Smartphone application-estimated sleep duration before and during COVID-19 in five major metropolitan areas on three different continents

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Abstract

Background: Public health officials have acted swiftly to curb the spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and associated coronavirus disease 2019 (COVID-19), often resulting in significant alterations to daily routines among the general population. Sleep deficiency adversely affects immune function and could negatively impact the course of COVID-19.

Objective: We examined changes to sleep episode duration in five major metropolitan areas before and after the start of the COVID-19 pandemic.

Methods: We conducted a prospective observational study using data from a smartphone-based sleep tracking software application. Data were obtained from regular users of the smartphone application before and after the World Health Organization declared COVID-19 a pandemic in March 2020. Sleep and wake times were used to calculate sleep episode duration. We compared sleep episode duration before and during COVID-19 using generalized linear mixed models.

Results: We analyzed 2.9 million sleep episodes. Among the nights analyzed, 34% were from those residing in London, 18% in Los Angeles, 30% in New York City, 9% in Seoul, and 9% in Stockholm. Overall, participants were 52% male and 48% female. Average age among the sample was 35 years (±11 years). Prior to COVID-19, those residing in Seoul had the shortest sleep episode duration (mean=6h15m±0.27m) and those residing in Stockholm and London had the longest sleep episode durations (mean=7h20m±0.25m and 7h17m±0.14m, respectively). The onset of the COVID-19 pandemic was associated with a 14.06m increase of sleep episode duration comparing March 2019 and March 2020 (95%CI: 13.35-14.77m, P <.001) and an increase of 22.31m comparing April 2019 and April 2020 (95%CI: 21.26-23.36m, P<.001).

Conclusions: Average sleep episode duration unexpectedly increased sharply in the months after the onset of the COVID-19 pandemic. These findings suggest that the implementation of COVID-19 mitigation strategies have provided people worldwide with an increased opportunity to sleep, which may itself enhance the response of the immune system to viral pathogens.

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Abstract

Background:
Amidst the coronavirus disease 2019 (COVID-19) pandemic, public health policies to curb the spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and associated COVID-19, have resulted in significant alterations to daily routines (e.g., work-from-home policies) that may have allowed for longer sleep duration among the general population.

Objective:
We examined changes in estimated sleep duration in five major metropolitan areas before and after the start of the COVID-19 pandemic.

Methods:
We conducted a prospective observational study using estimated sleep duration data from a smartphone application. Data were obtained from regular users of the smartphone application before and after the World Health Organization declared COVID-19 a pandemic in March 2020. We compared within subject estimated sleep duration before and during COVID-19 using generalized linear mixed models.

Results:
Among the data: 957,022 out of 2,871,037 observations (33%) were from users in London; 549,151observations (19%) were from users in Los Angeles; 846,527 (30%) were from users in New York City, 251,113 (9%) were from users in Seoul; and 267,224 (9%) were from users in Stockholm. Average age among the sample was 35 years (±11 years). Prior to COVID-19, those residing in Seoul had the shortest estimated sleep duration (mean= 6h28m ±11.6m) and those residing in Stockholm had the longest estimated sleep duration (mean= 7h34m ± 9.9m). The onset of the COVID-19 pandemic was associated with a 13.7m increase of estimated sleep duration comparing March 2019 and March 2020 (95%CI: 13.1-14.3m, *P* <.001) and an increase of 22.3m comparing April 2019 and April 2020 (95%CI: 21.5-23.1m, *P*<.001).

Conclusions:
Average estimated sleep duration increased sharply in the months after the onset of the COVID-19 pandemic. This finding suggests that the implementation of COVID-19 mitigation strategies have provided people worldwide with an increased opportunity to sleep, which may enhance the response of the immune system to viral pathogens.

Keywords:
Sleep health, immune system, sleep tracking, mobile health

Introduction

Public health officials have acted dramatically to curb the spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and associated coronavirus disease 2019 (COVID-19). In some regions, actions to mitigate COVID-19 have been drastic, such as mandatory shelter-in-place regulations, while others have been more lenient. In either case, life has changed markedly for the much of our global population.

Research conducted amidst crises of similar magnitude to COVID-19 has shown that sleep is disrupted during and after such events [1–4]. For instance, research conducted after the 2003 SARS outbreak in China demonstrated an increase in insomnia symptoms associated with the onset of the outbreak [3]. In the context of a natural disaster, researchers found that 40% of those who survived an earthquake in Japan reported sleep difficulties in the years following the disaster and 8% reported short sleep duration [5]. Although previous literature would suggest sleep duration is likely to decline, there are several reasons sleep duration may increase across the globe during COVID-19. First, due to the highly contagious nature of COVID-19 and lack of a vaccine, social distancing and work-from-home recommendations and policies have been widely implemented to curb the spread of the virus [6]. As much of the global population spent less time commuting, more time at home, and less time socializing, it could be that their sleep duration increased, as opposed to decreased as has been observed among previous crises.

Sleep is a critical element of immune system function [7,8]. Experimental studies have shown that inadequate sleep results in increased susceptibility to viral infection [9,10]. Research has also shown a heightened ability to mount an immune response among those who obtain a healthy, sufficient duration of sleep (i.e, 7 to 9 hours) [11–13]. As the COVID-19 pandemic unfolds, surveillance of sleep duration may be important in order to identify poor sleep practices, and to develop evidence-based interventions and campaigns to enhance sleep in response to this crisis as necessary. To further our understanding of sleep during the COVID-19 pandemic, we analyzed smartphone estimated sleep durations from individuals residing in London, England; Los Angeles, California, United States; New York City, New York, United States; Seoul, South Korea; and Stockholm, Sweden before (January 2019 through April 2019) and after the onset of the COVID-19 pandemic (January 2020 to April 2020).

Methods

Participants

We conducted a prospective observational study using data obtained from the smartphone-based sleep tracking software application SleepCycle™. We obtained data from regular users of the application who tracked sleep on 80% (374 out of 468 days) or more of the days between January 1, 2019 and April 12, 2020. To understand geographic variation in sleep amidst the COVID-19 pandemic, we obtained data from individuals living in five major metropolitan areas (London, Los Angeles, New York City, Seoul, and Stockholm).

The selection of geographical regions was guided by several factors. First, urban regions were included in this study as there is lower density of users in rural regions, which could have hindered comparison between rural and urban regions. Second, there were interesting differences in COVID-19 prevalence, preparedness, and mitigation strategies from one geographic region to the next. For instance, Sweden did not limit social mobility among its residents as strictly as other regions, such as the US. Additionally, South Korea had experience combatting a pandemic from the 2003 SARS outbreak. Therefore, we requested data from large urban centers on three different continents with the hope of exploring different patterns in estimated sleep duration from country to country that may be reflective in part of different prevalence, preparedness, or mitigation strategies implemented in these various countries.

The application logs a participant's place of residence by the coordinates identified by their smartphone global positioning system which participants agree to provide when using the application. Only users who agreed to SleepCycle™'s privacy policy, which dictates that data may be used for research purposes, were included in the dataset.

Estimated sleep duration

Users open the application when they get in bed and first attempt to sleep, either place their smartphone next to their bed or on their mattress, then close the app either after the built-in alarm clock wakes them or they wake naturally from sleep. Sleep is calculated by the application as the time interval between these two digital sleep diary events (first attempt to sleep and waking) [14], in accordance with the 2016 Consumer Technology Association standards for wearable sleep monitors [15], herein termed "estimated sleep duration." We obtained an anonymized dataset which included dated estimated sleep durations for each user between January 1, 2019 and April 12, 2020. The dataset was comprised of 2,974,922 observations. We removed observations with a duration shorter than 1 hour from the dataset to mitigate the impact of napping on estimated sleep duration. These shorter observations represented 3.5% of the sample (103,885 out of 2,974,922 observations). Removal of these shorter observations resulted in a final dataset with 2,871,037 observations for analysis.

Statistical analyses

Descriptive statistics were used to characterize demographic characteristics of the sample. To evaluate population-level changes in estimated sleep duration during the COVID-19 pandemic, while accounting for established seasonal variation, we compared estimated sleep duration by geographic location in the same calendar month between years using generalized linear mixed models. This method included hierarchical random effects for city and study participant which accounted for the dependence between repeated measures and the clustering of respondents in each location. This design enabled us to compare estimated sleep duration over time before and after COVID-19 (e.g., March 2019 versus March 2020) in each geographic location. All analyses were performed in Stata Statistical Software for Mac Version 16 (College Station, TX, USA).

Results

In total, 2,871,037 nights from 8,218 unique users between January 1, 2019 and April 12, 2020 were available for analysis. Of the estimated sleep durations analyzed: 957,022 (33%) were from London; 549,151 (18%) were from Los Angeles; 846,527 (30%) were from New York City, 251,113 (9%) were from Seoul; and 267,224 (9%) were from Stockholm. Average age of users in the sample was 35 years. Prior to the COVID-19 pandemic, those residing in Seoul had the shortest average estimated sleep duration (mean=6h28m ±11.6m) and those residing in Stockholm had the longest average estimated sleep duration (mean=7h34m ± 9.9m); the average estimated sleep durations were 7h32m ± 5.5m in London, 7h21m ± 8.4m in Los Angeles and 7h22m ±6.3m in New York City. Table 1 displays descriptive demographic and estimated sleep duration characteristics by city prior to COVID-19.

Table 1. Descriptive statistics summarizing descriptive statistics and sleep by city prior to COVID-19.

	London		
	N=957,022 nights		
		95% CI	

	Mean or %	***Lower***	***Upper***	***SE***
Age (years)	34.4	34.3	34.4	0.0
Gender				
Male	53.5%	53.4%	53.6%	0.0%
Female	45.8%	45.7%	45.9%	0.1%
Estimated Sleep Duration	7h32m	7h32m	7h33m	5.5m
	Los Angeles			
	N=549,151 nights			
		95% CI		
	Mean or %	***Lower***	***Upper***	***SE***
Age (years)	36.0	36.1	36.1	0.02
Gender				
Male	54.2%	54.0%	54.3%	1.0%
Female	45.9%	45.7%	46.0%	1.0%
Estimated Sleep Duration	7h21m	7h21m	7h22m	8.4m
	New York			
	N=846,527 nights			
		95% CI		
	Mean or %	***Lower***	***Upper***	***SE***
Age (years)	35.0	34.9	35.1	0.0
Gender				
Male	50.2%	50.1%	50.3%	5.0%
Female	49.5%	49.4%	49.6%	0.4%
Estimated Sleep Duration	7h22m	7h22m	7h22m	6.3m
	Seoul			
	N=251,113 nights			
		95% CI		
	Mean or %	***Lower***	***Upper***	***SE***
Age (years)	33.8	33.8	33.8	0.0
Gender				
Male	60.6%	60.5%	60.8%	0.1%
Female	39.4%	39.2%	39.5%	0.1%
Estimated Sleep Duration	6h28m	6h28m	6h28m	11.6m
	Stockholm			
	N=267,224 nights			
		95% CI		
	Mean or %	***Lower***	***Upper***	***SE***
Age (years)	40.7	40.7	40.8	0.0
Gender				
Male	52.3%	52.1%	52.4%	0.9%
Female	47.7%	47.6%	47.9%	0.9%
Estimated Sleep Duration	7h34m	7h33m	7h34m	9.9m

As shown in Figures 1 and 2, there was an increase in estimated sleep duration starting in February 2020 as compared to February 2019, which coincided with the onset of the COVID-19 pandemic in five cities across three continents.

(Figure 1)

(Figure 2)

Results from the generalized linear mixed models are displayed in Figures 3 through 8. As shown in Figure 3, estimated sleep duration increased after the onset of COVID-19 in the total sample. In the total sample, comparing January 2019 to January 2020, we observed increases of 4.9m of estimated sleep duration (95%CI: 4.3-5.5m, *P* <.001); comparing February 2019 to February 2020, we observed increases of 5.2m of estimated sleep duration (95%CI: 4.81-5.91m, *P* <.001); comparing March 2019 to March 2020, we observed increases of 13.7m of estimated sleep duration (95%CI: 13.1-14.3m, *P* <.001); and when comparing April 2019 to April 2020 we observed increases of 22.3m of estimated sleep duration (95%CI: 21.5-23.2m, *P* <.001, Figure 3).

(Figure 3)

Models examining estimated sleep duration after COVID-19 by city are displayed in Figures 4 through 9. Seoul had the smallest increase comparing April 2019 and April 2020 (12.2m, 95%CI: 9.5-14.4m, *P* <.001), while New York had the largest (24.5m, 95%CI: 23.1-25.9m, *P* <.001), followed by London (20.8m, 95%CI: 19.5-22.1m , *P* <.001).

(Figure 4)

(Figure 5)

(Figure 6)

(Figure 7)

(Figure 8)

Discussion

These results demonstrate—using 2.9 million nightly recordings of smartphone-estimated sleep duration—an abrupt, significant increase in estimated sleep duration in the months after COVID-19 was declared a pandemic and international health crisis by the World Health Organization [16] compared with matched months from the same individuals in the prior year. Further, estimated sleep duration in several regions was at or below the lower range of the recommendation for healthy sleep before the pandemic (i.e., 7 hours or less), yet increased to be within the range for healthy, sufficient sleep amidst the onset of the COVID-19 pandemic. Our data, gathered from a daily sleep tracker smartphone application, reveal that on average there has been a significant increase in estimated sleep duration in London, Los Angeles, New York City, Seoul, and Stockholm concomitant with the onset of the COVID-19 pandemic, consistent with data from subjective, retrospective self-reports among 425 adults in three European countries [17]. We hypothesize that this increase in smartphone-estimated sleep duration, together with the recently reported increase in sleep/wake time regularity following the onset of the COVID-19 pandemic [18], have occurred as a consequence of stay-at-home orders, non-essential business closures, and work-from-home policies implemented to slow community spread of the infection. Sufficient sleep duration is a critical element of immune system functioning, with inadequate sleep resulting in increased susceptibility to viral infection and reduced antibody production after vaccination [7,8]. We cannot exclude the possibility that individuals in this study were experiencing longer time in bed as opposed to longer estimated sleep duration. Nevertheless, if the observed increase in estimated sleep duration, as detected by the app, in fact represents an increase in actual sleep amidst the COVID-19 pandemic, this may be have been an important factor in reducing the risk of progression to COVID-19 following exposure to SARS-CoV-2 [9,10], and in enhancing the ability of those with COVID-19 to mount an effective immune response [11,12].

Additionally, we detected notable differences in sleep by geographic region. Average estimated sleep duration prior to COVID-19 of those in Seoul was over one hour shorter than those in London and Stockholm and over 40 minutes shorter than those in New York City and Los Angeles. This could be explained by previous research which has documented that sleep deprivation is common in South Korea [19,20]. Moreover, those in Seoul also demonstrated the smallest increase in estimated sleep duration during the COVID-19 era at 11 minutes per night compared to the increases of 20 minutes in other cities. The smaller increase in Seoul compared to other cities could be explained by the outbreak of SARS in South Korea in 2003, which perhaps afforded an opportunity for the country to prepare and contain the spread of the virus without the more drastic mitigation measures, such as extended stay-at-home regulations, that were levied in other countries. Further, as the increase was very small it is also possible that this was natural month-to-month variation as opposed to trending in the direction of increased sleep duration as observed in the other cities. Although Sweden did not institute the stringent COVID-19 containment measures other countries chose to enact (e.g., shelter-in-place policies), estimated sleep duration increased in Stockholm at a rate similar to other regions that did institute stringent containment policies. This may reflect that those residing in Stockholm are following similar precautions as others around the world despite not being restricted to their homes. Finally, the observed increase in estimated sleep duration in New York City of more than 20 minutes could be explained in part by the high number of cases of COVID-19 in New York City and associated strict stay-at-home policies.

The increase in the duration of estimated sleep duration observed in this study in response to COVID-19 of between 12 and 24 minutes is of similar magnitude to the approximate 25 minute increase in total sleep time induced by zolpidem CR [21]. Thus, the COVID-19 mitigation policies are associated with an increase in estimated sleep duration comparable to the impact of a hypnotic medication. This may be clinically important, as sleep deficiency – which is highly prevalent in developed countries – increases susceptibility to viral infection and diminishes the immune response to vaccination [9,10].

While we detected an increase in estimated sleep duration after the onset of COVID-19 in several different metropolitan areas, the amount of sleep disturbance may have changed after the onset of the pandemic. Previous research has shown that sleep quality has suffered in the face of major crises [1]. Specifically, research has documented a significant increase in sleep difficulty and arousals from sleep amidst the 2003 SARS outbreak [3], the bombings in Israel during the Persian Gulf War [2], and in the aftermath of natural disasters [4,5], consistent with the reported increase in self-reported insomnia symptoms in Wuhan, China at the start of the COVID-19 pandemic [22]. Our data indicating an increase in the estimated sleep duration do not preclude the possibility that more people were suffering from disturbed sleep. Additional studies administering validated questionnaires assessing insomnia symptoms as well as self-reported sleep quality would be required to address this question.

Limitations and Future Research

This study is subject to a number of limitations. (1) While a strength of our study is the large number of respondents offering user-generated sleep data over time and across several geographic regions, a limitation is that we do not have data pertaining to sleep latency, awakenings from sleep, or time in bed after waking. (2) Although users do not commonly use the application for napping, we removed observations that were shorter than 60 minutes. Future research may examine naps and how these behaviors changed due to COVID-19 and its mitigation strategies. Further, we did not have access to sleep timing data, which would have been useful in understanding whether users were going to sleep earlier or sleeping later as a result of COVID-19. (3) Employment or income demographics, which are not collected by SleepCycle™, may represent unmeasured, confounding variables in our study. For instance, individuals from higher socioeconomic brackets were more likely to remain employed and working from home during COVID-19 [23]. Those who were furloughed or remained employed and were allowed to work from home may have had more flexible work hours and spent significantly less time commuting, allowing them to spend more time in bed [24]. Moreover, with the proliferation of low-cost delivery services (e.g., food and other goods) in major urban centers, those able to work from home may have had increased available time for sleep [25]. These results may therefore not generalize to those working essential jobs whose work hours and commuting time may have increased during the COVID-19 pandemic and who may be underrepresented in this sample. (4) The sleep tracker smartphone application is not validated and because it does not account for wake after sleep onset, it is possible that the tracker overestimates sleep duration. (5) Those who download and use the sleep tracker smartphone application may be more interested in sleep and health, in general, which may present selection bias and less generalizability to the general public.

Our study identifies several avenues for future research; some reflect the limitations of the application. First, it is important to explore whether the finding we observed is transient or persists for an extended period and whether other aspects of sleep that have changed amidst COVID-19. Second, data from the SleepCycle™ application should be validated using objective measures, such as polysomnography or actigraphy. Third, it would be informative to determine the prevalence of sleep disturbance or insomnia symptoms, such as difficulty falling asleep or difficulty maintaining sleep, among users of this application. Finally, an exploratory qualitative investigation with users of

SleepCycle™ may help to determine if actual sleep duration in fact increased during COVID-19 or if users experienced more sleep difficulties, despite having an increase in time-in-bed.

Conclusion

Public officials' policies to mitigate the COVID-19 pandemic have required profound changes to daily routines across the globe. Using 2.9 million nights of objectively recorded sleep on three continents via a sleep tracking smartphone application, we observed an abrupt, significant increase in average estimated sleep duration among 8,218 unique users in all five cities in the months after the onset of the COVID-19 pandemic. Thus, not only have COVID-19 mitigation strategies reduced the potential of infection with the novel coronavirus, but the resulting increase in sleep episode duration may also have improved the ability of the immune system to resist infection. Future research should explore whether this observation is transient or persists over the long term and whether other aspects of sleep have changed amidst COVID-19.

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Conflicts of Interest

Authors disclose all industry relationships below, in accordance with ICMJE recommendations:

Dr. Robbins has received fees from Denihan Hospitality, Rituals Cosmetics, Dagmejan, Asystem, and SleepCycle.

Dr. Quan reports personal fees from Jazz Pharmaceuticals and Best Doctors, and is a consultant to Whispersom.

Dr. Weaver reports support from grants from NIOSH and the Brigham Research Institute, and fees from the National Sleep Foundation and the University of Pittsburgh.

Mr. Czeisler reports personal fees from Vanda Pharmaceuticals and grants from Australian-American Fulbright Commission.

Dr. Barger reports consulting fees from University of Pittsburgh, Sygma, Insight and Puget Sound Pilots.

Dr. Czeisler reports grants to BWH from NHLBI, NIA, NIOSH, and DOD; is/was a paid consultant to Bose, Boston Celtics, Boston Red Sox, Cephalon, Institute of Digital Media and Child Development, Klarman Family Foundation, Jazz Pharma, Merck, Purdue Pharma, Samsung, Teva Pharma Australia, AARP, American Academy of Dental Sleep Medicine, Eisenhower Medical Center, M. Davis and Company, Physician's Seal, UC San Diego, University of Washington, University of Michigan, Maryland Sleep Society, National Sleep Foundation, Sleep Research Society, Tencent, and Vanda Pharmaceuticals, in which Dr. Czeisler also holds an equity interest; receives research/education support through BWH from Cephalon, Mary Ann & Stanley Snider via Combined Jewish Philanthropies, NFL Charities, Jazz Pharmaceuticals Plc Inc, Philips Respironics Inc, Regeneron Pharmaceuticals, Teva Pharmaceuticals Industries Ltd, Sanofi SA, Optum, ResMed, San Francisco Bar Pilots, Sanofi, Schneider, Simmons, Sysco, Philips, Vanda Pharmaceuticals; is/was an expert witness in legal cases, including those involving Advanced Power Technologies, Alvarado Hospital, LLC, Amtrak; Bombardier, Inc., C&J Energy Services; Casper Sleep, Inc., Columbia River Bar Pilots, Complete General Construction Company, Dallas Police Department, Delta Airlines/Comair, Enterprise Rent-A-Car, Fédération des Médecins Résidents du Québec

(FMRQ), FedEx, Greyhound Lines, Inc./Motor Coach Industries/FirstGroup America, H.G. Energy LLC, Maricopa County, Arizona, Sheriff's Office, Murrieta Valley Unified School District, Pomerado Hospital, Palomar Health District, Puckett EMS, Purdue Pharma, South Carolina Central Railroad Company, LLC., Steel Warehouse, Inc., Union Pacific Railroad, United Parcel Service, and Vanda Pharmaceuticals; serves as the incumbent of an endowed professorship provided to Harvard University by Cephalon, Inc.; and receives royalties from McGraw Hill, and Philips Respironics for the Actiwatch-2 & Actiwatch Spectrum devices. Dr. Czeisler's interests were reviewed and are managed by Brigham and Women's Hospital and Partners HealthCare in accordance with their conflict of interest policies.

Abbreviations

SARS: Severe acute respiratory syndrome

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2

COVID-19: Coronavirus disease 2019

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Supplementary Files

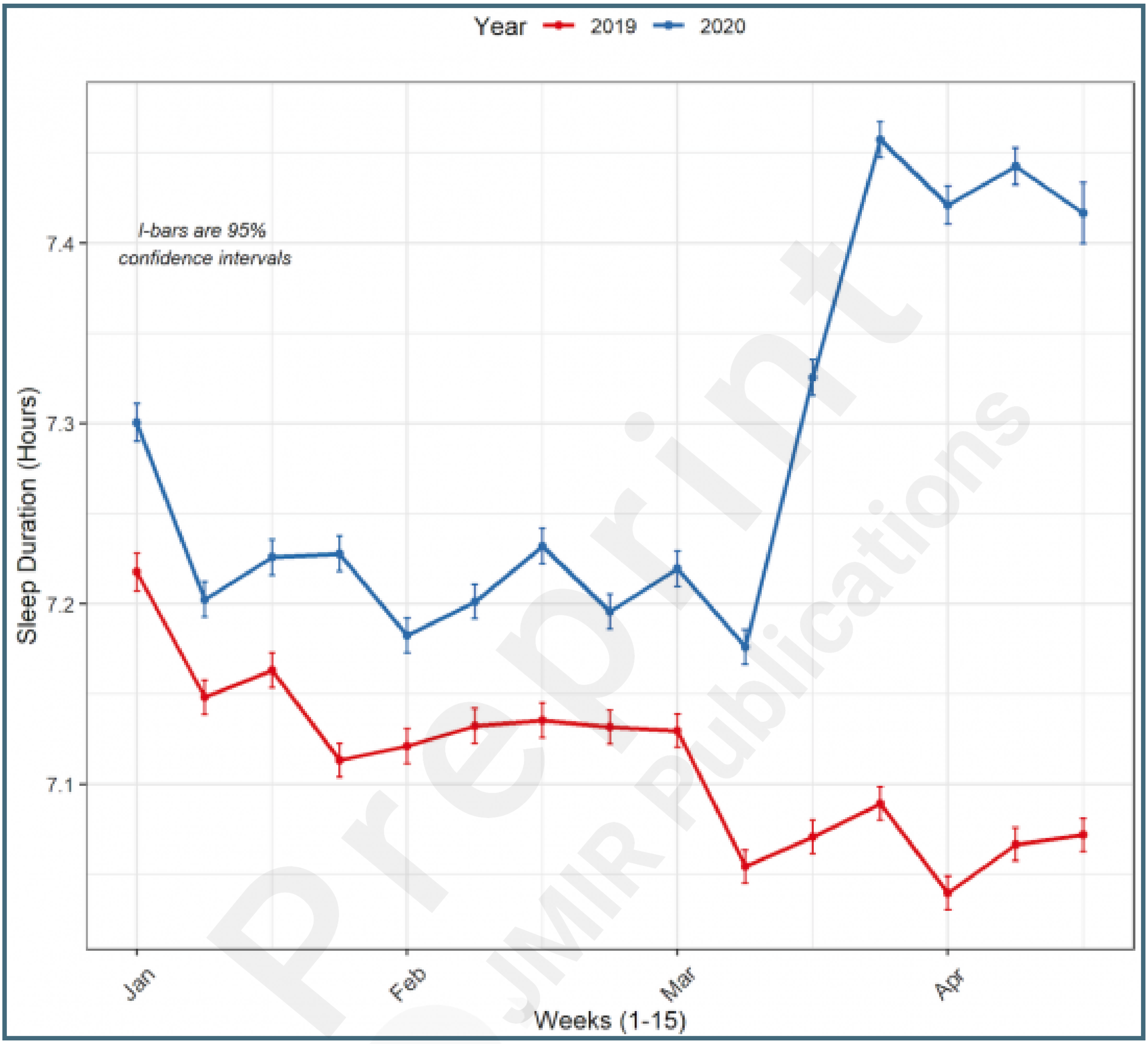
The Revised Manuscript (Revision B) - Track Changes.
URL: https://asset.jmir.pub/assets/57a9ba8a0ff88d59dfd27c174bd6a105.docx

Response to Reviewers.
URL: https://asset.jmir.pub/assets/f4ffa91d88d1fa6e0cc9648a1cc834cc.docx

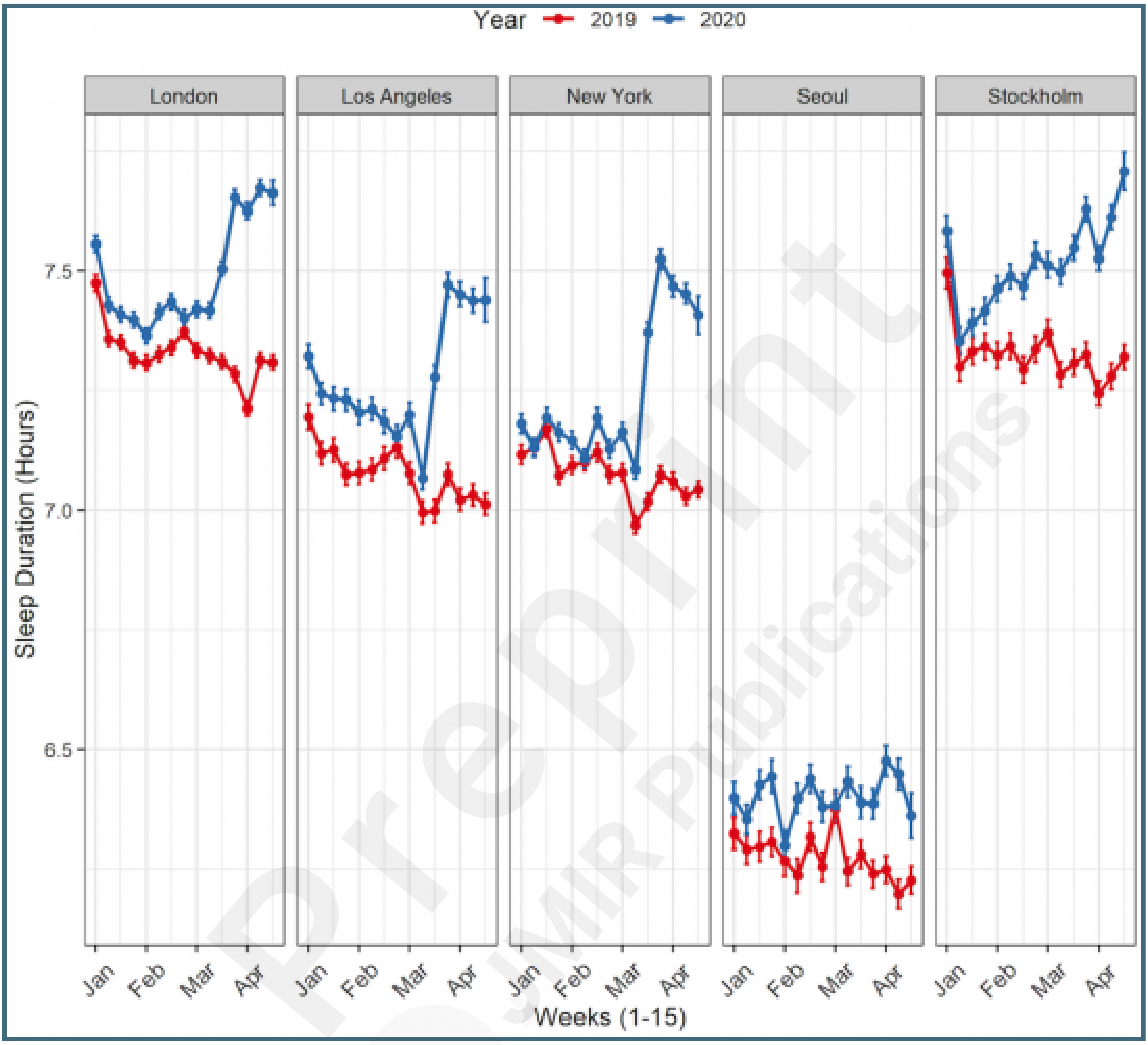
CLEAN Version of the Revised Manuscript.
URL: https://asset.jmir.pub/assets/1e4a154556e816b54d59e52d25b478f5.docx

Figures

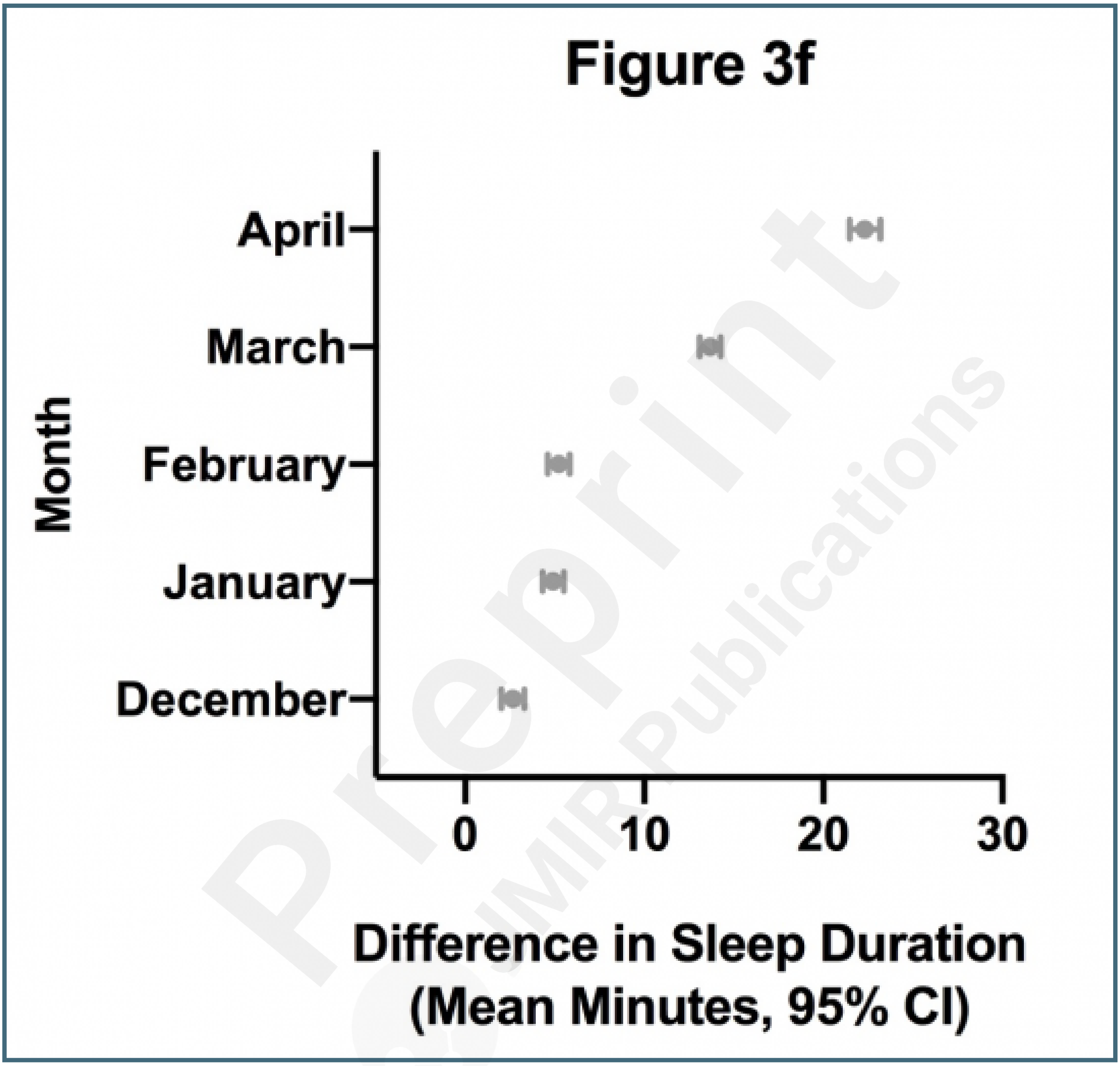
Sleep duration by months (January to April) in 2019 and in 2020 for the total sample.



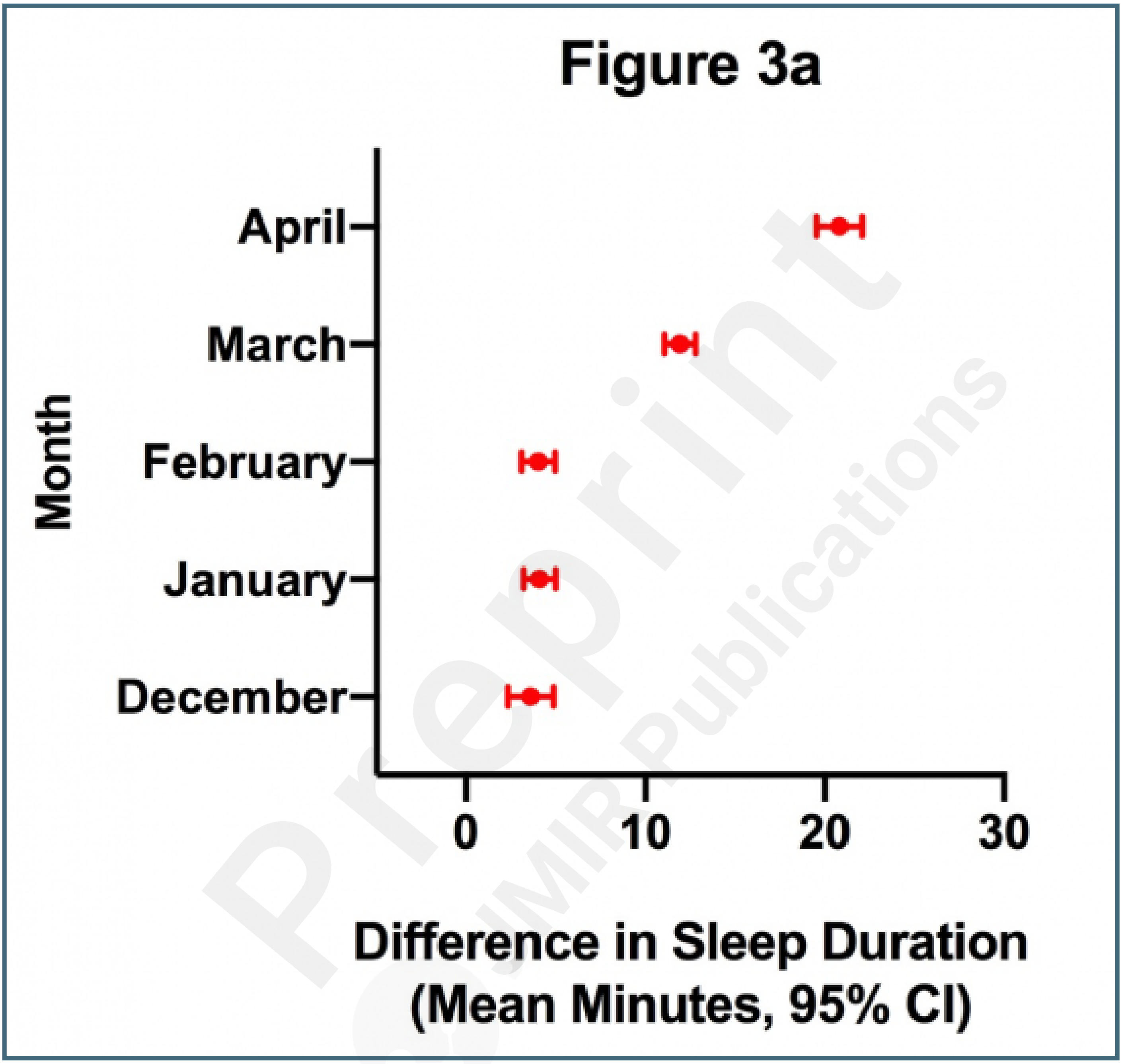
Sleep duration by months (January to April) in 2019 and in 2020 for the total sample by city.



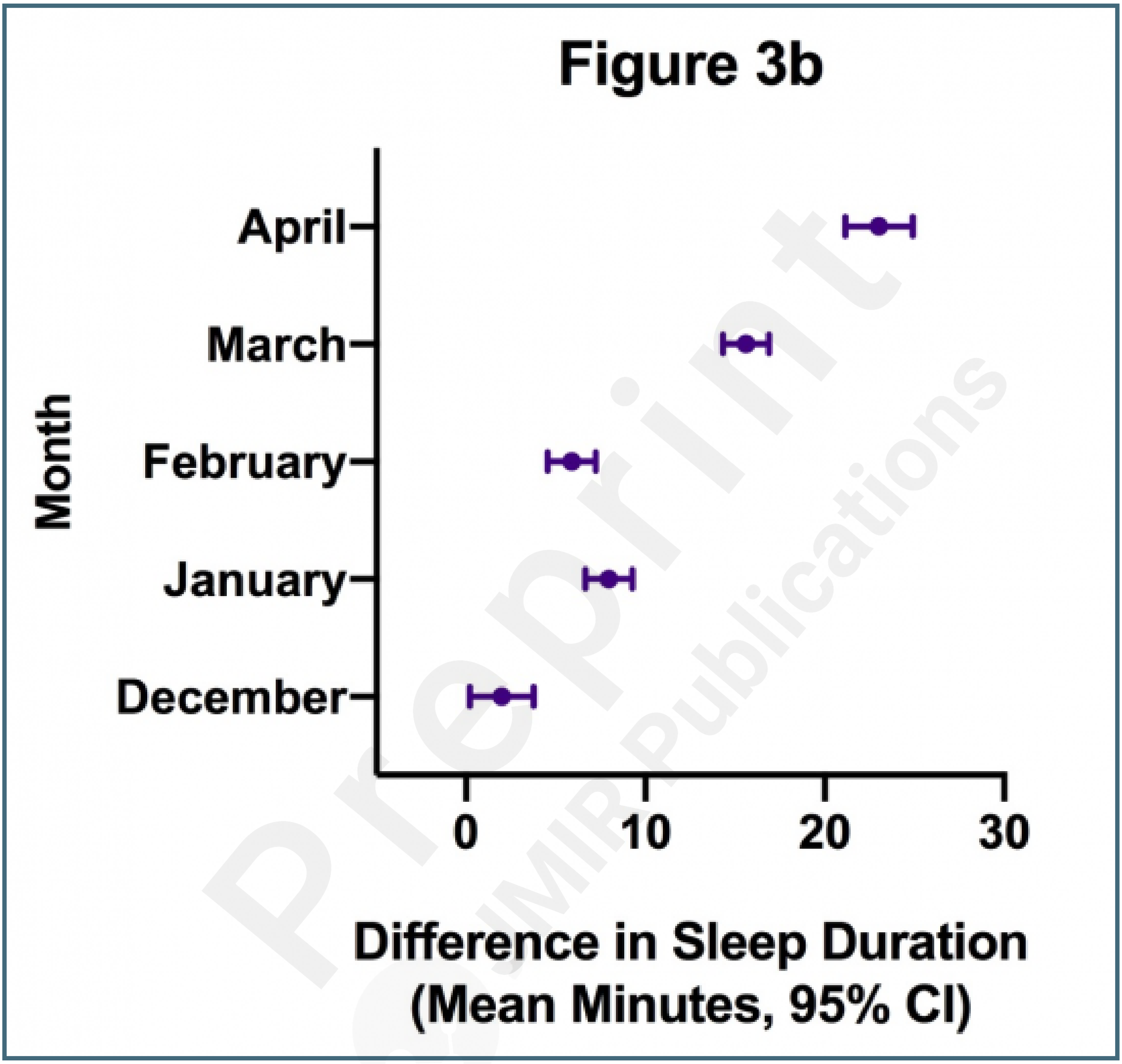
Difference in sleep episode duration during COVID-19 compared to the same month in the previous year in the total sample.



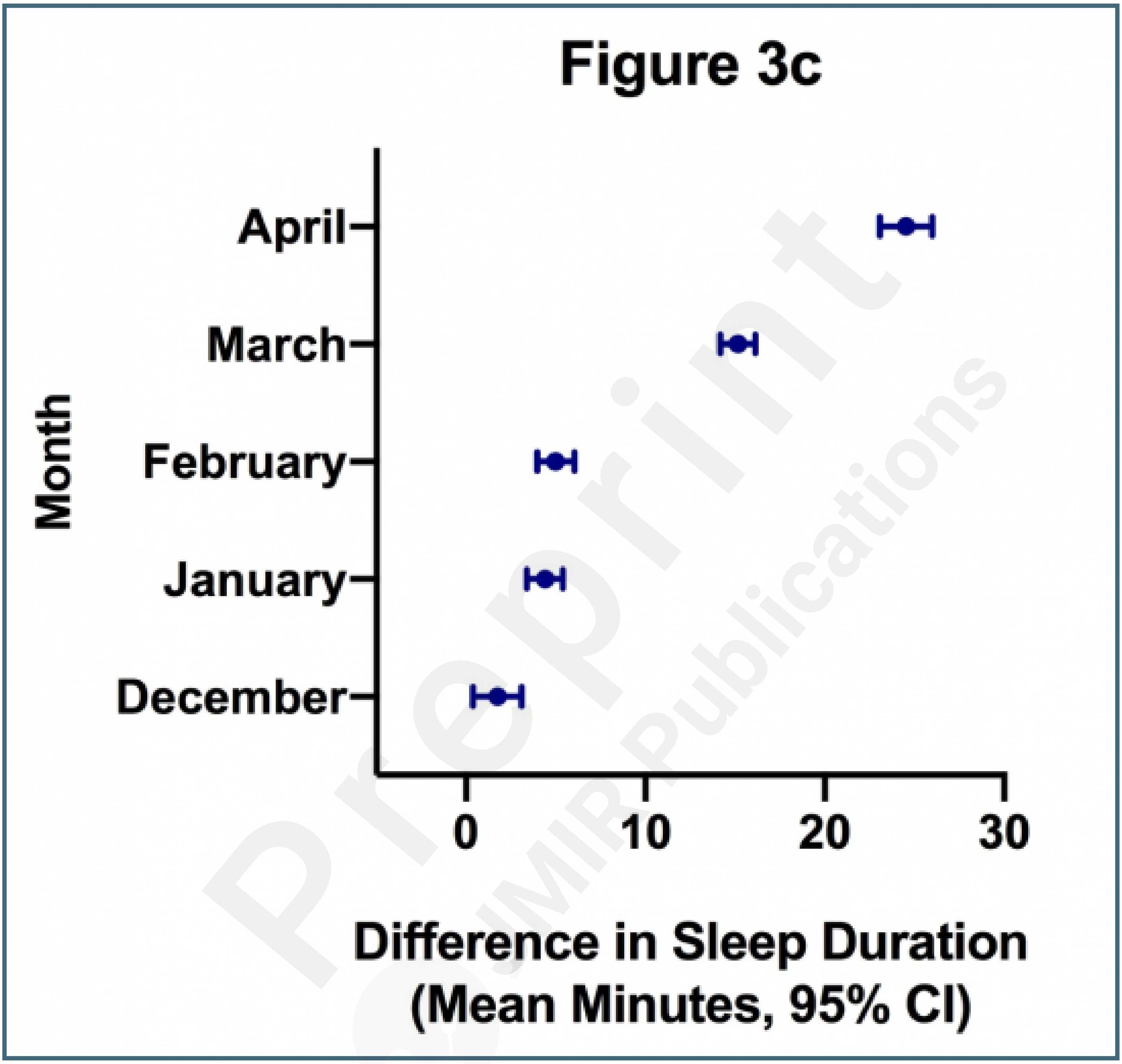
Difference in sleep episode duration during COVID-19 compared to the same month in the previous year in London.



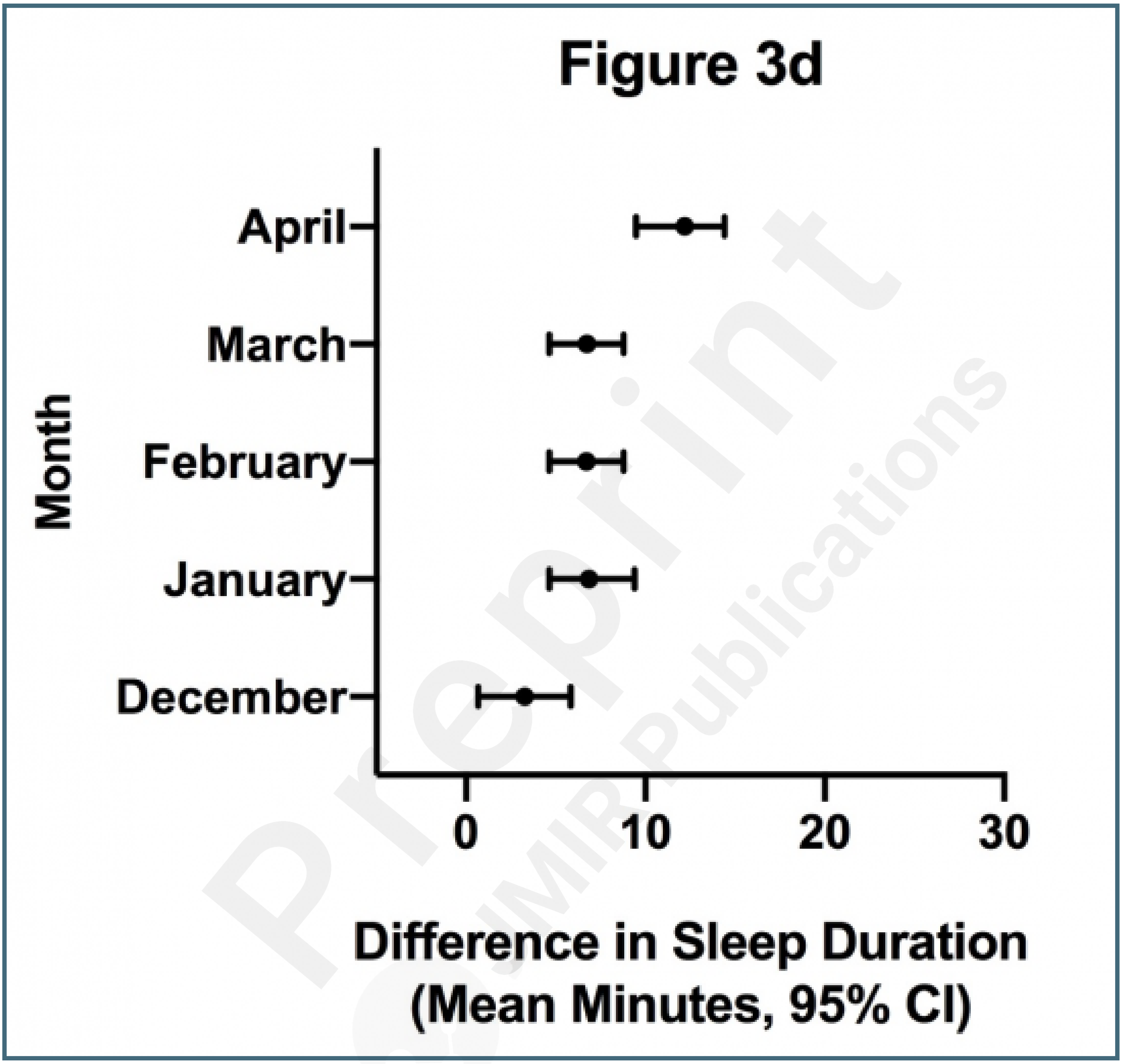
Difference in sleep episode duration during COVID-19 compared to the same month in the previous year in Los Angeles.



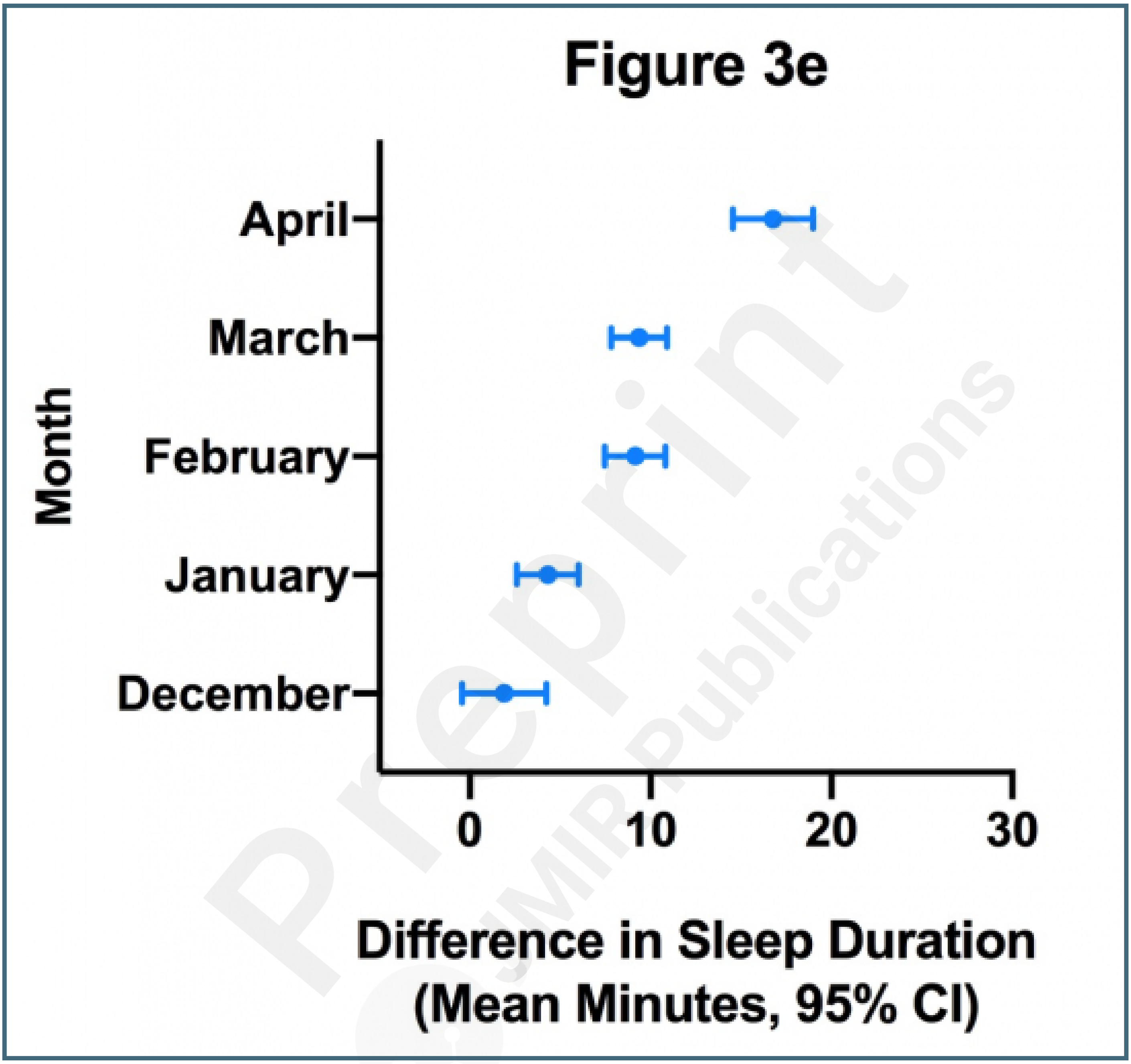
Difference in sleep episode duration during COVID-19 compared to the same month in the previous year in New York.



Difference in sleep episode duration during COVID-19 compared to the same month in the previous year in Seoul.



Difference in sleep episode duration during COVID-19 compared to the same month in the previous year in Stockholm.



TOC/Feature image for homepages

Our analysis of over 2.9 million nights of objectively recorded sleep demonstrate a sharp increase in sleep episode duration after COVID-19.