Does Sleep Deprivation Cause Online Incivility? Evidence from a Natural Experiment

Completed Research Paper

Feng Mai
Stevens Institute of Technology
Hoboken, NJ, USA
fmai@stevens.edu

Zihan Chen
Stevens Institute of Technology
Hoboken, NJ, USA
zchen61@stevens.edu

Aron Lindberg
Stevens Institute of Technology
Hoboken, NJ, USA
alindber@stevens.edu

Abstract

Incivility between members is a major concern for many online communities. This paper provides empirical evidence that sleep deprivation is an important cause of incivility in online communities. Identification comes from the shift to Daylight Saving Time (DST) which leads to individuals experiencing reduced sleep time. Using an archival dataset from English Wikipedia and an annotated corpus, we train machine learning algorithms to automatically identify personal attack, aggressive, and toxic comments. We show that compared to other days, about 22% more uncivil messages originate from the impacted regions on the Mondays following the switch to DST. We also find that the effect is stronger for incivility on article talk pages compared with incivility on user talk pages. We discuss the strategies that can mitigate the harms to online communities due to sleep deprivation.

Keywords: online communities, incivility, natural experiment, machine learning, digital collaborations

Introduction

Many online communities operate on the belief that more open and connected platforms increase participation and lead to higher quality work. Indeed, studies show that computer-mediated social interaction can motivate knowledge sharing, sustain group engagement, help retain new members, and drive high-quality content creation (Faraj et al. 2015; Joyce and Kraut 2006; Ridings and Wasko 2010; Wasko and Faraj 2005). However, the affordances of online platforms also bring out negative social behavior (Kraut and Resnick 2012; Ransbotham et al. 2016). Harassment, personal attacks, and other types of incivility plague even the most successful and collaborative communities. On Wikipedia, for example, 68% of the respondents reported having experienced harassment (Wikimedia 2018). As online communities increasingly play a prominent role in people's everyday life, uncivil behaviors online are afflicting society at large. A nationally representative survey shows that 41% of U.S. adults have been victims of online harassment, and 66% have witnessed online abusive behavior toward others (Pew Research 2017).

The negative consequences of online incivility are well documented. From an organizational point of view, incivility hurts the commitment of the members and induces intention to quit (Lim and Teo 2009). In addition, online incivility can evoke polarized perceptions on divided issues (Anderson et al. 2014). This, in turn, undermines the consensus building process towards a neutral point of view that many peer production communities rely on (Greenstein and Zhu 2016; Ransbotham and Kane 2011). Furthermore, online incivility entails substantial social costs. Extreme cases such as cyberbullying often cause significant psychological harm and health problems to victims (Moore et al. 2012)—perhaps more so than offline bullying due to the high visibility and networked nature of online abuse (Lowry et al. 2016). Evidence also suggests that incivility disproportionately affects adolescents, females, and ethnic minorities (Slavtcheva-Petkova et al. 2015; Vitak et al. 2017). Thus, many online communities face pressure to limit uncivil behaviors and their impacts.

Preventing incivility depends crucially on the causal factors of why such behavior arises. It is true that the digital nature of online platforms lends itself to automated tools for detecting foul language and blocking violators. Yet such measures are retroactive—some of the damage is already done when the corrective actions are taken. Case in point, according to a recent annual survey by Wikipedia, user-reported experience of incivility has been steady despite the implementation of various automated tools (Wikimedia 2018). Not surprisingly, researchers contend that less tangible and more behavioral remedies may be more effective than automated tools at regulating behavior in online communities (Kiesler et al. 2012).

In this study, we investigate the causal effect of sleep deprivation on online incivility. Prior research has examined what variables are associated with various types of incivility including cyberbullying (see review in Lowry et al. 2016), flaming (Alonzo and Aiken 2004), and aggression (Zimmerman and Ybarra 2016). But most of the work focuses on socio-demographical, contextual, and technical factors. Sleep deprivation as a *physiological* antecedent is overlooked. Although sleep is vital for our normal biological and social function, the modern society is dangerously sleep deprived, to the extent that the Centers for Disease Control and Prevention (CDC) calls sleep deprivation a "public health epidemic" (Devlin 2017; Pinholster 2014). Since constant online interaction has become an integral part of our personal and business lives, the link between sleep and online incivility, if any, can be a potent one that shapes our well-being.

In addition, most prior work on incivility relies on survey data. Direct evidence from archival data is surprisingly rare.[1] While survey data are able to present a bird's-eye view of many factors at play, isolating the causal effect of individual physiological factors is difficult (Lindberg 2019). In the case of sleep and incivility, sleep quality can be endogenous with respect to how people behave online. A negative correlation between self-reported sleep time and the tendency of online incivility does not necessarily indicate causation. One may argue reverse causality, i.e., exposure to online incivility leads to psychological harms such as sleep deprivation. The correlation could also be driven by other omitted variables that are difficult to measure (e.g. chronic distress).

To deal with the endogeneity problem, we exploit the time shift due to the Daylight-Saving Time (DST) as a natural experiment. Designed as an energy conservation policy, DST is practiced in more than 70 countries and affects more than 1.6 billion people (Kotchen and Grant 2011). On the second Sunday of March since 2005, most of the Americans set their clocks one hour forward. An unintended consequence of DST is that abrupt change of external clock disrupts circadian rhythm—the internal biological clock that regulates sleep patterns (The Nobel Assembly 2017). This causes reduced sleep quality and duration for people in the affected area while providing an ideal natural experiment to study the impacts of sleep deprivation.

We use machine learning methods to detect incivility on Wikipedia, one of the largest and successful online communities. The training set is a publicly available dataset with over 160K comments. The labelers annotate whether each comment is a personal attack, aggressive, or toxic comment. This crowdsourcing approach to identify incivility is consistent with Coe et al. (2014)'s definition, namely "features of discussion that convey an unnecessarily disrespectful tone toward the discussion forum, its participants, or its topic." Incivility can also include profanity and mean-spirited attacks on a person or idea (Chen and Ng 2016). We train and compare several machine learning models and deploy an efficient

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[1] According to the tally in Lowry et al. (2016), out of the 64 empirical studies, four were qualitative and all others use surveys.

deep learning model to classify all the comments on English Wikipedia from 2001 to 2015. We then model the daily number of uncivil messages that are generated by users from the regions in the U.S. that observe DST. Using a negative binomial regression model, we show that significantly more personal attacks are posted after the Mondays following the switch to DST. Our results are robust to alternative empirical specifications and a series of placebo tests. Interestingly, we do not see a significant increase in person-oriented incivility; rather, the increase is more pronounced for task-oriented incivility.

These findings have several important implications for the study of incivility online in general, and in volunteer-based, asynchronous online communities in particular. Our study suggests that scholars need to engage more with the particular ways in which work is distributed temporally, and how affordances embedded in the platforms supporting such work can be modified so as to distribute work in such a manner that it occurs at times where the risk of uncivil behavior can be minimized. Our results also suggest several practical implications for platform designs.

Background

Our study builds upon two streams of prior research. First, our work fits in the literature on the negative behaviors associated with online activities. In particular, our study responds to the AIS Bright ICT initiative, which calls for "restorative" research to identify the problems associated with ICT and provides insights on designing solutions (Lee 2016). This stream of literature can be further divided into studies that examine problems related to general Internet use (Castellacci and Tveito 2018), specific ICT tools such as social media and instant messaging (James et al. 2017; Tsai et al. 2019; Turel and Qahri-Saremi 2016), or negative byproducts of Internet use such as cyberbullying and incivility (Bogolyubova et al. 2018; Kim and Bock 2018; Kwon and Gruzd 2017; Lowry et al. 2016; Moore et al. 2012).

The majority of studies in the last category focus on the consequences of online incivility for the victims of such behavior. For example, Wright (2018) shows that cyberbullying leads to depression and anxiety. Lim and Teo (2009) find that exposure to online incivility negatively impacts employee's work commitment and behavior. Camacho et al. (2018) show that cyberbullying alters victims' belief about the technology. Rösner et al. (2016) conduct an online experiment and find that exposure to uncivil comments leads to hostile cognitions but exposure to a higher quantity of incivility does not increase the effect. A few studies use survey-based, structural equation models to establish theoretical frameworks to explain why uncivil behaviors arise. For example, Lowry et al. (2016) use a model incorporating both social structure and learning to explain why adults engage cyberbullying. Turel and Bechara (2017) propose a model to explain how sleep quality and impulsivity explains problematic online behavior, but they report that sleep quality has no direct effect.

Our study also draws upon a strand of the organizational literature focusing on the impact that sleep deprivation has on leadership and workplace behavior. Studies show that lack of sleep can increase workplace injuries (Barnes and Wagner 2009) and deviance (Christian and Ellis 2011), harm workplace performance (Van Eerde and Venus 2018; Jones et al. 2019; Weinger and Ancoli-Israel 2002), induce abusive leadership behaviors (Barnes et al. 2015, 2016), and strain workplace relationship (Guarana and Barnes 2017).

A priori, although research in organizational behavior suggests that sleep deprivation increases workplace deviance, whether the same effect manifests itself online is unclear. First, online communities mostly consist of volunteer-based workforce. According to a recent study (Slivko et al. 2019), online contribution complements regular employment. It is plausible that a sleep deprived person simply forgoes online activities and rests. When the day job is more draining due to sleep deprivation, online activities, civil or not, may be more subdued. Second, compared with workplace, intrinsic motivation and pro-social behavior play more important roles in online communities. A key channel through which sleep deprivation affects human behavior is negative mood. Yet experimental studies in economics and psychology have shown that good mood can increase selfishness, and bad mood increases likelihood to share (Capra 2004; Tan and Forgas 2010). Taken together, these considerations suggest that the link between sleep deprivation and incivility in online communities remains an open empirical question.

Our work adds to the existing literature in several ways. First, we establish the causal linkages between an offline, physiological factor and online behaviors, thereby providing important insights for platform design. Second, compared to studies that rely on surveys as the main data source, our paper analyzes a

large archival dataset of user comments. As Baumeister et al. (2007) point out, the study of "actual behavior" is valuable to theory building even if it entails learning less about the inner processes. Specifically, we are able to draw causal conclusions across a large population using a natural experiment. Finally, while not being our main focus, we compare different machine learning models for detecting uncivil online comments, which can help improve automated tools for curbing incivility (Lee et al. 2018).

Hypothesis Development

Does sleep deprivation cause online incivility? Extant theory suggests that, compared with conventional organizations, several characteristics of online communities should mitigate the impact of sleep deprivation on incivility (Faraj et al. 2011). First, online communities are volunteer-based (Oh et al. 2016). Therefore, individuals may choose to disengage from a particular community or conversation, rather than resorting to incivility. Second, online interactions often rely on asynchronous communication (Jarvenpaa and Leidner 1999; Maryam 2013), which should provide participants with the opportunity to choose *when* they engage with the community. For example, participates of online communities have the option to disengage in situations where they are stressed, sleep-deprived, or otherwise limited in their capacity to contribute in a positive manner.

Despite these mitigating factors, we posit a causal link between sleep deprivation and online incivility based on the psychological and medical literatures. First, according to the ego depletion theory of self-regulation, all acts of self-regulation draw upon a limited common pool of resources which renews over time (Muraven and Baumeister 2000). Interactions with other users in an online community inherently entail clashes of different viewpoints, beliefs, personalities, and identities. It takes self-control and willpower to remain civil in such interactions. Studies in ego depletion theory indicate that sleep is important to the replenishment of psychological self-regulation resources (Christian and Ellis 2011). Sleep deprivation means that self-control behaviors will deplete self-regulatory resources faster. As a result, members of online communities are less likely to be able to override the impulses or urges to engage in uncivil behavior when this pool of self-regulatory resources is depleted.

Second, from a physiological perspective, sleep deprivation is known to reduce the metabolic rate in the amygdala and the prefrontal cortex region (Van Der Helm et al. 2011; Wimmer et al. 1992). The former is the emotional center of the brain, and the latter regulates the experience of emotion and is responsible for normative social behavior and moral thinking (Anderson et al. 1999; Baumgartner et al. 2011; Beauregard et al. 2001). Therefore, sleep deprived users are more likely to conduct socially deviant behavior, such as leaving aggressive comments or personal attacks, due to the fact that their prefrontal cortex is functionally impaired. They are also more sensitive to negative emotions (Prather et al. 2013). Features of online platforms can augment these mechanisms because of the perceived anonymity and the ease of leaving a nasty comment without having to face the consequences associated with doing so in a face-to-face situation (Lowry et al. 2016). Thus, we formulate the following hypothesis:

H1: Sleep deprivation of users leads to increasing levels of incivility in online communities.

If sleep deprivation indeed leads to online incivility, understanding the specific form of incivility may help us manage its negative impacts. Literature on intra-organization conflicts recognizes that there are two main types of conflicts between members: task-oriented and personal-oriented (Janssen et al. 1999; Wall and Nolan 1986). Task-oriented conflicts arise when there is disagreement about the work to be performed (Janssen et al. 1999). In such conflicts, the focus is placed on judgmental differences with regards to how common objectives should be achieved (Amason 1996). By contrast, person-oriented conflicts are defined as "personalized disagreement typically includes tension, animosity, and annoyance among team members not directly related to the task being performed"(Janssen et al. 1999). Although to the best of our knowledge, no such categorization has been made on online incivilities, distinguishing task versus non-task conflicts can also be applied to Wikipedia. Arazy et al. (2013) define task conflicts as "conflicting views and opinions regarding the article being authored." We extend the literature and define task-oriented incivility as incivility that arises from task conflicts and personal-oriented incivility consists of messages that escalated from person-oriented conflicts. Since extant theory suggests lack of tolerance is an important mechanism for conflicts to escalate into incivility, it is natural to ask whether task-oriented incivility or person-oriented incivility are more likely to be triggered by sleep deprivation.

Social presence theory informs us that person-oriented activities require media that is high in social presence, which is defined as the ability to facilitate interpersonal relationships (Miranda and Saunders 2003). Task-oriented activities, on the other hand, is less dependent on the social presence of the medium. By this definition, asynchronous, non-face-to-face communication in online communities is a low social presence communication channel. Mutual understanding is more difficult because the meaning of text is derived subjectively. Therefore, person-oriented activities in online communities are more likely to go awry especially when respect for social norms breaks down due to sleep deprivation. Further, person-oriented conflicts are also referred to as emotional conflicts. Compared to task-oriented conflicts which involve cognitive processes, person-oriented conflicts tend to revolve around affective processes (Garcia-Prieto et al. 2003). Since the physiology of sleep deprivation indicates that the emotional functions of the brain are affected, it is reasonable to expect that person-oriented conflicts are more susceptible to sleep deprivation. Therefore, we posit the following hypothesis:

H2: The effect of sleep deprivation on person-oriented incivility is stronger than the effect on task-oriented incivility.

Data and Context

Incivility on Wikipedia

We obtained our dataset from the Wikipedia Detox project (Wulczyn et al. 2017). Wikipedia is the largest online encyclopedia maintained by a community of voluntary editors (Gallus 2017). Because of the self-organizing nature of Wiki, different viewpoints often clash and need to be reconciled throughout the collaborative authoring process (Greenstein and Zhu 2018; Phang et al. 2014). When such conflicts arise, the "talk pages"—discussion pages associated with each article and user—provide a place for editors to resolve their disagreements (Arazy et al. 2011). Even though Wikipedia provides guidelines for talk page etiquette (Wikipedia 2019), conversations between editors may still escalate to personal attacks, aggression, or toxic comments.

The Wikimedia Foundation board initiated the Detox project to understand the dynamics and impact of such incivility on English Wikipedia's discussion pages. As a part of the effort, a collection of Wikipedia talk page datasets is released to the public in 2017. The talk page datasets include two types of data: the annotated corpus and the main corpus. The annotated corpus contains over 160K human-labeled comments from Wikipedia's talk pages. The human annotators went through a series of selection procedures to ensure data quality. In addition, each comment was labeled by more than 10 different annotators. The annotators rate each comment on the English Wikipedia talk pages on whether the comment is a personal attack, aggression (including passive-aggressive), or a toxic comment (likely to make people leave the discussion). Annotators can classify personal attack comment into four different types: attacks targeted at the recipient, a third party, quoted attack, and other types of attack. When evaluating the aggression and toxicity of the comments, the annotators also judge the extent of transgression using a 5-point scale, in which 3 is neutral. In this research, we define a comment to be uncivil if it belongs to at least one of the above categories.

The main corpus contains all comments on user and article talk pages of English Wikipedia from 2001 to 2015. We use the plain-text version of the comments without the HTML tags or Wiki markups. In total, there are 60.3M unlabeled comments.

Detecting Incivility using Machine Learning

We use the annotated corpus to train machine learning models and automatically detect incivility within the main corpus. We train three different models that each detects personal attacks, aggression, and toxicity.[2] Since each comment is labeled by multiple annotators, we take a binary classification approach by aggregating all annotators opinions. If more than half of the annotators believe the comment is uncivil, we set its class as one (positive), and zero (negative) otherwise. This essentially means that we take a

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[2] Training a single model to detect a combination of three types of incivility yields similar results in our study, but is less accurate at classifying the messages.

crowdsourcing approach to define incivility, as its definition is "very much in the eye of the beholder" (Coe et al. 2014).

We implement several state-of-the-art text classification methods, including bag-of-words with Naïve Bayes weighting (Wang and Manning 2012), convolutional neural networks (CNN) (Kim 2014) and FastText (Joulin et al. 2017). Using an 80/10/10 train-validation-test split of the annotated dataset, we compare the out-of-sample performance of the models using the best parameters determined by the validation set. Table 1 reports the results. We find that the CNN models slightly outperform the other two with an AUC of 96.5% for detecting personal attacks, 96.1% for detecting aggression, and 97.0% for detecting toxicity. Our main results are robust to the classification model used. In total, there are 760,597 uncivil messages that belong to either of three categories. Table 1 provides a summary of the classifiers' performance. Table 2 shows a few examples of different types of uncivil comments.

		NB-SVM	FastText	CNN
Personal Attacks	AUC	0.954	0.904	**0.965**
	Precision	**0.904**	0.820	0.733
	Recall	0.580	0.496	**0.813**
Aggression Comments	AUC	0.951	0.901	**0.961**
	Precision	**0.901**	0.830	0.778
	Recall	0.573	0.494	**0.757**
Toxic Comments	AUC	0.960	0.912	**0.970**
	Precision	**0.916**	0.826	0.808
	Recall	0.612	0.509	**0.779**

Table 1. Classifier Performance

DST and Sleep Deprivation

To estimate the causal effect of sleep deprivation on the level of incivility in Wikipedia, we exploit the change in DST that disrupts the sleeping schedule of most users in the United States. The idea of DST can be traced to Benjamin Franklin, who argued that adjusting activity schedules during the summer months could save energy (Kotchen and Grant 2011). Since 1918, following the footsteps of many European countries that were facing an energy crisis in World War I, individual cities and counties in the U.S. started observing DST (Bartky and Harrison 1979). In 1967, the Uniform Time Act took effect and the Federal government started regulating the DST. After several experimental changes throughout the years, DST currently begins on the second Sunday of March and ends on the first Sunday of November for most areas in the U.S.

Scientific research provides ample evidence on how time change disrupts normal human behavior (Monk and Folkard 1976). In particular, DST switch negatively affects sleep quality on the Sunday night following the phase advance, i.e., the first night of sleep after the clock time is set forward 1 hour. This is because the sudden time shift causes misalignment between circadian rhythms (our internal biological clock) and external clock time (Coren 1996; Wehr et al. 1979). Activities on Monday, such as work and school, are usually prescheduled and follow the external clock time. After the time shifts, getting the same amount of sleep requires people to sleep one hour earlier than the circadian period (the natural rhythm) suggests. Yet for biological reasons, it is especially difficult for humans to fall asleep earlier than normal (Barnes and Wagner 2009; Lavie 1986). This leads to reduced sleep quality and total sleep time during the Sunday night and sleep deprivation on Monday (Sletten et al. 2010). Using a nationally representative, multi-year survey, Barnes and Wagner (2009) found that on the Monday following the DST shift, on average, Americans sleep 40 minutes less than usual. Hence the Monday after the DST starts if often referred to as the "Sleepy Monday." Prior work has used DST as a quasi-experiment context to study the effects of sleep deprivation on human behavior, including increasing traffic and workplace accidents (Barnes and Wagner 2009; Cho et al. 2017; Coren 1996; Wagner et al. 2012).

	Articles Talk Pages	Users Talk Pages
Personal Attacks	"I give up .. you win .. there is NO harm having colleges as part of this list .. while I'm new to Wiki .. you are teaching me .. I can now see how the stupidity works .. have your little kingdom .. and I'll be on my way to other places. But know this, I will not be as stupid over minor things as I've seen here. Adios .." "Disagreement is when you talk about the content of what is written, regardless of its source. Prejudice is when you personalise it."	"SO then you want lies...ok thats cool" "Adam Bandt what the hell do you know about him you live in new jersey stay out of Asutralian politics and stick to pounching women."
Aggressive Comments	"Ezra, you have got to be kidding with this page. You are taking one of many interpretations of Judaism and giving it sole legitimacy, often with simple rhetorical claims. Even within Orthodox circles many of the views you express are controversial at best (and often considered shtus). Please fix it up or I will do it myself, and I do know my stuff." "That's ridiculous. Who would waste time creating a location and lore about a fake place based on a video game. Please people, we have lives, just cause we play LoL. Oh shit, I gave that away didn't I. Well I'm just going to walk over there now..."	"His tone is interesting; I don't ever recall Jimbo ever giving him the authority to speak for Wikipedia." "Your comment was NOT funny. I quit the project once over this, and I don't intend to do it again. You may very well be breaking the law with that posting. You have your ``childlove`` article. Please leave it at that."
Toxic Comments	"How many times do I need to say that I'm not going to be working on this to FAC? You're wasting your time telling me how rubbish it is." "Are you seriously Korean and claiming that 겉절이 is not a kimchi???"	"I don't take shit fron Nigerian scum." "What a bunch of crap, so I am the only person to get blocked for reverting? If any of you supposed admins would look, I was one of the ONLY people discussing the issue on talk, and the current consensus is that it should not be included. Seriously, how did any of you get to be admins? It is clear none of you know understand WP policies sufficiently."

Table 2. Examples of Incivility on Wikipedia

We identify comments from the geographical regions that are affected by DST using the network IP addresses following Zhang and Zhu (2011). Wikipedia does not disclose individual contributors' location information nor registered contributors' IP addresses. Therefore, we analyze uncivil comments left by unregistered users, who are identified only by their IP addresses. We use GeoLite2 City database to find the originating city, states, and country of each comment. For IP addresses (such as IPv6 addresses) that cannot be geo-located using the GeoLite2 database, we use IP2Location database as a second option.

Figure 1 provides a temporal overview of the sample. While the volume of incivility on Wikipedia declines after 2007, the decline largely coincides with the wane of Wikipedia's overall popularity. The year with highest percentage of uncivil message is 2008 (8.54%), and the year with the lowest percentage is 2001 (1.96%). We find that 279,192, or 36.7% of all uncivil comments, can be geolocated using IP addresses. Among them, 155,283 (55.6%) are from the U.S. We exclude comments from the following states that do not observe DST: Arizona, Hawaii, and Indiana before 2006. We also exclude the comments that are administrative comments or left by bots. As Figure 1 shows, from 2001-2003, only 320 total uncivil messages can be geo-located to the DST regions in the U.S. Therefore, we exclude these three years from our analysis. Our econometrics model thus focuses on the 154,664 uncivil messages from 2004-2015.
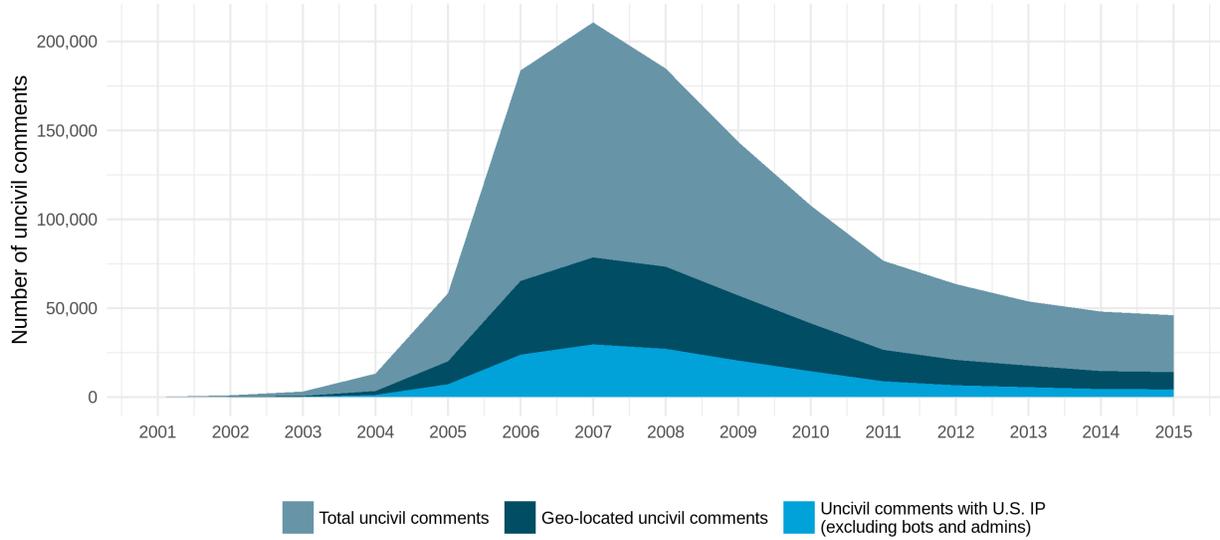
Figure 1. Temporal Distribution of Uncivil Comments on Wikipedia

Empirical Model and Results

Empirical Strategy

To test our hypotheses, we run the following regression model:

$$Incivility_t = \beta_0 + \beta_1 DST_t + TotalComments_t + Holiday_t +$$
$$YearFEs + MonthFEs + WeekDayFEs + \epsilon_t, \qquad (1)$$

where subscript t denotes each single day. The dependent variable $Incivility_t$ is the daily number of uncivil comments on Wikipedia. The main variable of interest DST_t is a dummy variable that is equal to one if it is the Monday right after an hour is lost, zero if otherwise. We include year, month, and weekday fixed effects to account for long-term trends, seasonality and weekday patterns of incivility. We also include the log total number of daily comments on the English Wikipedia as a control variable. Finally, we include a dummy to control for public holidays in the United States.

Because the dependent variable is a count variable, we use a negative binomial (NB) model (Cameron and Trivedi 2013; He et al. 2018) as our main modeling approach. The probability density of $Incivility_t$ has the form:

$$\Pr(Incivility_t = y \mid \mu_t) = \frac{\Gamma(y+\alpha^{-1})}{\Gamma(y+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu_t}\right)^{\alpha^{-1}}\left(\frac{\mu_t}{\alpha^{-1}+\mu_t}\right)^{y}, \qquad (2)$$

where $\ln(\mu_t)$ is decided by the right-hand side of equation (1).

We supplement the negative binomial model with two linear models. The first is an ordinary least square (OLS) regression model, and the second is a hierarchical linear model (HLM) akin to Barnes and Wagner (2009). In the OLS models, we use the percentage of uncivil messages as the dependent variable. That is: Incivility (%) = Number of Uncivil Comments with U.S. IP / Number of Comments with U.S. IP. In the HLM, the week of the year and the day of the week are entered as random effects. For example, the number of uncivil messages on a Sunday in the fifth week of the year will have a code 0501. The coding scheme captures variance in sleep that is due to weekday and seasonal effects, and separate the variance attributable to these effects from the variance attributable to DST Mondays and holidays. Table 3 provides summary statistics of the sample.

		Mean	SD	Median	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Incivility (Count)	(1)	34.43	29.24	23	0	199	1.00						
Incivility (%)	(2)	6.77	2.68	6.67	0.00	27.34	0.75*	1.00					
Personal Attacks	(3)	24.08	21.29	16	0	123	0.99*	0.75*	1.00				
Aggression	(4)	26.82	23.48	18	0	190	0.99*	0.75*	0.99*	1.00			
Toxicity	(5)	32.61	27.90	22	0	198	1.00*	0.75*	0.99*	0.99*	1.00		
DST	(6)	0.00	0.05	0	0	1	0.03	0.04*	0.03*	0.03*	0.03*	1.00	
Holiday	(7)	0.03	0.16	0	0	1	-0.02	-0.00	-0.02	-0.03	-0.02	-0.01	1.00
ln (Total Comments)	(8)	9.31	0.80	9.52	4.32	13.17	0.59*	0.42*	0.58*	0.58*	0.58*	0.01	-0.02

Note: * $p<0.05$. N = 4383

Table 3. Summary Statistics and Correlations

Main Results

Table 4 reports the main result with regards to whether sleep deprivation affects online incivility (H1). The first column shows the results from the negative binomial regression model. The coefficient on the main independent variable *DST* has a point estimate of 0.200 and is significant at the 1% level, indicating that the Monday after DST shift is associated with a significant increase of uncivil comments from the impacted region. The signs of control variables are as expected. Fewer uncivil comments are observed on holidays and Sundays. The number of uncivil comments is also positively associated with the overall activity in the community. The second and third column present alternative specifications from the OLS and HLM model. The results are consistent with the NB model. The point estimates of the effect of DST are 1.095 ($p < 0.05$) and 10.308 ($p < 0.01$) for the OLS and HLM models, respectively. Overall, the results lend support for our first hypothesis (H1).

To understand the magnitude of the results, we calculate the incidence rate ratio (IRR) from the negative binomial model, which is the natural exponent of the estimated coefficient. IRR indicates that the number of uncivil messages on Mondays after DST rises by 22% on average (95% CI: 5% - 41%). In contrast, the number of uncivil messages is 6% lower on holidays. In other words, the effect of losing 40 minutes of sleep on online incivility is at least three times more powerful than the effect of the rest that a holiday may entail. The magnitude of the OLS model is similar to that of the negative binomial model. On average, the percentage of uncivil messages out of all the messages from the U.S. increases by 1.01%, representing a 16% increase compared to the daily average. It is important to note that the effect estimate from the OLS model is likely to be more conservative than the NB model, because the incivility (%) does not account for the scenario where users switch to an anonymous account before posting uncivil messages.

Robustness Checks

First, the identification of our regression model rests on the assumption that, without the DST time shifts, there would have been no change in the level of incivility. In other words, after ruling out the controlled seasonal and holiday effects, the number of incivility messages on other days represents a valid counterfactual. To test this assumption, we conduct a placebo test in which the treatment days are the Mondays in the weeks directly before and after the sleepy Mondays. As column (1) and (2) in Table 5 show, we do not find significant differences in incivility on these two adjacent Mondays. The rise of incivility on Wikipedia is unique to the DST Mondays.

Second, we check the robustness of our results by controlling for past values and serial correlation. Column (3) shows results from a dynamic model that includes a lagged dependent variable. We also estimate the standard errors using the Newey-West method to correct for both autocorrelation and heteroskedasticity (Wooldridge 2013).[3] As the magnitude and the significance the coefficient remain

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[3] We use a lag length of 8 using the $t^{0.25}$ rule of thumb.

unchanged, we conclude that omitted past factors and serial correlation do not pose a threat to the validity of our results.

Variables	(1) Incivility Count (NB)	(2) Incivility (%) (OLS)	(3) Incivility Count (HLM)
DST	0.200***	1.095**	10.308***
	(0.076)	(0.460)	(3.984)
Holiday	-0.062*	-0.001	-2.072
	(0.032)	(0.002)	(1.325)
Weekday FE (Sunday as base group)			
Monday	0.056***	-0.106	
	(0.020)	(0.237)	
Tuesday	0.046**	0.453**	
	(0.023)	(0.170)	
Wednesday	0.054***	0.476***	
	(0.021)	(0.140)	
Thursday	0.043**	0.438**	
	(0.020)	(0.143)	
Friday	-0.013	0.353**	
	(0.018)	(0.125)	
Saturday	0.001	0.162	
	(0.020)	(0.124)	
ln (Total Comments)	1.032***	0.167	17.449***
	(0.071)	(0.135)	(0.695)
Constant	-6.275***	-1.820	-121.536***
	(0.515)	(2.759)	(5.019)
Year FE	Yes	Yes	Yes
Month FE	Yes	Yes	No
(Pseudo) R^2	0.885	0.422	0.800
BIC	30,551	34,411	34,825
Observations	4,383	4,383	4,383
Number of groups	--	--	371

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Cox-Snell R^2 is reported for the negative binomial model, and Snijders-Bosker R^2 is reported for the HLM.

Table 4. The Impact of Sleep Deprivation on Wikipedia Incivility

Third, it is unlikely that our results represent spurious relationships caused by non-stationarity. This is because our main independent variable is a time-based dummy variable. Changes in this independent variable are exogenous and cannot be attributed to a common trend that also affects the dependent variable. Nevertheless, in column (4) of Table 5 we report an OLS regression results in which both the incivility (%) and total comments are first-differenced.[4] Again, our result remains the same.

Fourth, we include an additional falsification test. We look at the non-U.S. comments on English Wikipedia from countries that either do not use DST, or switch to DST at a different date. If the increase of incivility is solely due to sleep deprivation and not for other reasons that are specific to the dates, we should not observe the effect in other countries. As column (4) of Table 5 shows, the number of incivility comments from these non-U.S. countries does not increase on the Monday after the DST change in the U.S.

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[4] Negative Binomial regression cannot be used because the first-differenced dependent variable is no longer a positive integer.

Variables	(1) Incivility Count (NB)	(2) Incivility (%) (OLS)	(3) Incivility Count (NB) Newey-West SE	(4) Incivility (%) (OLS) First Differenced Variables	(5) Incivility Count (NB) Non-U.S. Incivility
DST (U.S.)			0.228*** (0.069)	1.375** (0.539)	0.115 (0.107)
Prior Monday	0.028 (0.048)	0.448 (0.606)			
After Monday	-0.012 (0.065)	-0.139 (0.602)			
Holiday	-0.063* (0.032)	-0.111 (0.194)	-0.064** (0.031)	-0.079 (0.249)	
ln (Total Comments)	1.033*** (0.071)	0.896*** (0.119)	0.855*** (0.071)	-0.660*** (0.178)	0.835*** (0.033)
Incivility (t-1)			0.005*** (0.001)		
Constant	-6.282*** (0.515)	-1.831** (0.844)	-4.983*** (0.513)	-0.034 (0.213)	-5.535*** (0.242)
Weekday FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
(Pseudo) R^2	0.885	0.422	0.890	0.015	0.777
Observations	4383	4383	4382	4382	4383

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 5. Placebo Tests and Robustness Check

Task-Oriented and Person-Oriented Incivility

Our second hypothesis (H2) states that the effect of sleep deprivation is stronger on person-oriented incivility than on task-oriented incivility. To test this hypothesis, we separate the uncivil comments based on their destination. We treat uncivil comments on article page as task-oriented, and uncivil comments on user pages as person-oriented. Such categorization is a heuristic that is consistent with prior management and IS literature on team conflicts. Arazy et al. (2013) define task-related conflicts as "differences in viewpoints and opinions regarding the subject of a group task", which in our context is the article itself. On the contrary, Wikipedia user talk pages are used to draw the attention of a user (Wikipedia 2019). Therefore, uncivil comments on user pages indicate that personal beliefs and values are involved, to the extent that tension, annoyance, and animosity are directed towards another user (Janssen et al. 1999). It is important to note that, just like task and person-oriented conflicts, task and person-oriented incivility are not necessarily dichotomous. Our heuristic is based on the main differentiating factor that uncivil messages on user-pages are less "grounded in disagreements related to the article contents" (Arazy et al. 2013) are less likely to be directly linked to an article.

Table 6 presents the regression results by different destinations of incivility. Column (1) and (2) report results from a seemingly unrelated regression (SUR). SUR jointly estimates the impact of DST shift to user-page incivility and article-page incivility. It yields more efficient estimations by allowing the errors to correlate across two equations. We first-difference the dependent variables in SUR to ensure that the dependent variables are stationary. Column (3) and (4) are based on two separate negative binomial models. To test H2, we first examine the coefficients of DST across the two destinations. For both models, the effects of sleep deprivation on article-page incivility are statistically significant and greater in magnitude, whereas the effects on user-page incivility are not significant. Further, we test whether the coefficients of DST are equal across two equations using SUR. The *p*-value of the chi-squared test for the null hypothesis that coefficients in two equations are equal is 0.016. However, the direction is opposite to what we hypothesized in H2. Together, the results do not support H2. On the contrary, the evidence seems to suggest that sleep deprivation has a stronger effect on task-oriented (article-page) incivility.

Variables	(1)	(2)	(3)	(4)
	SUR		NB (Separate)	
	User-Page Incivility (%)	Article-Page Incivility (%)	User-Page Incivility	Article-Page Incivility
DST	0.154	1.221***	0.215	0.246**
	(0.372)	(0.396)	(0.150)	(0.104)
Holiday	0.098	-0.153	-0.091*	-0.225***
	(0.172)	(0.183)	(0.051)	(0.037)
ln (Total Comments)	-0.006	-0.654***	0.112**	0.069*
	(0.123)	(0.131)	(0.047)	(0.036)
Constant	0.012	-0.046	-0.004	0.651***
	(0.147)	(0.156)	(0.064)	(0.045)
Weekday FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 6. Destination of Incivility

Discussion and Conclusion

Our work is the first attempt to identify the causal effects of physiological predictors of online incivility using archival data. We use an annotated dataset released by Wikimedia Foundation to train machine learning models for detecting incivility on Wikipedia pages. We then model the volume of uncivil comments generated from areas that are affected by DST shift. Finally, we quantify the effect of sleep deprivation by comparing the number of uncivil comments on days that are likely to be affected by the time shift with days that are not. We find that sleep deprivation caused by the time shift results in a 22% increase in the volume of incivility on Wikipedia. The effect is more pronounced on article talk pages, suggesting that task-related incivility is more prone to sleep deprivation than person-related incivility. An important caveat of our results is that we analyzed anonymous comments on Wikipedia; it would be interesting to see if similar patterns can be observed on platforms with less anonymity.

Theoretical Implications

Our study offers several theoretical implications for IS literature. First, our findings introduce a new type of causal factor in influencing online community behavior. IS literature has proposed numerous antecedents that shape how members contribute and interact with each other, such as individual incentives and habits (Khansa et al. 2015), group composition and evolvement (Ren et al. 2015), and network structure and positions (Oh and Jeon 2007; Zhang and Wang 2012). Most of these antecedents are directly observable online. We add to a burgeoning stream of work that shows offline behavior can spillover to online volunteering activities (Slivko et al. 2019). As large swathes of economic activity, including innovation, knowledge creation, and negotiation are increasingly migrating to online spaces, the interaction between people's offline and online life needs more research attention.

Second, our results speak to the prevalence of uncivil behavior in online communities. Even as a platform known for its collaborative culture, a considerable percentage of messages on Wikipedia are still uncivil. Many studies call attention to membership turnover and the decline of open collaboration systems (Ransbotham and Kane 2011). As participants in the Internet-based volunteer workforce are more likely

to drop out after receiving negative social feedback (Moon and Sproull 2008), understanding the particular ways in which incivility is effectuated, and its consequences, are of crucial importance for this emerging space for organizing work (Puranam et al. 2014).

Third, we contribute to the literature on distributed teams and propose the notion that just as conflicts can be categorized into task-oriented and interpersonal-oriented (Hinds and Mortensen 2005), so can the escalation from conflicts to incivility. Importantly, we provide initial empirical evidence that the pathways to these two types of incivility are different. Incivility in Wiki user-pages, which is not directly linked to specific tasks, is not impacted by sleep deprivation. A possible reason is that bad mood accompanying sleep deprivation moderates information processing styles; it heightens attention paid to external information (tasks) but lessens the influence of internal preferences (Tan and Forgas 2010).

Practical Implications

Our results suggest several practical implications for managing online peer production platforms. First and foremost, from a platform design perspective, because incivility is unevenly distributed across the year, parts of the week, and possibly also across the 24 hours of an individual day, managers may find fruitful ground in designing and evaluating mechanisms for "nudging" work towards periods where incivility is less likely. Creating such mechanisms may involve both incentives and disincentives, as well as notifications and other affordances (Leonardi 2010) that may help to allocate work temporally in ways which minimize the chances of incivility to occur. For example, online communities can consider using dynamic color themes on their websites to promote a healthy sleep pattern. Warmer color-shifting themes should be available contributors in the evening based on local time. Such themes can promote sleep quality by reducing the amount of short-wavelength (blue range) light at night time (Cajochen et al. 2011).

In addition, when implementing various intervention mechanisms and automated tools to curb unwanted behaviors, platforms should pay attention to physiological factors such as sleep deprivation. For example, platforms can increase proactive intervention efforts at late night to prevent civil discussions from escalation. To the extent that proactive moderation policies work (Suh et al. 2018), it may be beneficial to watch out for editors with irregular temporal editing patterns. Also, the platform can detect community members who are traveling across time zones—an antecedent that can cause similar sleep disruption (Monk and Folkard 1976). The automated machine learning tools can also consider these factors at the model training stage.

Finally, society at large may rethink how regulation should evolve along with the technology to limit the impact of sleep deprivation on online incivility. Policymakers can start from protecting users who are most vulnerable to both forces. For example, it might be sensible to require platforms to remind adolescents limiting the number of hours online per day. This may help them to allocate their energy resources more effectively, and thus decrease the probabilities of incivility occurring. Of course, effective remedies require evidence-based policymaking, and our work is only a first step to understand the nature of the problem.

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