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DREAM RECALL FREQUENCY IS ASSOCIATED WITH ATTENTION RATHER THAN WITH WORKING MEMORY ABILITIES

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Abstract

Several factors influencing dream recall frequency (DRF) have been identified, but some remain poorly understood. One way to study DRF is to compare cognitive processes in low and high dream recallers (LR and HR). According to the arousal-retrieval model, long-term memory encoding of a dream requires wakefulness while its multisensory short-term memory is still alive. Previous studies showed contradictory results concerning short-term memory differences between LR and HR. It has also been found that extreme dream recall frequencies are associated with different electrophysiological traits related to attentional processes. However, to date, there is no evidence for attentional differences between LR and HR at the behavioural level. To further investigate attention and working memory in HR and LR, we used a newly-developed challenging paradigm, called MEMAT: it allows to study selective attention and working memory interaction, during memory encoding of non-verbal auditory stimuli. We manipulated the difficulties of the distractor to ignore and of the memory task. The performance of the two groups were not differentially impacted by working memory load. However, HR were slower and less accurate in presence of hard, rather than easy, to-ignore distractor, while LR were much less impacted by the distractor difficulty. Therefore, we show behavioural evidence towards less resistance to hard-to-ignore distractors in HR. Using a challenging task, we show for the first time attentional differences between HR and LR at the behavioural level. The impact of auditory attention and working memory on dream recall is discussed.

Keywords

Dreaming; Dream recall; Short-Term Memory; Non-verbal; Memory encoding; Attentional Filter; Audition

Introduction

The experimental research on dream reports since the end of 19th century improved significantly our understanding of dreaming (for reviews and state of the art see Nir & Tononi, 2010; Ruby, 2011; Scarpelli et al, 2021; Schredl, 2018). Yet the definition of dreaming is currently still debated (Montangero, 2018; Pagel et al., 2001; Ruby, 2020; Solms, 2000; Windt et al., 2016) and several questions remain unanswered (e.g., why and how interest in dreams leads to a rapid increase in DRF). Most researchers consider dreaming as a subjective experience that occurs during sleep and that can be recalled and reported during wakefulness (e.g., Guénolé & Nicolas, 2010; Ruby, 2020; Windt et al., 2016). Dream recall frequency (DRF) varies within subject across time but also between subjects. In average, in a representative sample of the population, DRF is around 1 dream recall per week, with a large dispersion (Schredl & Reinhard, 2008). Some only remember a few dreams a year, while others recall dreams every morning with many details (Nielsen, 2012; Vallat et al. 2018). In order to better understand the origin of the within and between-subject differences in DRF, several studies awakened dreamers in different contexts and times of the night and/or compared persons with a high dream recall frequency (HR) to persons with a low dream recall frequency (LR), using various tasks and questionnaires (for a review, see Schredl, 2018). State and trait factors were identified (Schredl & Montasser, 1996) and the results of these studies yielded several models of dream recall (see Table 1) such as the state-shift hypothesis (Koukkou & Lehmann, 1983), the life-style hypothesis (Schonbar, 1965), the interference hypothesis (Cohen & Wolfe, 1973), the salience hypothesis (Cohen & MacNeilage, 1974), and the arousal-retrieval model (Koulack & Goodenough, 1976). According to this last model, recently updated and complexified (Schredl, 2018; Vallat, 2017), the encoding of a dream into long-term memory requires wakefulness while its multisensory short-term memory is still alive.

Reference	Hypothesis name	Hypothesis description
Schonbar 1965	Life-style hypothesis	<i>Dream recall frequency would be a consequence of lifestyle, which includes personality and motivations. The “inner-acceptant” lifestyle (efficient access to one’s inner world, and a sense of control over one’s life) would be associated with a higher DRF than the “inner-rejectant” lifestyle.</i>
Cohen & Wolfe 1973	Interference hypothesis	<i>Distractions at awakening (thoughts, actions/movements, or stimuli) would increase the chances of dream recall failure.</i>
Cohen & MacNeilage 1974	Saliency hypothesis	<i>Dreams with a more salient content would be easier to remember.</i>
Koulack & Goodenough 1976	Arousal-retrieval model	<i>The transfer from short-term memory to long-term memory would require wakefulness. In other words, for dreams to be recalled, an awakening would have to happen when the dream is still encoded into short-term memory.</i>
Koukkou & Lehmann 1983	Functional state-shift hypothesis	<i>Dream recall would be more likely if a dream happens during a functional state similar to wakefulness</i>

Table 1. Hypotheses explaining dream recall success/failure. These hypotheses are not incompatible between each other; for example, Koulack & Goodenough (1976) agreed with the interference hypothesis.

This hypothesis fits with results showing that 1) repeatedly waking up participants increases their DRF, 2) HR demonstrate more intra-sleep wakefulness than LR (Eichenlaub, Bertrand, et al., 2014; Koulack & Goodenough, 1976; Schredl et al., 2003; Vallat et al., 2017, 2020). Interestingly, an EEG study from our lab linked intra-sleep wakefulness to brain reactivity and more specifically to electrophysiological markers of attention orientation (Eichenlaub, Nicolas, et al., 2014). The P3a, an Event-Related Potential following novel stimuli (salient, rare, and randomly presented) and considered as a marker of involuntary attention orientation (Polich, 2007) was found larger in HR as compared to LR, during both wakefulness and sleep (Eichenlaub et al., 2014). It was also confirmed that the larger the brain response to sensory stimuli during sleep, the higher the probability that the stimulation leads to an awakening (Bastuji et al., 2008; Vallat et al., 2017). These results, obtained during passive listening, suggest that HR present a stronger attentional reactivity to salient and unexpected events. Such potential attentional differences between HR and LR could explain, at least partly, their difference in DRF. Increased bottom-up processes in HR could increase intra-sleep wakefulness which is known to facilitate dream recall.

To further investigate attentional abilities in LR and HR, these two groups were tested on a task specifically designed to assess bottom-up and top-down processes of attention: the Competitive Attention Task (CAT, Bidet-Caulet et al., 2015). During the CAT, participants are asked to detect as quickly and accurately as possible visually-cued monaural target sounds while in some trials an unexpected binaural task-irrelevant distracting sound pops up before the target sound. In this context, HR showed a larger Contingent Negative Variation (CNV) before the target and a greater P3a (also called early-P3) in response to distractors than LR, pointing towards enhanced recruitment of both top-down and bottom-up attention processes (Ruby et al., 2021). However, these electrophysiological differences between groups were not associated with significant differences in behavioral performance. These results suggest that HR might compensate the enhanced bottom-up responses to distracting sounds by increasing the recruitment of top-down processes. In this way, HR could preserve the balance between top-down and bottom-up attention, probably at a higher energy/cognitive cost (increased brain response amplitude). If this interpretation is correct, HR should present difficulties in maintaining the attentional balance in a more challenging context, where differences in attentional performance might thus arise between HR and LR. One way to test this hypothesis is to use a highly demanding task, which may prevent HR from compensating and result in larger behavioural differences between LR and HR.

In the arousal-retrieval model, short-term memory plays a central role in dream recall (i.e., the model states that if an awakening arises when a dream is in short-term memory, and if the awakening process does not erase short-term memory content, then, and only then, the dream memory can be transferred into long-term memory before its content vanishes). According to this model, one could consider the possibility that better short-term and/or long-term memory abilities could contribute to inter-individual dream recall differences. It is the reason why several studies investigated long and short-term memory in HR and LR during wakefulness (Belicki et al., 1978; Blagrove & Akehurst, 2000; Bloxham, 2018; Butler & Watson, 1985; Cohen, 1971; Cory et al., 1975; Eichenlaub, Nicolas, et al., 2014; Martinetti, 1983, 1985; Nakagawa et al., 2016; Schredl et al., 1995, 1997, 2009; Solms, 1997; Waterman, 1991). Results from studies focusing on long-term memory exclude a clear and large difference between HR and LR (e.g., Blagrove and Pace-Schott, 2010; Ruby 2011; Eichenlaub, Nicolas, et al., 2014). Regarding short-term and working memory, some studies found better performance in HR but results lacked consistency and were thus inconclusive (see Table 2). In studies focusing on narrative memory (participants read or listen to a text and then

immediately recall its content or answer questions about it), whatever the sensory modality (visual or auditory), no correlation was observed between DRF and memory performance (Cohen 1971; Bloxham 2018; Blagrove & Akehurst 2000). For more traditional working/short-term memory tests such as the digit span, HR showed repeatedly significantly better performance than LR when numbers were presented orally (Butler & Watson 1985; Martinetti 1983, 1985), but not when numbers were presented visually (corr. between DS & DRF, $r=0.02$, Nakagawa et al. 2016). Note that for a visuo-spatial version of the digit span, a significant correlation between performance and DRF was observed but with a very low correlation coefficient (Nakagawa et al. 2016). Investigations of visuo-spatial short-term memory (complex pictures or route recall) resulted in significantly better performance in HR than in LR in some studies (Solms 1997; Schredl et al. 1995) but this finding was not replicated in other studies (Schredl et al. 1997; Schredl 2009). Regarding visual short-term memory (immediate recall of presented numbers, items, text, pictures, or a short movie), most studies revealed no significant differences in performance between HR and LR (Cohen 1971; Cory et al. 1975; Belicki et al. 1978; Waterman 1991; Schredl et al. 1995, 1997; Solms 1997; Schredl 2009; Bloxham 2018; Nakagawa et al. 2016), except for 4 of them (Cory et al. 1975; Schredl 1995; Solms 1997; Nakagawa et al. 2016). Regarding auditory short-term memory, in studies with verbal stimuli, HR proved better than LR at the digit span except for patients (Butler & Watson 1985; Martinetti 1983, 1985; Solms 1997), but not at story recall (Cohen 1971; Blagrove & Akehurst 2000). Note that in nearly all the studies presented here, authors expected/hypothesized that HR would show better memory performance than LR. Remarkably, most studies investigating the memory of HR and LR focused on the visual modality, even though the auditory experience is as intense and frequent as the visual experience in dreams (e.g., Plailly et al., 2019). To our knowledge, no studies compared non-verbal auditory short-term/working memory in LR and HR so far.

Based on the literature reviewed above, participants with high vs. low DRF might be expected to differ more on their attentional abilities than on their short-term memory abilities. The hypothesized more fragile attentional balance between top-down and bottom-up processes in HR may be expected to fail in challenging tasks and lead to impaired performance under high cognitive demand and distraction. Here, we tested directly this hypothesis with a paradigm recently developed in our lab (Blain et al., 2021). This auditory task, called MEMAT (for MEMory and ATtention), has been designed to simultaneously assess short-term memory, attentional abilities, and their possible interactions. Participants have to encode and maintain in short-term memory a four-tone melody presented in one ear

while a distracting melody is presented in the other ear (2 levels of memory load and 2 levels of distractions are presented). Given the available results on working memory and DRF, we did not expect the groups to be differentially affected by the memory load in MEMAT. By contrast, we expected the group to differ in their ability to resist interference during the working memory task, i.e., we expected that HR would be more distracted/impaired than LR by the distracting sounds presented during the working memory task, especially when the distraction increases.

Reference	N	Type of short-term memory	Type of test	Results
Butler & Watson 1985	12	Auditory verbal	Digit Span	HR > LR (corr. DS & DRF, $r=0.69$)
Martinetti 1983	30	Auditory verbal	Digit Span	(13±3) HR > LR (9±2)
Martinetti 1985	70	Auditory verbal	Digit Span	(14±2) HR > LR (11±2)
Nakagawa et al. 2016	779	Visual verbal	Digit Span	=
		Visuo-spatial	Visuo-spatial Span	HR > LR (corr. DS & DRF, $r=0.07$)
Solms 1997*	361	Auditory verbal	Digit Span	=
		Visuo-spatial	Pictures recall	(14/36) HR > LR (11/36)
Cohen 1971	?	Auditory verbal	Story recall	=
	20	Visual	Pictures recall	=
Belicki et al. 1978	44	Visual	Pictures recall	=
		? verbal	Words recall	=
Cory et al. 1975	100	Visual implicit	Pictures recall	(12/50) HR > LR (10/50)
		Visual explicit	Pictures recall	(24/40) HR > LR (21/40)
Schredl et al. 1995	50	Visual	Pictures recall	=
		Visuo-spatial	Route recall	HR > LR (corr. test & DRF, $r=0.36$)
		Visual	Movie recall	=
Schredl et al. 1997	51	Visual	Pictures recall	=
		Visuo-spatial	Route recall	=
Schredl 2009	444	Visual	Pictures recall	=
		Visuo-spatial	Route recall	=
		Visual	Movie recall	=
Waterman 1991	93+80	Visual	Movie recall	=
Bloxham 2018	57	Visual verbal	Story recall	=
Blagrove & Akehurst 2000	93	Auditory verbal	Story recall	=

*Table 2. Review of the literature about short-term and working memory in high and low dream recallers (HR and LR respectively). HR > LR, HR showed significantly better performance than LR (each group scores are between brackets), or a significant correlation between DRF and memory score was observed. corr., stands for “correlation between”. DRF, dream recall frequency. DS, digit span. =, no significant link between DRF and memory performance was observed. * in this study the population tested is mainly patients with cerebral lesions.*

Methods

The experimental protocol is adapted from the first MEMAT study (Blain et al., 2021). The main difference is that the current data are based on a much larger number of trials. The present behavioural data were indeed collected during MEG recordings (which will be described in a separate paper), which required a larger number of trials than the original behavioural-only study.

Participants

Twenty-two non-musician participants (20 right-handed, 10 men and 12 women, aged 20-33 years) took part in the experiment. Participants were considered as non-musicians when they practiced less than 1 year of instrument or singing outside compulsory educative programs. Among them, 11 were low-frequency dream recallers (LR, less than 2 dreams recalled per month at awakening) and 11 high-frequency dream recallers (HR, more than 5 dreams recalled per week at awakening). These frequency ranges for LR and HR have been previously used in several related studies (Eichenlaub, Bertrand, et al., 2014; Eichenlaub, Nicolas, et al., 2014; Ruby et al., 2013; Vallat et al., 2017, 2020). The two groups were matched in terms of school education, age, laterality, and gender. Demographics are presented in Table 3.

All participants were free from neurological or psychiatric disorder and had normal hearing and normal vision. They gave their written informed consent to participate and received a small monetary compensation for their participation. Experimental procedures were approved by the appropriate local ethics committee.

Variable	LR		HR		Group comparison LR vs HR	
	mean	SD	mean	SD	BF ₁₀	error %
Sex	men: 6 women: 5		men: 5 women: 6		0.5	
Laterality	left-handed: 1 right-handed: 10		left-handed: 1 right-handed: 10		0.7	
Years of music education	0.4	0.5	0.1	0.3	0.8	4e-3
Years of school education	15.9	1.9	15.2	2.2	0.5	6e-3
Age	23.5	3.6	24.0	3.0	0.4	5e-3
Hours of sleep (per night)	7.5	1.1	8.0	0.7	0.6	9e-3
Dream recall frequency (per week)	0.12	0.2	5.8	0.9	1.8e+11	1.9e-15
PSQI	6.0	3.1	5.7	3.5	0.4	5e-3
STAI: state	31.9	10.3	34.2	9.8	0.4	5e-3
STAI: trait	35.7	9.9	42.3	10.3	0.9	4e-3
BFI: openness	3.7	0.6	3.8	0.8	0.4	5e-3
BFI: conscientiousness	3.8	0.7	3.4	0.7	0.6	8e-3
BFI: extraversion	3.4	0.8	3.2	0.7	0.5	5e-3
BFI: agreeableness	4.0	0.6	3.7	0.5	0.8	6e-3
BFI: neuroticism	2.2	0.8	2.9	0.7	1.7	1e-3
GAUT	24.6	12.7	28.1	11.1	0.4	5e-3

Table 3. Demographic and questionnaire information for the two groups of participants. Mean and standard deviation (SD) in each group. Comparisons between groups were carried out using Bayesian statistics (contingency table for gender and laterality, non-paired t-test otherwise), we report Bayesian Factors (BF₁₀) for each comparison. **LR**: Low Recaller, **HR**: High Recaller. **PSQI**: Pittsburgh Sleep Quality Index; it assesses sleep quality with scores ranging from 0 to 21 (lower scores denote better sleep quality). **STAI**: State-Trait Anxiety Inventory; scores range between 20 and 80. **BFI**: Big Five Inventory; scores range between 0 and 4. **GAUT**: Guilford Alternative Use Test; the fluency score reported here refers to the mean number of uses proposed for a given object.

Procedure

First, participants have to fill in neuropsychological and demographical tests and questionnaires. Then, they are installed in the MEG in a seated position, in a sound-attenuated, magnetically shielded recording room, at 50-cm distance from the screen. All stimuli are delivered using Presentation software (Neurobehavioural Systems, Albany, CA, USA). Sounds are delivered through air-conducting plastic ear tubes. They undergo a volume calibration so that the auditory stimuli are easy to hear (hearing threshold +60 dB). They then perform the main MEMAT task. They are instructed to answer as accurately as possible and to keep fixating the cross during the recordings. Prior to the actual task, they perform two

short training blocks (12 trials) for each memory load. Training melodies (S1, DIS, and S2) are specific to the training sessions. Finally, they perform the ten experimental blocks (48 trials each), 5 under each memory load (low or high). They are aware in advance of the difficulty of the memory task but not of the difficulty of the distractors, which is randomized within each block. The order of the blocks is randomized between participants. Trials last 9400 to 9800ms, leading to eight-minute-long blocks.

Neuropsychological tests and questionnaires

All neuropsychological tests and questionnaires were performed before the main task. Participants were asked to fill in the State Trait Inventory Anxiety questionnaire about their anxiety state and trait (STAI; Spielberger, 1983), the Big Five Inventory questionnaire for personality traits (BFI; John et al., 1991), and the Pittsburgh questionnaire for sleep quality (PSQI; Buysse et al., 1988). The STAI is an assessment of anxiety as a situation-specific emotional state (STAI state: feelings of apprehension, tension, nervousness and worry that the subject experiences at a specific time) and anxiety as a personality trait (STAI trait: feelings of apprehension, tension, nervousness and worry that the subject usually experiences). The BFI designates a descriptive model of personality in five central traits. They also had to perform a creativity test in which they had to invent possible alternative use for a chair, a teacup, or a pen in a free monologous way during 2 minutes for each object; it measures a level of divergent thinking, exploring multiple answers using creativity (Guilford Alternative Use Task, GAUT) (Bonk, 1967). Neuropsychological data are summarized in Table 3.

Stimuli

240 four-sound-long melodies were created thanks to combinations of eight-harmonic synthetic sounds from the C major scale, spanning four octaves between 65 and 1046Hz. The maximal interval between any two sounds of a melody is 7 semi-tones. Sounds are 250-ms long and the interval between sounds (offset to onset) is 250 milliseconds.

In each melody, there are no consecutive identical sounds. Every melody contains at least an ascending and a descending interval.

The MEMAT Paradigm

Attention manipulation

The melody of interest (S1) and the distracting melody (DIS) melodies are played one in each ear. The tones of the two melodies are interleaved, thus not played simultaneously. S1 is played in the ear indicated by an arrow on the screen, and DIS is played in the other ear, each

tone one after the other. The first sound to be played is the first tone of S1, and the last tone to be played is the last tone of DIS (See Figure 1-A.).

The DIS melodies can be rather easy (easy DIS) or hard (hard DIS) to filter (see Figure 1-B.). An easy DIS melody is composed of sounds in a frequency range 6 to 7 semi-tones higher (or lower) than the corresponding S1 melody frequency range. A hard DIS melody frequency range is the same than the corresponding S1 melody frequency range. DIS melodies are constructed with the same rules as for the S1 melodies, as described above.

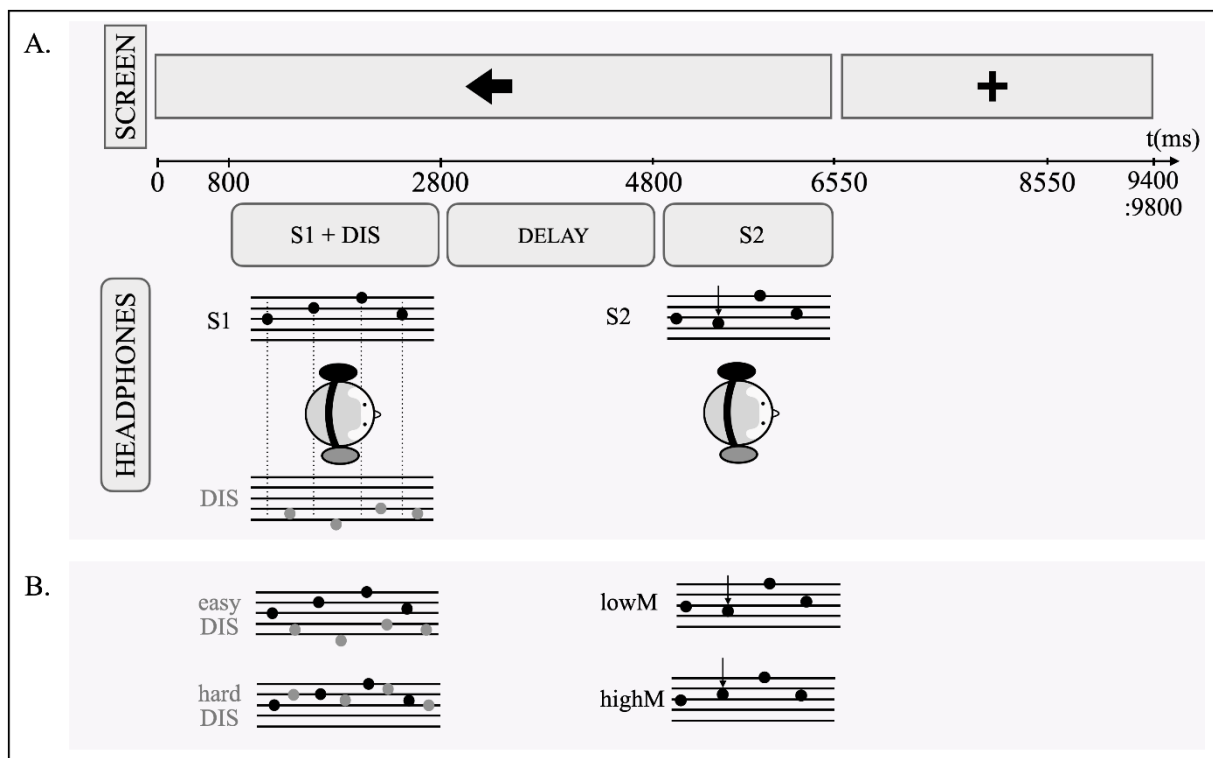


Figure 1 - Trial design. A. Trial timeline. The ear of interest is indicated at the beginning of each trial by an arrow on the screen. Participants have to encode the target melody presented in the ear of interest in memory (S1, black headphone), while filtering out an interleaved distracting melody presented in the other ear (DIS, grey headphone). After a silent retention delay, a second melody (S2) is presented in the ear of interest, and participants have to compare S1 and S2. **B. Examples of the different experimental conditions.** Distracting melodies can be either easy (easyDIS) or hard (hardDIS) to ignore, depending of their frequency proximity with the S1 melody. In trials where S2 differs from S1, the changed sound is 6 or 7 semi-tones different from the original one in the low difficulty memory task (lowM) vs. 1 or 2 semitones in the high difficulty memory task (highM).

Memory task

For each trial (see Figure 1-A.), the participant is informed of the ear of interest by an arrow (all visual contents are seven-centimeter-wide black elements displayed individually at the center of a white screen). 800ms after the arrow presentation onset, S1 and DIS are played in the ear of interest and in the other ear, respectively. After a 2000-ms pause, the melody (S2)

to compare to S1 is played in the ear of interest. At the end of S2 presentation, the indicative arrow is replaced by a central cross. The participant has then 2000 ms to answer to the question “Is S2 identical or different from S1?”. When S2 differs from S1, only one sound out of four differs, and it can be either the second, third, or fourth one, never the first one which would be too salient. The answer period starts at the end of the S2 melody. At the end of the 2-second-long answering period, there is a pause jittered from 850ms to 1250ms before the start of the next trial.

In the low memory load task (low-M), when S2 differs from S1, one sound is replaced by another which is 5 to 6 semi-tones apart (within the C-major scale, ascending or descending) and induces a change in the melody contour. In the high memory load task (high-M), when S2 differs from S1, the changed sound differs from the original one only by 1 or 2 semi-tones (within the C-major scale) and does not induce a change in the melody contour (see Figure 1-B.).

Balancing – within blocks

Each block contains 48 trials. All the combinations of ear of interest (Left or Right), distractor difficulty (easy DIS or hard DIS), and associated answer (same or different) are equiprobable within block (6 trials/block each). For each combination with an expected answer “different”, the direction of the change is equiprobably ascending or descending in frequency (3 trials/block each). This within-block balancing allows to control for side, expected answer, and change direction.

Balancing – between blocks

For a given S1 melody, the expected answer, the direction of the change in S2 when different, the level of DIS difficulty, and the side of presentation are balanced across blocks. A given melody is used twice in each block.

Block order is balanced between subjects (Latin square). For half of the participants in each group, melodies S1 and DIS are inverted and become respectively DIS and S1. Association between one S1 melody and another DIS melody changes across participants, enabling us to limit the impact in the results from any unfortunate easy or difficult match.

Analysis

All analysis were conducted using Bayesian statistics, which allow to test the similarity between measures and to estimate a degree of logical support or belief regarding specific results, as implemented in the JASP software (Marsman & Wagenmakers, 2017; Wagenmakers et al., 2018). We report Bayes Factor (BF_{10}) as a relative measure of evidence (compared to the null model). To interpret the strength of evidence against the null model, we considered a BF between 1 and 3 as weak evidence, a BF between 3 and 10 as positive evidence, a BF between 10 and 100 as strong evidence and a BF higher than 100 as a decisive evidence (Lee & Wagenmakers, 2014). Similarly, to interpret the strength of evidence in favour of the null model, we considered a BF between 0.33 and 1 as weak evidence, a BF between 0.01 and 0.33 as positive evidence, a BF between 0.001 and 0.01 as strong evidence and a BF lower than 0.001 as a decisive evidence.

Additionally, we report for each factor and interaction the $BF_{inclusion}$ that compares models that contain the effect to equivalent models stripped of the effect and was considered as a relative measure of evidence supporting the inclusion of a factor.

Trial rejection

Trials in which participants gave no answer, several answers, or did answer at an inappropriate moment (*i.e.*, outside of the indicated period) are excluded from analysis. Average number (\pm SD) of trials excluded per participant is 4 trials (\pm 4) (out of 480).

Measurements

Data were analysed using Signal Detection Theory measures. d' (d prime) is the difference between normalized “Hits” and normalized “False alarms”. Hits are the proportion of correct “different” answer over all “different” trials, and False alarms are the proportion of incorrect “different” answer over all “same” trials. Criterion (c) indicates the response bias. Positive values indicate the tendency of answering “same” and negative values reflect the tendency of answering “different”. Median Reaction Times (RTs) are computed out of correctly answered trials and correspond to the time between the end of the S2 and the button press.

Group comparison

We compared demographics and neuropsychological data between groups thanks to Bayesian unpaired t-test and contingency tables (for sex and laterality only).

We compared results (d' , RT, c) between groups thanks to Bayesian repeated-measure ANOVAs with MEMORYload (memory load, two levels: low, high), DISdiff (difficulty of the DIStractor, two levels: easyDIS, hardDIS) as within-participant factors, and GROUP (two levels: LR, HR) as a between-participant factor. Post-hoc comparisons for main effects or interactions were conducted using Bayesian t-tests.

As we planned to test the interaction between GROUP and DISdiff, we performed Bayesian paired t-tests between easyDIS and hardDIS conditions for each group, and Bayesian unpaired t-tests between LR and HR for each DISdiff level, for both d' and RT.

As we planned to test the interaction between GROUP and MEMORYload, we performed Bayesian paired t-tests between lowM and highM conditions for each group, and Bayesian independent t-tests between LR and HR for each MEMORYload level, for both d' and RT.

Results

Demographics and neuropsychological data

Bayesian t-tests confirm that the two groups were matched in school education, age, laterality, and gender ($0.4 < \text{BF}_{10} < 0.8$; see Table 3). Also, as expected, there is decisive evidence ($\text{BF}_{10} = 5.4e+7$) for a difference of dream recall frequency between groups. The evidence towards an absence or a presence of an effect of the GROUP for PSQI, STAI, BFI, and GAUT measures is weak ($0.4 < \text{BF}_{10} < 1.7$; see Table 3).

MEMAT Behavioural results

For d' (see Figure 2-A., Sup.Table 1), the best model explaining data in LR and HR is the model with the factors GROUP, MEMORYload, DISdiff, the interaction between MEMORYload and DISdiff, and the interaction between GROUP and DISdiff ($\text{BF}_{10} = 3.3e+23$). There is decisive evidence for an effect of MEMORYload ($\text{BF}_{\text{inclusion}} = 4.7e+20$) and DISdiff ($\text{BF}_{\text{inclusion}} = 4.2e+7$), positive evidence for an effect of GROUP ($\text{BF}_{\text{inclusion}} = 3.9$) and of the interaction between MEMORYload and DISdiff ($\text{BF}_{\text{inclusion}} = 6.4$), and weak evidence for an effect of the interaction between GROUP and DISdiff ($\text{BF}_{\text{inclusion}} = 1.6$) (see Sup.Table 2). d' are higher for LR compared to HR, for easy compared to hard distractors, and for low versus high memory load.

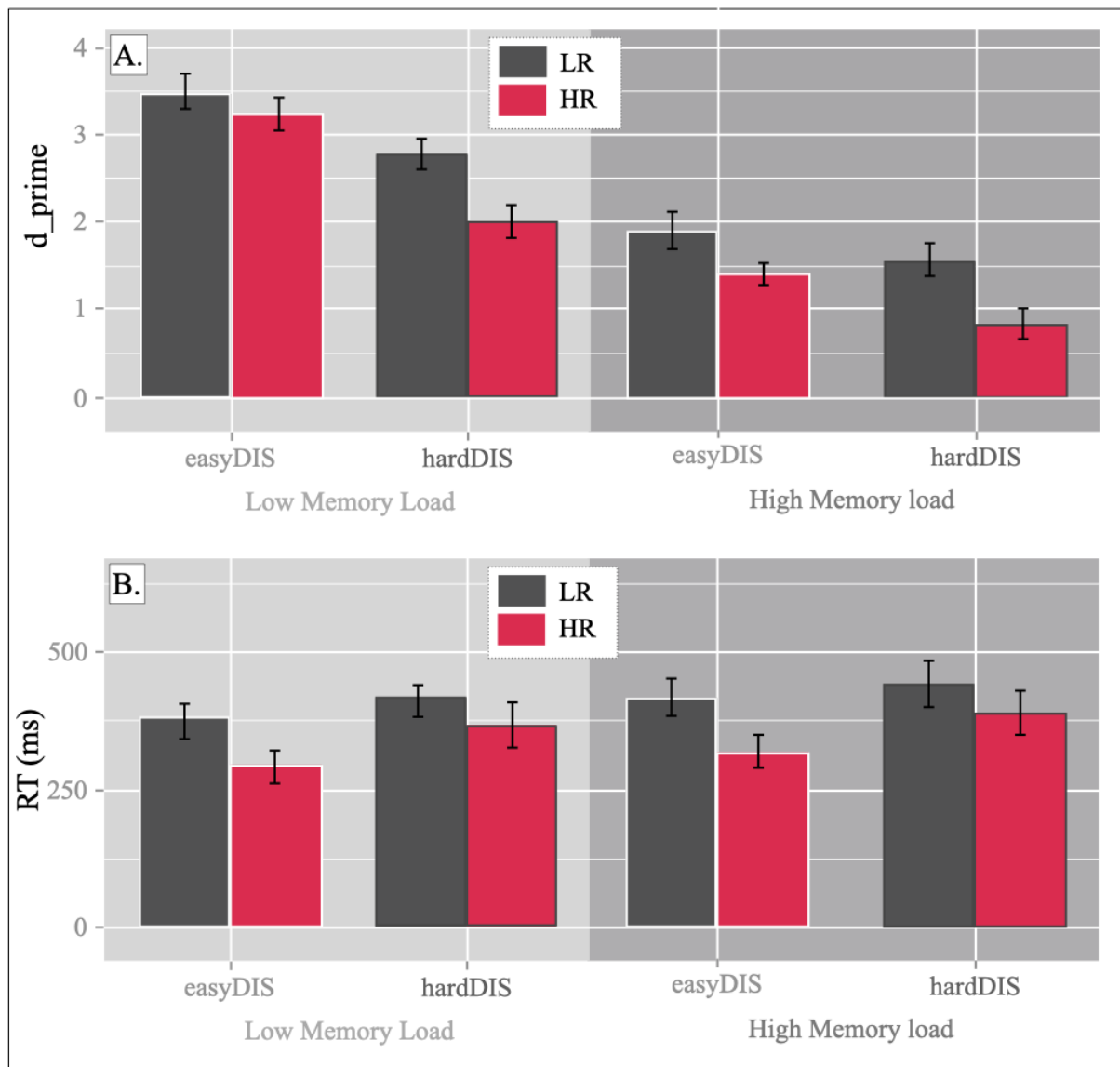


Figure 2 - Behavioural results of low and high dream recallers. Effects of the distractor difficulty and task load on d' -primes (A.) and RTs (B.) for each group separately. Error bars represent standard error of the mean.

These results are consistent with the results of a separate group of non-musicians tested with this same paradigm, yet with fewer trials (Blain et al., 2021): there is an effect of memory load and distractor difficulty upon d' , with better performance for low compared to high memory load, and better performance for easy- compared to hard-to-ignore distractors, and an effect of the interaction between memory load and distractor difficulty, with greater differences between easy- and hard-to-ignore distractors under low memory load than under high memory load. For more information about the interaction between DISdiff and MEMORYload, see Sup. Figures 1 and 2.

Concerning the planned investigation of the interaction between GROUP and DISdiff for d' , Bayesian t-tests reveal weak evidence for no difference between groups under easyDIS

($BF_{10}=0.8$) and positive evidence for a difference between groups under hardDIS ($BF_{10}=8.5$). They also reveal strong evidence for a difference between easyDIS and hardDIS in both groups (LR: $BF_{10}=18.3$; HR: $BF_{10}=91.2$). d' are higher in LR compared to HR, and this difference is higher under hardDIS than under easyDIS (see Figure 3-A.).

Concerning the planned investigation of the interaction between GROUP and MEMORYload for d' , t-tests reveal weak evidence for a difference between groups under lowM ($BF_{10}=1.8$) and weak-to-positive evidence for a difference between groups under highM ($BF_{10}=2.9$). They reveal decisive evidence for a difference between lowM and highM in both groups (LR: $BF_{10}=10\ 385$; HR: $BF_{10}=130\ 780$). There is only weak evidence, if any, of between-group differences regarding the impact of the memory load (see Figure 4-A.).

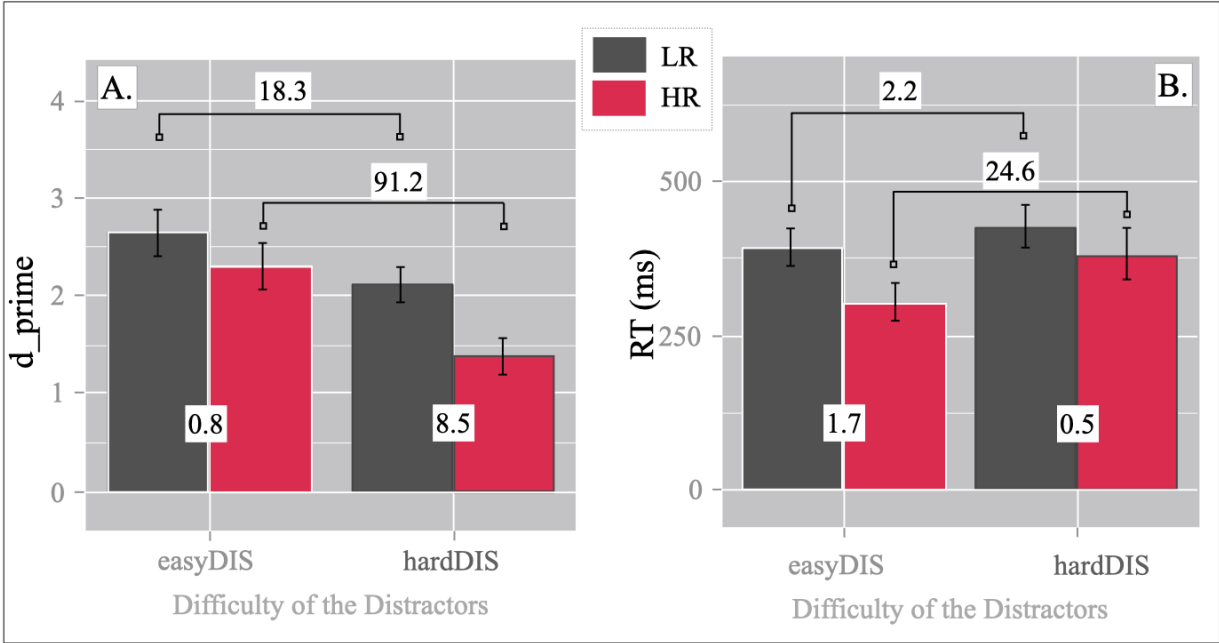


Figure 3 – Effects of GROUP and DISdiff on d -primes (A.) and RTs (B.) for lowM and highM pooled together. Numbers above the lines correspond to the BF_{10} resulting from paired Bayesian t -tests, while numbers on top of the bars correspond to the BF_{10} resulting from unpaired Bayesian t -tests.

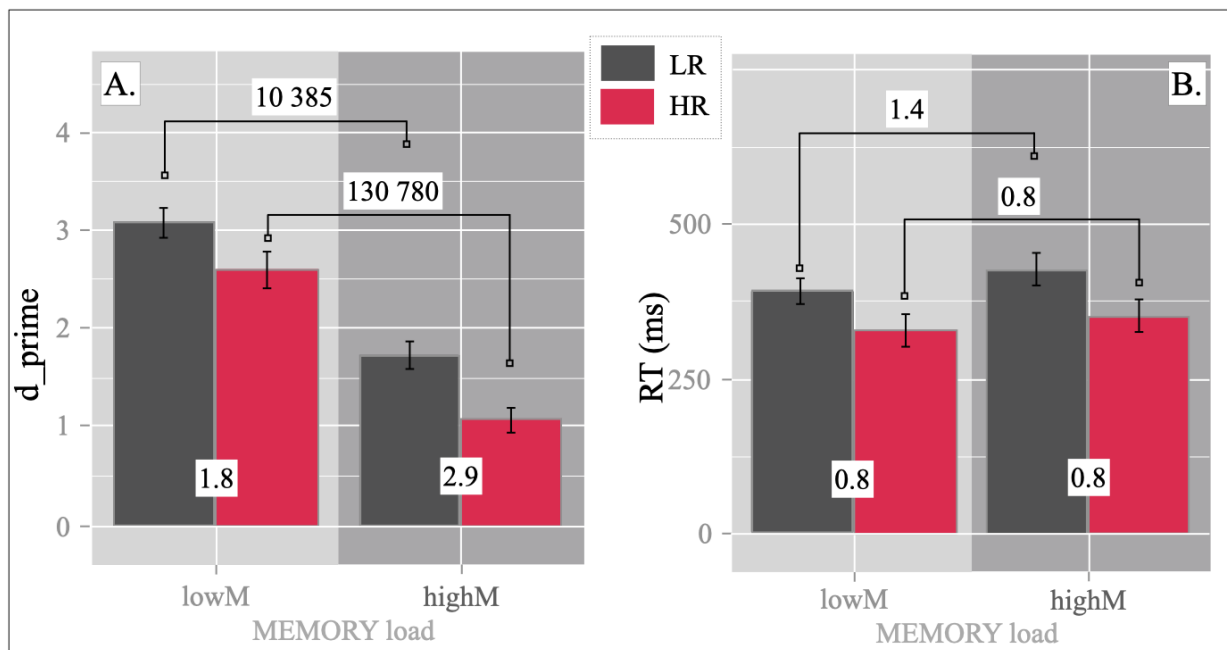


Figure 4 - Effects of GROUP and MEMORYload on d-primes (A.) and RTs (B.) for easyDIS and hardDIS pooled together. Numbers above the lines correspond to the BF_{10} resulting from paired Bayesian t-tests, while numbers on top of the bars correspond to the BF_{10} resulting from unpaired Bayesian t-tests.

For the RTs, the best model explaining the results is the one with MEMORYload, DISdiff, GROUP and the interaction between GROUP and DISdiff ($BF_{10}=110550.17$; see Figure 2-B. and Sup.Table 3). There is decisive evidence for a DISdiff effect ($BF_{inclusion}=13121.84$), positive evidence for a MEMORYload effect ($BF_{inclusion}=9.4$), and weak evidence for a GROUP ($BF_{inclusion}=0.91$) and for the interaction between GROUP and DISdiff ($BF_{inclusion}=2.7$) effects (see Sup.Table 4).

RTs are longer for hard DIS compared to easy DIS, they are longer for high- compared to low-memory load.

Concerning the planned investigation of the interaction between GROUP and DISdiff for RTs, t-tests reveal weak evidence for a difference between groups under easyDIS ($BF_{10}=1.7$) and weak evidence for no difference between groups under hardDIS ($BF_{10}=0.5$). They also reveal weak evidence for a difference between easyDIS and hardDIS in LR ($BF_{10}=2.2$) and strong evidence for a difference between easyDIS and hardDIS in HR ($BF_{10}=24.6$). RTs are higher under hardDIS than under easyDIS in HR but not in LR (see Figure 3-B.).

Concerning the planned investigation of the interaction between GROUP and MEMORYload for RTs, t-tests reveal weak evidence for no difference between groups under lowM ($BF_{10}=0.8$) and under highM ($BF_{10}=0.8$). They reveal weak evidence for no difference

between lowM and highM in both groups (LR: $BF_{10}=1.4$; HR: $BF_{10}=0.8$). There is no difference between groups, whatever the memory load, and no difference between memory loads, whatever the group (see Figure 4-A.).

For the criterion, in agreement with previous studies using delayed-matching-to-sample tests, there is weak to strong evidence for positive c values (see Sup.Table 5, especially in the difficult memory conditions, underlining that participants tended to miss differences between melodies.

The best model explaining criterion data (see Sup.Table 6) is composed of the factors MEMORYload, DISdiff, and the interaction between MEMORYload and DISdiff ($BF_{10}=2.2e+12$). These results are consistent with the results of a separate group tested with this same paradigm, yet with fewer trials (Blain et al., 2021). However, the second-best model is very close to this best model, with a BF_{10} equals to $1.0e+12$. This second model is composed of factors MEMORYload, DISdiff, GROUP, and the interaction between MEMORYload and DISdiff. There is decisive evidence for an effect of MEMORYload ($BF_{inclusion}=4.2e+10$) and DISdiff ($BF_{inclusion}=3221.5$). There is weak evidence for an effect of the interaction between MEMORYload and DISdiff ($BF_{inclusion}=2.5$) and weak evidence for no effect of the factor GROUP or of any interaction with the factor GROUP ($BF_{10}<0.7$, see Sup.Table 7).

Discussion

In the MEMAT task, low dream recallers (LR) are more accurate (d') and tend to be slower to answer than high dream recallers (HR). Furthermore, both accuracy and reaction times are more impacted by the difficulty of the attentional filtering in HR compared to LR. In particular, there is a greater d' difference between groups in trials with hard-to-ignore distracting melodies in comparison with trials with easy-to-ignore melodies. The impact of working memory load is similar in the two groups, for both d' and RT.

Attention and Working Memory in HR and LR

MEMAT is an auditory working memory task requiring an active attentional filtering of sounds. The difference of performance between groups can be due either to differences in short-term/working memory ability, or to differences in the capacity to filter out irrelevant and distracting elements. The difference of performance between LR and HR is not impacted by the memory load, and whatever the group, there is a similar difference between low and high memory load conditions. In other words, HR are not more impacted than LR by increasing the load in the short-term memory task.

The comparison between LR and HR performance under high memory load is close to lead to positive evidence towards a difference between the groups ($BF_{10}=2.9$, see Figure 4-A). However, this effect would go in favour of better auditory non-verbal short-term memory in LR than in HR, which is the opposite pattern of that observed in previous studies (Butler & Watson, 1985; Cory et al., 1975; Martinetti, 1983, 1985; Nakagawa et al., 2016; Schredl et al., 1995; Solms, 1997, see Table 1). Therefore, we cannot conclude towards a difference of auditory working memory between LR and HR.

In the MEMAT task, LR are less sensitive to the difficulty of the distractors than HR: HR performance is much more impacted by hard-to-ignore distractors than LR performance. Thanks to the MEMAT paradigm, and in particular because it is a challenging task, we show for the first time attentional differences between LR and HR at the behavioural level. Differences between LR and HR have been investigated for several cognitive processes (memory, verbal fluency, visual imagery, creativity, IQ, for reviews see Ruby 2011, Schredl 2018), but attention has been only scarcely explored so far. Contrary to the present results, a previous study using the Competitive Attention Task (Ruby et al., 2021) did not reveal any significant differences between groups at the behavioural level, while showing differences at the electrophysiological level. Namely, HR exhibited, compared to LR, (1) exacerbated bottom-up attention with a larger P3a to distractors, and (2) enhanced top-down facilitatory

attention processes, with a larger CNV and target-P3. In this previous study, the absence of behavioural effect could be explained by a compensatory strategy preserving the top-down/bottom-up balance: increased bottom-up processes would be compensated by enhanced top-down facilitatory attention processes. Such a compensation mechanism is, however, likely to fail when less cognitive resources are available to enhance top-down facilitatory attention (Bidet-Caulet et al. 2010). As a demanding task recruiting cognitive resources (Blain et al., 2021), MEMAT challenges this compensatory strategy and allows to reveal differences in behavioural performance between HR and LR. In other words, in the MEMAT task, a great amount of cognitive resources is devoted to the memory task, resulting in less cognitive resources available for the top-down attention mechanisms necessary to compensate for increased bottom-up processes in hard-to-ignore-distractor conditions.

We therefore here show a difference of cognitive trait between LR and HR, which is coherent with previously identified differences in neurophysiological trait between HR and LR (Ruby et al. 2013; Eichenlaub et al. 2014a,b; Vallat et al. 2017, 2020; Ruby et al. 2021). The analysis of the electrophysiological data collected together with the behavioural data reported here will help to specify on which attention-related components HR and LR differ in the MEMAT task. According to previous results, HR had both higher bottom-up processing and top-down control of attention (Eichenlaub et al., 2014; Ruby et al., 2021). In MEMAT, HR are more sensitive to hard-to-ignore distracting sounds. This could be either caused by 1) increased bottom-up processing (more resources are automatically devoted to process the surrounding environmental sounds), or 2) greater difficulties to inhibit the distracting sounds (insufficiently efficient top-down attention).

Under high memory load, cognitive resources are taken away from active inhibition of distractors (Blain et al., 2021). Following the second hypothesis above, one would expect that the lack of resources to inhibit the distracting sounds would lead to smaller difference between easy- and hard-to-ignore distractor in HR under high memory load compared to low memory load. Such an interaction between memory load and distractor filtering difficulty is observed in the data (Sup.Figure 2) but is not further modulated by the group factor (no triple interaction between group, DISdiff, and MEMORYload). The difference between LR and HR thus does not seem to be related to differences in the amount of available resources to inhibit distractors, but rather to increased bottom-up processing of irrelevant sounds in HR. This interpretation is in keeping with previous ERP findings of an increase in bottom-up processes in HR (Eichenlaub et al., 2014; Ruby et al., 2021).

Implication for the role of Short-Term Memory and Attention in Dream Recall

Short-Term memory

According to the arousal-retrieval model (Koulack & Goodenough, 1976), dreams can be recalled if still in short-term memory at awakening. This might lead to the hypothesis that higher short-term/working memory ability could be associated with higher DRF, especially for the main senses involved in dreaming, such as vision and audition (Plailly et al., 2019). Despite the difficulty of the MEMAT task, we found no differential impact of working memory load on performance in LR and HR, which adds to previous negative results in the auditory modality showing no short-term memory difference between HR and LR (Blagrove & Akehurst, 2000; Cohen, 1971; Solms, 1997; Table 1). There is also no conclusive evidence in the literature for an association between visual short-term memory ability and DRF. In other words, in the context of the existing literature, the results of this study suggest that short-term memory ability during wakefulness is not a determinant factor of dream recall frequency. Rather, the resistance of the short-term memory content to the sleep-wake transition could be a determinant parameter of DRF, and attention has many reasons to play a role in this ability.

Bottom-Up and Top-down Attention

Enhanced bottom-up processes have been observed in HR in the present study and in previous ones (Eichenlaub, Bertrand, et al., 2014; Ruby et al., 2021; Vallat et al., 2017). Being more reactive to the environment can favor dream recall by inducing abrupt awakenings which are more associated with dream recall than gradual awakenings (Shapiro et al., 1963), and by yielding longer awakenings during sleep, which are necessary for the storage of short-term memory into long-term memory according to the arousal-retrieval model (Koulack & Goodenough 1976). This hypothesis is supported by several results in HR (Eichenlaub, 2014; Vallat et al., 2017) and notably by those showing an increase of dream recall rate in LR when they are woken up several times during the night (Eichenlaub, Bertrand, et al., 2014; Goodenough et al., 1959; Vallat et al., 2020). However, increased bottom-up attention in HR may also have an adverse effect on dream recall by increasing distraction and interference effects at awakening. Indeed, according to the interference hypothesis, distraction at awakening promotes the vanishing of the dream content in short term memory (Cohen & Wolfe 1973).

Though using the MEMAT task, the present study could not show differences in top-down processes between HR and LR, increased electrophysiological markers of top-down attention

have been observed in HR during another task recruiting attentional processes (Ruby et al., 2021). This increased recruitment of top-down attention could result from a strategy to compensate exacerbated bottom-up processes and to preserve the bottom-up/top-down attentional balance in HR. A similar compensatory strategy could also trigger an enhanced recruitment of top-down attention processes during sleep and/or at awakening in HR, increasing the focus of attention on dream content and strengthening its maintenance in short-term memory. This hypothesis is coherent with recent results (Vallat et al., 2020) showing an increased connectivity in HR at awakening in a network comprising the dorsolateral prefrontal cortex known to be involved in top-down attention and consciousness (e.g., Dresler et al., 2012; Legrand & Ruby, 2009; Voss et al., 2014; Bidet-Caulet et al., 2015; Corbetta & Shulman, 2002; Petersen & Posner, 2012). Interestingly, this hypothesis could explain why increased interest in dreams result in enhanced DRF (Ruby et al. 2021), both in a state (temporary) or in a trait manner (Cory et al., 1975; Schredl, 2002, 2004; Schredl et al., 2003) since interest and motivation have been linked to increased top-down attention (Bourgeois et al., 2016; Robinson et al., 2012).

Limitations

The interpretation of the results could have been improved if we had added a short-term memory baseline condition without auditory distractors. With such a supplementary condition, we could have known if auditory short-term memory is significantly different between HR and LR in undisturbed conditions with the MEMAT paradigm. Unfortunately, the addition of such a condition made the experiment too long and was not feasible to simultaneously acquire MEG data of good quality.

To conclude, if LR and HR show performance in the normal range at the MEMAT task according to previous results (Blain et al. 2021), they appear to have different attentional traits: HR appear less resistant to irrelevant and hard-to-ignore sounds. This difference is most likely due to increased bottom-up attention and a more fragile balance between top-down and bottom-up processes in HR than LR (Ruby et al 2021). These traits may mostly promote dream recall but may also have adverse effects in case of external or internal distraction at awakening. Further studies will have to investigate more precisely the brain processes underlying these attentional differences. Importantly, these results open new avenues of research to understand better the links between dreaming, dream recall, and attention and how the modulation of one of these processes may causally modify the other ones.

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