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Original Article

Pre-sleep social media use does not strongly disturb sleep: a sleep laboratory study in healthy young participants

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ABSTRACT

Objective: Sleep is critical for our mental health and optimal cognitive functioning. Social media use is increasingly common and suspected to disturb sleep due to increasing bedtime arousal. However, most studies rely on self-reported sleep.
Methods: We tested the effects of 30 min social media use on arousal and subsequent sleep in the sleep laboratory in 32 healthy young volunteers. Effects of blue-light were excluded in this study. We compared it to 30 min progressive muscle relaxation (PMR) and neutral sleep in a within-subject design.
Results: Thirty minutes of social media use immediately before sleep did not significantly increase arousal and did neither disturb objective nor subjective sleep. After social media use, participants only spent less time in sleep stage N2. In contrast, PMR had the expected positive effects on pre-sleep arousal level indicated by reduced heart rate. In addition, PMR improved sleep efficiency, reduced sleep onset latency, and shortened the time to reach slow-wave sleep compared to a neutral night. Oscillatory power in the slow-wave activity and spindle bands remained unaffected.
Conclusion: Social media use before sleep (controlling for effects of blue-light) had little effect on bedtime arousal and sleep quality than what was previously expected. The most notable effect appears to be the additional time spent engaging in social media use at bedtime, potentially keeping people from going to sleep. As wake up-time is mostly determined externally, due to school or working hours, limiting personal media use at bedtime—and especially in bed—is recommended to get sufficient hours of sleep.

1. Introduction

The last decades have brought a rapidly increasing spread and use of new (mobile) communication technologies [1–4]. Increasing portability and affordability can be seen as a gateway for devices, such as TVs, laptops, or mobile phones, to enter peoples' bedrooms. This increasing prevalence has led to an ongoing and recurring discussion about the adverse effects of using such technologies in the bedroom and especially immediately before sleeping. Studies have shown that the availability of electronic devices (such as a television, a gaming console, or a mobile phone) in the bedroom impairs subjective reports of sleep [5–7]. In children and adolescents the availability and use of electronic devices is associated with shorter total sleep time (TST) due to delayed bedtime [5]. In addition, adolescents with an increased use of laptops (for gaming, communicating, and surfing the internet) and mobile phones have been found to have poorer sleeping habits, thus leading to increased day-time tiredness compared to those with less use [8]. Similar effects are reported for adults [6]. Moreover, social media use – in particular on mobile phones – at bedtime impairs sleep, as indexed by later bedtime and sleep latencies, consequently decreasing daytime functioning [9]. Finally, social media use has been linked to a decrease in mental health and subjective sleep quality [10–12]. Despite the increased interest and efforts in research, studies to date almost exclusively rely on self-reports to assess the effects of social media use on sleep. Therefore, existing

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findings are based on subjective perceptions. There is a clear lack of data substantiating these effects from a sleep physiological perspective. This study aims to fill this gap by investigating the potentially harmful effects of media use immediately before sleep in a laboratory setting as indexed by physiological parameters (ie, objectively measured sleep architecture and sleep-related brain oscillations like slow-waves, which are associated with a high sleep quality [13–15]).

1.1. The physiology of social media use before bedtime

On a physiological level, studies demonstrate that the impairing effect of social media use at bedtime on subsequent sleep could be attributed to an increased arousal [16,17]. This assumption is supported by several correlational studies which find subjective arousal at bedtime to be a significant explanatory factor for the positive association between media use at bedtime and sleep impairments, as indexed by, eg, subjective reports of reduced sleep quality, interrupted sleep [17–19]. Insight from patients with insomnia also attribute a central role to increased arousal to explain sleep disturbances [20,21]. This line of research identifies cognitive factors such as rumination or worrying as contributing to increase psychophysiological arousal (eg, the activity of the sympathetic nervous system [SNS]), which consequently inhibits sleep-inducing processes and results in sleep delays and disturbances. Decreasing physiological and cognitive arousal using cognitive-behavioural interventions are effective treatments of insomnia disorders and are, thus, key elements in cognitive-behavioural therapy of insomnia [22,23]. As social media use – especially before bedtime – promotes cognitive and biological aspects of arousal [24–27], it seems logical to assume that degradations in sleep can be attributed and explained by this process.

Despite the face validity of this explanation and outlined above, there is a lack of experimental studies that aim to rigorously investigate the effects of social media use at bedtime on objective sleep parameters (ie arousal and sleep itself). This study aims to contribute to fill this existing gap. In light of the existing theorizations and empirical findings outlined above, we predict that social media use at bedtime will impair sleep quality as indexed by both subjective and objective parameters. The interference should be attributable to an increase in pre-sleep arousal induced by social media use. In contrast, preforming PMR before sleep should decrease pre-sleep arousal and improve sleep quality.

In addition to sleep parameters, we included a memory measurement [28] and a vigilance test [29] to capture behavioural consequences of impaired sleep: Consolidation of memory benefits from sleep [30,31] and Vigilance is a sensitive measure of low-quality sleep [32,33]. We therefore hypothesized that lower sleep quality induces by social media use leads to impaired memory consolidation and vigilance, while higher sleep quality should improve both behavioural measures.

2. Material and methods

2.1. Experimental design and conditions

To investigate these assumptions, we conducted a within-subject experimental study in a sleep laboratory. In these well-controlled conditions the effects of pre-sleep social media use can be investigated using both subjective and objective measures of sleep quality and sleep architecture. The within-subject design serves to insure high statistical power and enables the detection of medium effect sizes. In addition to an adaptation night, it included three experimental conditions which will be described below.

2.1.1. Neutral night (control)

In the “neutral” night participants were told to sleep as regularly as possible and went straight to bed without any intervention after completing questionnaires and preparatory procedures for sleep recording (see below). Thus, the “neutral” night serves as a baseline in the analyses.

2.1.2. Progressive muscle relaxation (PMR, relax)

In the “relax” condition participants performed an established intervention that aimed to reduce arousal (progressive muscle relaxation [PMR], [34,35]), instead of using social media. A 30-min instruction tape was used to ensure a comparison with the pre-sleep social media condition and to standardize the PMR. Participants followed a male voice guiding them through the PMR exercises by providing instructions [36]. We used the long form of 20 exercises. The instructions started with clenching the right hand into a fist and subsequent relaxation. Following this scheme and to reach deep relaxation, the major muscle groups of the body were tensed and relaxed throughout the PMR session. The experimenter checked the EMG several times to verify that participants performed the PMR. The tape was started 30 min before the lights were turned off. Participants were already lying in bed while performing this task.

2.1.3. Pre-sleep social media use

For the social media use condition, we chose to focus on social media use since it has been previously reported to have very severe effects on subsequent sleep [37–39]. To keep internal validity high, we limited the services to two social messaging providers, ie, WhatsApp (WhatsApp LLC., Mountain View) and Snapchat (Snap Inc., Santa Monica), based on their capacity to allow individuals to engage in direct communication instead of passive consumption [40,41]. Passive social media use (eg viewing posts, scrolling through news feeds) means to consume information on social media platforms without connecting to others or commenting [42]. WhatsApp was chosen as it is (or was at that time) the most popular social messaging provider. Snapchat was chosen because of its ability to allow active communication over passive consumption. In doing so, we limited the variety of other forms of usage, such as posting on other people's profiles, news consumption, etc. Introducing more ways of media use would have potentially introduced confounding factors that, given the complexity of studies in a sleep laboratory, we wouldn't have been able to account for in the subsequent analysis. Participants were instructed to use social media for 30 min. The use was restricted to the previously mentioned social media providers, which are both popular [43] and allow users to actively engage in conversations instead of passive consumption of ([audio-]visual) content [11]. WhatsApp is a social messaging service allowing users to send and receive text and voice messages (WhatsApp LLC, Mountain View). Snapchat is a social multimedia service allowing person-to-person photo and video sharing within a restricted timeframe (Snap Inc., Santa Monica). To ensure only those two social media apps were used, only the servers of WhatsApp (WhatsApp LLC., Mountain View) and Snapchat (Snap Inc., Santa Monica) could be reached through the wireless located area network (WLAN) available to participants.[1] Therefore, a so-called “whitelist” (the opposite of a blacklist, which contains all prohibited servers) was created, where access to all other connections was denied. This setting was active for 30 min before the experimenter collected the smartphone and locked it away.

[1] The WLAN was created using a modem (TP-LINK Archer C9 AC 1900 Wireless Dual Band Gigabit Router) with a separate router (D-Link 4G LTE Router N300) that connected to the internet via the mobile network on 4G basis.

2.2. Procedure

The within-subject design included one adaptation and three experimental nights in the sleep laboratory at the University of Fribourg. The adaptation night serves to get to know the complex setting in a sleep laboratory, to get used to sleep with electrodes, and to adapt to the situation of sleeping in a new environment. The procedure for all experimental conditions was identical until the instructions for the specific night were provided. Consequently, participants they were blind towards the condition until the very moment before sleeping (see Fig. 1). The order of the conditions was randomly assigned and balanced between the participants.

Upon arrival at the sleep laboratory, participants gave written informed consent before handing in their smartphone to the experimenter and answering the pre-sleep questionnaires. Afterwards electrodes for polysomnography (PSG including electroencephalogram [EEG], electromyogram [EMG], electrooculogram [EOG], electrocardiogram [ECG]) were attached by the experimenter. As a first task, participants were instructed to complete a memory task where they learned 80 semantically associated word pairs (paired associated learning [PAL] task [28]) before laying down in bed. Thereafter, they received the instructions for the night. In both the media condition and the relax condition, the last 30 min before sleep included the experimental manipulations described above. In the “media” condition, participants wore glasses which blocked blue light of 400–520 nm (Uvex Winter Holding GmbH & Co. KG, Fürth) to control for any effects of blue light [44]. They used their own smartphone to connect to a specially modified WLAN, modified to only allow them to use the services of WhatsApp (WhatsApp Inc., Menlo Park) and Snapchat (Snap Inc., Santa Monica), see above. No other server or service was reachable. Usage time was restricted to the last 30 min before sleep. The ambience light during this time was 62.3–68.9 lux (measured at the pillow). Before switching off the lights, the experimenter went back into the room and collected glasses and smartphone. In the “relax” condition, participants were instructed to not fall asleep while listening to the tape – approximately 30 min. Participants were lying in bed with the light on (light level at the source of light: 2000–3500 lux). Afterwards the experimenter went back into the room, turned off the speakers and the light. The participants were woken up 8 h after lights off. Immediately after getting up, participants filled in the post-sleep questionnaires (assessing subjective sleep quality and mood), and completed a psychomotor vigilance test (PVT), as well as the morning-recall of the PAL. The session ended with the removal of the PSG (see Fig. 1).

2.3. Participants

Thirty young and healthy students (21 women) with a mean age of 22.5 ± 3.0 [SD] completed the study. They were recruited through an advertisement and newsletter for students. Participants were regular users of social media (the recruitment process required them to be users of WhatsApp [WhatsApp Inc. Menlo Park], Snapchat [Snap Inc., Santa Monica], or both services). Participants were required to have a regular day–night rhythm, ie, not working night shifts and a regular sleep rhythm. Furthermore, they were screened for extreme chronotypes of morningness or eveningness. Based on the German translations of the Morningness–Eveningness Questionnaire (D-MEQ [45]) six participants were classified as moderate morningness-types and two were moderate eveningness-types, which were included in the dataset. None of the participants reported to suffer from any known sleep disorders. The overall reported subjective sleep quality (Pittsburgh Sleep Quality Index [PSQI, 46] was $M = 5.8 \pm 1.4$ [SD]; scale range: 3 (min) to 9 (max)). They were also instructed to abstain from alcoholic and caffeinated beverages within 48 h prior to participation. After completing the study, participants either received course credits or financial compensation of at least 200 CHF. In case of an early drop out compensation was provided proportionately. All procedures throughout the study followed the ethical recommendations of the Declaration of Helsinki. In addition, the study was approved by the local ethics committee of the University of Fribourg.

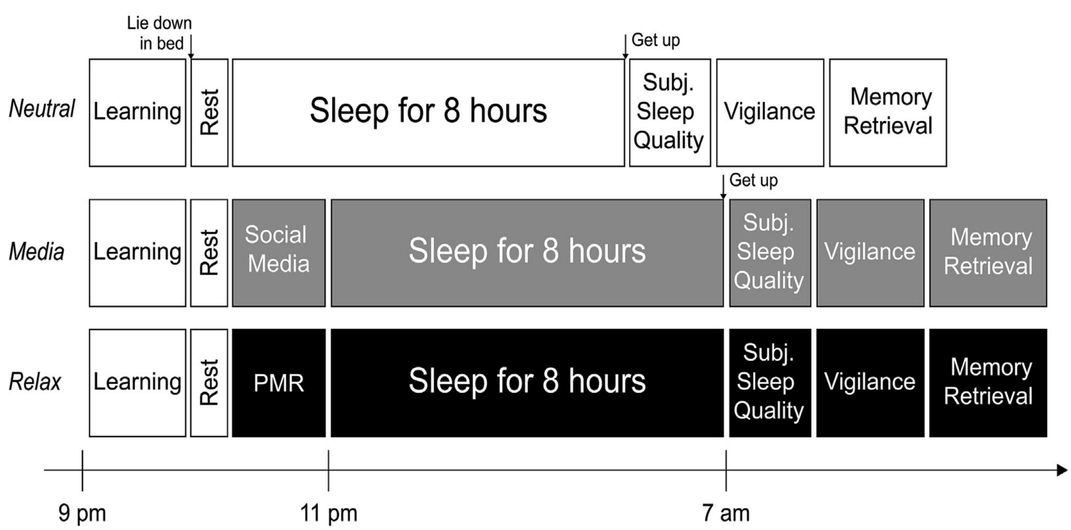

Fig. 1. Procedure and experimental design. Participants spent one adaptation night and three experimental nights in the sleep lab, all four nights separated by one week. Directly before going to sleep and when lying in bed participants received their condition. In “media” participants were instructed to use WhatsApp (WhatsApp Inc. Menlo Park) and Snapchat (Snap Inc., Santa Monica) for 30 min. In “relax” participants listened to a tape with instructions to a PMR (progressive muscle relaxation) training for 30 min. In “neutral”, participants went to bed directly after a 10–15 min rest and were allowed to sleep straight away. Sleep was recorded using PSG. Before the instructions for the conditions, participants filled out questionnaires, performed a word-pair learning (PAL) task [28] and while already lying in the bed they rested for 10–15 min to calibrate the PSG. In the morning after sleep participants filled out questionnaires, performed a psychomotor vigilance test (PVT) and retrieved word-pairs learned before sleep.

2.4. Measurements

2.4.1. Polysomnographic recordings

EEG, EMG, EOG and ECG were used to measure sleep as it is suggested by the American Association for Sleep Medicine [AASM; see 47 for more information]. EEG was recorded using 10 single gold-cap-electrodes following the 10-20-EEG-system with a sampling rate of 500 Hz. No participant complained about the electrodes neither for the nights nor for the pre-sleep examination. Physiological parameters were recorded using Brain Vision Recorder (Brain Products GmbH, Gilching). Impedances were kept below 5 kΩ. Following the AASM Manual for the Scoring of Sleep and Associated Events (short *AASM guidelines*, [47]), electrodes were referenced against Cz during recording and then re-referenced to the mastoids when conducting offline analyses. Data were preprocessed with Brain Vision Analyzer 2.0 (Brain Products GmbH, Gilching), filtering the data by 0.3–35 Hz following the guidelines suggested by the American Association of Sleep [47]. Two trained sleep scorers visually scored sleep independently (interrater variability of Cohen's $\kappa = 0.83$) in 30 s periods based on derivations F4, C4, O4, EOG (left and right), and EMG. Stages N1–N3, REM sleep, and WASO were scored following the AASM-guidelines [47]. The scorers were blind to conditions. Sleep efficiency (SE) figured as objective sleep quality. SE is based on polysomnographic recordings and is the calculated ratio of TST to TIB (time in bed from lights off to lights on).

2.4.2. Questionnaires

General information (T1, evening): A self-created questionnaire was used to qualitatively assess further information regarding participants general health, sleep and sleep habits, or experience in sleep laboratories.

Handedness (T1, evening): The German version of the Edinburgh Inventory for Handedness [48; 10 items with 3 response options (left, right, mixed)] was used as a measure for participants' dominant hand to provide further information about the distribution within the sample (93.1% right, 3.4% left, and 3.4% mixed handed).

General sleep quality (T1, evening): Pittsburgh Sleep Questionnaire Index [PSQI; 46; 19 items (each weighted on a 0–3 interval scale); core ranging from 0 to 21] was used to asses participants subjective sleep quality for the last month ($M = 5.8$, $SD = 1.4$; scale range: 3 (min) to 9 (max)), with lower scores denoting a healthier sleep quality.

Chronotype (T1, evening): The German version of the Morning–Evening-Questionnaire [D-MEQ; 45; 19 items, scale ranging 14 to 86] was used to exclude extreme chronotypes (<13 = clear night owls and >70 = clear early birds) in the sample. In our sample were 2 moderate evening-types ($M = 39$, $SD = 0$), 22 neutral-types ($M = 49$, $SD = 3.81$), and 6 moderate morning-types ($M = 61$, $SD = 1.67$).

Mood (T1–4, evening and morning): To assess state mood before sleep as well as in the morning, and to look for any effects of social media/sleep quality on mood, participants filled in the multidimensional mood questionnaire [MDBF; 49; 12 items, each weighted on a 1–5 interval scale]. The MDBF score is divided in three subscales (Good-Bad, Awake-Tired, and Calm-Nervous [= Subjective arousal]) with higher scores denote better mood/wakefulness/calmness.

General health and drug use (T2–4, evening): In every experimental session, participants filled in a (self-created, qualitative) questionnaire about actual health problems (eg participants having a cold or headache), control for alcohol, and caffeine, drug, or nicotine abuse during the study. Regarding the answers, participants with drug or alcohol abuse to exclude participants.

Subjective sleep quality (T1–4, morning): In the morning, participants were asked to rate their subjective sleep quality [SF-A-R; 50; 25 items; scale range 0–21; cut-off < 6]. Questions 2, 9, and 23 were used to analyze subjective SOL, WASO, and sleep depth.

Social media consumption and smartphone use (T2/3/4, morning): In the “social media” condition, participants filled in a created questionnaire [some items adapted to Ref. 51] to qualitatively asses their smartphone use and social media consumption. This provided further information about participants' smartphone habits, the apps they use the most, and the social media providers they follow.

Experience with relaxation techniques (T2/3/4, morning): In the “relax” condition, participants filled in a created questionnaire to qualitatively assess previous experience with relaxation techniques (eg PMR, meditation, hypnosis), which would be used as a control if participants regularly practice any relaxation technique (which was not the case in this sample).

About the experiment (T4, morning): A created post-experiment questionnaire was used to qualitatively assess further information regarding participants hypothesis of the experiment, satisfaction with the setting and the experimental situation in the sleep laboratory, open questions, or any remarks for the experiment.

2.4.3. Memory measurement

Episodic memory was assessed with a paired-associated learning (PAL) task [28]. To avoid a ceiling effect, we expanded the list from Rasch and colleagues to 80 semantically related word-pairs [52]. Each trial started with the presentation of all word-pairs, where each pair was presented for 3000 ms, followed by a 500 ms blank interval to separate two word-pairs. The words were presented in black font on a white screen via E-Prime (Psychology Software Tools, Pittsburgh). Each pair was presented only once while the order was kept constant across subjects. Immediately after learning, participants were confronted with a cued recall test. Here, they had to complete the word pairs by typing in the corresponding second word. During the recall test, the cue word was presented for an infinite amount of time, or until the participant pressed enter. The correct answer was then presented for 1000 ms followed by a 500 ms blank interval which, again, separated the single trials. A second cued recall test followed in which the participants did not receive feedback; right after filling in the answer, a 500 ms blank interval followed before the next cue word was displayed. During recall the order of the word pairs differed from the learning phase but was kept constant across subjects. A third recall test took place in the morning. Performance was measured as the percentage of words recalled in the morning relative to the number of words remembered in the second recall phase.

2.4.4. Psychomotor vigilance test (PVT)

In the morning, participants performed a psychomotor vigilance test (PVT) designed to measure the effect of sleepiness on vigilance [29]. Subjects were asked to press the space key with their non-dominant hand as soon as they recognized the millisecond counter on the screen, which appeared at random intervals. After the keypress, the reaction time in milliseconds was shown for 1 s. Performance was measured as reaction time (RT) in milliseconds (ms), numbers of reactions, and numbers of errors.

2.5. Analytical procedures

2.5.1. Analysis of the EEG data and power analysis

For the EEG, the mean power was calculated for different frequency bands. This power analysis provides additional information to the sleep stages and allows a more nuanced analysis of sleep. Therefore, we used the SleepTrip toolbox [53; github.com/Frederik-D-Weber/sleeptrip] for Matlab (Mathworks, Natick). SleepTrip is a branch of FieldTrip with added functions for sleep analysis to provide a Matlab-based analysis of different frequency bands relevant for sleep [for further information and validation see Ref. 53]. Data were preprocessed semi-automatically with Brain Vision Analyzer 2.0 (Brain Products GmbH, Gilching) before spectral analysis. We calculated the average power of oscillatory activity in different frequency bands: slow-wave activity (SWA) (0.5–4.5 Hz), slow spindles (11–13 Hz) and fast spindles (13–15 Hz). Data from lights off in the evening to lights on in the morning were analyzed, segmented for NREM sleep (N2 and N3 sleep) and REM sleep.

2.5.2. Analysis of sleep cycles

Sleep follows a cyclic pattern [54], which can be analyzed in a cycle analysis. This cycle analysis was performed following the criteria of Feinberg and Floyd [55]. These criteria define that a NREM period (NREMP) starts with N1 and has a minimum duration of 15 min. NREMP with a duration longer than 120 min excluding waketime can be split in two parts. These periods can include waketime but no epochs of REM sleep. An epoch of REM sleep (REMP) is defined to start after a NREMP of 5 min. One exception is the first REMP, as its duration can be less then 5 min. The first cycle includes the first NREMP and the first REMP. A new cycle starts with the first N3 episode following a phase of more than 12 min with any other stage other than N3 [56–58]. For each cycle, we calculated the amount of N1, N2, N3, REM, and WASO as well as the duration for each cycle. In addition, oscillatory power in the slow-wave and spindle bands across sleep cycles was used as a fine-grained measure.

2.5.3. Analysis of ECG

ECG (electrocardiogram) analysis was carried out using Kubios HRV Premium 3.2.0 (Kubios Oy, Kuopio). The ECG signal was segmented in resting-states (RS) of approximately two minutes [see eg, Ref. 59]. A first RS was taken while participants were in bed during the calibration of the polysomnographic recording, a second one was taken after the calibration. In the experimental conditions, a third resting state was taken 5 min before the condition ended. Additionally, we segmented an RS while participants fell asleep (the first 2 min after turning off the light) and for pre-sleep (lights off to the first stage of N1). We exported all segments in EDF+-format using BrainVisionAnalyzer Version 2.0 (Brain Products GmbH, Gilching) and analyzed them with Kubios HRV Premium (Kubios Oy, Kuopio). This software offers an automatic artifact correction based on RR series (the interval between two R-signals) to eliminate ectopic beats and artifacts in unfiltered data [60]. Afterwards, data were analyzed in a time and frequency domain and subsequently used for calculating the mean heart rate (mean HR measured in beats per minutes) which served as an index for physiological arousal [61]. As a second index of physiological arousal, Kubios provides an index to analyze the heart rate variability (HRV Triangular Index), which is based on the RR interval [60]. One participant was excluded from analysis due to insufficient ECG data quality throughout one of the nights.

2.5.4. Statistical analyses

According to the pre-sleep experimental manipulation (see section 2.1), the main outcome variables for the analyses were subjective and objective sleep quality, SOL, WASO, and sleep depth. For each of these main outcome variables, a repeated measures analysis of variance (ANOVA) with the within-subject factor condition ("neutral", "media", and "relax") and a contrast of no-pre-sleep manipulation ("neutral") vs. pre-sleep manipulation ("media" and "relax") was calculated.

In a separate analysis, we used a 2 × 3 ANOVA with the within-subject factors "type of parameter" (subjective vs. objective) and condition ("neutral", "media", and "relax") for the four main outcome variables. In addition, we reported Pearson's correlation coefficient (r) for the strength of association between these objective and subjective sleep parameters.

In exploratory analyses we examined further sleep parameters, vigilance, sleep-associated memory consolidation, and heart rate variability (HRV) by means of repeated measures ANOVAs with condition ("neutral", "media", "relax") as within-subject factor. For oscillatory power during NREM and REM sleep, a 3 × 2 × 3 repeated measurements ANOVA with factors "condition" ("neutral", "media", "relax), "hemisphere" (left, right) and "topography" (frontal, central, parietal) was conducted. A Pearson's correlation coefficient (r) was calculated to indicate the strength of association between sleep parameters and vigilance.

In case of a significant main or interaction effect, post-hoc paired t-tests with a Bonferroni correction were computed; level of significance $p \leq 0.05$, effect sizes (η^2) were only reported for significant data. Data analysis was carried out using IBM SPSS Statistics 25 (IBM Corp., Armonk) and R Studio (RStudio Team, Boston). Results are presented as means ± standard errors of the mean (SEM).

2.6. Data availability

Datasets analyzed during the current study are available online on https://osf.io/z9af2/.

3. Results

3.1. Subjective sleep parameters

Contrarily to our expectations, consuming social media before sleep did not affect subjective sleep quality (measured by the SFAR questionnaire [50]). Participants reported similar subjective sleep quality (on a scale from 7 up to 35, with higher value indicating better sleep quality) in the neutral (25.17 ± 0.54) compared to the "media" condition (24.88 ± 0.58, $p > 0.90$, for a post hoc pairwise comparison, see Fig. 2a). However, participants indicated better subjective sleep quality in the "relax" compared with the other two conditions (26.80 ± 0.44, both $p < 0.001$ for post hoc tests, main effect of condition: $F(2, 58) = 7.186$, $p = 0.002$, $\eta^2 = 0.199$). Reports of subjective sleep onset latency (SOL) did not differ in the neutral (16.50 ± 2.89 min) and "media" conditions (15.33 ± 2.35 min, $p > 0.90$, see Fig. 2b). Again, performing PMR improved SOL to only 5.0 ± 1.34 min compared to the other two conditions (both $p < 0.01$). The main effect of condition was significant; $F(2, 58) = 9.157$, $p < 0.001$, $\eta^2 = 0.240$. Results for subjective sleep depth showed the same pattern, with comparable ratings for neutral and "media" conditions, the deepest sleep ratings occurring in the "relax" sessions (Fig. 2c). Other subjective sleep parameters were not affected by the experimental manipulation (see Table 1).

Interestingly, participants also reported to feel more awake after sleep in the "relax" condition (3.28 ± 0.14), scale from 1 (not at all awake) to 5 (very much awake), as measured by the multidimensional mood questionnaire (MDBF) [49]. Ratings in the "neutral" (3.02 ± 0.15) and "media" conditions (3.03 ± 0.14) did not differ ($F(2, 58) = 3.28$, $p = 0.045$, $\eta^2 = 0.10$), see Fig. 2d. The remaining two subscales of the measure (good-bad and calm-nervous) did not differ, neither between conditions nor for time of measurement (all $p > 0.14$, see Table 1).

3.2. Objective sleep parameters

The results concerning objective sleep parameters confirm findings the findings reported above. Sleep efficiency was generally

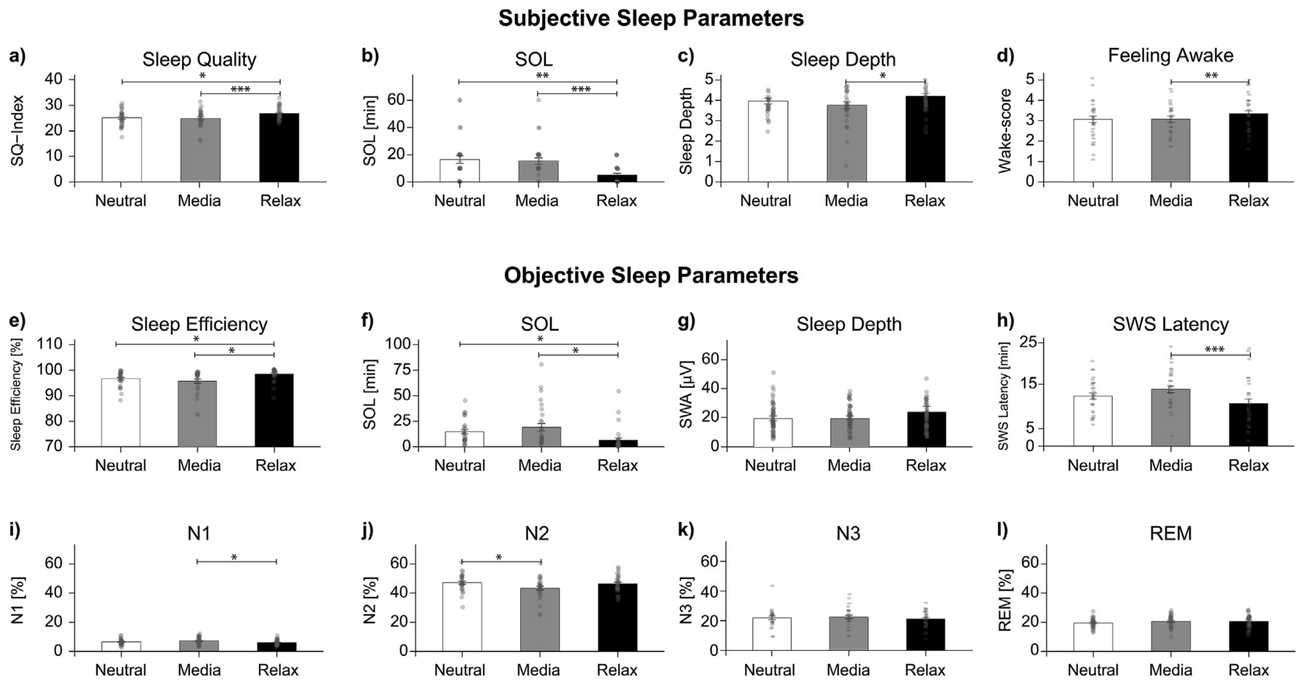

Fig. 2. Subjective and objective sleep parameters. On a subjective level, participants reported to sleep worse (sleep quality (a)) and less deep (c) after using social media (grey bar) compared to "relax" (black bar). For sleep onset latency (SOL (b)), participants showed significant differences between "media" and "relax" and between "relax" and "neutral". Participants felt significantly more rested in the morning after the "relax" condition compared to "media" (d). On an objective level, we showed an effect of sleep quality (sleep efficiency (e)) as after social media consumption the sleep efficiency was the lowest and differed significantly to "relax". Furthermore, sleep efficiency was the highest in "relax" and differed significantly to "neutral". Both results for SOL shown in the subjective parameters we confirmed in our data objectively (f). Sleep depth (slow wave activity (SWA) (g)) confirmed the subject results as well as there was no difference between the three conditions. Additionally the different sleep stages were analyzed (i–l). N1 (i) showed significant difference between the "media" and "relax" condition with less N1 (as percentage of total sleep time, TST) in "relax". N2 (j) showed a significant reduction of N2 after social media consumption compared to the "neutral" condition. N3 (k) and REM (l) showed any significant changes. Means ± standard errors of the mean are indicated. Significant pair-wise comparisons from post-hoc tests are indicated by *: $p \leq 0.05$. **: $p \leq 0.01$. ***: $p \leq 0.001$.

high and did not differ between "media" (95.71 ± 0.83%) and "neutral" (96.70 ± 0.52%, $p > 0.60$) conditions. However, sleep efficiency significantly improved in the "relax" condition (98.54 ± 0.45%, both $p > 0.016$, main effect condition $F(2,58) = 6.738$, $p = 0.002$, $\eta^2 = 0.189$, see Fig. 2e). Similarly, objective time to fall asleep (SOL) did not differ between "media" (19.23 ± 3.59 min) and neutral conditions (14.78 ± 2.11 min; $p > 0.40$), but was significantly shortened in the "relax" condition to only 6.50 ± 2.16 min (both $p < 0.03$, main effect condition: $F(2,58) = 7.095$, $p = 0.002$, $\eta^2 = 0.197$, see Fig. 2f). Sleep depth did not differ between conditions ($F(2, 58) = 0.61$, $p = 0.484$, see Fig. 2g).

The sole indications for an influence of media use before sleep can be found in individuals' sleep architecture. As total sleep time (TST) in minutes differed significantly between the conditions ($F(2,58) = 8.911$, $p < 0.001$, $\eta^2 = 0.235$), percentages of sleep stages were analyzed instead. Participants slept less after media consumption (457.72 ± 4.04 min, $p = 0.005$) compared to "relax" (474.62 ± 2.68 min, $p = 0.005$) and "neutral" (463.87 ± 2.53 min, $p = 0.199$) conditions, which both differed significantly as well ($p = 0.01$). The relative amount of N1 sleep in the "media" conditiotypical decrease in powerover the cyclesn (7.19 ± 0.47%) did not differ compared to the neutral condition (6.51 ± 0.34%, $p = 0.18$) but decreased after "relax" (6.11 ± 0.33%, $p = 0.044$, main effect of condition: $F(2,58) = 4.507$, $p = 0.015$, $\eta^2 = 0.135$, see Fig. 2i). The relative amount of N2 sleep (43.37 ± 1.33%) after media use was significantly reduced compared to the neutral condition (47.19 ± 1.09%, $p = 0.008$). However, we did not find differences compared to the "relax" condition (46.40 ± 1.04%, $p = 0.12$, main effect of condition: $F(2,58) = 5.935$, $p = 0.005$, $\eta^2 = 0.170$, see Fig. 2j). The time spent in N3 (SWS) was not affected by social media consumption before sleep and did not differ between the three conditions (main effect condition: $F(2,58) = 1.173$, $p = 0.317$, see Fig. 2k). In addition, participants reached SWS earlier when they had performed PMR before sleep (10.33 ± 1.06 min) compared to the "media" condition (13.78 ± 0.86 min, $p = 0.009$), but not compared to the neutral condition (12.12 ± 0.74 min, $p > 0.19$, main effect of condition $F(2,58) = 5.570$, $p = 0.006$, $\eta^2 = 0.161$, see Table 1 and Fig. 2h). Time spent awake during the night (WASO) or in the other sleep stages was comparable across all conditions (all $p > 0.11$, see Table 1).

In addition to sleep architecture, we investigated the dynamics of sleep using a power analysis for frontal slow-wave activity (SWA; 0.5–4.5 Hz), frontal slow sleep spindles (11–13 Hz) and parietal fast sleep spindles (13–15 Hz). The analysis was conducted with the additional factor of sleep cycle using Feinberg and Floyd's [55] criteria. For SWA power, we observed the typical decrease in power over the cycles; $F(3, 84) = 41.75$, $p < 0.001$, $\eta^2 = 0.60$, see Fig. 3a. However, neither social media nor PMR had an effect on SWA power over all cycles ($p > 0.58$). We also did not observe any effects of the experimental manipulation on power in the slow or fast spindle bands (all $p > 0.30$). Both, slow spindle power ($F(3, 84) = 4.73$, $p = 0.024$, $\eta^2 = 0.024$) and fast spindles ($F(3, 84) = 7.85$, $p = 0.006$, $\eta^2 = 0.22$) generally differed between sleep cycles (see Fig. 3b and c).

Generally, the three conditions did not differ in average number of sleep cycles ("neutral": 5.14 ± 0.11; "media": 4.89 ± 0.11, and "relax" 5.15 ± 0.14 cycles, respectively, $p = 0.198$). The same applied for mean cycle length ("neutral": 91.78 ± 6.30; "media": 95.09 ± 5.60; "relax": 93.96 ± 5.77, $p = 0.538$).

Table 1
Overview of the assessed parameters, i.e., objective and subjective indicators of sleep quality, arousal, memory, vigilance, and mood.

	Neutral	Media	Relax	*F*-test	*p*-Value
	M ± *SEM*	*M* ± *SEM*	*M* ± *SEM*		
Subjective sleep parameters					
Sleep quality	25.17 ± 0.54	24.88 ± 0.58	26.80 ± 0.44	7.186	**0.002*****
SOL [min]	16.50 ± 2.89	15.33 ± 2.35	5.0 ± 1.34	9.157	**<0.001*****
WASO [min]	8.48 ± 1.62	10.63 ± 4.64	11.53 ± 2.52	0.284	0.75
Sleep depth	3.97 ± 0.14	3.77 ± 0.16	4.20 ± 0.13	3.167	**0.05***
Objective sleep parameters					
Sleep efficiency [%]	96.70 ± 0.52	95.71 ± 0.83	98.54 ± 0.45	6.738	**0.002*****
SOL [min]	14.78 ± 2.11	19.23 ± 3.59	6.50 ± 2.16	7.095	**0.002*****
WASO [min]	14.62 ± 3.44	20.82 ± 5.49	18.10 ± 4.54	0.61	0.48
Sleep depth [SWA in Hz]	30.76 ± 4.62	28.01 ± 4.54	32.11 ± 5.55	1.79	0.14
N1 [min]	30.18 ± 1.59	32.80 ± 2.11	28.92 ± 1.52	3.099	0.05
N2 [min]	218.97 ± 5.30	199.02 ± 6.71	220.18 ± 5.06	8.297	**0.001*****
N3 [min]	101.60 ± 5.08	102.32 ± 5.17	100.75 ± 4.92	0.088	0.92
REM [min]	90.23 ± 2.81	94.72 ± 3.63	98.40 ± 3.80	2.258	0.11
Move [min]	8.27 ± 0.65	8.05 ± 0.67	8.27 ± 0.55	0.116	0.89
N1 [%]	6.51 ± 0.34	7.19 ± 0.47	6.11 ± 0.33	4.507	**0.015****
N2 [%]	47.19 ± 1.09	43.37 ± 1.33	46.40 ± 1.04	5.935	**0.005****
N3 [%]	21.92 ± 1.11	22.46 ± 1.20	21.21 ± 1.02	1.173	0.32
REM [%]	19.46 ± 0.59	20.65 ± 0.75	20.70 ± 0.77	1.419	0.25
Move [%]	1.79 ± 0.14	1.76 ± 0.14	1.75 ± 0.12	0.068	0.94
WASO [%]	3.14 ± 0.74	4.56 ± 1.20	3.83 ± 0.97	1.711	0.50
TST [min]	463.87 ± 2.53	457.72 ± 4.04	474.62 ± 2.68	8.911	**<0.001*****
SWS latency [min]	12.12 ± 0.74	13.78 ± 0.86	10.33 ± 1.06	5.57	**0.006****
REM latency [min]	93.00 ± 5.82	85.58 ± 6.00	78.67 ± 6.55	1.549	0.22
Sleep cycles					
Number of cycle	5.14 ± 0.11	4.89 ± 0.11	5.15 ± 0.14	1.66	0.20
Mean cycle duration [min]	91.78 ± 6.30	95.09 ± 5.60	93.96 ± 5.77	0.63	0.54
Cycle 1 ($n = 30$)	91.33 ± 4.20	87.20 ± 4.29	82.25 ± 4.39	1.41	0.25
Mean duration: Cycle 2 ($n = 30$)	88.25 ± 4.31	94.50 ± 4.84	105.17 ± 6.65	3.57	**0.034***
Mean duration: Cycle 3 ($n = 30$)	100.43 ± 6.16	107.33 ± 4.09	108.82 ± 4.34	0.91	0.41
Mean duration: Cycle 4 ($n = 29$)	113.05 ± 7.40	113.286.27	101.294.63	1.26	0.29
Mean duration: Cycle 5 ($n = 15$)	110.9 ± 10.62	110.57 ± 6.82	104.70 ± 4.97	0.25	0.71
Heart rate variability (HRV)					
Mean HR [bpm]	67.84 ± 10.90	68.37 ± 12.32	63.62 ± 11.55	5.99	**0.004****
HRV triangular index	13.20 ± 1.94	13.61 ± 2.16	13.22 ± 18.83	0.17	0.85
Memory					
Encoding (evening)	53.83 ± 2.38	53.66 ± 2.32	53.72 ± 2.78	0.005	0.99
Recall (morning)	53.21 ± 2.45	52.51 ± 2.60	51.35 ± 2.78	0.511	0.60
Consolidation [%]	98.93 ± 1.76	97.02 ± 1.63	96.49 ± 2.30	0.468	0.63
Vigilance (Morning)					
Reaction time (RT)	338.24 ± 6.77	340.64 ± 8.04	340.24 ± 7.80	0.061	0.94
Reactions	77.00 ± 0.42	76.47 ± 0.46	76.60 ± 0.32	0.64	0.38
Errors	3.53 ± 2.08	4.63 ± 1.92	5.97 ± 3.76	0.793	0.43
Mood					
Good-Bad, Evening	4.33 ± 0.11	4.33 ± 0.11	4.27 ± 0.10	0.14	0.87
Good-Bad, Morning	4.21 ± 0.12	4.05 ± 0.11	4.16 ± 0.13	0.99	0.38
Awake-Tired, Evening	3.15 ± 0.16	3.11 ± 0.15	3.18 ± 0.16	0.09	0.88
Awake-Tired, Morning	3.02 ± 0.15	3.03 ± 0.14	3.28 ± 0.14	3.28	**0.045***
Arousal (Calm-Nervous), Evening	3.83 ± 0.14	4.06 ± 0.11	3.87 ± 0.13	1.47	0.24
Arousal (Calm-Nervous), Morning	3.92 ± 0.12	3.78 ± 0.13	3.90 ± 0.14	0.56	0.58

Notes. Subjective parameters are based on subjective ratings in the SF-A-R [50]. Objective values are based on polysomnographic recordings. Non-rapid eye movement (NREM)-sleep, stage 1, 2, and 3 sleep (N1, N2, N3), rapid eye movement sleep (REM), waketime after sleep onset (WASO), total sleep time (TST), sleep onset latency (SOL), slow wave sleep latency (SWS latency), REM sleep latency (REM latency) are all measured in minutes [min] and the percentages indicate parietal percentage of TST [%]. Sleep cycles were calculated using the criteria of Feinberg and Floyd [55]. The numbers of participants (n) differed between the cycles as not all participants reached the fourth and fifth cycle. Heart rate (HR, in beats per minute [bpm]) and heart rate variability (HRV) indexes (provided by Kubios [Kubios Oy, Kuopio]) were used as an objective measurement of arousal. For memory, numbers indicate absolute or relative values of correctly recalled words that were presented in the evening (learning phase with first recall) and in the morning (retrieval phase with second recall). Consolidation refers to the difference in performance between learning and retrieval phases. For vigilance, the reaction time (RT), the number of reactions, and number of errors during the 10 min of the psychomotor vigilance task (PVT) were measured. Mood parameters are based on subjective ratings in the mood questionnaire with the three subscales (Good-Bad, Awake-Tired, and Calm-Nervous) [49]. Calm-Nervous indicates the subjective arousal. Values are means (M) ± standard error of mean (SEM). * indicates $p \leq 0.05$. ** indicates $p \leq 0.01$. *** indicates $p \leq 0.001$. Significant results are highlighted in bold.

3.3. Physiological arousal

To identify the role of pre-sleep physiological arousal on subsequent changes in sleep, we analyzed the effect of social media use on heart rate and heart rate variability during the period of falling asleep (2 min after lights off) compared to the "neutral" and "relax" conditions. We expected social media consumption to increase pre-sleep arousal. Contrary to our expectations, using social media before sleep did not significantly impact heart rate (68.37 ± 12.32 bpm) as compared to "neutral" (67.84 ± 10.90 bpm; $p > 0.72$). In contrast, PMR decreased heart rate significantly (63.62 ± 11.55 bpm) compared to the two other conditions (both $p < 0.008$, main effect of condition: $F(2, 58) = 5.99$, $p = 0.004$, $\eta^2 = 0.17$, see Fig. 4a). Heart rate variability (HRV triangular index) did not significantly differ between the experimental conditions; $F(2, 58) = 0.17$, $p = 0.846$, for the HRV triangular index provided by Kubios (Kubios Oy, Kuopio). For all results, see Table 1.

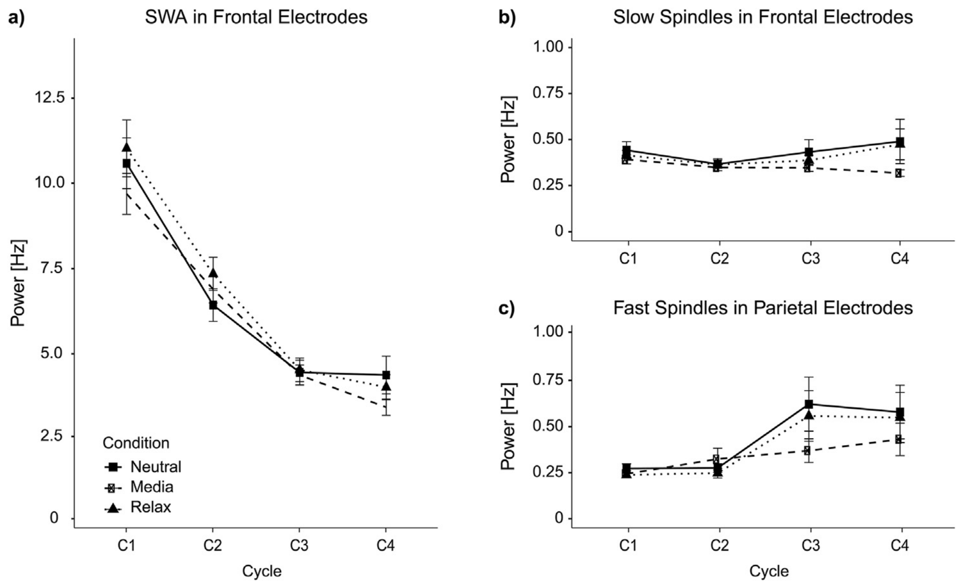

Fig. 3. Sleep dynamics for slow-wave-activity, fast and slow spindles. Power analysis in the first four cycles (C1–C4) for slow-wave activity (SWA; 0.5–4.5 Hz) measured in frontal electrodes (F3 and F4) (a), slow spindles (11–13 Hz) measured in F3 and F4 (b), and fast spindles (13–15 Hz) measured in parietal electrodes (P3 and P4) (c). No significant effect on condition was found in any frequency band.

To test whether the differences between the experimental conditions in HR and HRV predicted the differences in sleep parameters, an explorative correlational analysis was computed. To control for general individual differences, values were corrected for the neutral condition, which resulted in ΔMedia (“media” − “neutral”) and ΔRelax (“relax” − “neutral”), both for pre-sleep arousal and sleep parameters. For the “media” condition, changes in pre-sleep arousal after social media use (ΔMedia) was not related to any differences in objective sleep parameters. Particularly, the reduction in N2 sleep was not correlated with pre-sleep changes in

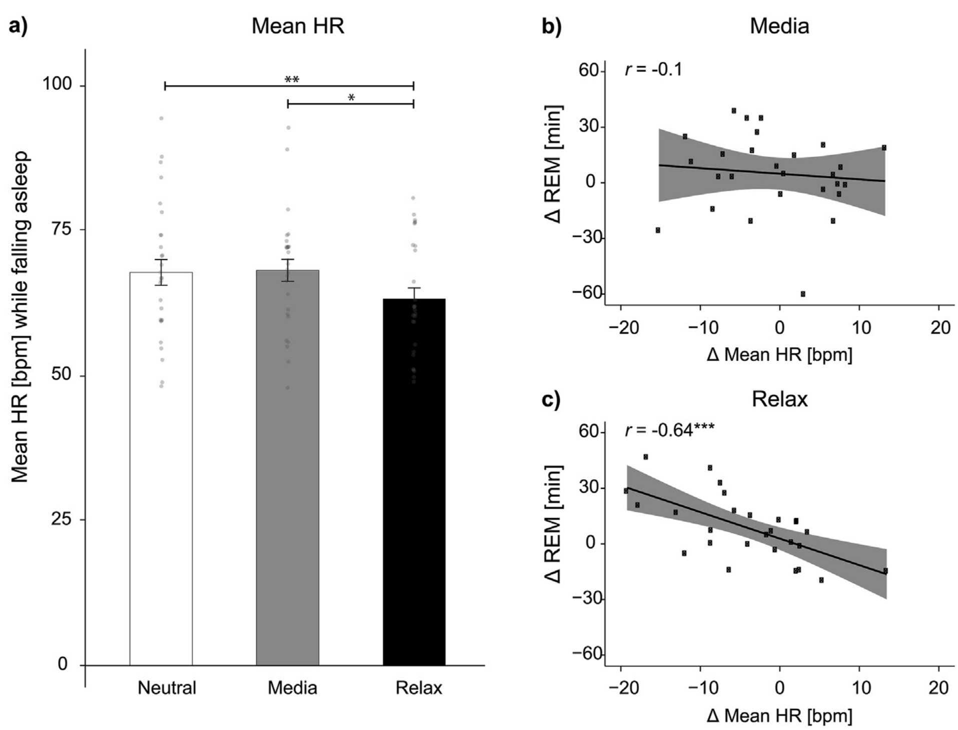

Fig. 4. Effects of social media and PMR on pre-sleep arousal. Pre-sleep arousal was measured using mean heart rate (HR) in beats per minute (bpm) while participants fell asleep. (a) Social media consumption had no arousing effect of mean HR ($p > 0.72$), whereas progressive muscle relaxation (PMR) decreased mean HR compared to “media” ($p = 0.004$) and “neutral” ($p = 0.008$). Means ± standard errors of the mean are indicated. (b) In the “media” condition, the overall increase in arousal (mean HR) did not correlate with the amount of REM sleep (in min). Both values were corrected for “neutral” (ΔMean HR = Mean HR “media” − Mean HR “neutral” and ΔREM = REM “media” − REM “neutral”). (c) In the “relax” condition, the change in ΔMean HR (“relax” corrected for “neutral”) correlated positively with the change in Δ REM sleep (in minutes and corrected for “neutral”). * indicates $p \leq 0.05$. ** indicates $p \leq 0.01$. *** indicates $p \leq 0.001$.

HR or HRV (Mean HR: ΔMedia: $r = -0.0804$, ΔRelax: $r = 0.207$ and HRV Triangular Index: ΔMedia: $r = -0.082$, ΔRelax: $r = -0.002$). Results for the remaining objective sleep parameters show the same pattern (see Table 2 and Fig. 4b for REM sleep). For subjective sleep evaluations, changes in heart rate tended to predict subjective sleep quality (Mean HR: ΔMedia: $r = -0.36$, $p = 0.060$), subjective SOL (Mean HR: ΔMedia: $r = 0.34$, $p = 0.074$) and subjective sleep depth (Mean HR: ΔMedia: $r = -0.36$, $p = 0.060$, see Table 2).

In the “relax” condition, a higher reduction in heart rate predicted an increase in REM sleep (relative to the neutral condition, $r = -0.563$, $p = 0.002$, see Fig. 4c). The reduction in SOL, the early SWS latency, the increase in SWS or the increase in N1 sleep was not associated with the reduced pre-sleep arousal after performing PMR (all $r < 0.262$, all $p > 0.177$). HRV triangular index was not correlated with any sleep parameter (all $r < 0.356$, all $p > 0.06$). We did not find any significant correlations or subjective sleep parameters in the “relax” condition; neither for mean HR nor the HRV triangular index (see Table 2).

3.4. Effects on memory consolidation and vigilance

We did not observe any differences on neither sleep dependent memory consolidation in our experimental conditions ($p > 0.80$), nor on psychomotor vigilance tested after sleep ($p > 0.90$, see Table 1).

4. Discussion

This study investigated the effect of pre-sleep media use on subjective and objective sleep parameters in a controlled experimental setting, ie, sleep laboratory. We assumed that pre-sleep social media use would impair sleep as indexed by subjective (self-report) and objective (arousal, sleep) indicators. To investigate these effects, a condition with social media use was compared to a neutral (no specific pre-sleep activity) and a pre-sleep relaxation (progressive muscle relaxation, PMR) condition. Contrarily to our assumptions, social media use did not impair subjective sleep parameters. This result contradicts findings from previous studies providing proof for the existence of such an adverse effect as indicated by self-reports about a decrease in sleep quality [12,17,38,62], shorter sleep duration [63,64], prolonged sleep onset [65,66], and more wake reactions [66]. Regarding objective indicators, we only found a reduction in the percentage of N2 sleep after social media use compared to the neutral night. This was, however, not at the expense of other sleep stages. Rather, this change seemed to be equally distributed across all sleep stages as it was accompanied by non-significant increases in WASO, N1, N3 and REM sleep. None of the other objective sleep measures were affected by social media use.

In going beyond existing studies relying on self-reports, this study took place in a sleep laboratory. This setting not only standardises measurements, but it also increases controllability of confounding factors, such as reachability via smartphones during the night. As smartphones were removed from the sleep cabin during the night, participants as well as their social contacts (peers, family, partners, etc.) with whom they regularly interact, were aware that they would not be reachable during the night. This is important because having a smartphone in the bedroom together and being potentially reachable throughout the night reduces subjective sleep quality [67]. This finding is supported by another study conducted in our laboratory, in which we demonstrated that performing on-call duty during the night leads to differences in sleep quality. We showed that the instruction to be on-call, even only for one night, reduced sleep quality. Importantly, this effect is apparent even if no physical interruption occurs during the night (Combertaldi, Wick, & Rasch, in preparation). Consequently and irrespective of its usage, the presence of a smartphones reduces sleep quality, TST and leads to daytime sleepiness [68].

By taking away our participants' smartphone for the night we aimed to minimize nocturnal disturbances. However, by taking into account findings on the so called “Fear of Missing Out” [FoMO; 69], which is defined as the need to stay up to date and connected with others [70], we cannot be sure if this led to an increased arousal or discomfort for some of our participants. FoMO has been associated with a decrease total sleep time (TST) and delayed sleep onset [37,71–73], probably after promoting cognitive pre-sleep arousal [18,23,73,74]. Following our goal to reduce potential and effective nocturnal disturbances, we might have introduced an unsystematic error.

We expected that disturbed sleep after social media use would be mediated by pre-sleep arousal. We found no disturbing effects on sleep, nor did media use increase subjective or objective pre-sleep arousal. Subjective ratings of calmness indicated that participants did not feel more aroused after social media use compared to directly going to sleep. Physiologically, neither heart rate (HR) nor heart rate variability (HRV) were affected by social media consumption. Even though the latter has been found to be a particularly sensitive marker for (psychosocial) stress [75–77]. Neither HR nor HRV correlated with the reported N2 reduction after social media use, rendering a contribution of pre-sleep arousal to the N2 differences unlikely. One explanation for the difference between this and previous studies might be the lack of blue-light. Human alertness is blue-light sensitive and heart rate increases with short wavelength light [78]. Normally, smartphone use is associated with exposure to blue-light which can delay sleep onset [79]. In our study we used blue-light blocking glasses, which differs from everyday life and existing studies.

While we did not find detrimental effects of social media use – compared to the neutral night – progressive muscle relaxation (PMR) clearly had positive effects on pre-sleep arousal and sleep. After practicing PMR, heart rate (while falling asleep) and sleep onset latency were reduced. Moreover, PMR also improved subjective and objective sleep quality. Consequently, participants in

Table 2
Relationships between arousal and the assessed sleep parameters (subjective and objective).

		Mean HR [bpm]		HRV triangular index	
		Δ Media	Δ Relax	Δ Media	Δ Relax
Subjective	Δ Sleep quality	−0.360	0.148	0.056	−0.146
	Δ SOL	0.340	−0.037	−0.022	0.164
	Δ WASO	0.073	0.015	0.194	−0.152
	Δ Depth	−0.363	0.224	0.032	0.021
Objective	Δ Sleep efficiency	−0.110	−0.184	−0.002	−0.102
	Δ SOL	0.096	0.197	−0.007	0.104
	Δ WASO	0.180	0.016	0.170	0.208
	Δ Depth/SWA	0.140	0.262	0.356	0.289
	Δ N1	0.058	0.161	−0.082	−0.026
	Δ N2	−0.080	0.207	−0.082	−0.002
	Δ N3/SWS	−0.033	0.166	0.108	0.078
	Δ REM	−0.170	**−0.563****	−0.163	−0.316
	Δ TST	−0.015	−0.025	0.046	−0.120
	Δ SWS latency	0.114	0.293	−0.121	−0.110
	Δ REM latency	0.166	0.272	0.065	0.021

Notes. Correlations were calculated separately for the “media” and “relax” conditions. All parameters are corrected for the values obtained in the neutral condition (ΔMedia: “media” – “neutral” and ΔRelax: “relax” – “neutral”). Subjective parameters were measured by SF-A-R [50]: Sleep quality, sleep onset latency (SOL), wake time after sleep onset (WASO), numbers of awakenings (NWAK) and sleep depth. Objective sleep parameters are based on polysomnographic recordings (Sleep quality = sleep efficiency, SOL, WASO, NWAK, depth = sleep stage N3 in minutes). Significant correlations are highlighted in bold. ** indicates $p \leq 0.01$.

the PMR condition felt more awake the next morning. Practicing PMR instead of using social media might be recommendable to improve sleep. This not only applies when compared to social media use but even when compared to a neutral condition. When compared to the other two conditions, PMR before sleep improved sleep quality, sleep efficiency, and SOL. Other indicators (eg reduction of SWS latency, reduction in N1 sleep etc.) were only found to differ between the PMR and the social media condition. Hence, these effects can only to a limited extent be interpreted as improvements resulting from PMR. As we tested a healthy sample of young adults, we cannot exclude potential ceiling effects. Regardless of these effects, our results are still in line with previous research and demonstrate why relaxation (eg PMR) is a frequently chosen treatment for insomnia [34,35,80,81]. In our study, the positive effects of PMR on sleep not only demonstrate that pre-sleep arousal can influence sleep, but also provide evidence that the applied methods of measurements are well-suited and sufficiently sensitive to map these changes. Conversely, this also underpins the findings that the use of SM at bedtime had a neglectable influence on sleep parameters. One might still argue that changes in pre-sleep arousal or sleep might have been too fine grained for the applied measurement. However, any impairments would have also be likely to result in poorer daytime performance [82]. The non-impact of social media use on sleep is, thus, further supported by the fact, that neither morning indicators of vigilance nor memory differed between conditions; even though we cannot be absolutely sure that such effects could appear later in the day.

On a related note, this study's findings are limited to two specific ways of social media use, ie, communication via WhatsApp and Snapchat. Even though these apps are widely used and we did require our participants to be active users of at least one of the two, other ways of communicating with peers before sleep as well as other forms of media use might produce different effects. One could assume that being able to communicate with others before sleep serves as a way of clearing one's mind; thereby working as a calming buffer. Contrarily, the use of news, entertaining, and stimulating audiovisual content might provide additional cognitive and physiological stimulation, leading to an increased arousal. Therefore, future studies should investigate and compare the effects of different ways of media use its interaction with the resulting arousal on sleep as well as on daytime alertness, preferably not only in the morning.

4.1. Limitations

In this study, the exposure to blue light was reduced, thereby attempting to isolate the effects of electronic social media use independent of nocturnal light exposure. While the use of blue-blocking glasses to exclude the effect of light is interesting and helps to distill more specifically the effects of social media use per se, another experimental condition with normal light (including short wavelengths) exposure would have been useful. Although the aim of this study was to observe effects of social media on sleep, the question of whether or not light from personal devices impairs sleep remains open for further research.

Due to the standardization of the type of use, real-time chatting was used as an active way of engaging in social media (WhatsApp chatting and Snapchat) rather than more passive ways of engaging with social media (eg Facebook, Instagram). It could be possible that real-time chatting is less arousing than other types of activities on social media (eg reading dubious or provocative news stories on Facebook etc.). Thus, we cannot exclude that other types of social media use might result in stronger effects on sleep. Further it was not possible to check for the content of their social media use due to data protection of the participants. In a next study it would be helpful to get this information to get an impression about the arousing effect some content might cause.

Another limitation given by the controlled setting of a sleep laboratory is not only the reduced external validity, but also that social media use was restricted to 30 min. This restriction might be not long enough to result in potential sleep disturbing effects. Although we choose the long format of a PMR (30 min) for comparability purposes, there was no possibility to expand the social media exposure. To remove this limitation in a next study, a non-laboratory setting at the participants' home would be helpful to investigate the potential disturbing effects of social media on sleep.

4.2. Conclusion

In sum, this study does not provide empirical evidence for a *general* adverse effect of social media consumption on pre-sleep arousal, sleep, or performance the following day. Thereby, it contradicts findings from previous studies. However, negative effects of pre-sleep social media use on subjective and objective pre-sleep arousal and sleep emerged when comparing social media use nights to those nights in which participants actively applied PMR. Thus, performing progressive muscle relaxation is clearly a better alternative to social media use before sleep. This is substantiated, as social media use before sleep in real-life oftentimes exceeds 30 min (the limit in our study procedure). Delaying bedtime due to prolonged media use might have additional impairing effects on sleep and on the duration of sleep going beyond the findings of this study, especially if we consider when wake-up times are externally determined by school hours or working schedules. Thus, while the sole activity of using social media itself does not appear to have strong detrimental effects on sleep architecture, it is still recommendable to limit the use of any media activity at bedtime in order to get a sufficient amount of restorative sleep.

Author contributions

Selina L. Combertaldi: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft Preparation, Writing - Review & Editing, Visualization, Project administration. **Alexander Ort**: Conceptualization, Methodology, Writing - Review & Editing. **Maren J. Cordi**: Writing - Original Draft Preparation. **Andreas Fahr**: Conceptualization, Methodology, Writing - Review & Editing. **Björn Rasch**: Conceptualization, Methodology, Validation, Writing - Original Draft Preparation, Writing - Review & Editing, Supervision, Funding acquisition.

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Conflict of interest

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