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Systematic decrease of slow-wave sleep after a guided imagery designed to deepen sleep in low hypnotizable subjects

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Abstract

Slow-wave sleep is one of the most important restorative components of sleep and central for our health and cognitive functioning. Although the amount of slow-wave sleep depends on sleep drive, age and other factors, also the pre-sleep mental state might influence sleep depth. We had shown that a pre-sleep hypnotic suggestion to sleep more deeply increased slow-wave sleep duration in hypnotizable subjects. In contrast, low-hypnotizable participants decreased sleep depth after this intervention. A possible reason might be an aversion to and active resistance against hypnosis. To overcome this potential opposition, we introduced the procedure as 'guided imagery'. We replaced the hypnotic induction by a breathing relaxation. Importantly, the suggestion 'to sleep more deeply' remained identical. We expected that these changes would make it easier for low-hypnotizable subjects to benefit from the suggestion. In contrast, young healthy low-hypnotizable participants did not show positive effects. Similar to our previous studies, they exhibited a reduced slow-wave sleep duration after the intervention. Additionally, the ratio between slow-wave activity and beta band power decreased. Subjective sleep quality remained unaffected. Our results indicate that suggestions to sleep more deeply result in decreased sleep depth in low-hypnotizable participants regardless of the mental technique (guided imagery versus hypnosis). Thus, the aversion against hypnosis *per se* cannot explain the detrimental effect of the intervention on slow-wave sleep in low-hypnotizable subjects. The results support the notion that our mental state before sleep can influence subsequent slow-wave sleep. However, the mechanisms of the contradictory decrease in low-hypnotizable subjects remain unknown.

KEYWORDS

cognitive intervention, hypnotizability, imagery, slow-wave sleep

1 | INTRODUCTION

Sleep plays an essential role in physical and psychological health. An increasing amount of evidence shows its involvement in immune functions (Irwin, Olmstead, & Carroll, 2016), cardiometabolic health (Cappuccio & Miller, 2018), pain (Whibley et al., 2019) and metabolite clearance (Xie et al., 2013). Insufficient sleep reduces quality of life (Kyle, Morgan, & Espie, 2010), attention and information processing (Franzen, Siegle, & Buysse, 2008), and impairs memory and learning (see Rasch & Born, 2013). Moreover, disturbed sleep may worsen other psychiatric illnesses (Taylor, Lichstein, Durrence, Reidel, & Bush, 2005) and can even act as risk factor for their development (Neckelmann, Mykletun, & Dahl, 2007).

Besides other characteristics, slow-wave sleep (SWS) is one of the most important components contributing to the functions of sleep. It is associated with memory retention (Mander et al., 2013), pain perception (Weingarten et al., 2016), of for hypertension (Fung et al., 2011), type 2 diabetes (Tasali, Leproult, Ehrmann, & Van Cauter, 2008) and Alzheimer's disease (Ju et al., 2017). Insufficient SWS predicts symptom severity and cognitive impairments in chronic insomnia (Li et al., 2016). Reduced SWS mediates the detrimental effect of disruption of sleep continuity on positive mood reduction (Finan, Quartana, & Smith, 2015). Finally, due to its relation with sleep quality ratings and sleep continuity (Dijk, Groeger, Deacon, & Stanley, 2006), it is assumed to be 'the most restorative sleep stage' (Dijk, 2009). This broad health-related impact highlights the importance of finding means to promote or enhance SWS. As most hypnotics are not recommended for long-term use due to their adverse side effects and risk of addiction (Riemann et al., 2017), the understanding and development of non-pharmacological approaches to increase SWS is highly warranted.

In several previous studies (Cordi, Hirsiger, Mérillat, & Rasch, 2015; Cordi, Rossier, & Rasch, 2020; Cordi, Schlarb, & Rasch, 2014) we utilized a hypnotic suggestion to sleep more deeply. Hypnosis is defined as 'a state of consciousness involving focused attention and reduced peripheral awareness characterized by an enhanced capacity for response to suggestion' (Elkins, Barabasz, Council, & Spiegel, 2015). The intervention consisted of three parts: (a) an explicit explanation of the beneficial effects of hypnosis in general and on sleep in particular; (b) a 4-min hypnotic induction procedure to reach a hypnotic state; and (c) a 12-min suggestion to sleep more deeply, involving a story of a fish swimming deeper and deeper into the sea. Parts 2 and 3 are a standardized tape played via loudspeakers while the participants are lying in bed ready for sleep. This intervention increased SWS compared to a neutral control text during a nap and night-time sleep in healthy young and old participants (Cordi et al., 2014, 2015, 2020). However, only participants that were suggestible to hypnosis benefitted. In all studies, low-hypnotizable participants reduced SWS after the hypnotic suggestion to sleep more deeply.

Behaviour that actively opposes hypnotic suggestions has been reported from other domains such as auditory sensitivity, and motoric and amnestic suggestions (see Lynn, Stafford, & Kirsch, 1998). Additionally, negative attitudes towards hypnosis might suppress responsiveness (Barber & Calverley, 1964; Lynn et al., 1998; Yu, 2007). Framing the same test as a creative thinking test instead of hypnosis led to significantly higher scores in low-hypnotizable participants (Barber & Wilson, 1977). In a similar study, they invited subjects to participate in either a hypnosis experiment or a study about imagination (Spanos, Gabora, Jarrett, & Gwynn, 1989). Again, hypnotizability scores were significantly higher in the 'imagination' condition. Thus, framing an intervention as 'hypnotic' might be a crucial factor explaining opposing behaviour from low-hypnotizable participants.

To test this hypothesis, we framed the hypnotic suggestion to sleep more deeply as 'guided imagery'. In part 1 we explained the beneficial effects of guided imagery (instead of hypnosis). In part 2 we replaced the hypnotic induction procedure by a 4-min breathing relaxation. The suggestion to sleep more deeply (part 3) remained identical. The same neutral control text was used. We expected that reframing would decrease opposing behaviour of low-hypnotizable participants, possibly even allowing them to extend SWS compared to the control text. Hypnotizability of all participants was tested after the entire experimental procedure, in an unexpected additional session. As slow-wave activity during NREM sleep had been strongly influenced previously (Cordi et al., 2014) and the ratio between slow-wave activity and beta band frequency had been shown to vary in a music intervention in low hypnotizable subjects (Cordi, Ackermann, & Rasch, 2019), we also expected changes in these measures.

2 | METHODS

2.1 | Participants

Twenty-nine healthy young subjects (11 males) participated in the study. Three participants had to be excluded as they did not participate in the hypnotizability testing at the end. The final low-hypnotizable sample consisted of 21 subjects (six males). They were 21 to 33 ([mean ± *SD*] 22.52 ± 2.66) years old and their mother tongue was German. The other five subjects (four males) scored as highly hypnotizable (aged 21–25, mean 22.60 ± 1.52 years). We compared the effect on SWS in the current study to the effect of hypnotic suggestions from our previous study (Cordi et al., 2014). These data had been collected in 15 low-hypnotizable females (mean age 23.47 ± 3.0). The exclusion criteria in the current sample were acute health problems, neurological or psychological problems, regular intake of sleep medication, sleep disturbances, shift work or intercontinental flights with more than 4 hr time shift in the last 6 weeks, an operation within the last 3 months, and regular napping. On the experimental days, participants refrained from caffeine and alcohol and got up before 08:00 hours. Participation was voluntary and a compensation of 150 CHF was offered. The study was approved by the local Ethics Committee of the Department of Psychology at the University of Fribourg, Switzerland (Ref-No: 319).

2.2 | Procedure

Following a within-subjects design, subjects were invited to four sessions. The procedure was identical to our previous two hypnosis 'nap' studies (Cordi et al., 2014,2015), except that the term hypnosis was not mentioned in any way until the end of session three. The naps were taken in the first three sessions at around 14:00 hours (session 2, mean 14:14, standard deviation [*SD*] = 19 min; session

3, mean 14:05, *SD* = 17 min), respectively. The first session served as adaptation to the sleep laboratory setup and the environment to overcome first-night effects. Here, sleep recording time was limited to 60 min. In this session, we explicitly informed the subjects about the study intent, previous research and our expectations about the effect of the relaxing tape on sleep. The following two sessions were experimental sessions taking place on the same weekday, spaced 1 week apart. In those, subjects listened either to the guided imagery tape or a control text while lying in bed. They were allowed to fall asleep whenever they wanted. Those naps were allowed within a period of 90 min. Before and after the nap, questionnaires and cognitive tasks were performed (methods and results for all cognitive tasks, see Supplementary Information). Only after the third session, were subjects informed that the suggestion included in the guided imagery had been a part of the hypnotic tape we had used in a previous study. Subjects were free to decide to take part in the last session in which hypnotizability was assessed in a group setting. Thus, before the end of session three hypnosis as a technique was never mentioned. In case subjects signed up for further participation, they were invited to the group session.

2.3 | Materials

2.3.1 | Audio files

The guided imagery and the control text were recorded on mp3 and presented right before falling asleep via loudspeakers placed next to the beds. The imagery was spoken with a soft and calming voice, not including arousing words. It started with a 4-min self-written breathing relaxation based on mindfulness techniques to establish a relaxed state. The breathing relaxation was followed by a 12-min metaphor of a fish swimming in the sea, descending deeper and deeper, which suggested subjects should sleep deeply. This part was taken from the hypnosis study in Cordi et al. (2014), Cordi et al. (2015) and Cordi et al. (2020). Thus, the very same suggestion was used, but we excluded concrete hypnotherapy-based techniques as induction of a hypnotic state before the suggestion. Still, we aimed to create a relaxing state with the breathing exercise. The control text was the documentary about mineral deposits that we had also used in previous studies (Cordi et al., 2014,2015,2020). The content was taken from Wikipedia and was kept as neutral as possible regarding arousing or relaxing words. It was read with a normal, everyday voice and speed by the same speaker (Björn Rasch). It was supposed to control any unspecific effects of listening before falling asleep. Both tapes had a duration of around 16 min and were played at a comfortable volume.

2.3.2 | Questionnaires

Schlaffragebogen Version A (SF-A). The questionnaire measured the subjective sleep quality of the nap (Görtelmeyer, 2011). We focused on the subscale 'Allgemeine Schlafcharakterisierung' (ASC), for which subjects rated the previous sleep period using six adjectives. Originally, seven items were included in this scale, but we did not include one of them in the analysis of whether subjects slept abundantly. Additionally, we analysed the scale asking subjects to judge their well-being after the sleep period, which is rated on seven items. The mean of those was taken as the value for sleep quality. Higher values mean lower sleep quality.

Harvard Group Scale of Hypnotic Susceptibility (HGSHS) (Shor & Orne, 1962). This standardized questionnaire measures hypnotizability. During this test, a tape, recorded and translated to German by Walter Bongartz (Bongartz, 1985), is played in a group session. It includes an introduction on hypnosis and an induction leading into a hypnotic state. Thereafter, the listener is invited to follow several suggestions. Finally, the listeners self-rated how deeply (scale from 1 to 10) they felt they had been in a hypnotic state during each of these suggestions. Low hypnotizability was considered below a mean of 7. We tested 21 low-hypnotizable subjects (six males, mean score 4.52 ± 1.39, mean ± *SD*). The other five subjects scored as highly hypnotizable (four males, mean score 7.47 ± 1.49, mean ± *SD*). The mean score of the low-hypnotizable group from our previous study (Cordi et al., 2014) was 5.07 ± 0.3. The scores on the Harvard scale did not correlate with the Tellegen Absorption Scale ($p = 0.20$).

Tellegen Absorption Scale (TAS). This measure assesses the openness to absorbing experiences (Tellegen & Atkinson, 1974). On a five-point Likert-scale the questionnaire encompasses 34 items. The sum of all answers was calculated. Its mean is 80 ± 18 (Glisky, Tataryn, Tobias, Kihlstrom, & McConkey, 1991).

2.4 | Assessment of sleep data

Sleep was recorded polysomnographically with electromyographic (EMG), electrocardiographic (ECG) and electroencephalographic (EEG) electrodes. The EEG electrodes were placed in a 32-channel Easycap Net (Easycap GmbH). Impedances were kept below 10 kΩ. The sampling rate was set to 500 Hz. For sleep scoring, the data were re-referenced with Brain Vision Analyzer 2.1 (Brain Products) against the opposite mastoids of the respective electrodes and filtered according to the guidelines of the American Association of Sleep Medicine (AASM). Two scorers blind to condition independently scored 30-s segments of sleep according to the standard criteria (AASM) as the stages wake, N1, N2, N3 or rapid eye movement (REM) sleep, on derivations F4, C4, O2, EOG and EMG. In the case of disagreement, a third blind scorer was consulted. Sleep efficiency was defined as the sum of minutes of N1, N2, N3 and REM sleep divided by the minutes of total sleep, including sleep latency and minutes spent awake after sleep onset. Sleep latency was defined as time until the first N1 epoch, after which no other wake epoch was scored before the first N2 epoch appeared.

2.4.1 | EEG data analysis

Electroencephalographic data were preprocessed using Brain Vision Analyzer 2.1 (Brain Products). Data were filtered (low cut-off filter, 0.1 Hz; high cut-off filter, 50 Hz; Notch filter, 50 Hz). All epochs scored as N2 or N3 were extracted and again segmented into equally sized sections of 4,096 data points (~8 s). To compensate for a later applied Hamming window of 10% during the fast Fourier transformation (FFT), we allowed an overlap of 409 data points to the segments. A semi-automatic artifact correction first selected all segments with differences in EEG amplitudes higher than 600 muV. Afterwards, all segments were additionally manually checked for artifacts. On the clean data, an FFT was run with a periodic window and a resolution of 0.2 Hz. We extracted the areas (muV *Hz) from each frequency band (i.e., slow-wave activity [SWA], 0.5–4.5 Hz, theta 4.5–8 Hz, alpha 8–11 Hz, sigma 11–15 Hz, beta 15–30 Hz, SWA/beta ratio) and performed the statistical tests on those. One low-hypnotizable subject did not show NREM sleep in one session and is thus missing in the analysis of NREM frequency bands. For ECG analysis see Supplementary Information.

2.4.2 | Statistical analysis

Data were analysed using pairwise *t* tests with 'audio type' (guided imagery versus control text) as within-subjects factor. In the analyses of power bands, we used repeated measure analyses of variance with a 3 × 2 × 2 design (within-subjects factors topography [frontal, central, parietal], hemisphere [left, right] and audio type). For follow-up tests, paired samples *t* tests (to investigate sound effects) were used. In the comparison to the data of the previous study we used an ANOVA with 'audio type' as within-subjects factor (hypnotic suggestions or guided imagery, respectively, versus the control text) and experiment as between-subjects factor. The level of significance was set to $p = 0.05$.

3 | RESULTS

3.1 | Sleep parameters

Percentage of SWS was significantly affected by the type of audio in low-hypnotizable subjects ($t(20) = -3.53$, $p = 0.01$). In contrast to our hypothesis, %SWS was higher after listening to the control text (25.66 ± 4.91%) than after the guided imagery (12.01 ± 2.72%) (see Table 1). The same pattern occurred also for SWS minutes ($t(20) = -3.01$, $p = 0.007$, with 18.98 ± 3.38 min and 9.02 ± 2.15 min after the control text versus the guided imagery, respectively). When setting the amount of deep sleep after the control text to 100%, a decrease of 53.2% in low-hypnotizable subjects was detected after listening to the guided imagery. We compared the effect of guided imagery on percentage SWS with the effect of hypnotic suggestions in the low-hypnotizable sample of our previous nap study (Cordi et al., 2014). The ANOVA with experimental group as between-subjects factor and audio type as within-subjects factor showed a main effect of audio ($F(1, 34) = 13.77$, $p = 0.001$, $eta^2 = 0.29$) but no interaction with experimental group ($p = 0.53$). The same pattern was true for SWS minutes (main effect $F(1, 34) = 19.93$, $p > 0.001$, $eta^2 = 0.37$, interaction $p = 0.95$) (for both see Figure 1). Total sleep time (TST) in the recorded naps did not differ between those two groups ($p > 0.40$) nor depending on condition ($p > 0.10$) (TST: 68.98 ± 5.73 min after guided imagery, 69.88 ± 4.71 min after control text. Cordi et al. (2014): 70.00 ± 5.89 min after hypnosis and 79.53 ± 6.22 min after control text). For all other sleep stages see Cordi et al. (2014).

For all other sleep stages measured in the current sample, all effects and interactions were $p > 0.15$ (for N1, N2 and REM sleep). Sleep latency ($p > 0.60$), SWS latency ($p = 0.07$) and sleep efficiency ($p > 0.70$) were not affected by pre-sleep audio type.

TABLE 1 Results for the sleep stages per session in low-hypnotizable subjects

	Low-hypnotizable subjects (*n* = 21)		
Sleep stage	**Adaptation**	**Guided imagery**	**Control**
Wake, min	1.79 ± 0.78	8.88 ± 3.06	8.29 ± 2.75
N1, min	5.07 ± 0.81	9.62 ± 1.53	8.07 ± 0.98
N2, min	19.60 ± 2.58	34.41 ± 4.06	30.86 ± 4.04
SWS, min	10.10 ± 2.10	**9.02 ± 2.15**[a]	**18.98 ± 3.38**
REM, min	0.21 ± 0.21	7.02 ± 2.58	3.69 ± 1.09
Total, min	36.79 ± 4.21	68.98 ± 5.73	69.88 ± 4.71
SE	0.61 ± 0.06	0.69 ± 0.06	0.71 ± 0.06
Sleep latency, min	20.05 ± 3.62	15.86 ± 4.28	13.91 ± 3.13
Wake%	3.60 ± 1.40	11.53 ± 3.79	14.93 ± 5.43
N1%	18.74 ± 4.68	14.44 ± 2.06	12.90 ± 1.85
N2%	49.72 ± 4.98	48.59 ± 4.52	42.02 ± 4.37
SWS%	**22.79 ± 4.55**	**12.01 ± 2.72**[a,b]	**25.66 ± 4.91**
REM%	0.39 ± 0.39	8.67 ± 3.05	4.50 ± 1.32
Subj. SQ	2.67 ± 0.19	2.66 ± 0.23	2.79 ± 0.26
WB after nap	2.79 ± 0.12	2.73 ± 0.13	2.94 ± 0.14

Notes: [a]Significant difference ($p \le 0.05$) to the control condition in paired samples *t* tests, indicated in bold. [b]Significant difference ($p \le 0.05$) to the adaptation nap in the paired samples *t* test, indicated in bold.

Abbreviations: SE, sleep efficiency; Subj. SQ, subjective sleep quality; SWS, slow-wave sleep; WB, well-being after the nap.

3.2 | Analysis of covariates for the results in the sleep parameters

The subjective attitude towards the intervention might have influenced the results. Therefore, we split the low-hypnotizable

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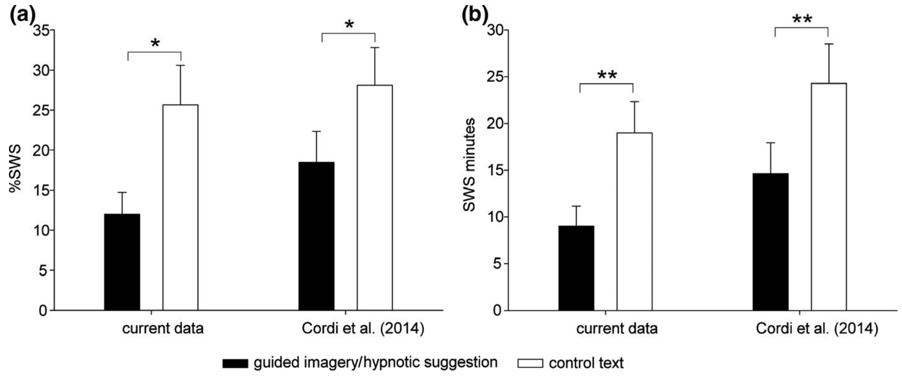

FIGURE 1 Effects of the intervention "to sleep more deeply" on slow-wave sleep (SWS) in percentage of total sleep period time (a) and minutes (b). Black bars indicate results of the intervention; white bars results after the control text. Guided imagery resulted in significantly reduced SWS percent and minutes as compared to the control text in low-hypnotizable participants (current data, left side of graphs (a) and (b)). The reductions in SWS were comparable to our previous results in low-hypnotizable subjects when framing the intervention as "hypnosis" including a hypnotic induction. Error bars display standard error of the mean. *$p \geq 0.01$, **$p \geq 0.001$

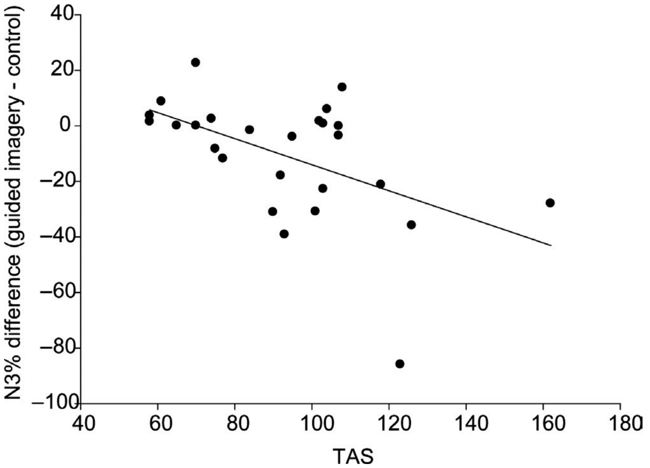

FIGURE 2 The linear correlation between the absorption value measured with the Tellegen Absorption Scale (TAS) and the difference in the percentage of slow-wave sleep between the guided imagery and the control condition

group according to their post-experimental vote on whether they think guided imagery is helpful for sleep problems or not ($n = 12$ rated it helpful, $n = 9$ were neutral or thought it does not help). Again, guided imagery decreased %SWS ($F(1, 19) = 7.02$, $p = 0.016$, eta$^2 = 0.27$), without any interaction with participant's attitude ($p > 0.40$). The same applied when splitting subjects into those who had a positive ($n = 13$) versus neutral or negative ($n = 8$) opinion about guided imagery (main effect of audio $F(1, 19) = 6.08$, $p = 0.023$, eta$^2 = 0.24$, other effects $p > 0.10$). So low-hypnotizable subjects' attitude towards guided imagery being helpful or positive did not have an influence on the effect of guided imagery on SWS. We additionally correlated the value of the absorption scale (TAS) with the difference between guided imagery and control nap in %SWS and found a significant negative correlation ($r(19) = -0.58$, $p = 0.006$) (see Figure 2). This was significant also after exclusion of the outlier with an SWS score > 3 *SD*.

3.3 | Comparisons to the adaptation nap

Our experimental design is lacking a neutral nap without listening to any audio material before falling asleep. We were only able to compare our results to amounts of SWS during the adaptation. These comparisons have to be interpreted with caution as first-night effects in the adaptation nap are expected. In addition, the adaptation nap was shorter in duration (60 min) as compared to experimental naps (90 min). Therefore, we focus on percentage of SWS only. Low-hypnotizable subjects spent on average 22.79 ± 4.55% in SWS in the adaptation nap. The main effect over all three nights (adaptation versus guided imagery versus control text) was significant ($F(2, 40) = 4.26$, $p = 0.021$, eta$^2 = 0.18$). Post hoc pairwise comparisons indicated that the amount of SWS after guided imagery was significantly lower (12.01 ± 2.72%) than in the adaptation nap (22.79 ± 4.55%, $t(20) = 2.21$, $p = 0.039$). Percentage of SWS after the control text (25.66 ± 4.91%) and in the adaptation session did not differ ($p = 0.58$).

Again, no difference was observed in N1 sleep, N2 sleep, SWS latency and sleep efficiency (all $p > 0.20$), whereas a main effect was detected in REM sleep ($F(2, 40) = 5.23$, $p = 0.010$, eta$^2 = 0.21$). The amount of REM sleep during adaptation was significantly lower (0.39 ± 0.39%) than after guided imagery (8.67 ± 3.05%, $t(20) = -2.68$, $p = 0.014$) and the control condition (4.50 ± 1.32%, $t(20) = -3.57$, $p = 0.002$). This result was still valid after correction of multiple testing (critical $p < 0.05/8 = 0.006$), but again note that adaptation sleep was shorter than experimental sleep.

3.4 | Subjective sleep quality

Subjectively, participants slept equally well after listening to the guided imagery as compared to the control text ($p > 0.50$) (see Table 1). Similarly, ratings of well-being did not differ after the two experimental naps ($p > 0.10$). Including the rating for the adaptation nap did not result in a main effect of text ($p = 0.73$ and $p = 0.08$ for rating of sleep quality and well-being after the nap, respectively).

3.5 | Power analyses during NREM sleep

The type of audio did not significantly influence SWA power during NREM sleep ($p > 0.08$). The effect of the interaction between topography and text on SWA power was significant ($F(2, 38) = 3.85$, $p = 0.03$, $eta^2 = 0.17$); all other interactions were $p > 0.10$. The follow-up *t* tests were all non-significant (all $p > 0.06$), but descriptively, SWA power was higher after the control text compared to the guided imagery. This difference was more pronounced in parietal and central than frontal electrodes.

The ratio between power in slow and fast frequency bands has been proposed to indicate 'objective' sleep quality during (NREM) sleep. In low-hypnotizable subjects we had found an effect of relaxing music for this parameter (Cordi et al., 2019). Therefore, we calculated the ratio between slow-wave activity (0.5–4.5 Hz) and beta activity (15–30 Hz) during NREM sleep in low-hypnotizable subjects. Consistent with the results from SWS, the ratio was significantly higher after the control text (73.23 ± 12.27%) than after the guided imagery (46.33 ± 6.71%, $F(1, 19) = 6.29$, $p = 0.021$, $eta^2 = 0.25$). The effect was less pronounced in frontal brain regions ($t(19) = -2.40$, $p = 0.027$) than in central ($t(19) = -2.48$, $p = 0.023$) and parietal electrodes ($t(19) = -2.59$, $p = 0.018$), which was expressed in a significant interaction between the audio file and topography ($F(2, 38) = 3.71$, $p = 0.034$, $eta^2 = 0.16$). In addition, we observed a significant three-way interaction between topography, hemisphere and text ($F(2, 38) = 4.46$, $p = 0.018$, $eta^2 = 0.19$). Although the parietal dominance of the effect was mainly observed in the right hemisphere, the effect was more pronounced frontally on the left (see Figure 3b) (for information on other frequency bands, see Supplementary Information).

3.6 | Power analyses during listening to the audio file

In post hoc analyses, we investigated possible differences in the power bands already during listening to the control versus the guided imagery audio file. Again, consider that the *p* value has to be adjusted with $0.05/5 = 0.01$.

In relative SWA power, the interaction between topography and text ($F(2, 40) = 3.48$, $p = 0.040$, $eta^2 = 0.15$) and between hemisphere and text were significant ($F(1, 20) = 5.50$, $p = 0.019$, $eta^2 = 0.25$). Other effects were $p \geq 0.40$. Following-up with *t* tests on the two-way interactions, none of the comparisons was significant anymore (all $p \geq 0.10$). Descriptively, power was higher after the control compared to the guided imagery condition. It was rather more pronounced in frontal than central and parietal electrodes (contrary to the dominance later in sleep). Also, it was stronger on the left than the right hemisphere.

In the SWA/beta ratio, both two-way interactions, topography * text ($F(2, 40) = 3.45$, $p = 0.042$, $eta^2 = 0.15$) and hemisphere * text, were significant ($F(1, 20) = 9.88$, $p = 0.005$, $eta^2 = 0.33$). Other effects were $p \geq 0.057$. The post hoc tests of the significant two-way interactions were all $p \geq 0.09$. Descriptively, the ratio was higher after the control compared to the guided imagery condition, like later in the sleep period. Contrary to later in the sleep period but similar to the effect on SWA power, this was rather pronounced in frontal electrodes and stronger in the left than the right hemisphere (see Figure 3a). SWA/beta ratio power during listening and NREM sleep did not correlate ($p > 0.30$), nor when analysing separately for the topographic regions (all $p > 0.20$) (for other frequencies see Supplementary Information).

4 | DISCUSSION

Due to the high importance of slow-wave sleep (SWS), we aimed to find a non-pharmacological way to increase the amount of this sleep stage. In our previous studies only highly hypnotizable subjects benefited from a hypnotic intervention by sleeping more deeply. Here we aimed to reduce reluctance in low-hypnotizable subjects by reframing the setting. We thus presented the evidence-based suggestion of deepening sleep in the frame of guided imagery instead of hypnosis. The results of our study show that guided imagery presented before a nap in healthy young adults decreases the amount of SWS in the following nap compared to a neutral control text. This was not different from the effect we found in low-hypnotizable subjects after hypnotic suggestions (Cordi et al., 2014). No other sleep

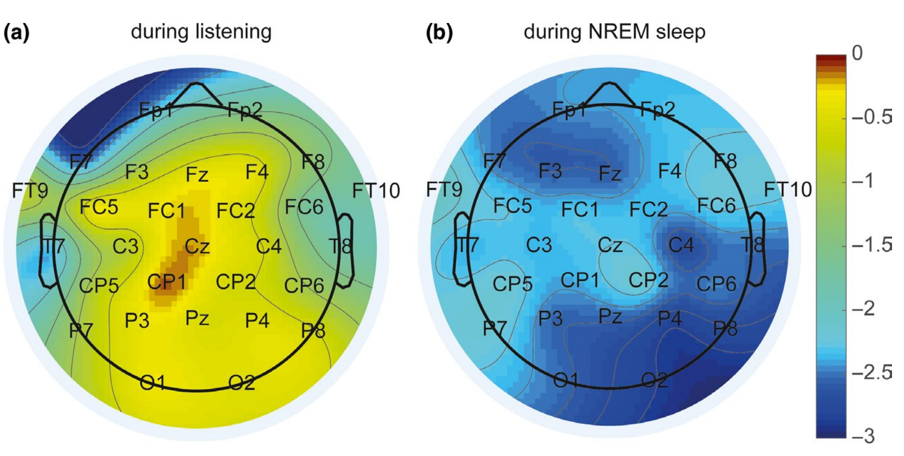

FIGURE 3 T-values of the difference between slow-wave activity (SWA)/beta ratio power during (a) listening to the guided imagery versus the control text, and (b) during non-rapid eye movement (NREM) sleep after guided imagery versus the control text

stage was affected. Subjective sleep quality was not increased, even though subjects were informed that we expect deeper sleep after guided imagery. This indicates a limited influence of expectation or task-demand characteristics. Thus, we cannot conclude that the framing or the hypnotic induction procedure are responsible for the decrement in SWS of low-hypnotizable subjects.

Unfortunately, we did not measure any nap without previous listening. We can thus not determine whether the control text increased or the guided imagery decreased SWS. When, however, comparing the adaptation nap with the two experimental naps, amounts of SWS are comparable in the adaptation and the control condition. Both naps contained more SWS than the nap after guided imagery. This rather favours the conclusion that guided imagery indeed reduced SWS. We also tested the ratio between high and low frequencies during NREM sleep as this was discussed as an indicator for restorative sleep (Krystal & Edinger, 2008; Maes et al., 2014). This SWA/beta ratio was lower after guided imagery than the control text during listening to the audio file and later during NREM sleep. Thus, the number of high frequencies increased while low frequencies decreased, favouring the interpretation of a lower sleep quality. This contradicts our expectations.

In our previous studies we repeatedly used the very same suggestion in the frame of hypnosis, including a hypnotic induction procedure instead of a breathing relaxation. In those studies, highly hypnotizable subjects consistently increased SWS, whereas low-hypnotizable subjects descriptively or significantly reduced SWS. Others reported this negative subject effect and assumed it is probably due to reluctance or scepticism regarding hypnosis (Barber & Calverley, 1964; Barber & Wilson, 1977; Lynn et al., 1998; Spanos et al., 1989; Yu, 2007). Our current results now show that discarding hypnotic aspects from the procedure still decreases the amount of SWS in low-hypnotizable subjects. Although this is clearly against our expectations and intentions, the results show that also low-hypnotizable subjects change their SWS depending on their pre-sleep mental state. We can only speculate about the aspects of our experimental texts that might be responsible for this reaction. One possibility is that the control text was spoken more fluently. The hypnotic suggestion and guided imagery included many long breaks. These interrupted texts might require vigilance and willingness to follow the story. In contrast, the high density of information in the control text might have offered the possibility to shift attention away and enable mind wandering. This might have facilitated relaxation. In a previous study we had demonstrated for low-hypnotizable subjects that a relaxing piece of music can induce SWS and SWA (Cordi et al., 2019). Also, listening to music does not require focused listening and might have triggered relaxed mind wandering, which supported deeper sleep. As we used exactly the same control text in the music study as here, we can even conclude that music might be even better adapted for induction of relaxation, as SWS, SWA and the SWA/beta ratio were higher after music than control conditions. Generally, it seems that what is commonly considered relaxing might not necessarily be calming for everybody. Some people might rather need a vacuous background in front of which they can disconnect from the external and allow a switch to the inside to experience relaxation. Others might benefit from external guidance for their soul searching.

Although none of the subjects gave this particular feedback, it could have been irritating to focus on the breath during the breathing relaxation and then imagine (during the suggestion) swimming below sea level. Without entering a trance-like state, this contradiction might result in a discomfort, probably eliciting physiological stress. However, we did not see an increase in heart rate after guided imagery, rendering an increase in pre-sleep physiological arousal rather unlikely as an explanatory factor.

With respect to the effects of hypnotic suggestions, a growing body of research (see Horing, Weimer, Muth, & Enck, 2014) attributes a central role to the influence of expectation, preconception of hypnosis, willingness to cooperate and ability to be absorbed. Orne (1959) demonstrated that trance behaviour was affected by the preconceptions that subjects had about hypnosis. Only if informed that induction goes along with arm catalepsy, were subjects prone to show this behavior. In our sample, attitudes towards guided imagery or whether it was considered helpful for sleep did not influence the effect on SWS. Apart from hypnotizability, we had no other *a priori* assumption regarding possibly relevant interpersonal differences. We, however, measured absorption, which had been related to hypnotizability (Lichtenberg, Bachner-Melman, Ebstein, & Crawford, 2004; Tellegen & Atkinson, 1974). Although it did not correlate with hypnotizability in our sample, we analysed its relation to the percentage of SWS after both conditions. Subjects familiar with the experience of being absorbed in thoughts, feelings or images were more likely to reduce SWS after the guided imagery than subjects who feel themselves to be more distant from these phenomena. If absorption was important for being able to follow suggestions, the correlation should have been positive. Hence, our data do not favour this explanation for our results.

In sum, presenting the hypnotic suggestion to sleep more deeply in a setting of guided imagery again reduced the amount of deep sleep for low-hypnotizable subjects. Hence, a particular reluctance towards hypnosis cannot explain why low-hypnotizable subjects reduced the amount of SWS after our intervention, which was highly effective for highly hypnotizable subjects. The underlying mechanism of this systematic reaction to our intervention is still unclear.

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CONFLICT OF INTEREST

The authors both declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

MC collected and analysed the data; both authors designed the study and wrote the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study (SPSS file and syntax) will be made available on Open Science Framework https://osf.io when the manuscript is published.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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