



**High sleep fragmentation parallels poor subjective sleep quality during the third wave of the Covid-19 pandemic: an actigraphic study**

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# High sleep fragmentation parallels poor subjective sleep quality during the third wave of the Covid-19 pandemic: an actigraphic study

## Running Head: Sleep in the third wave of the Covid-19 pandemic

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## Abstract

Studies on sleep during the Covid-19 pandemic have mostly been conducted during the first wave of contagion (spring 2020). To follow up on two Italian studies addressing subjective sleep features during the second wave (autumn 2020), here we assess sleep during the third wave (spring 2021) in a sample of healthy adults from Campania (Southern Italy).

Actigraphic data (on 2 nights) and the Pittsburgh Sleep Quality Index were collected from 82 participants (40 F, mean age:  $32.5 \pm 11.5$  years) from March 11<sup>th</sup> to April 18<sup>th</sup> 2021, when Campania was classified as “red zone”, i.e., it was subjected to strict restrictions, only slightly looser than those characterizing the first national lockdown (spring 2020).

Although objective sleep duration and architecture appeared in the normal range, the presence of disrupted sleep was indexed by a relevant degree of sleep fragmentation (number of awakenings  $\geq 1$  min:  $12.7 \pm 6.12$ ; number of awakenings  $\geq 5$  min:  $3.04 \pm 1.52$ ), paralleled by poor subjective sleep quality (PSQI global score:  $5.77 \pm 2.58$ ).

These data suggest that the relevant subjective sleep impairments reported during the first wave could have relied on subtle sleep disruptions which were undetected by the few objective sleep studies from the same period. Taken together with sleep data on previous phases of the pandemic, our findings show that the detrimental effects on sleep determined by the initial pandemic outbreak have not abated across the subsequent waves of contagion and highlight the need for interventions addressing sleep health in global emergencies.

**Key words:** Covid-19 pandemic, objective sleep quality, subjective sleep quality, sleep schedules, actigraphy

## Introduction

Early evidence from the Covid-19 crisis has shown wide-ranging disruptions to personal schedules, psychological health, and sleep throughout the world, with pooled data from international populations placing the prevalence of sleep problems at 35.7% (as reviewed in Jahrami et al., 2021).

During the first lockdown in Italy, individuals reported delayed sleep schedules, increased time in bed, and poorer sleep quality compared to before the lockdown (Cellini et al., 2020a, 2021; Gualano et al., 2020; Casagrande et al., 2020). Over 40% of an Italian sample reported sleep disturbances (Gualano et al., 2020) and 18% met criteria for a diagnosis of clinical insomnia (Bacaro et al., 2020). Taken alongside results from surveys conducted worldwide, it appears that there has been a global decline in sleep quality (Huang and Zhao, 2020; Kokou-Kpolou et al., 2020; Leone et al., 2020; Stanton et al., 2020; Voitsidis et al., 2020).

Two Italian surveys, conducted longitudinally across the first and second pandemic lockdowns (spring and autumn 2020, respectively), show that the impoverishment of sleep quality persisted through the waves of contagion (Salfi et al., 2021; Conte et al., 2021a). In Italy, in fact, the loosening of restrictions over the summer 2020 resulted in a second, larger wave of infections, to the point that another lockdown, though slightly less restrictive, was mandated in November 2020. Despite the effectiveness of these new measures, a third wave of contagion occurred toward the end of winter, so that most Italian regions underwent a third lockdown in March 2021.

Here we assess objective and subjective sleep features through actigraphic recordings and the Pittsburgh Sleep Quality Index (PSQI, Buysse et al., 1989), respectively, during the third Italian lockdown in a sample of healthy adults, in order to describe the longitudinal evolution of the pandemic's effects on sleep schedules and quality.

An additional aim is to specifically assess sleep fragmentation, which has been neglected in the few objective sleep studies from the first pandemic wave (Wang et al., 2021; Sañudo et al., 2020; Ong et al., 2021; Pepin et al., 2021). Indeed, these studies point to a milder impact of the pandemic on objective sleep quality than what suggested by the survey studies reviewed above: for instance, no changes in sleep efficiency or wake after sleep onset were found during the lockdowns (Ong et al., 2021; Pepin et al., 2021). Therefore, a more in-depth evaluation of sleep fragmentation measures, consistently reported as main determinants of perceived sleep quality (Della Monica et al., 2018; Conte et al., 2021b), could shed light on the discrepancy between subjective and objective assessments of sleep during the pandemic.

Finally, we also address gender differences in subjective and objective sleep measures, in

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3 order to compare our findings with data collected during previous waves of the pandemic, which  
4 point to female gender as a risk factor for greater worsening of sleep quality with the Covid-19  
5 emergency (e.g., Cellini, et al., 2021; Casagrande et al., 2020).  
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## 10 11 **Materials and Methods**

### 12 13 *Participants and Procedure*

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16 The data collection phase was conducted from March 11<sup>th</sup> to April 18<sup>th</sup> 2021, i.e., when  
17 Campania, along with most other Italian regions, was considered a “red zone” according to the  
18 Governmental Decree of November 3<sup>rd</sup>, 2020. Since this decree, Italian regions are being classified  
19 as red, orange, yellow or white zones on a weekly basis, based on a set of risk parameters including  
20 the number of Covid-19 cases per inhabitant. “Red zones” are the areas considered at highest risk of  
21 contagion spread and thus subjected to the greatest restrictions: movements outside of home are not  
22 allowed except for basic necessities (related to work, health, grocery shopping, assistance), with the  
23 requirement to carry documentation of essential travel at all times; moving across municipalities is  
24 prohibited unless there are exceptional work- or health-related reasons. Only essential shops (such  
25 as pharmacies) are allowed to be open. Bars’ and restaurants’ services are limited to takeaway (until  
26 10 p.m.) and home delivery. Cinemas, theaters, museums and gyms are also closed. All in-presence  
27 activities of schools, universities and team sports are suspended; religious services may continue in  
28 strict accordance to social distancing norms.  
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39 This set of restrictions is very similar to that adopted during the first, national lockdown,  
40 which lasted throughout spring 2020, with the main difference being that limitations were  
41 somewhat more relaxed during the November and March “red zone” periods: a higher number of  
42 work activities requiring physical presence were possible, police controls were less strict and a few  
43 public events (such as some religious services) were allowed to be organized with social distancing  
44 precautions. The fact that most Italian regions showed a similar trend since November 2020 (with  
45 the implementation of “red zone” limitations for about a month in November-December 2020 and  
46 again in March-April 2021) allows to clearly identify, in Italy, a second and a third wave of  
47 contagion, based both on number of Covid-19 cases and on severity of restrictions, and to compare  
48 sleep data across the waves.  
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56 The recruitment phase was conducted along with data collection throughout the “red zone”  
57 period (March 11<sup>th</sup> to April 18<sup>th</sup>) and was ended as soon as the loosening of restrictions was  
58 announced (i.e., Campania becoming an “orange zone”), in order to assure that all participants were  
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3 evaluated under the same conditions. Specifically, a convenience sample of 87 volunteers from the  
4 metropolitan areas of Caserta and Napoli (Campania region, Italy) was screened through a brief  
5 telephone interview, to collect general demographic data and information on medical conditions and  
6 health habits (including specific questions on somatic and psychiatric disorders, on sleep disorder  
7 symptoms and on substance use). Inclusion criteria were: age 18-60 years; absence of any somatic  
8 or psychiatric illness; absence of any sleep apnea, respiratory or movement disorder symptoms;  
9 having a regular sleep/wake cycle; no history of drug or alcohol abuse; limited consumption of  
10 caffeine (no more than 150 mg caffeine per day, corresponding to about three cups of espresso or  
11 one cup of American coffee) and alcohol (no more than 250 ml per day, i.e. about a pint of standard  
12 beer, a full glass of wine, or a small liquor shot). Five volunteers had to be excluded because of:  
13 sleep apnea symptoms (1 subject), anxiety symptoms (2 subjects), regular consumption of caffeine  
14 and/or alcohol exceeding the criterion limit (2 subjects). The final sample consisted of 82  
15 participants (40 F, 48,78%; 42 M, 51,22%; age range: 18-56 years; mean age:  $32.5 \pm 11.5$  years).

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26 All participants signed an informed consent prior to participation and received no money or  
27 credit compensation for their participation.

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29 Each subject wore an actigraph on his non-dominant wrist for about 40 hours (on weekdays  
30 only): the actigraph was delivered in the afternoon and retrieved the morning after the second  
31 recording night. Participants were also requested to fill in the Italian version of the PSQI (Curcio et  
32 al., 2013), as well as two sleep diaries (upon awakening on the morning after each night of  
33 recording), and to maintain their regular sleep/wake habits during recording days.

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The Ethical Committee of the Department of Psychology, University of Campania  
"Vanvitelli", approved the research protocol (code 15/2021) and certified that the involvement of  
human participants was performed according to acceptable standards. All methods were carried out  
in accordance with relevant guidelines and regulations.

### *Actigraphic sleep analysis*

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The actigraphs were Motionlogger® Microwatches (Ambulatory Monitoring, Inc.). The  
analysis of sleep data was performed on the two night periods, with a 30 seconds epoch time scale,  
by means of the Action-W 2 software, which uses the Cole-Kripke algorithm (Cole et al., 1992) to  
extract sleep variables. The resting period (i.e., lights off/on times) was automatically defined by  
the Action-W 2 software. Specifically, the variables we extracted were: bedtime (i.e., time at which  
the subject goes to bed), rise time (i.e., time at which the subject rises from bed), sleep midpoint  
(i.e. midpoint between the first and the last epoch scored as sleep), time in bed (TIB, i.e., total  
amount of time from bedtime to rise time), total sleep time (TST. i.e., total amount of time spent in

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3 sleep), sleep onset latency (SOL, i.e., amount of time from bedtime to the first epoch scored as  
4 sleep), wake after sleep onset (WASO, i.e., total duration of wake between sleep onset and wake  
5 time), sleep efficiency (SE, i.e.,  $100 \times \text{TST}/\text{TIB}$ ), number of awakenings lasting  $\geq 1$  minutes (i.e.,  
6 number of blocks of at least 2 contiguous wake epochs), mean duration of awakenings, number of  
7 long awakenings (lasting  $\geq 5$  minutes), duration of longest awakening.  
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11 Further, from these automatically extracted variables we calculated: wake time (i.e., time of  
12 morning final awakening), sleep period time (SPT, i.e., total amount of time from the first epoch  
13 scored as sleep to wake time), wake after sleep onset percentage (WASO%, i.e., percentage of  
14 WASO over SPT), frequency of awakenings lasting  $\geq 1$  minutes per hour of TST, frequency of long  
15 awakenings (lasting  $\geq 5$  minutes) per hour of TST.  
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### 20 21 22 *Data Analysis*

23 Descriptive statistics are reported as mean  $\pm$  standard deviation.

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25 In order to be able to pool data from the two nights of recording, we checked that actigraphic  
26 parameters did not significantly differ between the two nights. This was done using Student's t test  
27 for sleep schedule variables (bedtime, wake time, rise time and sleep midpoint) and Mann-  
28 Whitney's test for all other objective sleep parameters, which were not normally distributed (as  
29 assessed through the Shapiro-Wilk test).  
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34 Descriptive data on actigraphic variables are reported as average between the two nights of  
35 recording. Similarly, analyses of gender differences in actigraphic parameters were conducted on  
36 values averaged between the two nights.  
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39 Gender differences in age and sleep schedule variables were analyzed through Student's t  
40 test, whereas those in PSQI scores, objective sleep architecture and objective sleep fragmentation  
41 variables were evaluated through the Mann-Whitney test due to non-normal distribution.  
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44 Furthermore, to assess possible effects of Daylight Saving Time (DST, introduced on March  
45 28th), we analyzed differences in actigraphic variables (averaged between the two nights) between  
46 subjects who participated in the study before that date ( $n = 63$ ; 34 F, 29 M; mean age:  $34.5 \pm 11.7$   
47 years) and those who participated afterwards ( $n = 19$ ; 6 F, 13 M; mean age:  $25.7 \pm 7.72$  years).  
48 Sleep schedule measures were assessed through Student's t test, while sleep architecture and  
49 fragmentation variables were analyzed by means of the Mann-Whitney test.  
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54 Cohen's d and 95% Confidence Intervals are reported for parametric statistics and rank  
55 biserial correlations for non-parametric tests.  
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58 All analyses were performed by means of JAMOVI 1.6.16 (The Jamovi Project);  
59 significance was set at  $p \leq 0.05$ .  
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## Results

### *Subjective sleep quality*

Average PSQI global score was  $5.77 \pm 2.58$ , indicating a mild degree of poor subjective sleep quality. Specifically, 46.34% ( $n = 38$ ) of subjects were classified as good sleepers (PSQI score  $\leq 5$ , Buysse et al., 1989), and the remaining 53.66% ( $n = 44$ ) as poor sleepers (PSQI score  $> 5$ , Buysse et al., 1989). Men and women are equally distributed between the two groups (good sleepers: 18 F, 20 M; poor sleepers: 22 F, 22 M). Scores at the PSQI subscales (range 0-3 for each subscale, Buysse et al., 1989) are reported in Table 1.

**TABLE 1 HERE**

### *Objective sleep quality*

No significant differences were found in any actigraphic sleep parameter between the two nights of recording.

Descriptive data on sleep schedules and sleep fragmentation are reported in Table 2, whereas Figure 1 displays sleep architecture variables, in reference to the values recommended for each parameter by the National Sleep Foundation (NSF, Hirshkowitz et al., 2015; Ohayon et al., 2016). TIB and WASO%, not shown in the figure, are  $8.09 \pm 1.10$  hours and  $6.71 \pm 5.82$  %, respectively.

**TABLE 2 HERE**

**FIGURE 1 HERE**

### *Gender differences*

Males and females did not differ in age (M:  $32.7 \pm 10.7$  vs. F:  $32.3 \pm 12.4$ , Student's  $t = .163$ ,  $p = .871$ , Cohen's  $d = .036$ , 95%CI- = -0.40, 95%CI+ = 0.47), nor did gender differences emerge in PSQI global score or in any PSQI subscale (Table 3). Instead, men and women differed in several objective sleep parameters (Table 4), with men showing overall lower sleep quality as indexed by several variables.

**TABLE 3 HERE**



**TABLE 4 HERE***Effects of Daylight Saving Time*

As displayed in Table 5, all sleep schedule variables appeared delayed in subjects who participated in the study after DST compared to those whose recordings were collected before that date. No other actigraphic variable showed between-groups differences, except: sleep latency (before DST:  $8.24 \pm 4.07$  minutes vs. after DST:  $6.40 \pm 2.41$  minutes, Mann-Whitney's  $U = 410$ ,  $p = .038$ , effect size = .315), number of awakenings  $\geq 1$ min (before DST:  $11.81 \pm 5.95$  vs. after DST:  $15.60 \pm 5.89$ , Mann-Whitney's  $U = 373$ ,  $p = .013$ , effect size = .376) and frequency of awakenings  $\geq 1$ min/TSTh (before DST:  $1.67 \pm 0.94$  vs. after DST:  $2.16 \pm 0.86$ , Mann-Whitney's  $U = 384$ ,  $p = .019$ , effect size = .358).

**TABLE 5 HERE****Discussion**

This is the first study to address objective and subjective sleep features during the third wave of the Covid-19 pandemic. Actigraphic and PSQI data were collected from 82 healthy adults, during the lockdown imposed by the Italian government in March 2021 to confront the third wave of contagion.

Firstly, sleep schedules appear slightly delayed compared to what could be expected. In fact, we observed, through a longitudinal Italian survey, that sleep timing, initially delayed during the first pandemic wave (spring 2020), then linearly advanced when restrictions were lifted as well as through the second wave (autumn 2020) (Conte et al., 2021a). This trend suggested that sleep timing during the third wave would return to pre-pandemic levels, i.e., bedtimes between 23:00 and midnight, and wake times generally not exceeding 8:00 (Cellini et al., 2020a, 2021; Vitale et al., 2015). Instead, they were 00:33 and 8:33, respectively, in our sample, which more closely approximates what observed during the first lockdown (Ong et al., 2021; Cellini et al., 2020a, 2021). This appears surprising considering that the third lockdown was more similar to the second in terms of restrictions (which were looser relative to the first lockdown, with work routines partially recovered). However, we cannot exclude an effect of seasonal variations on sleep timing (e.g., Friberg et al., 2012), which would be congruent with the similarities between the first and third lockdown, or an effect of sample composition (differences in sleep timing between students, workers and unemployed individuals have been highlighted in several studies both before and during the pandemic, e.g., Cellini et al., 2020a, 2021).

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3 Instead, time in bed and sleep latency are coherent with the trend emerged in our  
4 longitudinal study (Conte et al., 2021a), in which an increase of these measures during the first  
5 lockdown (confirmed by other pandemic studies, e.g., Pepin et al., 2021; Cellini et al., 2021) was  
6 followed by a return to baseline in the second. Indeed, the duration of time in bed found here (8.09  
7 hours) is very similar to that reported by Italian surveys before the pandemic (Cellini et al., 2020a,  
8 2021) as well as during the second pandemic wave (Conte et al., 2021a). Also, sleep latency, which  
9 is less than 10 minutes, approximates that observed by pre-pandemic actigraphic studies (Tonetti et  
10 al., 2013; Cellini et al., 2020b) and is within the 15 minutes limit recommended by the NSF among  
11 “good sleep quality” features (Ohayon et al., 2016).  
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15 Concerning sleep amount, our participants displayed almost 8 hours of SPT and 7.22 hours  
16 of TST. These data are not easily comparable to self-report literature, considering that sleep  
17 duration is often underestimated (e.g., Jackson et al., 2018). As for objective data, although the few  
18 studies from the first wave were consistent on finding increased sleep duration with the lockdowns  
19 (Ong et al., 2021; Sañudo et al., 2020; Pepin et al., 2021), the total amount of sleep during the  
20 lockdown varies among studies from about 6.5 hours (Ong et al., 2021; Pepin et al., 2021) to more  
21 than 8 hours (Wang et al., 2021; Sañudo et al., 2020). Also, none of these studies provided  
22 operational definitions of their sleep duration measure, allowing to distinguish between TST and  
23 SPT. Nevertheless, our results on both measures suggest sufficient sleep duration in our sample  
24 according to the NSF’s 7-9 hours recommended range (Hirshkowitz et al., 2015), which confirms  
25 that sleep amount was relatively spared by the negative impact of the pandemic (Cellini et al., 2021;  
26 Wang et al., 2021; Ong et al., 2021). However, note that actigraphy tends to overestimate sleep and  
27 underestimate wakefulness (see, e.g., Goldstone et al., 2018).  
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31 Our results on subjective sleep quality confirm the trend observed in longitudinal surveys,  
32 which showed that its impairment remained high during the second lockdown (Salfi et al., 2021;  
33 Conte et al., 2021a). Indeed, average PSQI global score in our sample, though lower than that  
34 reported during the second wave (Salfi et al., 2021; Conte et al., 2021a), is higher than the cut-off  
35 for poor sleep (Buysse et al., 1989) and more than half of our participants are classified as poor  
36 sleepers.  
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40 These findings apparently contradict those on objective sleep quality. In fact, in line with  
41 objective sleep studies from the first wave (Wang et al. 2021; Sañudo et al., 2020; Ong et al., 2021;  
42 Pepin et al., 2021), we did not find a relevant impairment of classical sleep quality measures. As in  
43 Ong et al. (2021) and Pepin et al. (2021), sleep efficiency is within the recommended range (i.e.,  
44 above 85%, Ohayon et al., 2016). Wake after sleep onset time (31 minutes) shows liminal values,  
45 being slightly higher than that recommended by the NSF ( $\leq 20$  minutes, Ohayon et al., 2016), but  
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3 falls within the normal range when considering its percentage over SPT (Berger et al., 2005).  
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5 However, more specific sleep continuity measures reveal the presence of frankly disrupted sleep.  
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7 Indeed, the number of long awakenings ( $\geq 5$  minutes) exceeds the limit considered as indicative of  
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9 good sleep in adults (0 to 1 per night, Ohayon et al., 2016). Also, the total frequency of awakenings  
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11 lasting  $\geq 1$  minute is quite higher than that found in good sleepers (Conte et al., 2021b). Considering  
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13 previous literature pointing to number of awakenings as a main determinant of perceived sleep  
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15 quality (Della Monica et al., 2018; Conte et al., 2021b), the relevant sleep fragmentation observed  
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17 in our participants may also explain their poor sleep perception.

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18 Along the same line of reasoning, it may be hypothesized that the significant impairments of  
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20 subjective sleep quality widely reported during the first pandemic wave (Cellini et al., 2020a, 2021;  
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22 Casagrande et al., 2020) could have relied on the presence of subtle objective sleep quality  
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24 disruptions. These would have gone undetected by objective sleep assessments, performed during  
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26 the same period, which did not include fragmentation indices (Wang et al., 2021; Ong et al., 2021;  
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28 Sañudo et al., 2020; Pepin et al., 2021). To this regard, it is worth noting that, in our previous  
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30 longitudinal study, self-reported number of awakenings and their average duration showed a profile  
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32 of changes across the pandemic waves parallel to that of general subjective sleep quality (PSQI  
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34 global score), i.e., a significant worsening during the first lockdown, followed by a return to  
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36 baseline during the period with no restrictions and a renewed worsening during the second  
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38 lockdown (Conte et al., 2021a).

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37 Interestingly, gender differences emerged for most objective sleep variables. Women  
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39 showed earlier sleep schedules, stayed in bed and slept longer, displayed higher sleep efficiency,  
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41 lower WASO% and lower sleep fragmentation. In other words, despite the absence of gender  
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43 differences in subjective sleep quality, women slept much better than men (in line with findings  
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45 from a pre-pandemic actigraphic study on university students; Cellini et al., 2020b). Actually,  
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47 although the differences were non-significant, women's PSQI scores were even higher than men's  
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49 (both their global score and all but 2 sub-scores), in line with numerous studies pointing to female  
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51 gender as a risk factor for greater worsening of subjective sleep quality with the pandemic (e.g.,  
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53 Cellini, et al., 2021; Casagrande et al., 2020). This striking subjective/objective dissociation in  
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55 women is not surprising in light of pre-pandemic literature on sleep quality in the general  
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57 population. Indeed, as highlighted in Mong & Cusmano's review (2015), while women display  
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59 better PSG-defined sleep quality than men (e.g., Ohayon et al., 2004), they report disrupted and  
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61 insufficient sleep more frequently than men in a wide range of subjective studies (e.g., Groeger et  
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63 al., 2004). Therefore, our findings show that this general trend is still present during the pandemic,  
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65 and possibly is even exacerbated by it.

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3 Finally, our analysis of possible differences between actigraphic recordings collected before  
4 and after the introduction of DST revealed that sleep schedules were delayed of about an hour in  
5 subjects whose recordings were collected after the time change. Moreover, sleep latency was  
6 reduced in the latter group, possibly indicating increased sleepiness, whereas sleep fragmentation,  
7 as indexed by the number and frequency of brief awakenings, was increased. These findings are  
8 coherent with literature on the effects of spring transitions into DST (e.g., Tonetti et al., 2013) and  
9 suggest that the deterioration of the sleep/wake cycle linked to the third wave of the pandemic  
10 emergency may have been worsened by the concomitant transition into DST.  
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15 Our limited sample size and limited number of recording nights (compared to the minimum  
16 5 nights recommended by some authors, e.g., Aili et al., 2017) impose caution in interpreting our  
17 results. However, these caveats should be appraised in light of the numerous limitations imposed by  
18 the pandemic emergency. First, the unpredictability of changes in restrictions: since November  
19 2020, the Italian government started imposing lockdowns that were graded by severity according to  
20 regional case rates and changes in restrictions were announced with just a few days notice.  
21 Therefore, the planning phase of the research had to be conducted within this very brief time span.  
22 Indeed, our choice of a limited number of recording nights was specifically driven by this condition  
23 (i.e., once initiated, the end of the lockdown could not be predicted), balanced by the need to enroll  
24 a sufficiently numerous sample. Moreover, general fear of contagion significantly slowed down the  
25 recruitment process, despite the fact that procedures were conducted in strict accordance with health  
26 guidelines.  
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31 On the other hand, although our choice of using objective measurements unavoidably  
32 narrowed sample size, this methodology also represents the main strength of this research. In fact,  
33 unsurprisingly, very few studies have performed objective sleep assessments in previous phases of  
34 the pandemic. In addition, our in-depth evaluation of sleep fragmentation provides the first  
35 evidence, during the pandemic, of subtle sleep disruptions that could be masked by the appearance  
36 of general good sleep quality according to classical parameters (such as sleep efficiency). Indeed, it  
37 has been repeatedly proposed that more fine-grained analyses of sleep could be more adequate to  
38 evaluate its objective quality (Norman et al., 2006; Klerman et al., 2013).  
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43 In conclusion, our study contributes to describe the temporal profile of sleep across the  
44 different phases of this prolonged pandemic emergency. We highlight that, during the third wave,  
45 sleep is characterized by significant objective sleep fragmentation in the face of adequate sleep  
46 duration, suggesting a greater impoverishment of sleep quality than what could be expected from  
47 objective sleep studies conducted during the first wave. Taken together with sleep data on previous  
48 phases of the pandemic, our findings show that the detrimental effects on sleep determined by the  
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3 initial outbreak of the pandemic, with the abrupt implementation of strict confinement procedures,  
4 have not abated across the subsequent waves of contagion and related confinement periods. In this  
5 perspective, the recurrent and unpredictable periods of reinforced restrictions (and related social and  
6 financial costs), occurring over the course of the global health crisis, may be viewed as a form of  
7 “acute-on-chronic stress” (Gabrielli & Lund, 2020), with profound effects on sleep and well-being,  
8 which should be addressed by researchers, clinicians and politicians worldwide.  
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# High sleep fragmentation parallels poor subjective sleep quality during the third wave of the Covid-19 pandemic: an actigraphic study

Running Head: Sleep in the third wave of the Covid-19 pandemic

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### Abstract

Studies on sleep during the ~~the~~ Covid-19 pandemic have mostly been conducted during the first wave of contagion (spring 2020). To follow up on two Italian studies addressing subjective sleep features during the second wave (autumn 2020), here we assess sleep during the third wave (spring 2021) in a sample of healthy adults from Campania (Southern Italy).

Actigraphic data (on 2 nights) and the Pittsburgh Sleep Quality Index were collected from 82 participants (40 F, mean age:  $32.5 \pm 11.5$  years) from March 11<sup>th</sup> to April 18<sup>th</sup> 2021, when Campania was classified as “red zone”, i.e., it was subjected to strict restrictions, only slightly looser than those characterizing the first national lockdown (spring 2020).

Although objective sleep duration and architecture appeared in the normal range, the presence of disrupted sleep was indexed by a relevant degree of sleep fragmentation (number of awakenings  $\geq 1$  min:  $12.7 \pm 6.12$ ; number of awakenings  $\geq 5$  min:  $3.04 \pm 1.52$ ), paralleled by poor subjective sleep quality (PSQI global score:  $5.77 \pm 2.58$ ).

These data suggest that the relevant subjective sleep impairments reported during the first wave could have relied on subtle sleep disruptions which were undetected by the few objective sleep studies from the same period. Taken together with sleep data on previous phases of the pandemic, our findings show that the detrimental effects on sleep determined by the initial pandemic outbreak have not abated across the subsequent waves of contagion and highlight the need for interventions addressing sleep health in global emergencies.

**Key words:** Covid-19 pandemic, objective sleep quality, subjective sleep quality, sleep schedules, actigraphy

## 62 Introduction

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64 Early evidence from the Covid-19 crisis has shown wide-ranging disruptions to personal  
65 schedules, psychological health, and sleep throughout the world, with pooled data from  
66 international populations placing the prevalence of sleep problems at 35.7% (as reviewed in  
67 Jahrami et al., 2021).

68 During the first lockdown in Italy, individuals reported delayed sleep schedules, increased  
69 time in bed, and poorer sleep quality compared to before the lockdown (Cellini et al., 2020a, 2021;  
70 Gualano et al., 2020; Casagrande et al., 2020). Over 40% of an Italian sample reported sleep  
71 disturbances (Gualano et al., 2020) and 18% met criteria for a diagnosis of clinical insomnia  
72 (Bacaro et al., 2020). Taken alongside results from surveys conducted worldwide, it appears that  
73 there has been a global decline in sleep quality (Huang and Zhao, 2020; Kokou-Kpolou et al., 2020;  
74 Leone et al., 2020; Stanton et al., 2020; Voitsidis et al., 2020).

75 Two Italian surveys, conducted longitudinally across the first and second pandemic  
76 lockdowns (spring and autumn 2020, respectively), show that the impoverishment of sleep quality  
77 persisted through the waves of contagion (Salfi et al., 2021; Conte et al., [in press 2021a](#)). In Italy, in  
78 fact, the loosening of restrictions over the summer 2020 resulted in a second, larger wave of  
79 infections, to the point that another lockdown, though slightly less restrictive, was mandated in  
80 November 2020. Despite the effectiveness of these new measures, a third wave of contagion  
81 occurred toward the end of winter, so that most Italian regions underwent a third lockdown in  
82 March 2021.

83 Here we assess objective and subjective sleep features through actigraphic recordings and  
84 the Pittsburgh Sleep Quality Index (PSQI, Buysse et al., 1989), respectively, during the third Italian  
85 lockdown in a sample of healthy adults, in order to describe the longitudinal evolution of the  
86 pandemic's effects on sleep schedules and quality.

87 An additional aim is to specifically assess sleep fragmentation, which has been neglected in  
88 the few objective sleep studies from the first pandemic wave (Wang et al., 2021; Sañudo et al.,  
89 2020; Ong et al., 2021; Pepin et al., 2021). Indeed, these studies point to a milder impact of the  
90 pandemic on objective sleep quality than what suggested by the survey studies reviewed above: for  
91 instance, no changes in sleep efficiency or wake after sleep onset were found during the lockdowns  
92 (Ong et al., 2021; Pepin et al., 2021). Therefore, a more in-depth evaluation of sleep fragmentation  
93 measures, consistently reported as main determinants of perceived sleep quality (Della Monica et  
94 al., 2018; Conte et al., [20202021b](#)), could shed light on the discrepancy between subjective and  
95 objective assessments of sleep during the pandemic.

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3 96 Finally, we also address gender differences in subjective and objective sleep measures, in  
4 97 order to compare our findings with data collected during previous waves of the pandemic, which  
5 98 point to female gender as a risk factor for greater worsening of sleep quality with the Covid-19  
6 99 emergency (e.g., Cellini, et al., 2021; Casagrande et al., 2020).  
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## 13 102 **Materials and Methods**

### 14 103 15 104 *Participants and Procedure*

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17 105 The data collection phase was conducted from March 11<sup>th</sup> to April 18<sup>th</sup> 2021, i.e., when  
18 106 Campania, along with most other Italian regions, was considered a “red zone” according to the  
19 107 Governmental Decree of November 3<sup>rd</sup>, 2020. Since this decree, Italian regions are being classified  
20 108 as red, orange, yellow or white zones on a weekly basis, based on a set of risk parameters including  
21 109 the number of Covid-19 cases per inhabitant. “Red zones” are the areas considered at highest risk of  
22 110 contagion spread and thus subjected to the greatest restrictions: movements outside of home are not  
23 111 allowed except for basic necessities (related to work, health, grocery shopping, assistance), with the  
24 112 requirement to carry documentation of essential travel at all times; moving across municipalities is  
25 113 prohibited unless there are exceptional work- or health-related reasons. Only essential shops (such  
26 114 as pharmacies) are allowed to be open. Bars’ and restaurants’ services are limited to takeaway (until  
27 115 10 p.m.) and home delivery. Cinemas, theaters, museums and gyms are also closed. All in-presence  
28 116 activities of schools, universities and team sports are suspended; religious services may continue in  
29 117 strict accordance to social distancing norms.  
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34 118 This set of restrictions is very similar to that adopted during the first, national lockdown,  
35 119 which lasted throughout spring 2020, with the main difference being that limitations were  
36 120 somewhat more relaxed during the November and March “red zone” periods: a higher number of  
37 121 work activities requiring physical presence were possible, police controls were less strict and a few  
38 122 public events (such as some religious services) were allowed to be organized with social distancing  
39 123 precautions. The fact that most Italian regions showed a similar trend since November 2020 (with  
40 124 the implementation of “red zone” limitations for about a month in November-December 2020 and  
41 125 again in March-April 2021) allows to clearly identify, in Italy, a second and a third wave of  
42 126 contagion, based both on number of Covid-19 cases and on severity of restrictions, and to compare  
43 127 sleep data across the waves.  
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53 128 The recruitment phase was conducted along with data collection throughout the “red zone”  
54 129 period (March 11<sup>th</sup> to April 18<sup>th</sup>) and was ended as soon as the loosening of restrictions was  
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3 130 announced (i.e., Campania becoming an “orange zone”), in order to assure that all participants were  
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5 131 evaluated under the same conditions. Specifically, a convenience sample of 87 volunteers from the  
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7 132 metropolitan areas of Caserta and Napoli (Campania region, Italy) was screened through a brief  
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9 133 telephone interview, to collect general demographic data and information on medical conditions and  
10 134 health habits (including specific questions on somatic and psychiatric disorders, on sleep disorder  
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12 135 symptoms and on substance use). Inclusion criteria were: age 18-60 years; absence of any somatic  
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14 136 or psychiatric illness; absence of any sleep apnea, respiratory or movement disorder symptoms;  
15 137 having a regular sleep/wake cycle; no history of drug or alcohol abuse; limited consumption of  
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17 138 caffeine (no more than 150 mg caffeine per day, corresponding to about three cups of espresso or  
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19 139 one cup of American coffee) and alcohol (no more than 250 ml per day, i.e. about a pint of standard  
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21 140 beer, a full glass of wine, or a small liquor shot). Five volunteers had to be excluded because of:  
22 141 sleep apnea symptoms (1 subject), anxiety symptoms (2 subjects), regular consumption of caffeine  
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24 142 and/or alcohol exceeding the criterion limit (2 subjects). The final sample consisted of 82  
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26 143 participants (40 F, 48,78%; 42 M, 51,22%; age range: 18-56 years; mean age: 32.5 ± 11.5 years).

27 144 All participants signed an informed consent prior to participation and received no money or  
28  
29 145 credit compensation for their participation.

30  
31 146 Each subject wore an actigraph on his non-dominant wrist for about 40 hours (on weekdays  
32  
33 147 only): the actigraph was delivered in the afternoon and retrieved the morning after the second  
34 148 recording night. Participants were also requested to fill in the Italian version of the PSQI (Curcio et  
35  
36 149 al., 2013), as well as two sleep diaries (upon awakening on the morning after each night of  
37  
38 150 recording), and to maintain their regular sleep/wake habits during recording days.

39 151 The Ethical Committee of the Department of Psychology, University of Campania  
40  
41 152 “Vanvitelli”, approved the research protocol (code 15/2021) and certified that the involvement of  
42  
43 153 human participants was performed according to acceptable standards. All methods were carried out  
44  
45 154 in accordance with relevant guidelines and regulations.

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#### 47 48 156 *Actigraphic sleep analysis*

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50 157 The actigraphs were Motionlogger® Microwatches (Ambulatory Monitoring, Inc.). The  
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52 158 analysis of sleep data was performed on the two night periods, with a 30 seconds epoch time scale,  
53 159 by means of the Action-W 2 software, which uses the Cole-Kripke algorithm (Cole et al., 1992) to  
54  
55 160 extract sleep variables. The resting period (i.e., lights off/on times) was automatically defined by  
56  
57 161 the Action-W 2 software. Specifically, the variables we extracted were: bedtime (i.e., time at which  
58  
59 162 the subject goes to bed), rise time (i.e., time at which the subject rises from bed), sleep midpoint  
60 163 (i.e. midpoint between the first and the last epoch scored as sleep), time in bed (TIB, i.e., total

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3 164 amount of time from bedtime to rise time), ~~actual-total~~ sleep time (TAST, i.e., total amount of time  
4 165 spent in sleep), sleep onset latency (SOL, i.e., amount of time from bedtime to the first epoch  
5 166 scored as sleep), wake after sleep onset (WASO, i.e., total duration of wake between sleep onset  
6 167 and wake time), sleep efficiency (SE, i.e.,  $100 * \frac{TAST}{TIB}$ ), number of awakenings lasting  $\geq 1$   
7 168 minutes (i.e., number of blocks of at least 2 contiguous wake epochs), mean duration of  
8 169 awakenings, number of long awakenings (lasting  $\geq 5$  minutes), duration of longest awakening.

9 170 Further, from these automatically extracted variables we calculated: wake time (i.e., time of  
10 171 morning final awakening), ~~total~~-sleep period time (TSPT, i.e., total amount of time from the first  
11 172 epoch scored as sleep to wake time), wake after sleep onset percentage (WASO%, i.e., percentage  
12 173 of WASO over TSPT), frequency of awakenings lasting  $\geq 1$  minutes per hour of TAST,  
13 174 frequency of long awakenings (lasting  $\geq 5$  minutes) per hour of TAST.

### 14 175 15 176 *Data Analysis*

16 177 Descriptive statistics are reported as mean  $\pm$  standard deviation. ~~Actigraphic variables were~~  
17 178 ~~averaged between the two nights of recording.~~

18 179 In order to be able to pool data from the two nights of recording, we checked that actigraphic  
19 180 parameters did not significantly differ between the two nights. This was done using ~~To control that~~  
20 181 actigraphic parameters did not significantly differ between the two nights of recording, we used  
21 182 Student's t test for sleep schedule variables (bedtime, wake time, rise time and sleep midpoint) and  
22 183 Mann-Whitney's test for all other objective sleep parameters, which were not normally distributed  
23 184 (as assessed through the Shapiro-Wilk test).

24 185 Descriptive data on actigraphic variables are reported as average between the two nights of  
25 186 recording. Similarly, analyses of gender differences in actigraphic parameters were conducted on  
26 187 values averaged between the two nights.

27 188 Similarly, ~~G~~gender differences in age and sleep schedule variables were analyzed through  
28 189 Student's t test, whereas those in PSQI scores, objective sleep architecture and objective sleep  
29 190 fragmentation variables were evaluated through the Mann-Whitney test due to non-normal  
30 191 distribution.

31 192 Furthermore, to assess possible effects of Daylight Saving Time (DST, introduced on March  
32 193 28th), we analyzed differences in actigraphic variables (averaged between the two nights) between  
33 194 subjects who participated in the study before that date (n = 63; 34 F, 29 M; mean age:  $34.5 \pm 11.7$   
34 195 years) and those who participated afterwards (n = 19; 6 F, 13 M; mean age:  $25.7 \pm 7.72$  years).  
35 196 Sleep schedule measures were assessed through Student's t test, while sleep architecture and  
36 197 fragmentation variables were analyzed by means of the Mann-Whitney test.

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2  
3 198 Cohen's d and 95% Confidence Intervals are reported for parametric statistics and rank  
4  
5 199 biserial correlations for non-parametric tests.

6  
7 200 All analyses were performed by means of JAMOVI 1.6.16 (The Jamovi Project);  
8  
9 201 significance was set at  $p \leq 0.05$ .

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## 13 204 **Results**

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### 16 17 206 *Subjective sleep quality*

18  
19 207 Average PSQI global score was  $5.77 \pm 2.58$ , indicating a mild degree of poor subjective sleep  
20 208 quality. Specifically, 46.34% ( $n = 38$ ) of subjects were classified as good sleepers (PSQI score  $\leq 5$ ,  
21  
22 209 Buysse et al., 1989), and the remaining 53.66% ( $n = 44$ ) as poor sleepers (PSQI score  $> 5$ , Buysse et  
23  
24 210 al., 1989). Men and women are equally distributed between the two groups (good sleepers: 18 F, 20  
25 211 M; poor sleepers: 22 F, ~~18~~ 22 M). Scores at the PSQI subscales (range 0-3 for each subscale,  
26  
27 212 Buysse et al., 1989) are reported in Table 1.

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**TABLE 1 HERE**

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### *Objective sleep quality*

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36 217 No significant differences were found in any actigraphic sleep parameter between the two  
37  
38 218 nights of recording.

39 219 Descriptive data on sleep schedules and sleep fragmentation are reported in Table 2,  
40  
41 220 whereas Figure 1 displays sleep architecture variables, in reference to the values recommended for  
42  
43 221 each parameter by the National Sleep Foundation (NSF, Hirshkowitz et al., 2015; Ohayon et al.,  
44 222 2016). TIB and WASO%, not shown in the figure, are  $8.09 \pm 1.10$  hours and  $6.71 \pm 5.82$  %,  
45  
46 223 respectively.

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**TABLE 2 HERE**

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**FIGURE 1 HERE**

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### 56 229 *Gender differences in objective sleep measures*

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58 230 Males and females did not differ in age (M:  $32.7 \pm 10.7$  vs. F:  $32.3 \pm 12.4$ , Student's  $t = .163$ ,  
59  
60 231  $p = .871$ , Cohen's  $d = .036$ ,  $95\%CI^- = -0.40$ ,  $95\%CI^+ = 0.47$ ), nor did gender differences emerge  
232 in PSQI global score nor in any PSQI subscale (Table 3). Instead, men and women differed in

several objective sleep parameters (Table 4), with men showing overall lower sleep quality as indexed by several variables.

**TABLE 3 HERE**

**TABLE 4 HERE**

### Effects of Daylight Saving Time

As displayed in Table 5, all sleep schedule variables appeared delayed in subjects who participated in the study after DST compared to those whose recordings were collected before that date. No other actigraphic variable showed between-groups differences, except: sleep latency (before DST:  $8.24 \pm 4.07$  minutes vs. after DST:  $6.40 \pm 2.41$  minutes, Mann-Whitney's  $U = 410$ ,  $p = .038$ , effect size = .315), number of awakenings  $\geq 1$ min (before DST:  $11.81 \pm 5.95$  vs. after DST:  $15.60 \pm 5.89$ , Mann-Whitney's  $U = 373$ ,  $p = .013$ , effect size = .376) and frequency of awakenings  $\geq 1$ min/TSTh (before DST:  $1.67 \pm 0.94$  vs. after DST:  $2.16 \pm 0.86$ , Mann-Whitney's  $U = 384$ ,  $p = .019$ , effect size = .358).

**TABLE 5 HERE**

## Discussion

This is the first study to address objective and subjective sleep features during the third wave of the Covid-19 pandemic. Actigraphic and PSQI data were collected from 82 healthy adults, during the lockdown imposed by the Italian government in March 2021 to confront the third wave of contagion.

Firstly, sleep schedules appear slightly delayed compared to what could be expected. In fact, we observed, through a longitudinal Italian survey, that sleep timing, initially delayed during the first pandemic wave (spring 2020), then linearly advanced when restrictions were lifted as well as through the second wave (autumn 2020) (Conte et al., [in press 2021a](#)). This trend suggested that sleep timing during the third wave would return to pre-pandemic levels, i.e., bedtimes between 23:00 and midnight, and wake times generally not exceeding 8:00 (Cellini et al., 2020a, 2021; Vitale et al., 2015). Instead, they were 00:33 and 8:33, respectively, in our sample, which more closely approximates what observed during the first lockdown (Ong et al., 2021; Cellini et al., 2020a, 2021). This appears surprising considering that the third lockdown was more similar to the second in terms of restrictions (which were looser relative to the first lockdown, with work routines partially recovered). However, we cannot exclude an effect of seasonal variations on sleep timing

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(e.g., Friberg et al., 2012), which would be congruent with the similarities between the first and third lockdown, or an effect of sample composition (differences in sleep timing between students, workers and unemployed individuals have been highlighted in several studies both before and during the pandemic, e.g., Cellini et al., 2020a, 2021).

Instead, time in bed and sleep latency are coherent with the trend emerged in our longitudinal study (Conte et al., [in press 2021a](#)), in which an increase of these measures during the first lockdown (confirmed by other pandemic studies, e.g., Pepin et al., 2021; Cellini et al., 2021) was followed by a return to baseline in the second. Indeed, the duration of time in bed found here (8.09 hours) is very similar to that reported by Italian surveys before the pandemic (Cellini et al., 2020a, 2021) as well as during the second pandemic wave (Conte et al., [in press 2021a](#)). Also, sleep latency, which is less than 10 minutes, approximates that observed by pre-pandemic actigraphic studies (Tonetti et al., 2013; Cellini et al., 2020b) i.e., and is within the 15 minutes limit recommended by the NSF among “good sleep quality” features (Ohayon et al., 2016).

Concerning sleep amount, our participants displayed almost 8 hours of ~~TST~~-SPT and 7.22 hours of TAST. These data are not easily comparable to self-report literature, considering that sleep duration is often underestimated (e.g., Jackson et al., 2018). As for objective data, although the few studies from the first wave were consistent on finding increased sleep duration with the lockdowns (Ong et al., 2021; Sañudo et al., 2020; Pepin et al., 2021), the total amount of sleep during the lockdown varies among studies from about 6.5 hours (Ong et al., 2021; Pepin et al., 2021) to more than 8 hours (Wang et al., 2021; Sañudo et al., 2020). Also, none of these studies provided operational definitions of their sleep duration measure, allowing to distinguish between TAST and ~~SPT~~TST. Nevertheless, our results on both measures suggest sufficient sleep duration in our sample according to the NSF’s 7-9 hours recommended range (Hirshkowitz et al., 2015), which confirms that sleep amount was relatively spared by the negative impact of the pandemic (Cellini et al., 2021; Wang et al., 2021; Ong et al., 2021). However, note that actigraphy tends to overestimate sleep and underestimate wakefulness (see, e.g., Goldstone et al., 2018).

Our results on subjective sleep quality confirm the trend observed in longitudinal surveys, which showed that its impairment remained high during the second lockdown (Salfi et al., 2021; Conte et al., [in press 2021a](#)). Indeed, average PSQI global score in our sample, though lower than that reported during the second wave (Salfi et al., 2021; Conte et al., [in press 2021a](#)), is higher than the cut-off for poor sleep (Buysse et al., 1989) and more than half of our participants are classified as poor sleepers.

These findings apparently contradict those on objective sleep quality. In fact, in line with objective sleep studies from the first wave (Wang et al. 2021; Sañudo et al., 2020; Ong et al., 2021;



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3 302 Pepin et al., 2021), we did not find a relevant impairment of classical sleep quality measures. As in  
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5 303 Ong et al. (2021) and Pepin et al. (2021), sleep efficiency is within the recommended range (i.e.,  
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7 304 above 85%, Ohayon et al., 2016). Wake after sleep onset time (31 minutes) shows liminal values,  
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9 305 being slightly higher than that recommended by the NSF ( $\leq 20$  minutes, Ohayon et al., 2016), but  
10 306 falls within the normal range when considering its percentage over SPTST (Berger et al., 2005).  
11  
12 307 However, more specific sleep continuity measures reveal the presence of frankly disrupted sleep.  
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14 308 Indeed, the number of long awakenings ( $\geq 5$  minutes) exceeds the limit considered as indicative of  
15 309 good sleep in adults (0 to 1 per night, Ohayon et al., 2016). Also, the total frequency of awakenings  
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17 310 lasting  $\geq 1$  minute is quite higher than that found in good sleepers (Conte et al., 20202021b).  
18  
19 311 Considering previous literature pointing to number of awakenings as a main determinant of  
20  
21 312 perceived sleep quality (Della Monica et al., 2018; Conte et al., 20202021b), the relevant sleep  
22 313 fragmentation observed in our participants may also explain their poor sleep perception.

23  
24 314 Along the same line of reasoning, it may be hypothesized that the significant impairments of  
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26 315 subjective sleep quality widely reported during the first pandemic wave (Cellini et al., 2020a, 2021;  
27 316 Casagrande et al., 2020) could have relied on the presence of subtle objective sleep quality  
28  
29 317 disruptions. These would have gone undetected by objective sleep assessments, performed during  
30  
31 318 the same period, which did not include fragmentation indices (Wang et al., 2021; Ong et al., 2021;  
32  
33 319 Sañudo et al., 2020; Pepin et al., 2021). To this regard, it is worth noting that, in our previous  
34 320 longitudinal study, self-reported number of awakenings and their average duration showed a profile  
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36 321 of changes across the pandemic waves parallel to that of general subjective sleep quality (PSQI  
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38 322 global score), i.e., a significant worsening during the first lockdown, followed by a return to  
39  
40 323 baseline during the period with no restrictions and a renewed worsening during the second  
41 324 lockdown (Conte et al., in press2021a).

42  
43 325 Interestingly, gender differences emerged for most objective sleep variables. Women  
44  
45 326 showed earlier sleep schedules, stayed in bed and slept longer, displayed higher sleep efficiency,  
46  
47 327 lower WASO% and lower sleep fragmentation. In other words, despite the absence of gender  
48 328 differences in subjective sleep quality, women slept much better than men (in line with findings  
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50 329 from a pre-pandemic actigraphic study on university students; Cellini et al., 2020b). Actually,  
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52 330 although the differences were non-significant, women's PSQI scores were even higher than men's  
53 331 (both their global score and all but 2 sub-scores), in line with numerous studies pointing to female  
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55 332 gender as a risk factor for greater worsening of subjective sleep quality with the pandemic (e.g.,  
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57 333 Cellini, et al., 2021; Casagrande et al., 2020). This striking subjective/objective dissociation in  
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59 334 women is not surprising in light of pre-pandemic literature on sleep quality in the general  
60 335 population. Indeed, as highlighted in Mong & Cusmano's review (2015), while women display

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3 336 better PSG-defined sleep quality than men (e.g., Ohayon et al., 2004), they report disrupted and  
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5 337 insufficient sleep more frequently than men in a wide range of subjective studies (e.g., Groeger et  
6  
7 338 al., 2004). Therefore, our findings show that this general trend is still present during the pandemic,  
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9 339 and possibly is even exacerbated by it.

10 340 Finally, our analysis of possible differences between actigraphic recordings collected before  
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12 341 and after the introduction of DST revealed that sleep schedules were delayed of about an hour in  
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14 342 subjects whose recordings were collected after the time change. Moreover, sleep latency was  
15 343 reduced in the latter group, possibly indicating increased sleepiness, whereas sleep fragmentation,  
16  
17 344 as indexed by the number and frequency of brief awakenings, was increased. These findings are  
18  
19 345 coherent with literature on the effects of spring transitions into DST (e.g., Tonetti et al., 2013) and  
20 346 suggest that the deterioration of the sleep/wake cycle linked to the third wave of the pandemic  
21  
22 347 emergency may have been worsened by the concomitant transition into DST.

23  
24 348 Our limited sample size and limited number of recording nights (compared to the minimum  
25  
26 349 5 nights recommended by some authors, e.g., Aili et al., 2017) impose caution in interpreting our  
27 350 results. However, these caveats should be appraised in light of the numerous limitations imposed by  
28  
29 351 the pandemic emergency. First, the unpredictability of changes in restrictions: since November  
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31 352 2020, the Italian government started imposing lockdowns that were graded by severity according to  
32  
33 353 regional case rates and changes in restrictions were announced with just a few days notice.  
34 354 Therefore, the planning phase of the research had to be conducted within this very brief time span.  
35  
36 355 Indeed, our choice of a limited number of recording nights was specifically driven by this condition  
37  
38 356 (i.e., once initiated, the end of the lockdown could not be predicted), balanced by the need to enroll  
39 357 a sufficiently numerous sample. Moreover, general fear of contagion significantly slowed down the  
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41 358 recruitment process, despite the fact that procedures were conducted in strict accordance with health  
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43 359 guidelines.

44  
45 360 On the other hand, although our choice of using objective measurements unavoidably  
46 361 narrowed sample size, this methodology also represents the main strength of this research. In fact,  
47  
48 362 unsurprisingly, very few studies have performed objective sleep assessments in previous phases of  
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50 363 the pandemic. In addition, our in-depth evaluation of sleep fragmentation provides the first  
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52 364 evidence, during the pandemic, of subtle sleep disruptions that could be masked by the appearance  
53 365 of general good sleep quality according to classical parameters (such as sleep efficiency). Indeed, it  
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55 366 has been repeatedly proposed that more fine-grained analyses of sleep could be more adequate to  
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57 367 evaluate its objective quality (Norman et al., 2006; Klerman et al., 2013).

58 368 In conclusion, our study contributes to describe the temporal profile of sleep across the  
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60 369 different phases of this prolonged pandemic emergency. We highlight that, during the third wave,

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3 370 sleep is characterized by significant objective sleep fragmentation in the face of adequate sleep  
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5 371 duration, suggesting a greater impoverishment of sleep quality than what could be expected from  
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7 372 objective sleep studies conducted during the first wave. Taken together with sleep data on previous  
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9 373 phases of the pandemic, our findings show that the detrimental effects on sleep determined by the  
10 374 initial outbreak of the pandemic, with the abrupt implementation of strict confinement procedures,  
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12 375 have not abated across the subsequent waves of contagion and related confinement periods. In this  
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14 376 perspective, the recurrent and unpredictable periods of reinforced restrictions (and related social and  
15 377 financial costs), occurring over the course of the global health crisis, may be viewed as a form of  
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17 378 “acute-on-chronic stress” (Gabrielli & Lund, 2020), with profound effects on sleep and well-being,  
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19 379 which should be addressed by researchers, clinicians and politicians worldwide.

20 380  
21  
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## 24 383 25 384 26 385 27 386 28 387 29 388 30 389 31 390 32 391 33 392 34 393 35 394 36 395 37 396 38 397 39 398 40 399 41 400 42 401 43 402 44 403 45 404 46 405 47 406 48 407 49 408 50 409 51 410 52 411 53 412 54 413 55 414 56 415 57 416

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**Table 1.** Scores at PSQI subscales

| PSQI Subscales (m ± sd)  |             |
|--------------------------|-------------|
| Sleep Quality            | 1.24 ± 0.65 |
| Sleep Latency            | 1.17 ± 0.87 |
| Sleep Duration           | 0.65 ± 0.65 |
| Sleep Efficiency         | 0.73 ± 1.01 |
| Sleep Disturbances       | 1.16 ± 0.48 |
| Use of Sleep Medications | 0.04 ± 0.34 |
| Daytime Dysfunction      | 0.82 ± 1.16 |

Notes. Higher scores indicate worse sleep quality, longer sleep latency, shorter sleep duration, lower sleep efficiency, greater sleep disturbances, greater use of sleep medications, greater daytime dysfunction, respectively (Buysse et al., 1989).

**Table 2.** Actigraphic data on sleep schedules and sleep fragmentation

| <b>Sleep Schedules (m ± sd)</b>                   |              |
|---|--------------|
| Bedtime (hh:mm)                                   | 00:33 ± 1:36 |
| Wake Time (hh:mm)                                 | 08:33 ± 1:22 |
| Rise Time (hh:mm)                                 | 08:41 ± 1:19 |
| Sleep Midpoint (hh:mm)                            | 04:36 ± 1:21 |
| <b>Sleep Fragmentation (m ± sd)</b>               |              |
| Number of awakenings $\geq 1$ min                 | 12.7 ± 6.12  |
| Mean duration of awakenings $\geq 1$ min (min)    | 4.09 ± 2.72  |
| Frequency of awakenings $\geq 1$ min/TSTh         | 1.78 ± 0.94  |
| Number of long awakenings ( $\geq 5$ min)         | 3.04 ± 1.52  |
| Duration of longest awakening (min)               | 15.6 ± 9.22  |
| Frequency of long awakenings ( $\geq 5$ min)/TSTh | 0.46 ± 0.43  |

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**Table 3.** Gender differences in PSQI global score and sub-scores

| PSQI subscales          | Gender | m ± sd      | Mann-Whitney's U | p     | effect size |
|-------------------------|--------|-------------|------------------|-------|-------------|
| Sleep Quality           | M      | 1.19 ± 0.63 | 790              | .602  | .059        |
|                         | F      | 1.30 ± 0.68 |                  |       |             |
| Sleep Latency           | M      | 1.14 ± 0.89 | 802              | .713  | .045        |
|                         | F      | 1.20 ± 0.85 |                  |       |             |
| Sleep Duration          | M      | 0.66 ± 0.68 | 840              | 1.000 | .000        |
|                         | F      | 0.65 ± 0.62 |                  |       |             |
| Sleep Efficiency        | M      | 0.57 ± 0.88 | 712              | .183  | .152        |
|                         | F      | 0.90 ± 1.10 |                  |       |             |
| Sleep Disturbances      | M      | 1.21 ± 0.47 | 756              | .306  | .100        |
|                         | F      | 1.10 ± 0.49 |                  |       |             |
| Use of Sleep Medication | M      | 0.00 ± 0.00 | 798              | .150  | .050        |
|                         | F      | 0.10 ± 0.49 |                  |       |             |
| Daytime Dysfunction     | M      | 0.73 ± 0.73 | 831              | .927  | .013        |
|                         | F      | 0.92 ± 1.49 |                  |       |             |
| PSQI global score       | M      | 5.61 ± 2.54 | 814              | .812  | .031        |
|                         | F      | 5.92 ± 2.63 |                  |       |             |

Notes. Higher scores indicate worse sleep quality, longer sleep latency, shorter sleep duration, lower sleep efficiency, greater sleep disturbances, greater use of sleep medications, and greater daytime dysfunction, respectively (Buysse et al., 1989).



**Table 4.** Gender differences in objective sleep measures

| Sleep Schedules                           | Gender | m ± sd        | Student's T      | p               | effect size | 95%CI - | 95%CI + |
|---|--------|---------------|------------------|-----------------|-------------|---------|---------|
| Bedtime (hh:mm)                           | M      | 01:00 ± 1:45  | 2.76             | <b>.007</b>     | .728        | 0.15    | 1.37    |
|   | F      | 00:04 ± 1:17  |                  |                 |             |         |         |
| Wake time (hh:mm)                         | M      | 08:38 ± 1:22  | .577             | .565            | .128        | -0.25   | 0.46    |
|   | F      | 08:28 ± 1:22  |                  |                 |             |         |         |
| Rise time (hh:mm)                         | M      | 08:78 ± 1:21  | .596             | .553            | .132        | -0.24   | 0.45    |
|   | F      | 08:60 ± 1:19  |                  |                 |             |         |         |
| Sleep Midpoint (hh:mm)                    | M      | 04:53 ± 1:28  | 1.945            | .055            | .430        | -0.00   | 1.09    |
|   | F      | 04:19 ± 1:10  |                  |                 |             |         |         |
| Sleep Architecture                        | Gender | m ± sd        | Mann-Whitney's U | p               | effect size |         |         |
| Time in Bed (h)                           | M      | 7.46 ± 1.05   | 500              | <b>.002</b>     | .404        |         |         |
|   | F      | 8.34 ± 1.07   |                  |                 |             |         |         |
| Sleep Period Time (h)                     | M      | 7.30 ± 1.12   | 531              | <b>.004</b>     | .368        |         |         |
|   | F      | 8.17 ± 1.09   |                  |                 |             |         |         |
| Total Sleep Time (h)                      | M      | 6.53 ± 1.15   | 444              | <b>&lt;.001</b> | .472        |         |         |
|   | F      | 7.52 ± 1.06   |                  |                 |             |         |         |
| Sleep Onset Latency (min)                 | M      | 7.34 ± 2.47   | 808              | .769            | .038        |         |         |
|   | F      | 8.30 ± 4.45   |                  |                 |             |         |         |
| Sleep Efficiency (TST/TIB%)               | M      | 88.00 ± 10.13 | 600              | <b>.026</b>     | .285        |         |         |
|   | F      | 91.88 ± 4.15  |                  |                 |             |         |         |
| Wake After Sleep Onset (min)              | M      | 37.51 ± 28.20 | 631              | .053            | .248        |         |         |
|   | F      | 25.11 ± 18.61 |                  |                 |             |         |         |
| Wake After Sleep Onset (%)                | M      | 9.41 ± 7.01   | 572              | <b>.013</b>     | .313        |         |         |
|   | F      | 4.92 ± 3.52   |                  |                 |             |         |         |
| Sleep Fragmentation                       | Gender | m ± sd        | Mann-Whitney's U | p               | effect size |         |         |
| Number of awakenings ≥ 1 min              | M      | 13.50 ± 6.68  | 748              | .393            | .110        |         |         |
|   | F      | 11.85 ± 5.42  |                  |                 |             |         |         |
| Mean duration of awakenings ≥ 1 min (min) | M      | 4.41 ± 3.48   | 745              | .383            | .113        |         |         |
|   | F      | 3.75 ± 1.54   |                  |                 |             |         |         |
| Frequency of awakenings ≥ 1 min/TSTh      | M      | 2.03 ± 1.07   | 615              | <b>.037</b>     | .267        |         |         |
|   | F      | 1.51 ± 0.70   |                  |                 |             |         |         |
| Number of long awakenings (≥ 5 min)       | M      | 3.39 ± 1.62   | 622              | <b>.042</b>     | .259        |         |         |
|   | F      | 2.66 ± 1.33   |                  |                 |             |         |         |
| Duration of longest awakening (min)       | M      | 16.52 ± 10.80 | 808              | .770            | .038        |         |         |
|   | F      | 14.57 ± 7.21  |                  |                 |             |         |         |
| Frequency of long awakenings (≥ 5 min)    | M      | 0.56 ± 0.55   | 546              | <b>.006</b>     | .350        |         |         |
|   | F      | 0.34 ± 0.18   |                  |                 |             |         |         |

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Notes. Significant differences are in bold.

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**Table 5.** Differences in sleep schedules between subjects who participated in the study before Daylight Saving Time and those who participated afterwards

| Sleep Schedules        | Before/After DST | m ± sd       | Student's T | p           | effect size | 95%CI - | 95%CI + |
|------------------------|------------------|--------------|-------------|-------------|-------------|---------|---------|
| Bedtime (hh:mm)        | Before           | 00:21 ± 1:35 | -2.03       | <b>.050</b> | .400        | -1.38   | -0.00   |
|                        | After            | 01:11 ± 1:32 |             |             |             |         |         |
| Wake time (hh:mm)      | Before           | 08:20 ± 1:20 | -2.67       | <b>.011</b> | .699        | -1.22   | -0.16   |
|                        | After            | 09:16 ± 1:14 |             |             |             |         |         |
| Rise time (hh:mm)      | Before           | 08:28 ± 1:17 | -2.73       | <b>.009</b> | .714        | -1.24   | -0.18   |
|                        | After            | 09:23 ± 1:12 |             |             |             |         |         |
| Sleep Midpoint (hh:mm) | Before           | 04:24 ± 1:19 | -2.55       | <b>.016</b> | .669        | -1.19   | -0.14   |
|                        | After            | 05:15 ± 1:15 |             |             |             |         |         |

Notes. Significant differences are in bold. DST: Daylight Saving Time

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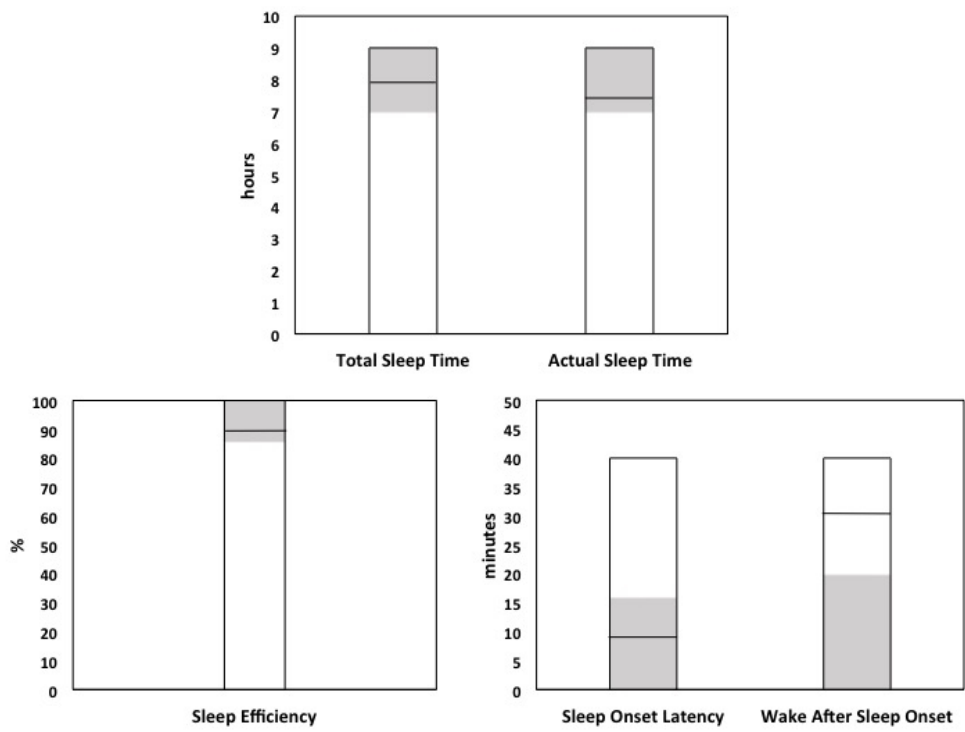


Figure 1. Objective sleep architecture parameters in our participants, in reference to values recommended by the National Sleep Foundation for each parameter. Grey areas represent recommended ranges for sleep duration (Hirshkowitz et al., 2015), sleep efficiency, sleep onset latency and wake after sleep onset (Ohayon et al., 2016). Black lines indicate the average value for each parameter observed in our sample.

254x190mm (72 x 72 DPI)

### Figure Legend

**Figure 1.** Objective sleep architecture parameters in our participants, in reference to values recommended by the National Sleep Foundation for each parameter. Grey areas represent recommended ranges for sleep duration (Hirshkowitz et al., 2015), sleep efficiency, sleep onset latency and wake after sleep onset (Ohayon et al., 2016). Black lines indicate the average value for each parameter observed in our sample.

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