the most important features of NREM, because of its crucial role in cortical plasticity. Many studies have shown the importance of SWA in memory consolidation (e.g., Holz et al., 2012; Huber et al., 2004; Pugin et al., 2015; Wilhelm et al., 2014). Other methods such as closed-loop stimulation have been used to enhance SWA and demonstrated that the SWA increases are associated with improved performance (Diep et al., 2020; Ong et al., 2016). SWS and the other important characteristics of it, the SO, are also shown to be essential for the consolidation of declarative memories (Ackermann et al., 2015; Cox et al., 2014; Hahn et al., 2020; Marshall et al., 2006; Oyanedel et al., 2014; Timofeev & Chauvette, 2017). More specifically, SOs play a key role in facilitating the synchronization of spontaneously reactivated hippocampal memories with thalamocortical spindle activity (Klinzing et al., 2019) which additionally highlights the importance of the SO in the long-term storage and strengthening the memory representations.

Our results are well in line with previous findings that used different TMR methods and memory tasks which reported increases in SWA/SO during cue presentation (Bar et al., 2020; Oyarzún et al., 2017; Rihm et al., 2014). The main reason for the observed SWA/SO increases in this study could be that TMR has successfully induced memory-related reactivation processes and triggered the integration of newly learned information from the hippocampal to the cortical regions facilitating the reconsolidation of the modified autobiographical memories. Moreover, lack of significant increases during the whole-night analysis might show that this effect was TMR-triggered and, therefore, time-locked to the odor presentation phase. However, not all studies report increases in slow oscillatory activities as a result of TMR. For instance, in the study by Cousins and colleagues (2014), using a motor sequence task, no significant differences in the SO power were observed in the TMR group. This suggests that other factors like the type of memory task, the timing and type of cueing, or the overall study design can shape how SWA or SO respond to TMR.

In summary, these findings are in line with most of the previous TMR studies demonstrating that the SWA/SO power increases as a result of TMR and support the idea

that these increases may indicate the ongoing reconsolidation processes of the modified memories.

4.2 Effect of odor-induced reactivation of modified autobiographical memories on FSA (12-15 Hz) during NREM sleep

Cluster-based permutation tests indicated that FSA was significantly reduced during the 4-minute period in the congruent odor-on compared to the odor-off periods. These results contradict our hypothesis, which predicted an increase in FSA in response to TMR. Given the important role of the FSA in memory consolidation and the numerous findings showing positive correlations between FSA and memory improvements, this result is striking. It raises the question of how the mechanisms of reconsolidation in an autobiographical memory task might differ from those in other tasks that have shown such effects.

To the best of our knowledge, the study by Pereira et al, (2017) is the only study that reported a similar reduction of spindle activity during TMR. In this study, subjects learned a finger-tapping sequence and later took a nap. During sleep, subjects received tactile stimulation on their fingertips which mimicked the sensation of pressing a computer keyboard similar to the finger-tapping task. They observed that spindle density decreased while SO increased during the cueing period, suggesting a disturbance in the SO-spindle coupling. This may explain the absence of behavioral improvements in both their study and ours. One possible explanation for the pattern we observed, i.e., an increase in SO and a decrease in FSA during TMR, could be that the odor-based reactivation, which was not precisely time-locked, interfered with the natural coupling between SO and FSA. As shown by Hahn et al. (2020), a precise temporal coordination between SO and spindle activity is necessary for the sleep-dependent memory consolidation. However, this remains unclear, especially given the differences in cue modality and memory content in this study compared to those using auditory or tactile stimulation.

Our findings, however, are in contrast with previous studies that have examined the effects of TMR in psychotherapy setting. A closely related study by Rihm and colleagues (2016) tested whether TMR can increase the positive effects of exposure therapy on patients suffering from spider phobia and found significant increases in spindle

activity during TMR. Similarly, the study by van der Heijden et al, (2024), with a design similar to ours on PTSD patients, found that TMR during nap increased SO-spindle coupling (time-locked increases in both SO and spindle activity) with this increase being positively correlated with PTSD symptom reduction. One main distinction between these studies and ours is the sleep paradigm. Both studies used a nap-based design, whereas our study examined the effects of TMR during a full-night sleep. This is an important difference because the findings from nap studies may not always generalize to whole-night sleep, especially when the stimulation protocols and neural dynamics differ so substantially. Unlike naps, whole-night sleep includes a more complete sleep architecture with multiple NREM-REM cycles, whereas shorter naps often do not even reach REM stage, as REM sleep begins approximately 90 minutes after sleep onset (Tucker et al., 2006). Research suggests that NREM (especially slow-wave sleep) and REM sleep play complementary roles in emotional memory consolidation, with each stage playing its own role to the strengthening and consolidating of memories (Cairney et al., 2015; Diekelmann et al., 2009; Schönauer et al., 2017). Therefore, isolating only one part of the natural sleep cycle, such as in a nap, without considering the effects of other sleep stages and their complementary roles in memory consolidation, and then comparing it directly to a full night of sleep, may be misleading, as the two involve fundamentally different processes. Additionally, cue presentations are naturally shorter in nap designs. These differences may lead to qualitative distinctions between the nap-based and full-night protocols.

Another important difference is the therapeutic intervention. In both studies, the focus of the therapy (EMDR and exposure therapy) is reducing the emotional distress, rather than altering the content of a memory. In contrast, IRRT not only downregulates the emotional response to the aversive memory, but also actively changes its content by introducing new and self-empowering imagery that must be integrated into the already existing networks. Moreover, IRRT not only focuses on learning new, positive, and adaptive information, it also involves the process of forgetting the more distressing aspects of autobiographical memories. Therefore, it is important to explore not just how memory consolidation, as well as how the processes of forgetting parts of the memory affects spindle production. Recent findings suggest that the reductions in the FSA may be related to the suppression of unwanted memory elements. Using a think/no-think paradigm, Dehnavi et al. (2019) explored the influence of sleep on motivated forgetting.

Their results showed that even though subjects remembered significantly fewer words in the no-think condition, the recall of no-think words was, on the one hand, negatively correlated with spindle power during S2 sleep, and, on the other hand, positively correlated with spindle power during SWS. Based on these findings, a decrease in spindle power in the congruent condition could indicate that participants were more successful in forgetting unwanted parts of their autobiographical memories, assuming the reduction in spindle power occurred during SWS. However, since we did not differentiate between S2 and SWS in our analysis, it is difficult to determine whether this decrease in spindle power was in support of successful suppression or unintentional retention of unwanted memories, especially without any significant behavioral outcomes. In a similar study using a directed forgetting paradigm, Blaskovich et al. (2017) also found that the spindle amplitude was positively correlated with poorer performance in the to-be-forgotten list. These findings indicate that higher sleep spindles may not always be in favor of suppressing unwanted memories. In fact, increased spindle activity might, in some cases, counteract suppression. Such qualitative changes in the original memory may engage memory networks in a different way and could, therefore, influence spindle dynamics during sleep differently compared to other therapy methods that only focus on reducing emotional distress.

Finally, one other factor that may have influenced our results was the context of data collection during COVID-19 pandemic. Discussing an aversive personal memory with a newly introduced therapist is stressful per se. This stress may have been further increased by the heightened risk of infection, especially in the close-contact setting of polysomnographic recordings. The pandemic introduced additional stressors including fear of illness of oneself and loved ones, prolonged disruptions of daily life and education, social isolation and lack of social support. All of these factors could have contributed to elevated stress levels in our subjects (Goldfarb, 2020). There are several lines of research that have reported that stress can influence spindle dynamics. These findings indicate that high emotional arousals might disrupt the effective function of the FSA and change their role in memory consolidation or the interaction between the SO and spindles (Denis & Payne, 2024; Kaestner et al., 2013; Natraj & Richards, 2023; Wilhelm et al., 2016). Stress may also interfere with the protective function of sleep spindles, that help maintain stable and uninterrupted sleep by lowering the arousal threshold and making individuals more

susceptible to disturbances (for review see Fernandez & Lüthi, 2020; Natraj & Richards, 2023).

In sum, our findings challenge the expected relationship between the TMR and FSA. Reductions in spindle power observed during NREM sleep in this study may play a role in facilitating forgetting of unwanted aspects of autobiographical memory. This finding may show that a reduction in FSA might sometimes serve an adaptive function, particularly where aspects of memory need to be modified, overwritten or selectively forgotten. However, drawing a direct conclusion is difficult in the absence of significant behavioral changes. Future studies should differentiate between the FSA in the sleep stages 2 and 3 to better clarify the main source of the FSA reductions.

4.3 Effect of odor-induced reactivation of modified autobiographical memories on theta (4.25 – 8 Hz) power during REM sleep

Cluster-based permutation tests showed no significant differences in theta power during REM sleep between the congruent and incongruent nights when analyzed across the entire night and in 4-minute periods. This finding contrasts with our hypothesis which predicted that theta during REM increases as a result of congruent odor presentation.

Research suggests that REM sleep is crucial for emotion regulation and selectively enhances emotional memories. REM is characterized by dominant theta activities, which is believed to play a key role in the consolidation and plasticity processes and is considered a feature of hippocampal activity (for review see Diekelmann & Born, 2010; Hutchison & Rathore, 2015). Findings of the study by Nishida and colleagues (2009) demonstrated this relationship between the theta activity and the consolidation of emotional memories. In their study, participants took a 90-minute nap, after viewing emotionally negative and neutral images. Results showed that the theta activity during REM was positively correlated with the emotional memory consolidation.

Similarly, previous studies have demonstrated that theta power, contrary to our findings, increases following successful cueing during NREM (e.g., Farthouat et al., 2017; Göldi et al., 2019; Groch et al., 2017; Oyarzún et al., 2017; Schreiner et al., 2015; Schreiner & Rasch, 2015) and REM sleep (e.g., Abdellahi et al., 2023; Lehmann et al., 2016b; Sifuentes Ortega & Peigneux, 2024). This pattern of the theta activity has also

been observed in studies examining the effects of TMR on emotional memory processing (Denis & Payne, 2024; Xia, Yao, et al., 2023).

However, a major difference between these studies and ours lies in the type of task. While our study combines stress exposure, emotional memory reconsolidation, and TMR of modified autobiographical memories, these studies used relatively simple associative or visual tasks in non-therapeutic settings with well-defined learning episodes. The modification of an autobiographical memory might engage a more distributed neural network as compared to the simple learning tasks. Moreover, the emotional intensity and personal significance of the task might have also contributed to the observed differences. Additionally, our cueing was delivered over a full night of sleep without precise targeting REM or NREM phases. This may have diluted any potential reactivation effects.

In sum, our findings do not support the hypothesis that TMR increases the theta power during NREM sleep. Instead, results suggest that factors like the memory complexities or the cuing precision might also play a role in these findings. Future research should focus more on complex memory tasks to better understand when and how TMR is most effective in the context of more emotionally rich memory contents.

4.4 Effect of odor-induced reactivation of modified autobiographical memories on the macrostructures of sleep

Consistent with our hypothesis, we found no significant differences in the total sleep time, sleep efficiency, or the percentage of time spent in each sleep stage between the congruent and incongruent odor conditions. Exploratory post-hoc analysis revealed a significant difference in the number of arousals during the N3 sleep between the two conditions, with arousals being significantly lower in the congruent condition.

Numerous research have been conducted to assess the effects of TMR on memory processing and sleep dynamics, with most of them reporting that even tactile TMR does not significantly change the overall macrostructure of sleep. For example, Cousins et al. (2014) used auditory cues during NREM sleep and reactivated button-press sequences. After sleep, the subjects showed no significant changes in the overall sleep macrostructure. The other TMR study using tactile stimulation during sleep stage 2 also did not lead to changes in the sleep macrostructure (Pereira et al., 2017). Also, Schwartz

et al. (2022) explored whether TMR during REM sleep could enhance the benefits of Imagery Rehearsal Therapy (IRT) for treating ND. The study found no significant differences in overall sleep macrostructure between the TMR and control groups. Similarly, Recher et al. (2024) studied how 5-8 cuing nights can increase the effects of IRT sessions on aversive autobiographical memories. Similarly in this study, TMR did not significantly change the general sleep architecture. Other studies using odor cues led to similar results. For instance, Bar et al. (2020) used a specific mask to unilaterally present odor cues during NREM sleep and Rihm et al. (2016) used odor cues to reactivate the exposure therapy success during NREM sleep. Both reported no differences between the TMR and the control condition in the sleep architecture.

Interestingly, we observed a significant decrease in the number of arousals during the N3 sleep in the congruent condition. This decrease may indicate that the contextual odor cue, when paired with positive and adaptive information, may even support the stabilization of deep sleep. This finding opens a new avenue for future studies into how the odor cues paired with positive emotions may protect sleep from disruptions; an essential component for effective reconsolidation processes. However, no studies, to our knowledge, have demonstrated that TMR directly reduces arousals during sleep. In contrast, auditory cues presented during the night are suggested to induce transient arousals or awaken participants (Cellini & Capuozzo, 2018).

In summary, the present findings add to the body of evidence indicating that TMR during sleep generally does not alter the macrostructure of sleep. Across various studies using auditory, odor, or tactile cues, the overall results are consistent with our results that TMR does not significantly change the sleep architecture.

4.5 Effect of odor-induced reactivation of modified autobiographical memories on the behavioral measures

ANCOVA analyses examining the three time points and two odor conditions across the sleep and wake groups showed no significant effects of TMR on behavioral outcomes. This contrasts with our hypothesis, that predicted the greatest reduction in behavioral measures associated with the modified memory in the sleep congruent odor condition. Although ANCOVA allowed for a more controlled analysis by adjusting for age, including

this covariate masked the main effect of time. In cases where testing the effect of psychotherapy was critical (arousal, valence, vividness, dominant emotion and cognition), ANOVA was additionally performed to examine the unadjusted time effects. This analysis confirmed that psychotherapy significantly reduced distress levels of the aversive memories over time.

Other studies have similarly reported changes in the oscillatory responses following TMR without improvements in the behavior. For instance, using a word-pair learning task, the study by Farthouat and colleagues (2017) could demonstrate increased theta and sigma activities in response to TMR. However, auditory TMR did not lead to measurable memory benefits. Similarly, using a tactile TMR, Pereira and colleagues (2017) observed increased SO and spindle density with no significant effect on post-sleep motor skills. Nuntheless, these findings raise important questions on how TMR interacts with more complex memory systems, such as aversive autobiographical memory alterations. Given that this study used a unique intervention approach, it is essential to examine research that has combined autobiographical memory or psychotherapy with sleep or TMR during sleep.

In this context, our null results are in line with a study by Borghese et al. (2022), in which SAD patients underwent exposure therapy. Similar to our findings, the exposure therapy alone successfully reduced anxiety over time in both groups whereas TMR did not further decrease anxiety symptoms compared to the control group. Consistently, Rihm et al. (2016) showed that presenting odor cue associated with the exposure therapy did not increase its effectiveness. Although the phobia symptoms reduced significantly as a result of the exposure therapy, the additional use of the TMR did not lead to further symptom reductions. This absence of improvement has been discussed to be caused by a ceiling effect, as the exposure therapy itself was so effective that there was little room for further improvement. These findings suggest that TMR may have limited influence once a certain threshold of learning or therapeutic success has been achieved. The lack of significant TMR effects in our study might be also caused in a similar fashion by the ceiling effect of IRRT as a powerful therapeutic tool. As demonstrated in the study by Grunert et al. (2007) IRRT is so powerful that 79% of previously treatment-resistant patients experienced a complete and sustained recovery from PTSD. Other than this study, numerous other investigations have consistently confirmed IRRT's effectiveness

across various settings (e.g., Dizaj Khalili et al., 2023; Soleimani et al., 2024). These findings show that while TMR may be a valuable tool, its effectiveness might be most noticeable when there is still room for further improvement. For instance, when applied in clinical populations with higher symptom severity and, therefore, requiring more than a single therapeutic and cueing session. Our non-clinical sample, being less distressed to begin with, may have limited the potential for observable changes. Additionally, prior research suggests that TMR can only be effective when the initial learning is not too strong (Cairney et al., 2016; Farthouat et al., 2017) because strong memories might be more rigid and less susceptible to further reactivation through interventions such as TMR. Therefore, the lack of behavioral change as a result of TMR in this study could be due to the strong associations formed through therapy in our non-clinical sample, leaving little room for further enhancement through reactivation.

The absence of measurable behavioral results in the present study contrasts with findings by Recher et al. (2024) who reported significant improvements in memory characteristics, including reductions in arousal, vividness, and emotional distress as a result of TMR. However, several methodological differences may account for this discrepancy. Most importantly, unlike this study, our research applied only a single night of cueing, which may have limited the extent of memory reconsolidation and reactivation. Sleep-dependent memory processing typically needs multiple nights to fully consolidate changes (Stickgold & Walker, 2013). This makes it rather unlikely that major and measurable behavioral effects would appear after only one night of cueing. Additionally, unlike Recher et al. (2024) our subjects stayed in the lab during the retention interval rather than their home environment. This could have contributed to their elevated stress levels (Sprajcer, 2018) and might have influenced the outcomes of our intervention. Lastly, while Recher and colleagues (2024) used a closed-loop cueing approach, our study used a fixed presentation approach, which may have further contributed to the differences in results. In line with the previous study, van der Heijden et al. (2024) recently conducted a study on PTSD patients and found that those in the TMR group exhibited greater improvements in avoidance symptoms compared to the control group. In their study, patients had one session of EMDR and received SO phase-targeted TMR during the following sleep. Unlike our study, van der Heijden and colleagues (2024) used EMDR; a difference in therapeutic approach that may account for variations in TMR effectiveness.

EMDR therapy focuses mainly on reducing the distress of the aversive memory, whereas in IRRT the main focus is on changing the content of the memory. Moreover, conducting research on PTSD patients might give the researchers more room for additional improvements (i.e., those from TMR) when working with highly effective therapeutic methods such as IRRT or EMDR. Additionally, van der Heijden and colleagues used a closed loop stimulation method allowing them to present the TMR cues only in the SO upwaves whereas in our study the fixed-interval presentation of the odor cues was regardless of the brain's endogenous oscillatory state. This key difference in the presentation timing may have impacted how effective TMR was in our study. It's possible that we have, for instance, had out-of-phase stimulation and, therefore, disrupted brain oscillations. Moreover, using an olfactometer in the present study, spread the odors through a certain area around the head of the subject, which may have led to continuous odor exposure. This prolonged presentation could have reduced the chances of TMR effectiveness. Additionally, one more factor that may have led to the null findings is the timing of the odor presentation during the IRRT. Our odor presentation started at the hotspot and continued during the disempowerment of the perpetrator and the interaction with the younger self (phase 2 and 3 of IRRT). In other words, one could argue that in the first minutes of the odor presentation, there existed the carryover effects of unpleasant emotions and cognitions related to the hotspot, so we probably did not accurately target solely the pleasant emotions but also the remaining unpleasant emotions which are also a difficult factor to control or check.

Interestingly, although TMR did not enhance therapeutic outcomes overall, we observed a significant effect related to odor congruency in the wake group. Specifically, we observed that one week after the intervention (at Post 2), participants in the wake group who had received the incongruent odor, rated their memory as more emotionally negative (i.e., showed higher valence ratings) compared to those in the wake congruent condition. This may suggest that the incongruent odor has disrupted the emotional processing that typically occurs during IRRT. One possible explanation is that the incongruent odor introduced a mismatch and disrupted the affective updating of the memory content. However, this pattern was not seen in the sleep condition which might suggest that the incongruent odors might only interfere with the emotional processing when the mismatch is experienced during wakefulness. During sleep, however, there

exists a stable environment that helps the emotional processing and reduce the emotional intensity regardless of an incongruent odor presentation. Overall, this finding may suggest that the mismatches in the external stimuli may only lead to significant behavioral changes when presented during wakefulness.

In addition to the valence findings, we also observed an unexpected effect related to the emotional tone of dreams in the wake group. Specifically, we observed that in the wake incongruent condition the emotional tone of the dreams improved from being unpleasant at baseline to being neutral after the therapy. The emotional tone of the dreams in the congruent condition, however, was neutral at the baseline and stayed unchanged after the therapy. This observed shift was possibly not an effect of TMR but rather a therapy-related normalization of an initially negative dream tone in the incongruent condition since this group already had a negative dream tone at baseline. Therapy has likely reduced the emotional intensity of the associated autobiographical memory and the related unpleasant dreams, making them neutral over time. This is also consistent with previous research finding no evidence that TMR alone can influence the emotional tone of dreams (for review see Salvesen et al., 2024).

We additionally observed a significant group (sleep vs. wake) difference in FRABO 4 (while recalling the event, I experienced many sensory inputs in the form of sounds, smells, tastes, touches, etc.) ratings at post 2. Although we observed reductions from pre to post 2 in both groups, indicating the positive effects of the therapeutic interventions, the ratings in the wake compared to sleep conditions were generally higher across all three time points making the interpretation of this difference challenging. Moreover, this difference only became statistically significant one week after the intervention. The sleep group’s ratings declined while the wake group remained almost unchanged. A potential explanation for this observation could be the effects of circadian rhythms, since the timing of measurements differed between the two groups. Previous research has shown that circadian rhythms influence cognitive and emotional processing as well as alertness and sensory perception (Byrne et al., 2019).

In summary, our study failed to find significant behavioral benefits of applying TMR to reactivate the IRRT effects on aversive memories. While in both sleep and wake groups we observed significant therapeutic gains over time, these changes were mostly accountable for the IRRT itself rather than the additional effects of TMR. This, might have

been due to the highly effective psychotherapeutic effects of IRRT combined with the relatively low distress levels of our non-clinical sample which may have left little room for further observable improvement through TMR. Further research is needed to test whether TMR on a clinical population and under optimized stimulation protocols can better demonstrate the potential of TMR in emotional memory reconsolidation.

4.6 Limitations and recommendations for future studies

While this study provides valuable insights into the effects of TMR on autobiographical memory modification, several limitations must be considered, as they may have influenced the findings. Recognizing these limitations also presents opportunities for refining future research and enhancing our understanding of the interaction between TMR and memory reconsolidation.

A primary limitation of this study is the use of a single night of cueing. It is unlikely that the memory reactivation and reconsolidation processes are fully optimized only after one night. Adding multiple cueing nights in future studies might provide a stronger and more stable opportunity for memory modification. Moreover, conducting the study in the controlled environment of the lab rather than in the subjects' home environment might have added up the already existing stress level and influenced the quality of sleep or the results in general. Future research should explore whether TMR in naturalistic sleep settings produces different or stronger effects.

The odor delivery method used for the present study also posed some challenges. By using an olfactometer, it is possible that we spread the scents throughout the lab environment. This may have resulted in unintended continuous or overlapping exposure, reducing the effectiveness of the memory reactivation cue and the specificity of the odor-memory associations. Additionally, individual differences in odor sensitivity could have introduced variability that was difficult to control. Future studies should consider more localized odor delivery methods, such as masks, to ensure that the cues are precisely targeted and minimize unintended environmental effects. Moreover, as discussed previously, the timing of the start of the odor presentation during the IRRT might have been too early risking the odor to be associated with a mixture of unpleasant and pleasant

emotions. In the later studies, the odor presentation could start in a later time point ensuring the positive associations (e.g., during the positive closing image of the IRRT).

Another important limitation is that this study was conducted on a non-clinical sample who had moderate to low levels of memory-related distress making it more difficult to observe TMR effects in the presence of a highly effective therapy method such as IRRT. Individuals with traumatic memories, such as those with PTSD, may respond differently to TMR. In these clinical populations, TMR combined with IRRT could lead to measurable behavioral outcomes. On the other hand, working with the PTSD patients might require multiple therapy sessions giving the therapists enough time to pair the odor with a positive outcome of the IRRT. This way, the day-to-day mood of the subjects, or their sleep quality on the previous night can have limited influence on the IRRT response and on the formation of the positive association between the therapy outcome and the odor cue.

Our relatively small sample size, especially for the EEG analysis, further limited our ability to detect subtle effects of TMR and reduced statistical power. Moreover, our sample included mostly female participants which might have also affected the results. Future studies should include larger and more diverse samples to enhance the generalizability of findings. Furthermore, age played a significant role in our results and complicated the analysis. Since we observed a significant age difference between the sleep and wake groups, age was included as a covariate to control for this effect. However, age had such a strong impact that it masked the otherwise significant main effect of time. To investigate this in detail, we tested whether there was a systematic relationship between age and memory change over time. For instance, whether older participants exhibited less change over time. However, no clear pattern could be observed, indicating that age-related effects might be more complex and influenced by other additional factors that we couldn't fully control in this study. Moreover, adjusting covariates in small sample studies can sometimes introduce imbalance and additional variance, making it harder to isolate the true effects (Hripcsak et al., 2024). Therefore, in future studies we need to use methods such as matching participants by age to reduce variability.

Finally, our design was such that we worked on two aversive autobiographical memories within a short time frame. Even though we attempted to minimize carryover effects by adding a 30-minute guided relaxation session between the completion of the follow-up session of the first memory and the start of the second, this may not have been

enough to completely eliminate the carryover effects. Therefore, emotional or cognitive influences from the first session could still have impacted on the effectiveness of the second memory modification. Additionally, processing two aversive autobiographical memories in a short time frame could have increased the overall emotional burden on the subjects, potentially limiting the effectiveness of the intervention. This might have made the process even more demanding, increasing the overall difficulty and stress of the experience for the subjects and the therapists.

Addressing these limitations in future research could provide important insights into the mechanisms of TMR and memory reconsolidation. Investigating multiple nights of TMR, extending the interval between sessions to reduce carryover effects, having a larger sample size and using patients instead of healthy subjects are some steps that could further refine this line of research. If successful, these findings could lead to practical applications in clinical practice, where TMR could become a simple and effective tool for psychotherapists to use with their patients.

4.7 Conclusion

This study examined whether TMR could further support the modification of autobiographical memories. By presenting a contextual odor cue during therapy and later during the subsequent sleep, our goal was to determine whether TMR can facilitate the reconsolidation of the adaptive version of an intrusive memory. While our findings confirmed the successful implementation of TMR, specifically by the increased SO and SWA during NREM sleep, these changes did not translate into significant behavioral changes. This discrepancy suggests that while such sleep-based interventions lead to oscillatory changes, the observation of real therapeutic benefits might depend on various other factors such as the intensity of the memory, the therapeutic method, the type and timing of the odor presentation and so on.

One main takeaway from this study was that psychotherapy itself might have been too effective and restricted further improvements though TMR. This raised the question as to whether TMR is a suitable method to increase the effectiveness of IRRT in healthy subjects. Additionally, our findings emphasize the need to improve the odor cue presentations regarding the timing, duration or the presentation method. Future research

should investigate whether multiple nights of odor presentation on the populations with more sever distress such as PTSD patients could lead to stronger outcomes.

Despite the absence of significant behavioral effects, our study highlighted the potential of TMR as a novel tool to facilitate memory processing and consolidation in psychotherapy. However, research should further explore how sleep and emotional memory reconsolidation interact in the context of therapy to be able to optimize cuing regarding the timing and method. If optimized, TMR provides an excellent opportunity as a non-invasive and easy to apply method in the clinical context that can potentially facilitate the emotional processing and memory reconsolidation in a way that the traditional therapy alone cannot.

5. References

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6. Appendices

6.1 Questions during SDI

Neutral memory

1. Wie innerlich aufgewühlt warst Du während der Imagination?
2. Wie unangenehm was das innere Bild für Dich während der Imagination?
3. Wie lebendig was das innere Bild für dich während der Imagination?

Emotional memory

1. Wie innerlich aufgewühlt warst Du während der Imagination?
2. Wie unangenehm was das innere Bild für Dich während der Imagination?
3. Wie lebendig was das innere Bild für dich während der Imagination?

FRABO:

1. Während ich das Ereignis erinnerte, hatte ich das Gefühl, ich würde es wiedererleben.
2. Der Abruf der Erinnerung fiel mir leicht.
3. Während ich das Ereignis erinnerte, erlebte ich viele sensorische Informationen in Form von Geräuschen, Gerüchen, Geschmäckern, Berührungen, usw.
4. Während ich das Ereignis erinnerte, klopfte mein Herz.
5. Während ich das Ereignis erinnerte, hatte ich schwitzige Hände.
6. Während ich das Ereignis erinnerte, war ich angespannt.
7. Während ich das Ereignis erinnerte, fühlte ich mich belastet.
8. Während ich das Ereignis erinnerte, fühlte ich eine emotionale Distanzierung in Bezug auf das Ereignis.

Protocol of Imagery Rescripting and Reprocessing Therapy for the First (pre), 2nd (Post 1) and 3rd (Post 2) sessions

Anfang SDI: Zeit: _____ Datum: _____

Ende SDI: Zeit: _____ VPN: _____

Imagery Rescripting and Reprocessing

EEG Aufnahme gestartet (_task-expo1)? ☐

Anfang Atemübung: Zeit: _____

Phase 1a: Zeit: _____ Marker gesetzt? ☐

Zeitpunkt + Was passiert gerade (kurze Beschreibung der Szene)	**Marker gesetzt:**	**Arousal**	**Valenz**	**Lebendigkeit**
Anfang				
Hotspot				
Schluss				

Phase 1a Ende: Zeit: _____ Marker gesetzt? ☐

Emotionen

Bevor wir dazu übergehen, die Erinnerung zu verändern, möchte ich nun erst einmal über die Gefühle sprechen, die Du empfunden hast, während Du gerade das Ereignis vor Deinem inneren Auge wiedererlebtest. Denn emotional belastende Situationen können bei unterschiedlichen Menschen ganz unterschiedliche Gefühle auslösen. Du hast während der Imagination beispielsweise berichtet, dass du XY empfunden hast. Wie stark war dieses Gefühl während der Imagination ausgeprägt? Wie sehr hat Dich dieses Gefühl während der Imagination belastet?
Welche Gefühle wir in einer Situation empfinden, hängt davon ab, wie wir diese Situation bewerten, das heißt, jede Bewertung löst häufig ein bestimmtes Gefühl aus. Welcher Gedanke über Dich selbst ist gerade während der Imagination mit dem Gefühl XY einhergegangen? Was hast Du über Dich selbst gedacht? Was hat Dich … gemacht? Wie belastend war dieser Gedanke während der Imagination für Dich? Wenn Du jetzt an die Situation XY und an den Gedanken XY denkst, auf einer Skala von 1-10 wie wahr fühlt sich der Gedanke für Dich an?

Emotion	**Ausmaß Emotion**	**Wie belastend?**	**Gedanke**	**Wie belastend?**	**Wie korrekt?**

Wir haben nun ja bereits schon ein paar Emotionen und Gedanken herausgearbeitet, die während der Imagination eine wichtige Rolle für Dich gespielt haben. Als Nächstes möchte ich gerne mit Dir noch ein paar typische Emotionen besprechen, die in emotional belastenden Situationen ausgelöst werden können, um zu schauen, inwieweit diese auch eine Rolle für Dich während der Imagination gespielt haben.

Emotion	Ausmaß Emotion	Wie belastend?	Gedanke	Wie belastend?	Wie korrekt?
Angst					
Schuld					
Scham					
Ärger					
Hilflosigkeit					
Trauer					
Einsamkeit					
Hoffnungslosigkeit					

Ab einem Ausmaß von 3 weiterfragen, wie belastend und mit welchen Gedanken verknüpft.

Wir haben nun ja vor allem über negative Gefühle gesprochen. Hast du eventuell auch positive Gefühle während der Imagination empfunden?

Typische positive Gefühle, die durch emotionale Situationen ausgelöst werden, sind z.B.: Freude, Zufriedenheit, Zuneigung, Zuversicht, Mut, Dankbarkeit, Stolz, Erleichterung.

Typische positive Gefühle, die durch emotionale Situationen ausgelöst werden, sind z.B.: Freude, Zufriedenheit, Zuneigung, Zuversicht, Mut, Dankbarkeit, Stolz, Erleichterung.

Emotion	Ausmaß Emotion	Gedanke	Wie korrekt?

Nun werde ich Dir noch 13 weitere Aussagen zu Deiner soeben wiedererlebten Erinnerung vorlesen, die Du bitte anhand einer 7-stufigen Skala beantwortest. Dabei bedeutet 1 überhaupt nicht und 7 vollkommen zutreffend.

1. ***Während ich das Ereignis erinnerte, hatte ich das Gefühl, ich würde es wiedererleben.***

1	2	3	4	5	6	7

2. ***Der Abruf der Erinnerung fiel mir leicht.***

1	2	3	4	5	6	7

3. ***Meine Erinnerung hat Lücken.***

1	2	3	4	5	6	7

4. ***Während ich das Ereignis erinnerte, erlebte ich viele sensorische Informationen in Form von Geräuschen, Gerüchen, Geschmäckern, Berührungen, usw.***

1	2	3	4	5	6	7

5. ***Während ich das Ereignis erinnerte, klopfte mein Herz.***

1	2	3	4	5	6	7

6. ***Während ich das Ereignis erinnerte, hatte ich schwitzige Hände.***

1	2	3	4	5	6	7

7. ***Während ich das Ereignis erinnerte, war ich angespannt.***

1	2	3	4	5	6	7

8. ***Während ich das Ereignis erinnerte, fühlte ich mich belastet.***

1	2	3	4	5	6	7

9. ***Während ich das Ereignis erinnerte, fühlte ich eine emotionale Distanzierung in Bezug auf das Ereignis.***

1	2	3	4	5	6	7

10. ***Ich trage die Hauptverantwortung für den Ausgang der Situation.***

1	2	3	4	5	6	7

11. ***Das Ereignis hatte auch positive Konsequenzen. Ja oder nein?***

Ja	Nein

11a. Was für positive Konsequenzen hatte das Ereignis?

12. Durch das Ereignis habe ich etwas hinzugelernt. Ja oder nein?

Ja	Nein

12a. Was hast Du gelernt?

Neue EEG-Aufnahme gestartet (_task-IRRT)? ☐

Phase 1b & 2 Zeit: _____ Marker gesetzt? ☐

Zeitpunkt + Was passiert gerade (kurze Beschreibung der Szene)	**Marker gesetzt:**	**Arousal**	**Valenz**	**Lebendigkeit**
Anfang				
Hotspot				
Entmachtung des x r Verursacher x in				

Olfactometer an: Zeit: _____ Marker gesetzt? ☐

Phase 3 Zeit: _____

Zeitpunkt + Was passiert gerade (kurze Beschreibung der Szene)	**Marker gesetzt:**	**Arousal**	**Valenz**	**Lebendigkeit**
Positive Interaktion mit vergangenem Ich				
Abschlussbild (30 Sek. warten)		—	—	—
Ende Abschlussbild				

Ende Phase 3 Zeit: _____ Marker gesetzt? ☐

Datum: _____
VPN: _____

Am Morgen
Anfang SDI: Zeit: _____
Ende SDI: Zeit: _____

EEG-Aufnahme gestartet (_task-expo2)?
Anfang Atemübung: Zeit: _____
Phase 1a: Zeit: _____ Marker gesetzt? ☐

Zeitpunkt + Was passiert gerade (kurze Beschreibung der Szene)	**Marker gesetzt:**	**Arousal**	**Valenz**	**Lebendigkeit**
Anfang				
Hotspot				
Schluss				

Phase 1a Ende: Zeit: _____ Marker gesetzt? ☐

Emotionen
So wie gestern/vorhin möchte ich nun über die Gefühle sprechen, die Du empfunden hast, während Du gerade das Ereignis vor Deinem inneren Auge wiedererlebtest. Zunächst einmal möchte ich mit Dir über die Gefühle sprechen, die wir

gestern/vorhin bereits erarbeitet haben. In einem zweiten Schritt möchte ich dann mit Dir schauen, ob bei diesem Mal eventuell zusätzlich neue Gefühle aufgetreten sind.
Du hast während der letzten Imagination beispielsweise berichtet, dass du XY empfunden hast. War das dieses Mal auch wieder der Fall? Wie stark war dieses Gefühl während der Imagination ausgeprägt? Wie sehr hat Dich dieses Gefühl während der Imagination belastet?
Dein typischer Gedanke über Dich selbst, der beim letzten Mal mit diesem Gefühl einhergegangen ist, lautete XX. Hattest Du jetzt auch wieder diesen Gedanken? Als wie belastend hast Du diesen Gedanken jetzt während der Imagination empfunden?
Wenn Du jetzt an die Situation XY und an den Gedanken XY denkst, auf einer Skala von 1-10 wie wahr fühlt sich der Gedanke für Dich an?

Emotion	Ausmaß Emotion	Wie belastend?	Gedanke	Wie belastend?	Wie korrekt?

Sind im Vergleich zum letzten Mal eventuell zusätzlich noch weitere negative Gefühle oder Gedanken aufgetreten? Hast Du diese vielleicht auch schon beim letzten Mal empfunden (**retrospektiv raten lassen und als solches notieren**)?

Hast Du eventuell auch zusätzlich neue positive Gefühle empfunden? Typische positive Gefühle, die durch emotionale Situationen ausgelöst werden, sind z.B.: Freude, Zufriedenheit, Zuneigung, Zuversicht, Mut, Dankbarkeit, Stolz, Erleichterung.

Emotion	**Ausmaß Emotion**	**Wie belastend?**	**Gedanke**	**Wie belastend?**	**Wie korrekt?**

Ab einem Ausmaß von 3 weiterfragen, wie belastend und mit welchen Gedanken verknüpft.

Bei positiven Gefühlen **nicht** den Belastungsgrad erfragen, aber grundsätzlich Ausmaß, Gedanke und Korrektheit des Gedankens.

Abschließend werde ich Dir noch 13 weitere Aussagen zu Deiner soeben wiedererlebten Erinnerung vorlesen, die Du bitte anhand einer 7-stufigen Skala beantwortest. Dabei bedeutet 1 überhaupt nicht und 7 vollkommen zutreffend.

1. ***Während ich das Ereignis erinnerte, hatte ich das Gefühl, ich würde es wiedererleben.***

1	2	3	4	5	6	7

2. ***Der Abruf der Erinnerung fiel mir leicht.***

1	2	3	4	5	6	7

3. ***Meine Erinnerung hat Lücken.***

1	2	3	4	5	6	7

4. ***Während ich das Ereignis erinnerte, erlebte ich viele sensorische Informationen in Form von Geräuschen, Gerüchen, Geschmäckern, Berührungen, usw.***

1	2	3	4	5	6	7

5. ***Während ich das Ereignis erinnerte, klopfte mein Herz.***

1	2	3	4	5	6	7

6. ***Während ich das Ereignis erinnerte, hatte ich schwitzige Hände.***

1	2	3	4	5	6	7

7. ***Während ich das Ereignis erinnerte, war ich angespannt.***

1	2	3	4	5	6	7

8. ***Während ich das Ereignis erinnerte, fühlte ich mich belastet.***

1	2	3	4	5	6	7

9. ***Während ich das Ereignis erinnerte, fühlte ich eine emotionale Distanzierung in Bezug auf das Ereignis.***

1	2	3	4	5	6	7

10. ***Ich trage die Hauptverantwortung für den Ausgang der Situation.***

1	2	3	4	5	6	7

11. ***Das Ereignis hatte auch positive Konsequenzen. Ja oder nein?***

Ja	Nein

11a. Was für positive Konsequenzen hatte das Ereignis?

12. Durch das Ereignis habe ich etwas hinzugelernt. Ja oder nein?

Ja	Nein

12a. Was hast Du gelernt?

Datum: _____
VPN: _____

Follow-up nach 7 Tagen
Anfang SDI: Zeit: _____
Ende SDI: Zeit: _____

EEG-Aufnahme gestartet (_task-expo3)? ☐
Anfang Atemübung: Zeit: _____
Phase 1a: Zeit: _____ Marker gesetzt? ☐

Zeitpunkt + Was passiert gerade (kurze Beschreibung der Szene)	**Marker gesetzt:**	**Arousal**	**Valenz**	**Lebendigkeit**
Anfang				
Hotspot				
Schluss				

Phase 1a Ende: Zeit: _____ Marker gesetzt? ☐

Emotionen

So wie beim letzten Mal möchte ich nun über die Gefühle sprechen, die Du empfunden hast, während Du gerade das Ereignis vor Deinem inneren Auge wiedererlebtest. Zunächst einmal möchte ich mit Dir über die Gefühle sprechen, die wir **bei den letzten beiden Malen** erarbeitet haben. In einem zweiten Schritt möchte ich dann mit Dir schauen, ob bei diesem Mal eventuell zusätzlich neue Gefühle aufgetreten sind.

Du hast während der letzten Imagination beispielsweise berichtet, dass du XY empfunden hast. War das dieses Mal auch wieder der Fall? Wie stark war dieses Gefühl während der Imagination ausgeprägt? Wie sehr hat Dich dieses Gefühl während der Imagination belastet?

Dein typischer Gedanke über Dich selbst, der beim letzten Mal mit diesem Gefühl einhergegangen ist, lautete XX. Hattest Du jetzt auch wieder diesen Gedanken? Als wie belastend hast Du diesen Gedanken jetzt während der Imagination empfunden? Wenn Du jetzt an die Situation XY und an den Gedanken XY denkst, auf einer Skala von 1-10 wie wahr fühlt sich der Gedanke für Dich an?

Emotion	Ausmaß Emotion	Wie belastend?	Gedanke	Wie belastend?	Wie korrekt?

Emotion	**Ausmaß Emotion**	**Wie belastend?**	**Gedanke**	**Wie belastend?**	**Wie korrekt?**

Sind im Vergleich zu den letzten Malen zusätzlich weitere negative Gefühle oder Gedanken aufgetreten? Hast Du diese vielleicht auch schon bei den letzten Malen empfunden (**retrospektiv raten lassen und als solches notieren**)? Hast Du eventuell auch zusätzlich neue positive Gefühle empfunden? Typische positive Gefühle sind z.B.: Freude, Zufriedenheit, Zuneigung, Zuversicht, Mut, Dankbarkeit, Stolz, Erleichterung.

Emotion	**Ausmaß Emotion**	**Wie belastend?**	**Gedanke**	**Wie belastend?**	**Wie korrekt?**

Ab einem Ausmaß von 3 weiterfragen, wie belastend und mit welchen Gedanken verknüpft.

Bei positiven Gefühlen **nicht** den Belastungsgrad erfragen, aber grundsätzlich Ausmaß, Gedanke und Korrektheit des Gedankens.

Nun werde ich Dir noch 13 weitere Aussagen zu Deiner soeben wiedererlebten Erinnerung vorlesen, die Du bitte anhand einer 7-stufigen Skala beantwortest. Dabei bedeutet 1 überhaupt nicht und 7 vollkommen zutreffend.

1. ***Während ich das Ereignis erinnerte, hatte ich das Gefühl, ich würde es wiedererleben.***

1	2	3	4	5	6	7

2. ***Der Abruf der Erinnerung fiel mir leicht.***

1	2	3	4	5	6	7

3. ***Meine Erinnerung hat Lücken.***

1	2	3	4	5	6	7

4. ***Während ich das Ereignis erinnerte, erlebte ich viele sensorische Informationen in Form von Geräuschen, Gerüchen, Geschmäckern, Berührungen, usw.***

1	2	3	4	5	6	7

5. ***Während ich das Ereignis erinnerte, klopfte mein Herz.***

1	2	3	4	5	6	7

6. ***Während ich das Ereignis erinnerte, hatte ich schwitzige Hände.***

1	2	3	4	5	6	7

7. ***Während ich das Ereignis erinnerte, war ich angespannt.***

1	2	3	4	5	6	7

8. ***Während ich das Ereignis erinnerte, fühlte ich mich belastet.***

1	2	3	4	5	6	7

9. ***Während ich das Ereignis erinnerte, fühlte ich eine emotionale Distanzierung in Bezug auf das Ereignis.***

1	2	3	4	5	6	7

10. Ich trage die Hauptverantwortung für den Ausgang der Situation.

1	2	3	4	5	6	7

11. Das Ereignis hatte auch positive Konsequenzen. Ja oder nein?

Ja	Nein

11a. Was für positive Konsequenzen hatte das Ereignis?

12. Durch das Ereignis habe ich etwas hinzugelernt. Ja oder nein?

Ja	Nein

12a. Was hast Du gelernt?

6.3 List of odors

The odors in this study were chosen following multiple tests of the olfactometer with different scents. It was important for the selected scents to have low viscosity, ensuring the olfactometer could release bursts properly. Consequently, the study used the following freely available essential oils from Gya Labs (https://gyalabs.com/):

1. Tea Tree
2. Lemongrass
3. Frankincense
4. Rose Geranium
5. Rosewood
6. Palmarosa
7. Cajeput

6.4 Odor rating questionnaire

Duft-rating Vp-Nummer: _____Datum: _____

Bitte markieren Sie Ihre Antworten für jeden Geruch.

1) Wie bekannt ist Ihnen der **Geruch Nr. 1**?

Sehr unbekannt		Weder noch		Sehr bekannt
1	2	3	4	5

2) Wie angenehm empfinden Sie den Geruch Nr. 1?

Sehr unangenehm		Neutral		Sehr angenehm
1	2	3	4	5

3) Wie intensiv empfinden Sie den Geruch Nr. 1?

Überhaupt nicht intensiv		Weder noch		Sehr intensiv
1	2	3	4	5

4) Erinnert Sie der Geruch Nr. 1 an eine bestimmte Erinnerung?
Nein ☐ Ja ☐

5) Wenn ja, an welche?

_____
_____
_____
_____

6.5 Sleep diary

TMR_2021 → schlafqualitaet_sf-a-r 19.07.2022, 14:10

Seite 01

Code

Schlaftagebuch

Proband*innen Nummer

z.B. TMR77

Seite 02

Instruktion

Guten Morgen!

Bitte nehmen Sie sich etwas Zeit, um die folgenden Fragen zu beantworten. Die Fragen beziehen sich darauf, wie Sie geschlafen haben. Wählen Sie bitte die Antworten aus, die für Sie am **ehesten** zutreffen!

Gehen Sie bei der Beantwortung der Fragen zügig voran und **lassen Sie keine Frage aus! Bitte so zeitnah wie möglich nach dem Erwachen ausfüllen!**

Seite 03

Zeit

Wann haben Sie sich gestern Abend schlafen gelegt?

Beispiel 23:00 Uhr

HH:MM Uhr

Seite 04

Einschlafdauer

Wie lange hat es gestern Abend gedauert, bis Sie eingeschlafen waren?

- ◯ weniger als 1 Minute
- ◯ 1 bis 5 Minuten
- ◯ 6 bis 15 Minuten
- ◯ 16 bis 30 Minuten
- ◯ mehr als 30 Minuten

Falls es länger gedauert hat, welches waren die Gründe?

Mehrfachnennungen möglich

- ☐ Persönliche oder berufliche Probleme
- ☐ Geräusche im Zimmer oder von draußen
- ☐ Beschäftigung mit zurückliegenden Ereignissen
- ☐ Gedanken an den bevorstehenden Tag
- ☐ Ich hatte Schmerzen
- ☐ Ich musste zur Toilette
- ☐ Gedanken drehten sich ständig um ein Thema
- ☐ Sonstige:

Seite 05

Aufwachen

Sind Sie gestern nach dem Einschlafen nachts wieder aufgewacht (auch eventuelles Halbwachsein)?

- ◯ Nein
- ◯ Ja, einmal
- ◯ Ja, zweimal
- ◯ Ja, dreimal
- ◯ Ja, mehr als dreimal

Seite 06
Aufwachen2

Woran hat es Ihrer Meinung nach gelegen, wenn Sie nachts wach wurden?

Mehrfachnennungen möglich

- [ ] Persönliche oder berufliche Probleme
- [ ] Geräusche im Zimmer oder von draußen
- [ ] Ich musste zur Toilette
- [ ] Ich wurde durch einen Traum geweckt
- [ ] Ich hatte noch keinen Schlaf gefunden
- [ ] Schmerzen
- [ ] Sonstige

Wie lange schätzen Sie, waren Sie insgesamt wach?

- ◯ weniger als 1 Minute
- ◯ 1 bis 5 Minuten
- ◯ 6 bis 15 Minuten
- ◯ 16 bis 30 Minuten
- ◯ mehr als 30 Minuten

Seite 07
Traum

Können Sie sich erinnern, ob Sie heute Nacht geträumt haben?

- ◯ Nein, ich kann mich nicht erinnern, geträumt zu haben.
- ◯ Ja, ich habe geträumt, kann mich aber nicht mehr an den Trauminhalt erinnern.
- ◯ Ja, ich habe geträumt und kann mich an den Trauminhalt erinnern.

Seite 08

Traum2

Mit welcher Erinnerung stand der Traum in Beziehung?

- ◯ mit der belastenden Erinnerung
- ◯ mit der veränderten Erinnerung
- ◯ weder noch

Beschreiben Sie den Inhalt des Traums.

Welche Gefühle hatten Sie während des Träumens?

- ◯ Angenehme Gefühle
- ◯ Neutrale Gefühle
- ◯ Unangenehme Gefühle

Seite 09

Aufstehen

Um wie viel Uhr sind Sie heute Morgen aufgewacht?

Beispiel 6:30 Uhr

HH:MM Uhr

Wie sind Sie heute Morgen aufgewacht?

- ◯ Von alleine aufgewacht
- ◯ Aus dem Halbschlaf geweckt
- ◯ Aus dem Tiefschlaf geweckt

Sind Sie heute Morgen zu früh aufgewacht und konnten dann nicht mehr einschlafen?

- ◯ Nein
- ◯ Ja

Seite 10

Alkohol Medis

Haben Sie seit gestern Abend nach dem Abendessen Alkohol (Bier, Wein, Schnaps oder andere) getrunken?

- ◯ Nein
- ◯ Ja

Haben Sie seit gestern Abend ein Schlafmittel (Medikament, Tee oder andere) benutzt?

- ◯ Nein
- ◯ Ja

Seite 11

WelcheMedis

Welche/s Schlafmittel haben Sie eingenommen?

Seite 12

Anstrengend

War der gestrige Tag für Sie besonders anstrengend?

- ◯ Nein
- ◯ Ja

Seite 13

Rating1

Anleitung

Im Folgenden finden Se einige Wörter, mit denen Sie beschreiben können, wie Sie sich gestern Abend, vor dem Schlafengehen, fühlten, wie Sie heute Nacht geschlafen haben und wie Sie sich heute Morgen fühlen. Kreuzen Sie hinter **jedem** Wort an, in welchem Ausmaß es für Sie zutrifft!

Wie haben Sie in der vergangenen Nacht geschlafen?

Gleichmäßig				
sehr	ziemlich	mittel	wenig	nicht
Tief				
sehr	ziemlich	mittel	wenig	nicht
Unruhig				
sehr	ziemlich	mittel	wenig	nicht
Entspannt				
sehr	ziemlich	mittel	wenig	nicht
Ungestört				
sehr	ziemlich	mittel	wenig	nicht
Gut				
sehr	ziemlich	mittel	wenig	nicht
Ausgiebig				
sehr	ziemlich	mittel	wenig	nicht

Seite 14
Rating2

Wie fühlten Sie sich gestern vor dem Schlafengehen?

Sorglos				
sehr	ziemlich	mittel	wenig	nicht
Erschöpft				
sehr	ziemlich	mittel	wenig	nicht
Schlafbedürftig				
sehr	ziemlich	mittel	wenig	nicht
Überfordert				
sehr	ziemlich	mittel	wenig	nicht
Ausgeglichen				
sehr	ziemlich	mittel	wenig	nicht
Ruhig				
sehr	ziemlich	mittel	wenig	nicht
Müde				
sehr	ziemlich	mittel	wenig	nicht
Entspannt				
sehr	ziemlich	mittel	wenig	nicht

Seite 15
Rating3

Wie fühlen Sie sich heute Morgen?

Ausgeglichen				
sehr	ziemlich	mittel	wenig	nicht
Dösig, schläfrig				
sehr	ziemlich	mittel	wenig	nicht
Tatkräftig				
sehr	ziemlich	mittel	wenig	nicht
Munter				
sehr	ziemlich	mittel	wenig	nicht
Frisch				
sehr	ziemlich	mittel	wenig	nicht
Ausgeschlafen				
sehr	ziemlich	mittel	wenig	nicht
Entspannt				
sehr	ziemlich	mittel	wenig	nicht

Seite 16
Bemerkung

Bemerkungen/Fragen:

Letzte Seite

Vielen Dank für Ihre Angaben!

Ihre Daten wurden gespeichert. Sie können das Browser-Fenster nun schließen.

6.6 Intrusion diary

TMR_2021 → intrusion_diary 19.07.2022, 14:12

Seite 01

Code

Intrusionstagebuch

Proband*innen Nummer

z.B. TMR77

Seite 02

Daten

Bitte tragen Sie jede aufgetretene Erinnerung und Gedanken an die von Ihnen ausgewählte Erinnerung ein.

Wann ist die Erinnerung aufgetreten?

Datum		
Uhrzeit	z.B. 16:00	Uhr

Inhalt der Erinnerung oder des Gedankens an die belastende Erinnerung:

Seite 03

Belastung

Wie belastend war die Erinnerung für Sie?

1	2	3	4	5
überhaupt nicht				sehr
○	○	○	○	○

Seite 04
Lebhaftigkeit

Wie lebhaft war die Erinnerung für Sie?

1	2	3	4	5
überhaupt nicht				sehr
○	○	○	○	○

Seite 05
Art

In welcher Art tauchte die Erinnerung auf?

Mehrfachnennungen möglich

- ☐ Gedanke
- ☐ Bild
- ☐ Geräusch

Seite 06
ploetzlich
Ist die Erinnerung plötzlich aufgetreten?

- ○ Ja
- ○ Nein

Seite 07
Ausloeser
Gab es einen Auslöser?

- ○ Ja
- ○ Nein

Seite 08
Ausloeser2
Was war der Auslöser?

Letzte Seite

Vielen Dank für Ihre Angaben!

Ihre Antworten wurden gespeichert. Sie können das Browser-Fenster nun schließen.

6.7 Hypothesis testing

SDI

Table G 1: Descriptive Statistics - arousal of emotional memory in SDI

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error(E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.29	.29	3.93	.32	27
Pre	Incongruent	Wake	4.14	.32	4.16	.32	28
Post 1	Incongruent	Sleep	2.29	.29	2.36	.24	27
Post 1	Incongruent	Wake	2.25	.27	2.18	.24	28
Post 2	Incongruent	Sleep	2.11	.25	2.04	.28	27
Post 2	Incongruent	Wake	1.78	.23	1.74	.27	28
Pre	Congruent	Sleep	3.88	.30	4.28	.32	27
Pre	Congruent	Wake	4.21	.30	4.15	.32	28
Post 1	Congruent	Sleep	2.37	.23	2.23	.29	27
Post 1	Congruent	Wake	2.17	.23	2.30	.28	28
Post 2	Congruent	Sleep	2.07	.27	2.00	.24	27
Post 2	Congruent	Wake	1.71	.25	1.88	.23	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.23.

* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 2: Descriptive Statistics - valence of emotional memory in SDI

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error(E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.56	0.42	4.95	.38	25
Pre	Incongruent	Wake	4.77	0.35	4.96	.36	27
Post 1	Incongruent	Sleep	2.72	0.39	2.56	.35	25
Post 1	Incongruent	Wake	2.66	0.40	2.47	.34	27
Post 2	Incongruent	Sleep	2.24	0.31	2.07	.37	25
Post 2	Incongruent	Wake	2.48	0.36	2.22	.35	27
Pre	Congruent	Sleep	4.88	0.33	4.56	.40	25
Pre	Congruent	Wake	5.03	0.34	4.77	.38	27
Post 1	Congruent	Sleep	2.52	0.30	2.60	.39	25
Post 1	Congruent	Wake	2.51	0.31	2.77	.37	27
Post 2	Congruent	Sleep	2.08	0.34	2.09	.30	25
Post 2	Congruent	Wake	2.22	0.29	2.61	.29	27

* Covariates appearing in the model are evaluated at the following values: Age = 24.21.

* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 3: Descriptive Statistics - vividness of emotional memory in SDI

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	-.71	.29	-.87	.40	28
Pre	Incongruent	Wake	-.78	.33	.19	.40	28
Post 1	Incongruent	Sleep	-.82	.28	-.26	.33	28
Post 1	Incongruent	Wake	-.71	.19	-.62	.33	28
Post 2	Incongruent	Sleep	-.78	.34	-.66	.33	28
Post 2	Incongruent	Wake	-.89	.27	-.54	.33	28
Pre	Congruent	Sleep	-.89	.28	-.78	.31	28
Pre	Congruent	Wake	-.21	.41	-.72	.31	28
Post 1	Congruent	Sleep	-.32	.39	-.83	.25	28
Post 1	Congruent	Wake	-.57	.18	-.70	.25	28
Post 2	Congruent	Sleep	-.71	.38	-.82	.32	28
Post 2	Congruent	Wake	-.50	.20	-.85	.32	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.
* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 4: Descriptive Statistics - FRABO 1 in SDI

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.82	.24	3.77	.24	28
Pre	Incongruent	Wake	4.11	.22	4.01	.24	28
Post 1	Incongruent	Sleep	3.00	.24	2.92	.24	28
Post 1	Incongruent	Wake	3.21	.28	2.93	.24	28
Post 2	Incongruent	Sleep	2.89	.18	2.70	.24	28
Post 2	Incongruent	Wake	2.68	.21	2.86	.24	28
Pre	Congruent	Sleep	3.71	.25	3.85	.23	28
Pre	Congruent	Wake	4.07	.20	4.07	.23	28
Post 1	Congruent	Sleep	2.89	.20	3.11	.26	28
Post 1	Congruent	Wake	2.96	.23	3.10	.26	28
Post 2	Congruent	Sleep	2.68	.20	2.89	.20	28
Post 2	Congruent	Wake	2.89	.25	2.68	.20	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 5: Descriptive Statistics - FRABO 2 in SDI

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.64	.29	4.63	.31	28
Pre	Incongruent	Wake	4.79	.28	4.61	.31	28
Post 1	Incongruent	Sleep	4.82	.23	4.37	.29	28
Post 1	Incongruent	Wake	4.71	.27	4.72	.29	28
Post 2	Incongruent	Sleep	4.54	.26	4.57	.28	28
Post 2	Incongruent	Wake	4.96	.27	4.78	.28	28
Pre	Congruent	Sleep	4.57	.30	4.68	.29	28
Pre	Congruent	Wake	4.68	.27	4.74	.29	28
Post 1	Congruent	Sleep	4.36	.25	4.87	.25	28
Post 1	Congruent	Wake	4.75	.27	4.66	.25	28
Post 2	Congruent	Sleep	4.50	.26	4.55	.27	28
Post 2	Congruent	Wake	4.86	.28	4.94	.27	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 6: Descriptive Statistics - FRABO 3 in SDI (equivalent to FRABO 5 in IRRT)

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.14	.26	2.97	.31	28
Pre	Incongruent	Wake	3.75	.25	3.35	.31	28
Post 1	Incongruent	Sleep	2.79	.22	2.59	.31	28
Post 1	Incongruent	Wake	3.36	.32	3.15	.31	28
Post 2	Incongruent	Sleep	2.36	.24	2.33	.26	28
Post 2	Incongruent	Wake	2.93	.30	2.98	.26	28
Pre	Congruent	Sleep	2.93	.29	3.15	.26	28
Pre	Congruent	Wake	3.39	.29	3.73	.26	28
Post 1	Congruent	Sleep	2.61	.26	2.78	.28	28
Post 1	Congruent	Wake	3.14	.32	3.35	.28	28
Post 2	Congruent	Sleep	2.29	.21	2.34	.28	28
Post 2	Congruent	Wake	3.04	.29	2.94	.28	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 7: Descriptive Statistics - FRABO 4 in SDI (equivalent to FRABO 6 in IRRT)

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.39	.32	3.45	.32	28
Pre	Incongruent	Wake	3.89	.33	3.47	.32	28
Post 1	Incongruent	Sleep	2.14	.21	2.13	.24	28
Post 1	Incongruent	Wake	2.96	.30	2.76	.24	28
Post 2	Incongruent	Sleep	2.21	.21	2.32	.25	28
Post 2	Incongruent	Wake	2.54	.24	2.35	.25	28
Pre	Congruent	Sleep	3.39	.29	3.40	.34	28
Pre	Congruent	Wake	3.54	.29	3.88	.34	28
Post 1	Congruent	Sleep	2.11	.13	2.07	.26	28
Post 1	Congruent	Wake	2.79	.29	3.03	.26	28
Post 2	Congruent	Sleep	2.25	.23	2.18	.23	28
Post 2	Congruent	Wake	2.43	.25	2.56	.23	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 8: Descriptive Statistics - FRABO 5 in SDI (equivalent to FRABO 7 in IRRT)

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	1.79	.21	1.72	.19	28
Pre	Incongruent	Wake	2.00	.28	1.69	.19	28
Post 1	Incongruent	Sleep	1.46	.13	1.23	.13	28
Post 1	Incongruent	Wake	1.50	.15	1.54	.13	28
Post 2	Incongruent	Sleep	1.39	.13	1.54	.16	28
Post 2	Incongruent	Wake	1.39	.13	1.38	.16	28
Pre	Congruent	Sleep	1.68	.23	1.76	.25	28
Pre	Congruent	Wake	1.75	.14	2.02	.25	28
Post 1	Congruent	Sleep	1.25	.09	1.43	.14	28
Post 1	Congruent	Wake	1.54	.16	1.52	.14	28
Post 2	Congruent	Sleep	1.54	.15	1.37	.13	28
Post 2	Congruent	Wake	1.39	.16	1.40	.13	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 9: Descriptive Statistics - FRABO 6 in SDI (equivalent to FRABO 8 in IRRT)

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.11	.28	4.31	.26	28
Pre	Incongruent	Wake	4.61	.27	4.61	.26	28
Post 1	Incongruent	Sleep	2.82	.20	2.60	.22	28
Post 1	Incongruent	Wake	2.93	.23	2.67	.22	28
Post 2	Incongruent	Sleep	2.46	.21	2.77	.27	28
Post 2	Incongruent	Wake	2.71	.24	2.76	.27	28
Pre	Congruent	Sleep	4.29	.25	4.08	.29	28
Pre	Congruent	Wake	4.64	.25	4.62	.29	28
Post 1	Congruent	Sleep	2.64	.25	2.82	.22	28
Post 1	Congruent	Wake	2.64	.18	2.92	.22	28
Post 2	Congruent	Sleep	2.75	.25	2.39	.22	28
Post 2	Congruent	Wake	2.79	.27	2.78	.22	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 10: Descriptive Statistics - FRABO 7 in SDI (equivalent to FRABO 9 in IRRT)

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.07	.24	4.00	.25	28
Pre	Incongruent	Wake	4.46	.23	4.52	.25	28
Post 1	Incongruent	Sleep	2.50	.24	2.39	.22	28
Post 1	Incongruent	Wake	2.75	.19	2.71	.22	28
Post 2	Incongruent	Sleep	2.32	.17	2.43	.23	28
Post 2	Incongruent	Wake	2.25	.19	2.42	.23	28
Pre	Congruent	Sleep	4.00	.25	4.06	.24	28
Pre	Congruent	Wake	4.54	.25	4.47	.24	28
Post 1	Congruent	Sleep	2.43	.17	2.44	.22	28
Post 1	Congruent	Wake	2.68	.22	2.80	.22	28
Post 2	Congruent	Sleep	2.39	.20	2.28	.19	28
Post 2	Congruent	Wake	2.46	.25	2.28	.19	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 11: Descriptive Statistics - FRABO 8 in SDI (equivalent to FRABO 10 in IRRT)

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.43	.26	3.44	.27	28
Pre	Incongruent	Wake	3.25	.30	3.19	.27	28
Post 1	Incongruent	Sleep	4.43	.29	4.32	.32	28
Post 1	Incongruent	Wake	4.11	.28	4.10	.32	28
Post 2	Incongruent	Sleep	4.79	.29	4.48	.30	28
Post 2	Incongruent	Wake	4.54	.29	4.69	.30	28
Pre	Congruent	Sleep	3.43	.26	3.53	.27	28
Pre	Congruent	Wake	3.21	.27	3.14	.27	28
Post 1	Congruent	Sleep	4.29	.28	4.46	.29	28
Post 1	Congruent	Wake	4.14	.30	4.07	.29	28
Post 2	Congruent	Sleep	4.46	.30	4.78	.30	28
Post 2	Congruent	Wake	4.71	.26	4.53	.30	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

IRRT

Table G 12: Descriptive Statistics - arousal hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	6.36	.35	6.34	.35	28
Pre	Incongruent	Wake	7.14	.34	7.15	.35	28
Post 1	Incongruent	Sleep	3.86	.31	3.80	.31	28
Post 1	Incongruent	Wake	3.89	.31	3.94	.31	28
Post 2	Incongruent	Sleep	3.43	.25	3.34	.27	28
Post 2	Incongruent	Wake	3.96	.29	4.04	.27	28
Pre	Congruent	Sleep	6.79	.33	6.79	.35	28
Pre	Congruent	Wake	7.43	.32	7.41	.35	28
Post 1	Congruent	Sleep	4.07	.32	4.03	.34	28
Post 1	Congruent	Wake	4.00	.32	4.04	.34	28
Post 2	Congruent	Sleep	3.71	.35	3.65	.38	28
Post 2	Congruent	Wake	3.93	.37	3.98	.38	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 13: Descriptive Statistics - valence hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	6.82	.31	6.80	.33	28
Pre	Incongruent	Wake	7.14	.34	7.16	.33	28
Post 1	Incongruent	Sleep	4.07	.41	4.02	.42	28
Post 1	Incongruent	Wake	4.18	.41	4.23	.42	28
Post 2	Incongruent	Sleep	3.43	.36	3.31	.38	28
Post 2	Incongruent	Wake	4.25	.40	4.36	.38	28
Pre	Congruent	Sleep	6.82	.35	6.86	.36	28
Pre	Congruent	Wake	7.54	.32	7.49	.36	28
Post 1	Congruent	Sleep	4.25	.33	4.24	.37	28
Post 1	Congruent	Wake	4.32	.35	4.33	.37	28
Post 2	Congruent	Sleep	3.93	.37	3.90	.40	28
Post 2	Congruent	Wake	3.64	.37	3.66	.40	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 14: Descriptive Statistics - vividness hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	6.96	.31	6.99	.32	28
Pre	Incongruent	Wake	7.50	.31	7.47	.32	28
Post 1	Incongruent	Sleep	6.29	.29	6.34	.36	28
Post 1	Incongruent	Wake	6.29	.41	6.22	.36	28
Post 2	Incongruent	Sleep	6.04	.33	6.06	.38	28
Post 2	Incongruent	Wake	6.14	.40	6.11	.38	28
Pre	Congruent	Sleep	7.07	.35	7.12	.35	28
Pre	Congruent	Wake	7.79	.28	7.73	.35	28
Post 1	Congruent	Sleep	6.29	.24	6.35	.32	28
Post 1	Congruent	Wake	6.39	.35	6.32	.32	28
Post 2	Congruent	Sleep	6.18	.31	6.28	.37	28
Post 2	Congruent	Wake	6.43	.39	6.32	.37	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 15: Descriptive Statistics - intensity of the dominant emotion hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	7.32	.27	7.37	.25	28
Pre	Incongruent	Wake	8.11	.23	8.05	.25	28
Post 1	Incongruent	Sleep	3.07	.38	2.89	.41	28
Post 1	Incongruent	Wake	3.75	.47	3.92	.41	28
Post 2	Incongruent	Sleep	2.32	.38	2.18	.44	28
Post 2	Incongruent	Wake	3.36	.50	3.49	.44	28
Pre	Congruent	Sleep	7.82	.32	7.87	.31	28
Pre	Congruent	Wake	8.36	.25	8.30	.31	28
Post 1	Congruent	Sleep	3.79	.37	3.66	.42	28
Post 1	Congruent	Wake	3.96	.40	4.08	.42	28
Post 2	Congruent	Sleep	3.00	.38	2.95	.49	28
Post 2	Congruent	Wake	3.86	.51	3.90	.49	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 16: Descriptive Statistics - distress of the dominant emotion hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	7.32	.37	7.30	.34	28
Pre	Incongruent	Wake	7.71	.30	7.73	.34	28
Post 1	Incongruent	Sleep	2.82	.36	2.63	.36	28
Post 1	Incongruent	Wake	3.04	.40	3.22	.36	28
Post 2	Incongruent	Sleep	2.14	.30	2.01	.39	28
Post 2	Incongruent	Wake	2.96	.47	3.09	.39	28
Pre	Congruent	Sleep	6.93	.44	6.88	.42	28
Pre	Congruent	Wake	7.64	.33	7.68	.42	28
Post 1	Congruent	Sleep	3.50	.41	3.38	.45	28
Post 1	Congruent	Wake	3.54	.43	3.65	.45	28
Post 2	Congruent	Sleep	2.64	.33	2.59	.44	28
Post 2	Congruent	Wake	3.11	.46	3.15	.44	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 17: Descriptive Statistics - distress of the dominant cognition hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	6.43	.30	6.46	.29	28
Pre	Incongruent	Wake	7.74	.27	7.47	.39	27
Post 1	Incongruent	Sleep	2.82	.39	2.79	.41	28
Post 1	Incongruent	Wake	3.26	.42	3.40	.42	27
Post 2	Incongruent	Sleep	2.29	.37	2.17	.39	28
Post 2	Incongruent	Wake	3.85	.42	2.61	.39	27
Pre	Congruent	Sleep	7.11	.35	7.11	.38	28
Pre	Congruent	Wake	7.48	.33	7.70	.29	27
Post 1	Congruent	Sleep	3.11	.38	3.00	.41	28
Post 1	Congruent	Wake	3.30	.41	3.28	.42	27
Post 2	Congruent	Sleep	2.32	.38	2.29	.38	28
Post 2	Congruent	Wake	2.59	.34	2.96	.40	27

* Covariates appearing in the model are evaluated at the following values: Age = 24.03.

Table G 18: Descriptive Statistics - correctness of the dominant cognition hotspot during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	7.21	.43	7.24	.45	28
Pre	Incongruent	Wake	7.25	.45	7.21	.45	28
Post 1	Incongruent	Sleep	3.93	.42	3.87	.51	28
Post 1	Incongruent	Wake	4.39	.56	4.44	.51	28
Post 2	Incongruent	Sleep	3.54	.45	3.37	.54	28
Post 2	Incongruent	Wake	4.18	.62	4.34	.54	28
Pre	Congruent	Sleep	7.29	.36	7.27	.35	28
Pre	Congruent	Wake	8.14	.27	8.15	.35	28
Post 1	Congruent	Sleep	4.61	.54	4.60	.62	28
Post 1	Congruent	Wake	5.68	.57	5.68	.62	28
Post 2	Congruent	Sleep	3.57	.51	3.56	.59	28
Post 2	Congruent	Wake	4.96	.58	4.96	.59	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 19: Descriptive Statistics - FRABO 1 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	5.07	.25	5.11	.24	28
Pre	Incongruent	Wake	4.75	.22	4.70	.24	28
Post 1	Incongruent	Sleep	4.32	.24	4.40	.27	28
Post 1	Incongruent	Wake	4.21	.30	4.13	.27	28
Post 2	Incongruent	Sleep	4.04	.24	4.06	.29	28
Post 2	Incongruent	Wake	3.79	.33	3.75	.29	28
Pre	Congruent	Sleep	4.93	.21	4.91	.25	28
Pre	Congruent	Wake	5.04	.24	5.05	.25	28
Post 1	Congruent	Sleep	3.96	.24	3.94	.30	28
Post 1	Congruent	Wake	3.93	.30	3.94	.30	28
Post 2	Congruent	Sleep	4.07	.27	4.16	.31	28
Post 2	Congruent	Wake	4.04	.33	3.94	.31	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 20: Descriptive Statistics - FRABO 2 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	5.39	.21	5.50	.25	28
Pre	Incongruent	Wake	5.25	.30	5.13	.25	28
Post 1	Incongruent	Sleep	5.64	.22	5.71	.26	28
Post 1	Incongruent	Wake	5.07	.29	4.99	.26	28
Post 2	Incongruent	Sleep	5.25	.22	5.35	.26	28
Post 2	Incongruent	Wake	5.11	.30	5.00	.26	28
Pre	Congruent	Sleep	5.39	.21	5.45	.26	28
Pre	Congruent	Wake	5.57	.27	5.51	.26	28
Post 1	Congruent	Sleep	5.21	.23	5.21	.32	28
Post 1	Congruent	Wake	5.11	.34	5.11	.32	28
Post 2	Congruent	Sleep	5.07	.26	5.10	.30	28
Post 2	Congruent	Wake	5.11	.31	5.07	.30	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 21: Descriptive Statistics – FRABO 3 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.53	.33	4.53	.33	28
Pre	Incongruent	Wake	4.89	.31	4.89	.33	28
Post 1	Incongruent	Sleep	4.00	.36	4.07	.33	28
Post 1	Incongruent	Wake	4.46	.28	4.39	.33	28
Post 2	Incongruent	Sleep	3.89	.33	3.93	.33	28
Post 2	Incongruent	Wake	4.17	.31	4.13	.33	28
Pre	Congruent	Sleep	4.25	.33	4.30	.35	28
Pre	Congruent	Wake	4.32	.32	4.26	.35	28
Post 1	Congruent	Sleep	4.10	.32	4.11	.34	28
Post 1	Congruent	Wake	3.82	.30	3.80	.34	28
Post 2	Congruent	Sleep	4.21	.36	4.28	.37	28
Post 2	Congruent	Wake	4.03	.33	3.96	.37	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 22: Descriptive Statistics – FRABO 4 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.03	.28	3.07	.30	28
Pre	Incongruent	Wake	4.17	.30	4.13	.30	28
Post 1	Incongruent	Sleep	3.03	.27	3.05	.31	28
Post 1	Incongruent	Wake	3.39	.35	3.36	.31	28
Post 2	Incongruent	Sleep	2.75	.28	2.79	.31	28
Post 2	Incongruent	Wake	3.50	.32	3.45	.31	28
Pre	Congruent	Sleep	3.50	.31	3.51	.32	28
Pre	Congruent	Wake	3.85	.29	3.83	.32	28
Post 1	Congruent	Sleep	2.96	.27	2.92	.30	28
Post 1	Congruent	Wake	3.64	.29	3.68	.30	28
Post 2	Congruent	Sleep	2.71	.24	0.25	.30	28
Post 2	Congruent	Wake	3.78	.25	3.71	.25	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 23: Descriptive Statistics – FRABO 5 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.53	.31	3.50	.32	28
Pre	Incongruent	Wake	4.00	.31	4.02	.32	28
Post 1	Incongruent	Sleep	2.03	.19	2.03	.27	28
Post 1	Incongruent	Wake	3.10	.32	3.10	.27	28
Post 2	Incongruent	Sleep	2.42	.27	2.36	.30	28
Post 2	Incongruent	Wake	2.82	.32	2.88	.30	28
Pre	Congruent	Sleep	3.57	.30	3.63	.33	28
Pre	Congruent	Wake	4.53	.30	4.47	.33	28
Post 1	Congruent	Sleep	2.32	.22	2.35	.25	28
Post 1	Congruent	Wake	2.71	.23	2.68	.25	28
Post 2	Congruent	Sleep	2.32	.28	2.36	.28	28
Post 2	Congruent	Wake	2.78	.25	2.74	.28	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 24: Descriptive Statistics – FRABO 6 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	2.39	.35	2.32	.35	28
Pre	Incongruent	Wake	2.42	.35	2.49	.35	28
Post 1	Incongruent	Sleep	1.67	.17	1.62	.22	28
Post 1	Incongruent	Wake	1.85	.26	1.91	.22	28
Post 2	Incongruent	Sleep	1.67	.17	1.64	.19	28
Post 2	Incongruent	Wake	1.75	.21	1.78	.19	28
Pre	Congruent	Sleep	2.07	.25	2.06	.31	28
Pre	Congruent	Wake	2.28	.34	2.29	.31	28
Post 1	Congruent	Sleep	1.35	.13	1.37	.23	28
Post 1	Congruent	Wake	1.92	.27	1.90	.23	28
Post 2	Congruent	Sleep	1.67	.20	1.67	.20	28
Post 2	Congruent	Wake	1.64	.18	1.65	.20	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 25: Descriptive Statistics – FRABO 7 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	4.96	.27	4.95	.27	28
Pre	Incongruent	Wake	5.21	.24	5.21	.27	28
Post 1	Incongruent	Sleep	3.00	.21	2.96	.26	28
Post 1	Incongruent	Wake	3.25	.29	3.28	.26	28
Post 2	Incongruent	Sleep	2.96	.29	2.91	.32	28
Post 2	Incongruent	Wake	3.28	.33	3.33	.32	28
Pre	Congruent	Sleep	5.07	.28	5.10	.28	28
Pre	Congruent	Wake	5.50	.24	5.47	.28	28
Post 1	Congruent	Sleep	3.00	.30	2.96	.29	28
Post 1	Congruent	Wake	3.07	.23	3.10	.29	28
Post 2	Congruent	Sleep	3.25	.27	3.25	.28	28
Post 2	Congruent	Wake	3.28	.27	3.27	.28	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 26: Descriptive Statistics – FRABO 8 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	5.10	.20	5.10	.22	28
Pre	Incongruent	Wake	5.21	.23	5.21	.22	28
Post 1	Incongruent	Sleep	2.89	.23	2.86	.26	28
Post 1	Incongruent	Wake	2.92	.28	2.95	.26	28
Post 2	Incongruent	Sleep	2.78	.25	2.75	.28	28
Post 2	Incongruent	Wake	2.96	.28	2.99	.28	28
Pre	Congruent	Sleep	4.96	.24	4.99	.27	28
Pre	Congruent	Wake	5.32	.26	5.29	.27	28
Post 1	Congruent	Sleep	3.03	.25	2.98	.27	28
Post 1	Congruent	Wake	2.78	.24	2.83	.27	28
Post 2	Congruent	Sleep	2.75	.27	2.72	.28	28
Post 2	Congruent	Wake	2.75	.26	2.77	.28	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 27: Descriptive Statistics – FRABO 9 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.35	.29	3.43	.30	28
Pre	Incongruent	Wake	3.10	.30	3.03	.30	28
Post 1	Incongruent	Sleep	4.71	.27	4.74	.34	28
Post 1	Incongruent	Wake	4.32	.39	4.28	.34	28
Post 2	Incongruent	Sleep	5.14	.27	5.18	.27	28
Post 2	Incongruent	Wake	5.25	.26	5.20	.27	28
Pre	Congruent	Sleep	3.35	.22	3.34	.27	28
Pre	Congruent	Wake	2.92	.27	2.94	.27	28
Post 1	Congruent	Sleep	4.71	.22	4.78	.27	28
Post 1	Congruent	Wake	4.71	.28	4.63	.27	28
Post 2	Congruent	Sleep	5.00	.28	5.02	.31	28
Post 2	Congruent	Wake	4.75	.30	4.72	.31	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 28: Descriptive Statistics – FRABO 10 during IRRT

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.71	.36	3.71	.40	28
Pre	Incongruent	Wake	3.42	.43	3.43	.40	28
Post 1	Incongruent	Sleep	3.75	.38	3.85	.40	28
Post 1	Incongruent	Wake	3.71	.42	3.61	.40	28
Post 2	Incongruent	Sleep	3.78	.37	3.91	.39	28
Post 2	Incongruent	Wake	3.78	.38	3.65	.39	28
Pre	Congruent	Sleep	3.46	.39	3.52	.39	28
Pre	Congruent	Wake	2.96	.40	2.90	.39	28
Post 1	Congruent	Sleep	3.14	.34	3.23	.43	28
Post 1	Congruent	Wake	3.35	.44	3.26	.43	28
Post 2	Congruent	Sleep	3.32	.38	3.43	.41	28
Post 2	Congruent	Wake	3.71	.42	3.60	.41	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

HR analysis: during SDI

Table G 29: Descriptive Statistics – Mean HR: during script listening

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	3.423	.58	3.42	.77	23
Pre	Incongruent	Wake	3.350	.71	3.35	.79	22
Post 1	Incongruent	Sleep	1.500	.83	1.69	.81	23
Post 1	Incongruent	Wake	1.531	.68	1.33	.83	22
Post 2	Incongruent	Sleep	1.749	.89	1.69	.87	23
Post 2	Incongruent	Wake	.715	.60	.77	.89	22
Pre	Congruent	Sleep	1.830	.58	1.78	.79	23
Pre	Congruent	Wake	4.977	.73	5.02	.81	22
Post 1	Congruent	Sleep	.468	.81	.37	1.01	23
Post 1	Congruent	Wake	1.088	.75	1.18	1.03	22
Post 2	Congruent	Sleep	.415	.52	.48	.65	23
Post 2	Congruent	Wake	1.869	.60	1.79	.67	22

***** Covariates appearing in the model are evaluated at the following values: Age = 24.35.

* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 30: Descriptive Statistics – Stress index: during script listening

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	1.69	.63	1.61	.62	21
Pre	Incongruent	Wake	1.33	.47	1.41	.62	21
Post 1	Incongruent	Sleep	1.28	.65	1.27	.66	21
Post 1	Incongruent	Wake	1.43	.57	1.43	.66	21
Post 2	Incongruent	Sleep	-1.29	.68	-1.29	.74	21
Post 2	Incongruent	Wake	-.03	.55	-.03	.74	21
Pre	Congruent	Sleep	.05	.53	-.12	.65	21
Pre	Congruent	Wake	1.42	.54	1.60	.65	21
Post 1	Congruent	Sleep	1.31	.58	1.37	.67	21
Post 1	Congruent	Wake	.62	.53	.56	.67	21
Post 2	Congruent	Sleep	1.12	.62	1.14	.54	21
Post 2	Congruent	Wake	.25	.51	.23	.54	21

* Covariates appearing in the model are evaluated at the following values: Age = 24.23.

* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 31: Descriptive Statistics – HRV: during script listening

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	-43.49	7.82	-44.57	8.94	24
Pre	Incongruent	Wake	-40.27	8.74	-39.05	9.57	21
Post 1	Incongruent	Sleep	-16.77	11.29	-19.63	10.22	24
Post 1	Incongruent	Wake	-24.14	9.45	-20.87	10.94	21
Post 2	Incongruent	Sleep	-16.10	8.63	-15.64	8.47	24
Post 2	Incongruent	Wake	-5.91	6.43	-6.43	9.07	21
Pre	Congruent	Sleep	-22.32	7.04	-21.62	8.69	24
Pre	Congruent	Wake	-48.52	8.94	-49.32	9.31	21
Post 1	Congruent	Sleep	-7.85	10.15	-7.18	11.72	24
Post 1	Congruent	Wake	-11.89	9.15	-12.66	12.55	21
Post 2	Congruent	Sleep	-5.92	5.61	-6.74	7.40	24
Post 2	Congruent	Wake	-21.84	7.20	-20.91	7.92	21

* Covariates appearing in the model are evaluated at the following values: Age = 23.97.
* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 32: Descriptive Statistics – Mean HR: during script imagining

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	-.17	.75	-.01	.92	23
Pre	Incongruent	Wake	1.65	.86	1.48	.95	22
Post 1	Incongruent	Sleep	.81	.88	.67	.87	23
Post 1	Incongruent	Wake	-.46	.60	-.32	.89	22
Post 2	Incongruent	Sleep	-.38	.59	-.35	.68	23
Post 2	Incongruent	Wake	-1.17	.58	-1.20	.70	22
Pre	Congruent	Sleep	.34	.60	.52	.83	23
Pre	Congruent	Wake	1.39	.77	1.21	.85	22
Post 1	Congruent	Sleep	.04	.60	.06	.68	23
Post 1	Congruent	Wake	-.24	.49	-.27	.69	22
Post 2	Congruent	Sleep	-1.05	.63	-.98	.68	23
Post 2	Congruent	Wake	-.76	.61	-.84	.69	22

***** Covariates appearing in the model are evaluated at the following values: Age = 24.20.
* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 33: Descriptive Statistics – Stress index: during script imagining

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	1.23	.72	1.28	.81	20
Pre	Incongruent	Wake	1.09	.77	1.04	.84	19
Post 1	Incongruent	Sleep	1.12	.67	1.20	.82	20
Post 1	Incongruent	Wake	.09	.70	.00	.84	19
Post 2	Incongruent	Sleep	-1.15	.82	-1.22	.90	20
Post 2	Incongruent	Wake	-.34	.90	-.27	.92	19
Pre	Congruent	Sleep	-.57	.65	-.53	.71	20
Pre	Congruent	Wake	-.12	.54	-.16	.73	19
Post 1	Congruent	Sleep	-.34	.63	-.17	.69	20
Post 1	Congruent	Wake	.49	.51	.30	.71	19
Post 2	Congruent	Sleep	1.04	1.18	.38	.93	20
Post 2	Congruent	Wake	1.03	.90	1.71	.96	19

* Covariates appearing in the model are evaluated at the following values: Age = 24.25.
* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

Table G 34: Descriptive Statistics – HRV: during script imagining

Time	Odor	Group	Mean (E-N) (unadjusted)	Std. Error (E-N) (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	.55	9.66	-1.17	11.82	23
Pre	Incongruent	Wake	-15.60	10.62	-13.79	12.09	22
Post 1	Incongruent	Sleep	-12.91	13.04	-11.51	12.64	23
Post 1	Incongruent	Wake	1.18	8.35	-.26	12.93	22
Post 2	Incongruent	Sleep	5.75	6.32	6.16	7.67	23
Post 2	Incongruent	Wake	13.08	6.65	12.65	7.85	22
Pre	Congruent	Sleep	-2.07	7.23	-3.47	9.68	23
Pre	Congruent	Wake	-12.83	9.14	-11.37	9.91	22
Post 1	Congruent	Sleep	-.69	9.06	.02	9.70	23
Post 1	Congruent	Wake	7.45	6.69	6.70	9.92	22
Post 2	Congruent	Sleep	12.59	7.07	11.87	7.88	23
Post 2	Congruent	Wake	8.96	6.90	9.71	8.07	22

* Covariates appearing in the model are evaluated at the following values: Age = 24.06.
* (E - N): The difference between emotional and neutral values, where E represents emotional values and N represents neutral values.

HR analysis: during IRRT

Table G 35: Descriptive Statistics – Mean HR: Start

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	80.03	1.96	79.69	2.33	19
Pre	Incongruent	Wake	82.32	2.09	81.09	2.21	21
Post 1	Incongruent	Sleep	80.55	1.83	79.48	1.79	19
Post 1	Incongruent	Wake	81.57	1.60	79.33	1.70	21
Post 2	Incongruent	Sleep	84.06	2.33	81.62	2.03	19
Post 2	Incongruent	Wake	81.44	2.01	83.84	1.92	21
Pre	Congruent	Sleep	80.09	1.81	79.86	2.42	19
Pre	Congruent	Wake	80.73	1.91	82.48	2.30	21
Post 1	Congruent	Sleep	79.58	1.25	80.49	1.95	19
Post 1	Congruent	Wake	79.25	1.89	81.63	1.85	21
Post 2	Congruent	Sleep	82.74	1.75	83.73	2.12	19
Post 2	Congruent	Wake	82.83	2.15	81.74	2.01	21

* Covariates appearing in the model are evaluated at the following values: Age = 23.60.

Table G 36: Descriptive Statistics – Mean HR: Hotspot

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	78.48	2.01	78.72	1.81	21
Pre	Incongruent	Wake	79.62	1.90	79.05	2.01	17
Post 1	Incongruent	Sleep	77.87	1.67	76.31	1.59	21
Post 1	Incongruent	Wake	79.43	1.25	79.47	1.77	17
Post 2	Incongruent	Sleep	81.13	2.06	80.29	1.65	21
Post 2	Incongruent	Wake	80.13	1.92	81.92	1.84	17
Pre	Congruent	Sleep	78.63	1.83	78.64	2.11	21
Pre	Congruent	Wake	79.17	1.42	79.43	2.35	17
Post 1	Congruent	Sleep	76.43	1.52	78.09	1.47	21
Post 1	Congruent	Wake	79.32	1.54	79.16	1.64	17
Post 2	Congruent	Sleep	80.72	1.72	80.93	2.05	21
Post 2	Congruent	Wake	81.39	1.68	80.38	2.28	17

* Covariates appearing in the model are evaluated at the following values: Age = 23.34.

Table G 37: Descriptive Statistics – Mean HR: Closing image

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	76.70	1.92	77.38	1.81	18
Pre	Incongruent	Wake	76.74	1.31	76.35	2.06	14
Post 1	Incongruent	Sleep	76.72	1.74	74.97	1.49	18
Post 1	Incongruent	Wake	78.10	1.60	77.73	1.70	14
Post 2	Incongruent	Sleep	77.91	2.09	77.03	1.73	18
Post 2	Incongruent	Wake	77.69	1.78	80.18	1.97	14
Pre	Congruent	Sleep	77.55	1.87	76.54	1.84	18
Pre	Congruent	Wake	76.13	1.28	76.95	2.10	14
Post 1	Congruent	Sleep	74.99	1.30	76.47	1.72	18
Post 1	Congruent	Wake	77.71	1.59	78.42	1.95	14
Post 2	Congruent	Sleep	77.41	1.85	77.51	2.14	18
Post 2	Congruent	Wake	79.70	1.74	78.20	2.44	14

* Covariates appearing in the model are evaluated at the following values: Age = 23.25.

Table G 38: Descriptive Statistics – Stress index: Start

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	14.16	1.15	14.67	1.34	15
Pre	Incongruent	Wake	14.00	1.28	14.25	1.18	19
Post 1	Incongruent	Sleep	15.39	1.29	15.14	1.67	15
Post 1	Incongruent	Wake	14.22	1.22	13.33	1.48	19
Post 2	Incongruent	Sleep	16.36	1.65	14.19	1.62	15
Post 2	Incongruent	Wake	14.28	1.28	14.72	1.44	19
Pre	Congruent	Sleep	14.35	1.00	14.32	1.52	15
Pre	Congruent	Wake	14.50	1.07	13.87	1.34	19
Post 1	Congruent	Sleep	14.94	1.06	15.79	1.24	15
Post 1	Congruent	Wake	13.48	1.18	13.90	1.10	19
Post 2	Congruent	Sleep	14.20	1.24	16.72	1.75	15
Post 2	Congruent	Wake	14.71	1.64	14.00	1.55	19

* Covariates appearing in the model are evaluated at the following values: Age = 23.79.

Table G 39: Descriptive Statistics – Stress index: Hotspot

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	13.44	1.24	13.90	1.27	19
Pre	Incongruent	Wake	15.11	1.18	13.47	1.34	17
Post 1	Incongruent	Sleep	14.53	1.10	14.47	1.16	19
Post 1	Incongruent	Wake	13.39	0.70	12.42	1.23	17
Post 2	Incongruent	Sleep	14.36	0.98	14.96	1.14	19
Post 2	Incongruent	Wake	14.51	1.03	13.65	1.21	17
Pre	Congruent	Sleep	13.89	1.18	13.09	1.42	19
Pre	Congruent	Wake	13.47	0.88	15.51	1.51	17
Post 1	Congruent	Sleep	14.55	1.12	14.33	1.09	19
Post 1	Congruent	Wake	12.33	0.80	13.61	1.15	17
Post 2	Congruent	Sleep	15.28	1.21	14.25	1.22	19
Post 2	Congruent	Wake	13.29	0.92	14.62	1.29	17

* Covariates appearing in the model are evaluated at the following values: Age = 23.13**.**

Table G 40: Descriptive Statistics – Stress index: Closing image

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	14.32	0.85	14.15	1.44	16
Pre	Incongruent	Wake	14.73	0.94	13.65	1.49	15
Post 1	Incongruent	Sleep	15.26	1.36	14.62	1.12	16
Post 1	Incongruent	Wake	15.57	1.40	15.28	1.16	15
Post 2	Incongruent	Sleep	16.65	1.31	13.24	1.51	16
Post 2	Incongruent	Wake	16.11	1.34	18.18	1.56	15
Pre	Congruent	Sleep	13.95	1.21	14.23	1.16	16
Pre	Congruent	Wake	13.87	1.06	14.82	1.20	15
Post 1	Congruent	Sleep	14.52	0.86	14.84	1.73	16
Post 1	Congruent	Wake	15.39	1.00	16.02	1.78	15
Post 2	Congruent	Sleep	13.23	1.66	16.50	1.88	16
Post 2	Congruent	Wake	18.19	1.36	16.27	1.95	15

* Covariates appearing in the model are evaluated at the following values: Age = 23.12.

Table G 41: Descriptive Statistics – HRV: Start

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	760.81	18.19	763.24	22.83	19
Pre	Incongruent	Wake	732.14	18.68	742.23	21.15	22
Post 1	Incongruent	Sleep	754.28	17.27	760.82	17.29	19
Post 1	Incongruent	Wake	734.06	13.81	756.23	16.02	22
Post 2	Incongruent	Sleep	722.45	21.30	741.91	18.18	19
Post 2	Incongruent	Wake	735.12	17.90	720.54	16.84	22
Pre	Congruent	Sleep	757.93	18.07	763.23	22.63	19
Pre	Congruent	Wake	746.82	19.13	730.06	20.97	22
Post 1	Congruent	Sleep	758.64	12.35	755.56	18.54	19
Post 1	Congruent	Wake	758.11	18.55	732.95	17.17	22
Post 2	Congruent	Sleep	731.36	17.16	726.45	19.75	19
Post 2	Congruent	Wake	729.65	19.14	731.66	18.30	22

* Covariates appearing in the model are evaluated at the following values: Age = 23.53.

Table G 42: Descriptive Statistics – HRV: Hotspot

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	777.78	19.36	770.88	16.99	21
Pre	Incongruent	Wake	753.01	19.07	760.91	18.38	18
Post 1	Incongruent	Sleep	778.40	17.49	794.55	16.66	21
Post 1	Incongruent	Wake	749.18	14.29	757.37	18.02	18
Post 2	Incongruent	Sleep	749.68	19.16	755.15	15.43	21
Post 2	Incongruent	Wake	746.14	18.02	730.59	16.70	18
Pre	Congruent	Sleep	771.74	17.57	777.00	20.91	21
Pre	Congruent	Wake	759.90	14.55	753.91	22.62	18
Post 1	Congruent	Sleep	793.41	16.70	777.35	15.78	21
Post 1	Congruent	Wake	758.71	15.38	750.42	17.07	18
Post 2	Congruent	Sleep	751.34	16.95	752.03	19.21	21
Post 2	Congruent	Wake	735.04	15.73	743.40	20.79	18

* Covariates appearing in the model are evaluated at the following values: Age = 23.28.

Table G 43: Descriptive Statistics – HRV: Closing image

Time	Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	Sleep	792.14	19.56	783.81	17.29	18
Pre	Incongruent	Wake	773.58	15.24	789.42	18.97	15
Post 1	Incongruent	Sleep	789.23	19.45	805.24	15.55	18
Post 1	Incongruent	Wake	762.15	18.44	773.53	17.05	15
Post 2	Incongruent	Sleep	781.60	20.94	787.41	16.91	18
Post 2	Incongruent	Wake	769.67	17.61	744.61	18.55	15
Pre	Congruent	Sleep	782.43	18.50	794.25	19.57	18
Pre	Congruent	Wake	791.09	14.47	771.05	21.47	15
Post 1	Congruent	Sleep	804.92	14.60	792.10	18.99	18
Post 1	Congruent	Wake	773.93	17.11	758.71	20.83	15
Post 2	Congruent	Sleep	784.04	17.37	785.25	21.68	18
Post 2	Congruent	Wake	748.66	17.36	765.28	23.78	15

* Covariates appearing in the model are evaluated at the following values: Age = 23.18.

Analysis of the narratives

Table G 44: Descriptive Statistics – Analytic thinking

Time	Odor	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	12.71	3.41	12.71	3.76	22
Post 1	Incongruent	24.54	4.63	24.54	5.03	22
Post 2	Incongruent	18.42	3.95	18.42	4.39	22
Pre	Congruent	7.14	2.09	7.143	2.31	22
Post 1	Congruent	21.73	4.61	21.73	5.05	22
Post 2	Congruent	23.87	6.10	23.87	6.42	22

* Covariates appearing in the model are evaluated at the following values: Age = 23.36.

Table G 45: Descriptive Statistics – Positive Emotions

Time	Odor	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	2.70	.23	2.70	.21	22
Post 1	Incongruent	2.38	.22	2.38	.22	22
Post 2	Incongruent	2.29	.27	2.29	.29	22
Pre	Congruent	2.48	.19	2.48	.21	22
Post 1	Congruent	2.13	.20	2.13	.22	22
Post 2	Congruent	2.14	.24	2.14	.24	22

* Covariates appearing in the model are evaluated at the following values: Age = 23.36.

Table G 46: Descriptive Statistics – Negative Emotions

Time	Odor	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	1.79	.20	1.79	.21	22
Post 1	Incongruent	1.41	.19	1.41	.20	22
Post 2	Incongruent	1.60	.26	1.60	.28	22
Pre	Congruent	1.89	.18	1.89	.18	22
Post 1	Congruent	1.72	.20	1.72	.21	22
Post 2	Congruent	1.42	.18	1.42	.21	22

* Covariates appearing in the model are evaluated at the following values: Age = 23.36.

Table G 47: Descriptive Statistics – narrativity overall

Time	Odor	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Pre	Incongruent	61.62	5.15	61.62	5.91	21
Post 1	Incongruent	68.25	5.39	68.25	5.99	21
Post 2	Incongruent	60.60	7.16	60.60	8.48	21
Pre	Congruent	24.75	7.48	24.75	7.74	21
Post 1	Congruent	48.35	9.02	48.35	10.01	21
Post 2	Congruent	55.14	7.72	55.14	8.81	21

* Covariates appearing in the model are evaluated at the following values: Age = 23.57.

Table G 48: Descriptive Statistics – memory gaps

Time	Odor	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Post 1	Incongruent	.00	.00	.00	.00	21
Post 2	Incongruent	.02	.02	.02	.02	21
Post 1	Congruent	.09	.04	.09	.05	21
Post 2	Congruent	.04	.04	.04	.04	21

* Covariates appearing in the model are evaluated at the following values: Age = 23.52.

Table G 49: Descriptive Statistics – story alterations

Time	Odor	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Post 1	Incongruent	.38	.14	.38	.16	21
Post 2	Incongruent	.42	.16	.42	.18	21
Post 1	Congruent	.23	.12	.23	.13	21
Post 2	Congruent	.19	.12	.19	.13	21

* Covariates appearing in the model are evaluated at the following values: Age = 23.52.

Sleep Diary

Table G 50: Descriptive Statistics – difficulty falling asleep

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	2.70	.10	2.70	.14	27
Baseline	Wake	3.01	.14	3.01	.14	28
Congruent	Sleep	2.45	.12	2.44	.15	27
Congruent	Wake	2.90	.16	2.92	.15	28
Incongruent	Sleep	2.40	.11	2.37	.16	27
Incongruent	Wake	2.89	.20	2.92	.16	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.27.

Table G 51: Descriptive Statistics – difficulty staying asleep

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	2.31	.09	2.31	.09	24
Baseline	Wake	2.26	.08	2.26	.09	22
Congruent	Sleep	2.34	.08	2.35	.09	24
Congruent	Wake	2.36	.10	2.35	.09	22
Incongruent	Sleep	2.33	.09	2.33	.09	24
Incongruent	Wake	2.32	.08	2.32	.09	22

* Covariates appearing in the model are evaluated at the following values: Age = 24.28.

Table G 52: Descriptive Statistics – early awakening

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	1.52	.14	1.58	.12	27
Baseline	Wake	1.22	.10	1.16	.12	28
Congruent	Sleep	1.18	.08	1.21	.07	27
Congruent	Wake	1.16	.05	1.13	.07	28
Incongruent	Sleep	1.51	.12	1.51	.10	27
Incongruent	Wake	1.22	.07	1.21	.10	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.27.

Table G 53: Descriptive Statistics – general sleep characteristics

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	1.97	.07	1.98	.09	27
Baseline	Wake	2.11	.08	2.10	.09	27
Congruent	Sleep	1.98	.07	1.97	.09	27
Congruent	Wake	2.03	.09	2.04	.09	27
Incongruent	Sleep	2.03	.07	2.04	.08	27
Incongruent	Wake	2.05	.09	2.04	.08	27

* Covariates appearing in the model are evaluated at the following values: Age = 24.25.

Table G 54: Descriptive Statistics – general sleep duration

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	7.84	.13	7.80	.10	27
Baseline	Wake	8.02	.10	8.06	.10	28
Congruent	Sleep	7.91	.10	7.87	.11	27
Congruent	Wake	8.22	.11	8.26	.11	28
Incongruent	Sleep	7.84	.13	7.79	.13	27
Incongruent	Wake	8.19	.14	8.24	.13	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.27.

Table G 55: Descriptive Statistics – sleep quality

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	3.32	.06	3.31	.06	24
Baseline	Wake	3.40	.05	3.41	.07	22
Congruent	Sleep	3.46	.04	3.45	.05	24
Congruent	Wake	3.42	.04	3.43	.05	22
Incongruent	Sleep	3.48	.05	3.49	.05	24
Incongruent	Wake	3.39	.07	3.38	.06	22

* Covariates appearing in the model are evaluated at the following values: Age = 24.28.

Table G 56: Descriptive Statistics – feeling of being refreshed after sleep

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	2.48	.09	2.48	.09	27
Baseline	Wake	2.79	.08	2.80	.09	28
Congruent	Sleep	2.53	.11	2.53	.12	27
Congruent	Wake	2.56	.11	2.57	.12	28
Incongruent	Sleep	2.58	.08	2.58	.11	27
Incongruent	Wake	2.61	.13	2.62	.11	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.27.

Table G 57: Descriptive Statistics – mental balance before going to sleep

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	2.25	.07	2.25	.10	27
Baseline	Wake	2.41	.11	2.42	.10	28
Congruent	Sleep	2.19	.08	2.19	.11	27
Congruent	Wake	2.31	.11	2.31	.10	28
Incongruent	Sleep	2.22	.06	2.23	.11	27
Incongruent	Wake	2.34	.13	2.33	.10	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.27.

Table G 58: Descriptive Statistics – mental exhaustion before going to sleep

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	2.69	.04	2.71	.05	27
Baseline	Wake	2.63	.05	2.61	.05	28
Congruent	Sleep	2.66	.07	2.66	.07	27
Congruent	Wake	2.55	.05	2.55	.07	28
Incongruent	Sleep	2.66	.05	2.64	.06	27
Incongruent	Wake	2.58	.06	2.60	.05	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.27.

Table G 59: Descriptive Statistics – number of dreams

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	2.53	.26	2.58	.42	13
Baseline	Wake	2.57	.26	2.53	.41	14
Congruent	Sleep	2.38	.26	2.45	.40	13
Congruent	Wake	2.78	.32	2.72	.38	14
Incongruent	Sleep	2.38	.32	2.33	.42	13
Incongruent	Wake	2.21	.30	2.25	.40	14

* Covariates appearing in the model are evaluated at the following values: Age = 24.07.

Table G 60: Descriptive Statistics – emotional tone of the dreams

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	1.96	.09	1.95	.09	25
Baseline	Wake	2.37	.09	2.38	.09	22
Congruent	Sleep	1.84	.08	1.83	.09	25
Congruent	Wake	1.88	.10	1.89	.09	22
Incongruent	Sleep	2.05	.10	2.09	.11	25
Incongruent	Wake	2.10	.11	2.05	.11	22

* Covariates appearing in the model are evaluated at the following values: Age = 23.70.

Intrusion diary

Table G 61: Descriptive Statistics – number of intrusions

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	.35	.12	.30	.18	28
Baseline	Wake	.67	.20	.73	.18	28
Congruent	Sleep	.21	.09	.20	.08	28
Congruent	Wake	.14	.06	.14	.08	28
Incongruent	Sleep	.07	.07	.04	.09	28
Incongruent	Wake	.21	.10	.24	.09	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 62: Descriptive Statistics – distress of the intrusions

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	.71	.24	.64	.24	28
Baseline	Wake	.90	.22	.97	.24	28
Congruent	Sleep	.41	.18	.37	.18	28
Congruent	Wake	.32	.14	.35	.18	28
Incongruent	Sleep	.12	.12	.07	.15	28
Incongruent	Wake	.39	.18	.43	.15	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

Table G 63: Descriptive Statistics – vividness of the intrusions

Odor	Group	Mean (unadjusted)	Std. Error (unadjusted)	Mean (adjusted)	Std. Error (adjusted)	N
Baseline	Sleep	.80	.27	.73	.28	28
Baseline	Wake	.98	.25	1.04	.28	28
Congruent	Sleep	.53	.22	.51	.21	28
Congruent	Wake	.39	.17	.41	.21	28
Incongruent	Sleep	.07	.07	.03	.16	28
Incongruent	Wake	.42	.22	.46	.16	28

* Covariates appearing in the model are evaluated at the following values: Age = 24.19.

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Mojgan, May 2025

Mojgan Ehsanifard

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List of publications

Sayk, C., Probst, A., Lange, F., Eickemeier, S., Amores, J., Ngo-Dehning, H. V. V., **Ehsanifard, M.,** & Wilhelm-Groch, I. (2025). Reactivating a relaxation exercise during sleep to influence cortical hyperarousal in people with frequent nightmares–a randomized crossover trial. *bioRxiv, 2025-03.*

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