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https://doi.org/10.1038/s41562-019-0543-4
nature human behaviour

Insufficient sleep reduces voting and other prosocial behaviours

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Insufficient sleep is a growing public health concern in industrial societies. Although a lack of sleep is known to negatively affect private behaviours—such as working or going to school—comparatively little is known about its consequences for the social behaviours that hold society and democracy together. Using three complementary methods, we show how insufficient sleep affects various measures of civic participation. With survey data from two countries, we show that insufficient sleep predicts lower voter turnout. Next, with a geographical regression discontinuity design, we demonstrate that individuals from the United States who tend to sleep less due to circadian impacts of time-zone boundaries are also less likely to vote. Finally, we experimentally manipulate short-term sleep over a two-stage study. We observe that the treatment decreases the levels of civic engagement, as shown by their willingness to vote, sign petitions and donate to charities. These results highlight the strong negative consequences that current levels of insufficient sleep have on vitally important measures of social capital.

In recent years, many industrialized societies have seen a decrease in the levels of sleep of their citizens[1]. In the United States, for example, polls show that over the past six decades, the number of citizens getting inadequate levels of sleep has increased fourfold[2–4]. Based on these trends, sleep scientists estimate that between 50 and 70 million Americans suffer from chronic sleep deprivation[5]. This problem is not restricted to the United States alone—indeed, studies have shown that insufficient sleep is a growing concern in developed countries across the globe[6]. Given the negative effects of insufficient sleep on individual health (for an overview of research on this topic, see refs. [7–11]), scholars and public officials have become increasingly concerned with these patterns—with some calling the recent sleep trends a public health 'crisis'[12,13]. The importance of research on sleep is evidenced by the recent (2017) awarding of the Nobel Prize in Physiology and Medicine for research on circadian rhythms[14], which fundamentally shape the sleep patterns of individuals.

In this paper, we focus on the consequences of insufficient sleep for civic attitudes and behaviours: a vital component of societal well-being. Extensive research has shown the negative consequences of insufficient sleep for private behaviours—such as working, living a healthy lifestyle and attending school (for example, refs. [8,9,15–21]). Other research has explored whether insufficient sleep affects bystanders, as in the case of sleepy driving[22–24]. However, little work has focused on how sleepiness affects real-world prosocial behaviours, such as the ones we explore—that is, proactive measures of civic participation such as voting, volunteering or donating to charity. This gap is unfortunate, as it limits our ability to fully understand the broader societal consequences of current trends towards less sleep. Simply put, it leaves us wondering whether sleep patterns merely have private consequences or, instead, influence vitally important metrics of social capital, prosociality and social connectivity[25,26].

Here, we provide evidence from multiple sources of the broader consequences of sleep deprivation. Our first approach (study 1) uses survey microdata from two countries, paired with control strategies to show that individuals who get insufficient sleep are also (conditional on observables) less likely to vote—a vitally important prosocial behaviour necessary for the health of democratic institutions[25]. As this first study leaves open the possibility of bias from unobserved factors, in study 2, we turn to a large-scale nationwide natural experiment that leverages discontinuous differences in sleep patterns in the vicinity of US time-zone boundaries (an approach that has been used in the past to study sleep's effects on health and productivity). Our results suggest that individuals nudged to lower levels of sleep are also less likely to vote. Finally, in study 3, we experimentally manipulate short-term sleep over a two-stage protocol. Among those participating in both stages, we observe a decreased willingness to take part in various real-world prosocial engagement behaviours, consisting of signing a real petition in support of increased recycling in their community, credibly committing to donate to a charitable organization and planning to vote. Although we acknowledge the limitations of each of these designs, we also show that they provide complementary evidence, which corroborates the notion that insufficient sleep decreases individuals' willingness to be civically engaged in their communities and democracy as a whole.

Our work contributes to a better understanding of the implications of sleep deprivation—we provide rich empirical evidence of the link between sleep and field measures of civic participation. Our results have important implications given growing concerns over patterns of insufficient sleep and stagnant (at best) or decreasing (at worst) levels of social engagement[25]. These shed light on one reason why many people fail to be civically active: because of insufficient sleep, many citizens are too tired and lack the attached bundle of downstream health[27] and skills[28] required to participate. These results have special meaning given the socially stratified distribution of sleep[29], which, as we suggest below, may serve to exacerbate socioeconomic gaps in prosocial engagement.

Conceptual framework

Prosocial acts of civic participation—such as voting, volunteering and donating—help to hold the fabric of society together. These

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behaviours shape communities' vitally important levels of social capital[25]. In addition to being important in their own right, previous research has shown that measures of prosociality may have multiplier effects in society, with these strongly predicting beneficial macro-outcomes, such as economic growth[30] and reduced government corruption[26]. However, by many accounts, the levels of prosociality have stagnated or declined in recent years.

Theoretical channels: why insufficient sleep and civic participation

There are multiple direct and indirect reasons to expect that sleep influences prosocial behaviours. Insufficient sleep may negatively affect behaviour in social environments, either directly or through its downstream effects on mental bandwidth and health. Engaging in civic behaviours is costly: it takes time, energy, self-control and cognitive capacity[28]. Individuals who sleep less and who are chronically fatigued may struggle to engage, even if they want to do so. Such individuals may lack the motivation, capacity and social connections to overcome the hurdles, distractions or costs that get in the way of participating in social processes that benefit society. Lack of sleep may lead one to sacrifice engagement in prosocial activities to preserve their energy for activities that directly benefit oneself.

Insufficient sleep may also influence prosocial behaviours indirectly through its bundle of downstream consequences. A broad literature indicates that sleep deprivation affects a host of human behaviours that work in political science has shown to be associated with political participation. For example, chronic sleep deprivation causes a noticeable deterioration of individual health[8,16], and scholars have recently shown that health levels seem to influence forms of participation such as voting[27]. Tiredness may also decrease productivity[16,31], hence reducing another channel linked to participation[32]. Similarly, a lack of sleep may lead to noticeable declines in cognitive ability[18,33]—a known predictor of voter turnout[32]. Finally, experimental work suggests that sleep deprivation lowers self-control[34] and social skills[35], which have recently been experimentally linked to forms of engagement such as voting[28]. In addition to lowering the overall levels of engagement, insufficient sleep may also widen participatory gaps in communities, discouraging participation from disadvantaged segments of the population who do not have the resources to overcome these additional hurdles to their engagement.

Our hypothesis that insufficient sleep will reduce prosocial behaviours, such as voting and signing petitions, among others, is also consistent with the literature on sleep deprivation and deliberative thinking. Deliberative thinking is active in prefrontal brain regions that are particularly at risk under conditions of sleep deprivation[36–38]. In addition, researchers have documented the importance of deliberative thinking in the formation of prosocial behaviours[39–42]. This has been suggested in laboratory experiments as a hypothesized mechanism to explain how insufficient sleep may harm prosocial behaviours[43], but here, we also note the additional effort that prosociality and civic engagement may require in real-world field settings.

Evidence from previous work

Previous empirical evidence on how sleep affects social decisions is relatively sparse. Still, we can take some hints from previous work. A recent examination of total sleep deprivation in highly controlled conditions showed negative effects on measures of simple bargaining and trust in a stylized two-person decision environment[35]. More externally valid, but somewhat less controlled, levels of chronic partial sleep restriction have also recently been shown to affect behaviour in simple trust and dictator games[43]. Finally, recent work found that sleep restriction may increase responsiveness to the threat of norm enforcement through punishment[44]. In short, previous work in this area has been limited, and what is available focuses on laboratory measures of prosociality that abstract away from field behaviours and may have limited validity in real-world environments. Our goal is to examine more direct links between insufficient sleep and field behaviours that directly reflect prosociality in domains important to the health of democratic institutions.

In this paper, we use three different methods to elicit the effect of sleep restriction on measures of civic participation: a conditional on observables approach, a natural experiment approach and a randomized controlled experiment approach. All of these come with their own strengths, weaknesses and assumptions, which we discuss in some detail below. Although none of these methods is perfect, together they help us to test whether a lack of sleep decreases prosocial behaviour. In each of the cases below, however, the data met the assumptions of the statistical tests used.

Study 1: observational evidence

To explore the effects of insufficient sleep on prosocial measures of civic engagement, we first conducted an analysis of survey data from both the United States and Germany. For the United States, we used data from the National Longitudinal Study of Adolescent to Adult Health (Add Health). This data set is nationally representative of the cohort it surveys (youth in 1994–1995) and is one of the few data sets in the United States that pairs multiple measures of sleep with measures of voting. The Add Health Tiredness Scale is constructed from the battery of sleep questions and allows us to code an indicator for insufficient or poor sleep (see Supplementary Information Appendix). In addition, Add Health includes a large subsample of sibling pairs that allows for statistical control of many unobserved characteristics in the analysis. The second data source comes from the German Socioeconomic Panel (SOEP), which is also a nationally representative longitudinal survey of about 20,000 voting-age Germans. In addition to questions on voting, the SOEP includes questions about sleep patterns that allowed us to code an indicator variable for insufficient sleep (a self-reported sleep level of less than the medically recommended 7 h per night on weekends, given that German Elections are held on Sundays). We include more information about these samples, the measures used and the statistical controls included in the models below in the SI Appendix.

We note that this study design using observational comparisons is inherently limited. The goal of this analysis is to establish a baseline, to see whether any relationship exists between insufficient sleep and measures of civic engagement. To show that individual differences in sleep levels might play a role in political behaviour, we control for a host of covariates (such as age, gender, income and education, to name a few) and provide evidence from two countries with different political systems. In some of our specifications in the Add Health sample, we isolate our comparisons down to sibling pairs in an attempt to control for certain unobserved factors (such as shared home culture or environment). However, as our findings still run the risk of exposure to bias from unobserved factors, readers should be careful in over-interpreting these correlational results.

Fig. 1 shows a coefficient plot of our estimates of the effect of insufficient sleep across three modelling approaches: bivariate (that is, no controls), controls and sibling fixed effects. The estimates provided in Fig. 1 across two waves of Add Health data and the SOEP data show consistent evidence that poor and insufficient sleep predict lower voter turnout. Using the Add Health data, we estimate that poor sleep is associated with a 7–14 percentage point (p.p.) decrease in reported voting. These estimates are sizeable and not statistically distinct from each other across model specification. Among the estimated coefficients for the insufficient sleep indicator, 4 out of 6 are significant at the 5% level. One other model finds a marginally insignificant effect at the 5% level (wave 4 voting, with control ordinary least squares (OLS) effect estimates: −6.6 p.p.; two-tailed $P = 0.055$; $N = 11{,}277$; 95% CI: −13.2 p.p. to 0.0 p.p.), and in the Add Health wave 3 model with sibling fixed effects, the effect of the high Add Health Tiredness Scale is not statistically

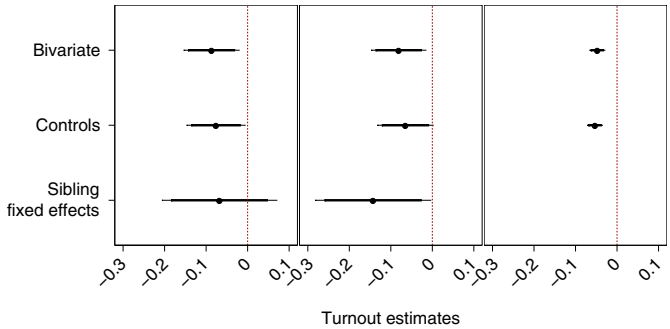

Fig. 1 | Observational estimates for insufficient sleep on voter turnout (Add Health and SOEP). Linear regression estimates for the relationship between insufficient sleep and self-reported voter turnout are shown. Insufficient sleep is operationalized as a composite scale (0–1) in Add Health waves 3 and 4 (left and centre panels) and as reporting less than 7 h of sleep in the SOEP (right panel). Coefficients are shown as points, with corresponding 90% (wider) and 95% (narrow) confidence intervals. Model statistics (effect, *N*, confidence interval) from top to bottom: Add Health wave 3: −8.7 p.p., 14,796, −15.4 p.p. to −2.1 p.p.; −7.7 p.p., 11,280, −14.7 p.p. to −0.8 p.p.; −6.9 p.p., 3,798, −20.6 p.p. to 6.9 p.p.; Add Health wave 4: −8.2 p.p., 14,316, −14.7 p.p. to −1.7 p.p.; −6.6 p.p., 11,277, −13.2 p.p. to 0.0 p.p.; −14.4 p.p., 3,797, −28.2 p.p. to −0.5 p.p.; SOEP: −4.8 p.p., 14,673, −6.6 p.p. to −3.1 p.p.; −5.4 p.p., 14,673, −7.1 p.p. to −3.6 p.p.

discernible from 0 (OLS effect estimates: −6.9 p.p.; two-tailed $P = 0.30$; $N = 3{,}798$; 95% CI: −20.7 p.p. to 6.9 p.p.). Although some results are less precise—in part because of the reduced sample of siblings in the Add Health data—our point estimates are consistently negative and on a similar order of magnitude. In the German sample, the association between insufficient sleep and self-reported turnout is consistent, being −4.8 p.p. in the bivariate model and −5.4 p.p. in the model with controls, and much more precisely estimated given the higher sample size (two-tailed $P < 0.001$ in both models).

Overall, these results provide observational evidence that insufficient sleep and sleepiness predict lower levels of voter turnout—a core form of civic participation—in advanced democracies. Given previous research on voter turnout, these relationships are fairly large. To help benchmark the magnitude of these effects, they are about half the size of the effect of finishing high school in the Add Health siblings sample. However, the null effects in one of the two sibling pair models are enough to give pause to a conclusion that sleep matters, as our results may be partially driven by bias from unobserved confounds. Hence, to determine whether sleep affects prosocial behaviour, we require a plausibly exogenous source of sleep deprivation.

Study 2: natural experiment

Our second analytic approach builds on recent research showing that time-zone boundaries create an as-good-as-random assignment (that is, orthogonal to confounding factors) of individuals to different levels of sleep. For reasons discussed in detail in the SI Appendix, individuals living near the immediate eastern side of the US time-zone boundaries have been shown to achieve a significant 20–25 min less sleep per night (on average) than those living near the immediate western side of the same time-zone boundary[16,45], and to exhibit the negative health consequences of insufficient sleep[10,16]. Thus, we can make comparisons on either side of the time-zone boundary in an attempt to see whether individuals exogenously nudged towards less sleep are less likely to engage.

The advantages of this approach are many. It provides plausibly exogenous variation in sleep times that runs orthogonal to many of the factors that contribute to voter turnout. In contrast to many geographical discontinuities, which follow state boundaries, time-zone boundaries do not always follow state lines. As such, we can amplify a standard geographical regression discontinuity design with state fixed effects (which we include in all our models, along with year and state-by-year fixed effects) that force comparisons across states split by time-zone boundaries. Scholars who have used this design previously have shown that this exogenous decline in sleep times is not confounded by shared state boundaries, contextual effects, county-specific factors (such as the administration of specific elections), the random allocation of counties around the cut-off, or the strategic location of more affluent or differential demographic patterns on either marginal side of the cut-off (to name a few)[16,45]. As best as we can tell with observable balance tests and fixed-effect or permutation tests, within states precise sorting around the time-zone boundaries is negligible. Time-zone boundaries, being (largely) determined a century ago, seem to be orthogonal to the factors that influence voter turnout today. Although time (and sleep as a result) is disrupted at the cut-off, this seems to be the primary mover. However, even though this cut-off has faced extensive validation, it is possible that at the time-zone boundary there is some other compound treatment of relevance that confounds our estimates. Thus, this design gets us a long way towards causality, although it comes with assumptions (which we more fully outline and explore in the SI Appendix).

We first seek to replicate the finding that motivates the use of this design for our purposes: sleep declines at the time-zone boundary. To do so, we use data from the American Time Use Survey and combine these data with demographic information from the US Census. In the SI Appendix, we also provide evidence from sleep tracker data supporting the notion that individuals living on the eastern side of US time zones sleep less than those on the western side. As shown in the SI Appendix, we are able to validate that individuals living on the marginally eastern side of the time-zone boundary sleep significantly less, but do not seem to differ on factors other than sleep. We then estimate the effect of living on the marginally eastern side of the time-zone boundary on voter turnout using geographical regression discontinuity design models. Our preferred specification for these geographical regression discontinuity design models includes fixed effects to absorb unobserved state-level differences that might confound our estimates. The voter turnout data for these models come from a proprietary sample of a nationwide voter file from Catalist LLC (see the SI Appendix for more details), which allows us to use one of the few validated measures of civic behaviour as our outcome measure.

Figure 2 shows the results from this natural experiment at the US time-zone boundaries. As we would expect if insufficient sleep reduced civic behaviours, individuals who live on the marginally eastern side of the time-zone boundary are less likely to vote than all-else-equal individuals living on the marginally western side of

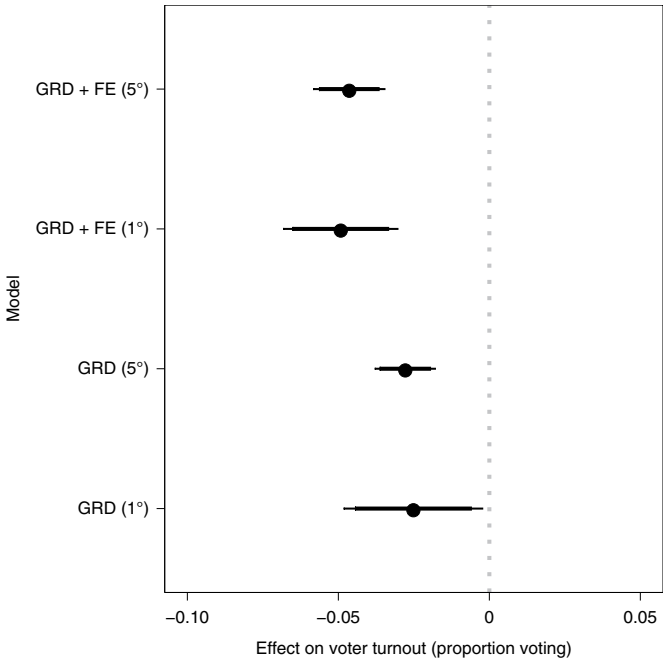

Fig. 2 | Quasi-experimental estimates of the effect of insufficient sleep on voter turnout. Estimates for our quasi-experiment based on the proximity to US time-zone borders (1° is ~50 miles). Coefficients show the effects of living on the marginally eastern side of the cut-off compared to living on the marginally western side. The outcome variable is the zip-code-level voter turnout for 2008–2012 (primary and general elections). Data are from the Catalist 1% sample timestamped May 2014. Models with fixed effects (FE) have state, year and state-by-year fixed effects and, as such, leverage states that are split between two time zones. Coefficient estimates are shown as points, with corresponding 90% (thicker) and 95% (narrower) confidence intervals. Regression discontinuity estimates: $N_{BW=1°}$: 1,904,958 (3,769 zip codes), $N_{BW=5°}$: 11,171,064 (20,057 zip codes); two-tailed P value from bottom to top: $P=0.031$, bottom, and $P<0.001$, top three; effect-size estimate from top to bottom: −2.5 p.p., −2.8 p.p., −4.9 p.p. and −4.7 p.p.; 95% CI from bottom to top: −4.8 p.p. to −0.2 p.p., −3.8 p.p. to −1.8 p.p., −6.8 p.p. to −3.0 p.p. and −5.8 p.p. to −3.5 p.p. GRD, geographical regression discontinuity.

the boundary. Our regression discontinuity estimates suggest that individuals exogenously nudged towards lower levels of sleep vote at a rate of 2–5 p.p. lower (regression discontinuity estimate statistics: $N_{BW=1°}$: 1,904,958, $N_{BW=5°}$: 11,171,064; two-tailed P value from bottom to top: $P=0.031$ and $P<0.001$ in the rest; effect-size estimate from top to bottom: −2.5 p.p., −2.8 p.p., −4.9 p.p. and −4.7 p.p.; 95% CI from bottom to top: −4.8 to −0.2, −3.8 to −1.8, −6.8 to −3.0 and −5.8 to −3.5; BW, bandwidth). These estimates are statistically precise, sizeable and are not the result of observable imbalances around the cut-off, state-level differences or precise sorting around the time-zone boundary.

Interestingly, these demobilizing effects are magnified in socially disadvantaged communities. If we break our models out (at the median level) by the percentage of individuals in the community that are African American—a strong proxy for the socioeconomic status of the area—we find that our treatment effects are nearly three times as large in disadvantaged communities (regression discontinuity $\beta=-7.1$ p.p.; $N=6{,}080{,}202$; two-tailed $P<0.001$; 95% CI: −8.5 to −5.6) than in advantaged communities (regression discontinuity $\beta=-2.5$ p.p.; $N=5{,}090{,}862$; two-tailed $P<0.001$; 95% CI: −3.7 to −1.3). When modelled together, this difference is highly significant (regression discontinuity $\beta_{difference}=-1.5$ p.p.; $N=11{,}171{,}064$; two-tailed $P<0.001$; 95% CI: −2.2 to −0.8). This suggests that the effects of sleep deprivation may weigh most heavily on socially disadvantaged segments of the population. As such, it may serve not only to reduce the overall levels of prosocial behaviour but also to further exacerbate social stratification in this vitally important domain[32,46].

Placebo tests: what does sleep restriction not affect?

It is possible that when nudged towards lower levels of sleep, individuals reduce not only prosocial behaviours but also all forms of private behaviours. If this were the case, what we would be observing would not be unique to the prosocial domain. However, our natural experiment allows us to perform placebo tests that contrast the effects of sleep on prosocial behaviours with potential effects on other types of behaviours.

We note that our goal in this paper is to focus on prosocial behaviours related to civic participation. This represents a vital contribution, as most of the literature on sleep deprivation focuses on private behaviours (with a few exceptions noted above). To be clear, we are not arguing that private behaviours are not affected by a lack of sleep. Claiming that sleep deprivation does not also affect some private behaviours would be incorrect, as a host of previous work with credible research designs shows that a lack of sleep affects non-prosocial behaviours—in the health and educational domains, for instance[8,9,15–21]. Still, if every individual behaviour, prosocial and non-prosocial, decreased as a response to a lack of sleep, our findings might be less valuable. Although not the primary focus of our paper, we think that it is valuable to start to establish the boundaries of where commonly experienced levels of insufficient sleep do not play a role.

To do so, we run a series of placebo tests on behaviours not previously studied by sleep scientists in a causal framework. Although some studies have looked at the conditional-on-observables relationship between sleep and certain private outcomes (for example, tobacco use[47] and television consumption[48]), these studies tend to leverage small sample sizes and leave open the possibility of bias from unobserved factors. For our placebo tests, we focus on our quasi-experimental design because it has better causal properties than the observational designs (study 1) and can be paired with more private outcomes than our experiment (study 3), which was preregistered and conducted to focus exclusively on prosocial behaviours.

Figure 3 shows the effect of our quasi-experimental treatment on our placebo outcomes. These behaviours are drawn from the American Time Use Survey—one of the largest, longest-running surveys on individual behaviours—and we use our regression discontinuity constructed sleep variable from the Fig. 2 analysis. With this data set, we estimate our geographical regression discontinuity design models for several behaviours that are much less prosocial than our measures of voting, donating and petitioning for social causes. These include: the amount of time one spends working, having free time, eating and drinking, cleaning their home, engaging in home repairs (by oneself), watching television, relaxing or thinking, using tobacco or drugs, reading for personal interest and using a computer for leisure. Although the American Time Use Survey contains many measures of individual behaviour, we have been intentional in choosing variables that one tends to do (largely) for private motives (for example, earning money at one's job) or that one tends to do while alone (for example, relaxing or thinking).

The first row in Fig. 3 plots the effect of our quasi-experimental design on sleep times (as a reference). The next ten rows plot the same time-zone cut-off effect on our placebo behaviours. As can be seen, when individuals are exogenously nudged towards lower levels of sleep, they do not uniformly participate in fewer private activities. As shown in the sixth row, when individuals sleep less, they mechanically have more free time (that is, time net of sleep, work and housework) ($\beta=40.3$; $N=27{,}649$; two-tailed $P=0.034$; 95% CI:

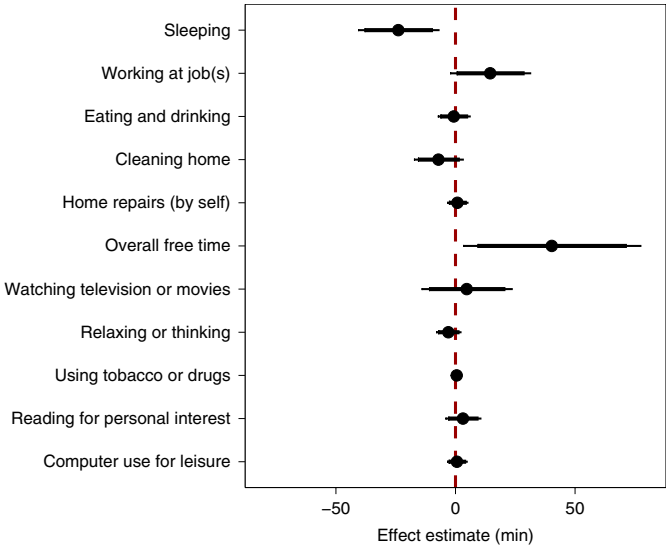

Fig. 3 | Quasi-experimental placebo estimates. Estimates for our quasi-experiment based on the proximity to US time-zone borders. Coefficients show the effects of living on the marginally eastern side of the cut-off. The outcome variables are drawn from the American Time Use Survey, 2003–2015. Models have state, year and state-by-year fixed effects and, as such, leverage split states. Coefficient estimates are shown as points, with corresponding 90% (thicker) and 95% (narrow) confidence intervals. Coefficient (in min), *N*, *P* value and 95% CI from top to bottom: sleeping: $\beta = -23.9$, $N = 37{,}059$, $P = 0.006$, 95% CI: −40.8 to −7.0; working at job(s): $\beta = 14.5$, $N = 27{,}649$, $P = 0.09$, 95% CI: −2.3 to 31.3; eating and drinking: $\beta = -0.7$, $N = 36{,}418$, $P = 0.83$, 95% CI: −7.4 to 6.0; cleaning home: $\beta = -7.1$, $N = 37{,}059$, $P = 0.17$, 95% CI: −17.4 to 3.1; home repairs (by self): $\beta = 0.8$, $N = 37{,}059$, $P = 0.71$, 95% CI: −3.5 to 5.0; overall free time: $\beta = 40.3$, $N = 27{,}649$, $P = 0.03$, 95% CI: 3.1–77.4; watching television or movies: $\beta = 4.7$, $N = 36{,}418$, $P = 0.62$, 95% CI: −14.2 to 23.6; relaxing or thinking: $\beta = -3.0$, $N = 36{,}418$, $P = 0.25$, 95% CI: −8.1 to 2.1; using tobacco or drugs: $\beta = 0.5$, $N = 36{,}418$, $P = 0.008$, 95% CI: 0.13–0.87; reading for personal interest: $\beta = 3.1$, $N = 36{,}418$, $P = 0.40$, 95% CI: −4.2 to 10.5; computer use for leisure: $\beta = 0.6$, $N = 36{,}418$, $P = 0.78$, 95% CI: −3.5 to 4.7.

3.1–77.4). Herein lies a fascinating finding: although reduced sleep implies people have more free time to participate, contrary to previous theoretical work, we find that individuals with more free time do not necessarily put that quantity of time to prosocial uses.

The effect on most other measures of private behaviour is small and not significant. Individuals who sleep less do not work less or spend less time eating or drinking, cleaning, repairing, watching TV, reading or using a computer. They may use tobacco and drugs a bit more; however, this effect—although significant ($P = 0.008$)—is small (equivalent to 0.5 of a minute increase).

These results suggest that sleep deprivation does not systematically depress all forms of private behaviour. In addition, our placebo test results call into question whether previous conditional-on-observables results from small, select samples[47,48] are really causal. Our placebo (null findings) in conjunction with our treatment findings seem sensible; when exposed to (modestly) lower levels of sleep (as is the case in the quasi-experimental design), prosocial behaviours are among the first things to be reduced. We know from previous research that the amount of time one engages in private behaviours that demand a high cognitive load—studying for school, exercising or eating healthfully—also declines[8,9,15–21]. But, many non-prosocial behaviours that individuals engage in from day to day are not disrupted. Indeed, the literature[16] suggests that some non-prosocial behaviours—such as unhealthy eating—may actually increase in response to a lack of sleep. In addition, activities that may have negative spillover effects on others—these could therefore be considered antisocial behaviours—may also increase as a result of insufficient sleep (for example, sleepy driving). Hence, the prosocial effects that we document are not a reflection of insufficient sleep causing a uniform decline in all individual behaviours.

Study 3: experiment

The results from our natural experiment go a long way towards establishing that insufficient sleep may be causally linked to decreased civic participation. That said, even these results are of necessity limited to one type of prosocial behaviour (voting)—after all, other measures of prosocial behaviour from surveys would probably be underpowered near the time-zone boundary—and leave open the possibility that the time-zone effects may be driven by a mechanism other than sleep. Hence, we turn to our final methodology, which comprised a randomized controlled experiment. This experiment comes with the added advantage of allowing us to gauge a longer, more diverse list of measures of prosocial engagement, although we lose some ecological validity compared to the natural experiment.

Our (preregistered) randomized controlled trial utilized a two-part survey on the Amazon Mechanical Turk platform, which is regularly used for survey research and has been shown to be a fairly valid way to generate survey and behavioural data[49,50]. The Amazon Mechanical Turk platform offers a ready workforce to complete various types of 'human intelligence tasks' (HITs) for a payment specified by the employer. Surveys are a common type of HIT available on the Amazon Mechanical Turk. Our advertised HIT was a two-part survey that clearly specified HIT payment only for completion of both the part-one and part-two surveys. At the end of our part-one survey, participants were randomly assigned to complete a part-two survey on prosocial attitudes and civic engagement either in the afternoon (between 14:00 and 16:00; that is, the control group) or during the middle of the night (between 03:00 and 05:00; that is, the treatment group) until the end of the week. Local time-zone timestamps were used to assess compliance with this random assignment approach. In total, 72% of returners complied with their assigned treatment group. (If we use a slightly looser definition of compliance—that is, within 1 h on either side of the assigned time—compliance was 89%.) Because of the higher attrition risk for those randomly assigned to the treatment group, a higher HIT payment was offered to those night-assigned participants as a way of balancing response and retention rates across conditions (see SI Appendix for further details). Data collection and analysis were not

performed blind to the conditions of the experiments. In determining the sample size, we preregistered that we 'anticipated recruiting 1,500' respondents who we hoped would take both waves of the survey. The number was based on very conservative power calculations based on a pilot study that we ran (in which we also calibrated the payment rates). However, despite our best efforts, only 1,117 (treatment: 539; control: 578) unique respondents returned to participate in wave 2 during the study window, despite a reasonable over-sample of just under 1,700 individuals who participated in wave 1. Among this sample, 58.2% were female, with a mean age of 36 years (range: 18–85 years).

Although this experimental design has been used in previous studies of the effects of sleep[43], we acknowledge several limitations to its internal and external validity. First, although we check for a host (28) of potentially important imbalances in the respondents who chose to return for the part-two (second wave) survey, and the retention rate was similar across treatment (65%) and control (67%), we cannot be exactly sure that the same types of individuals returned to take the follow-up survey. (This is, in essence, a potential threat for bias from attrition—a similar problem in all other multi-period interventions.) Second, we measure outcomes at the end of the second wave—that is, in the afternoon or at night—rather than in a third wave during the following day. Ideally, one might want a treatment that allows for a separation in time between when the treatment is administered and the outcomes are measured. Unfortunately, administering a third wave would significantly raise the cost of the experiment, (potentially) increase the rate of attrition and (potentially) not be conducive to a short-term sleep manipulation (depending on when the follow-up study was done). Nevertheless, we acknowledge the absence of a third wave as a limitation of study 3. In short, like the other designs that we leveraged, this study is not without flaws. But, it is useful in getting another look at the potential effects of sleep restriction on various measures of civic participation.

In the SI Appendix, we show the effect of our treatment (that is, assignment to taking the survey at night) on individuals' levels of self-reported sleepiness and the number of hours they slept the previous night. As can be seen, our manipulation check shows a sizeable effect on both measures. Individuals in the treatment group report being nearly twice as tired (unadjusted mean: 2.7 on the 9-item scale) as those in the control group (unadjusted mean: 5.3)—an increase of 96.1% over the base rate. This effect is about the same size as what is reported in the literature that uses 1–2 nights of controlled sleep restriction[51]. By another measure, individuals in the treatment group report having slept 0.66 h less than the control group—a decrease of 10% of the base rate (control group = 6.66 h) or 38% of a standard deviation. Put differently, this short-term sleep manipulation is roughly equivalent to the difference between (just below) recommended nightly sleep levels and the levels that cause the US Centers for Disease Control and Prevention (and others) to call insufficient sleep a public health problem. Both of these effects are substantively sizeable and estimated with a high degree of precision ($N = 1{,}117$; two-tailed $P < 0.001$, in both cases). These effects are robust to whether we specify it as a within-subjects design (comparing changes within individuals from wave 1 to wave 2) or a between-subjects design (comparing only part-two survey data across response time treatment assignments).

In short, our treatment induced a robust short-term level sleep restriction that can be used to make causal inferences for the question at hand. Balance tests (SI Appendix) show that lower levels of sleep seem to be the only factor that differentiates our two groups. This design was approved by the Yale University Institutional Review Board (2000020645) as posing minimal risk to participants. However, our consent form informed participants about the potential risks associated with short-term sleep restriction. In addition, although we induce significantly higher levels of sleepiness in participants, we detail in the SI Appendix that several risk management features are present in our randomized controlled trial. For example, our participants were given multiple options regarding the exact day to complete the part-two survey—presumably, they would chose the day or night that would affect them the least. Furthermore, no restrictions were placed on sleepiness countermeasures before or during participation, the online nature of the study allowed participation from the comfort and safety of one's home, the experiment was designed to be a short-term manipulation to sleep and participants could resume rest immediately following the survey completion.

Figure 4 shows the experimental results from our short-term sleep manipulation on measures of prosocial engagement. Given the random assignment to treatment and control conditions, here, we focus on the raw difference of mean results with no controls. For the sake of space, we report the results with our baseline controls in the SI Appendix, while also noting here where the results differ with controls. Here, we are focusing on the intention to treat effects; in the appendix, we report the local average treatment effects—that is, the effects local to those who complied with the treatment.

The first row in Fig. 4 shows our four primary measures of civic participation: signing a petition, donating money, intending to vote and a composite measure of the three. The second row shows our preregistered placebo test (civic duty) and two attitudinal questions about one's place relative to the government and overall mood. As we would expect if insufficient sleep reduces prosocial engagement, individuals in the treatment group were less willing to sign a petition to increase recycling in their community ($\beta = -6.1$ p.p.; $N = 1{,}117$). This sizeable effect is significant at the 5% level (two-tailed $P = 0.04$; robust $P = 0.04$; 95% CI: −11.9 to −0.3) and is the most robust of any of the individual engagement items. There is also some (albeit slightly less significant) evidence that those randomly assigned to less sleep are less willing to donate money to the Red Cross ($\beta = -5.5$ p.p.; $N = 1{,}117$; two-tailed $P = 0.062$; robust $P = 0.063$; 95% CI: −11.2 to 0.3) and have a lower intention to vote in an upcoming election ($\beta = -4.3$ p.p.; $N = 1{,}117$; two-tailed $P = 0.09$; robust $P = 0.09$; 95% CI: −9.1 to 0.6). However, as we show in the SI Appendix, the vote intention result is sensitive to the inclusion of controls. When combined into a simple mean scale that reduces residual variance—and, as such, is the most reliable measure of civic participation—the engagement effects are clear and robust: our short-term sleep deprivation treatment reduces engagement in civic activities by 5.3 p.p. ($N = 1{,}117$; two-tailed $P = 0.0036$; robust $P = 0.004$; 95% CI: −8.8 to −1.7). As we expected, there was no effect on our preregistered placebo measure of whether individuals saw voting as a civic duty ($\beta = -0.01$, two-tailed $P = 0.67$). In short, the strongest and most robust effects can be seen on measures of actual engagement (signing and donating) rather than on measures of political motivation (vote intentions and civic duty); this suggests that tiredness may be more about negatively affecting one's ability to follow through to participate rather than their orientation towards participating.

Our auxiliary tests of individual attitudes, which admittedly have slightly weaker theoretical predictions, show evidence of some other interesting broader effects of sleep restriction. Somewhat surprisingly, individuals in the treatment group also expressed higher levels of external political efficacy, perhaps as a result of lower monitoring capacity or greater apathy ($\beta = 0.12$; $N = 1{,}117$; two-tailed $P = 0.028$; robust $P = 0.029$; 95% CI: 0.01–0.22). As we would expect, individuals in the treatment group also expressed lower levels of overall well-being ($\beta = -0.15$; $N = 1{,}117$; two-tailed $P = 0.072$; robust $P = 0.073$; 95% CI: −0.31 to 0.01); however, this result is only significant at the 10% level. We explore other potential attitudinal effects in the SI Appendix, finding mostly null effects.

As in our natural experiment, we find some evidence that our negative engagement effects are largest among disadvantaged subgroups. However, these effects—like many heterogeneity

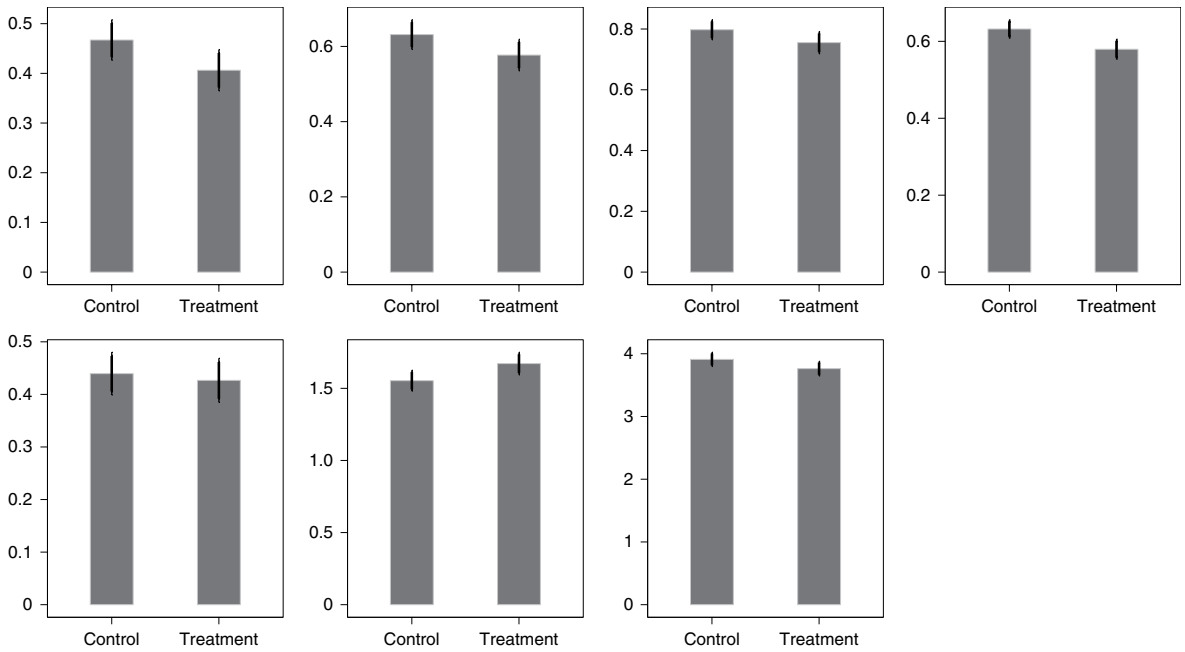

Fig. 4 | Randomized controlled trial estimate of the effect of sleep restriction on civic participation. The effect of our randomized controlled trial on participants' levels of civic participation. The top left panel shows individuals' willingness to sign a petition to increase recycling in their community. The second panel on the top row displays individuals' willingness to donate part of their bonus earnings to the Red Cross. The third panel reports individuals' intention to vote in the 2018 Midterm Elections. The fourth panel shows a mean scale of the first three measures that is constructed by calculating the proportion of activities an individual engages in. The bottom panels show the effects on measures of civic duty (our preregistered placebo) (left), external efficacy (middle) and overall mood (right). The bars display the raw mean levels; the lines represent corresponding 90% (thick) and 95% (narrow) confidence intervals. $N = 1{,}117$.

analyses—are, unfortunately, under-powered even in our fairly large experiment. We find that our adverse sleep treatment has a substantively larger effect on less-educated individuals (as defined, again, by the median value of this measure). This holds true when we look at planning to vote (low education: $\beta = -0.056$, two-tailed $P = 0.041$; high education: $\beta = 0.021$, two-tailed $P = 0.714$; difference two-tailed $P = 0.280$), signing a petition (low education: $\beta = -0.077$, two-tailed $P = 0.016$; high education: $\beta = 0.016$, two-tailed $P = 0.843$; difference two-tailed $P = 0.274$), donating to a social cause (low education: $\beta = -0.055$, two-tailed $P = 0.08$; high education: $\beta = -0.042$, two-tailed $P = 0.60$; difference two-tailed $P = 0.87$) and our composite engagement scale (low education: $\beta = -0.063$, two-tailed $P = 0.001$; high education: $\beta = -0.002$, two-tailed $P = 0.973$; difference two-tailed $P = 0.236$). We discuss other heterogeneities and potential mechanisms in the SI Appendix.

In short, these results show that individuals randomly assigned to short-term lower levels of sleep are less likely to be socially engaged. Our results are also suggestive, but not conclusive, that such sleepiness serves to exacerbate inequalities in prosocial engagement.

Discussion

Our complementary data sources and analytic techniques have shown that insufficient sleep reduces individuals' civic behaviours. Descriptively, individuals who do not get enough sleep are less likely to vote (above and beyond available control strategies). Similarly, individuals exogenously nudged towards lower levels of sleep (because they live near the eastern side of a time-zone cut-off) are less likely to vote. Finally, individuals who are randomly assigned to a short-term manipulation of lower levels of sleep are less likely to engage in prosocial behaviours, such as signing a petition, donating money to a good cause or intending to vote.

Our findings suggest that the levels of insufficient sleep that are increasingly common in society have broader effects than what has been previously recognized. In addition to having negative effects on private metrics of productivity, health and academic performance, trends of reduced nightly sleep levels should concern us owing to the deleterious effects of sleepiness on prosocial civic behaviours vital for community, societal and democratic well-being. Insufficient sleep may also serve to exacerbate participatory inequality. This suggests that the public health problem of insufficient sleep may also have downstream socioeconomic impacts not previously recognized. These results also help to explain why levels of civic participation or social capital have stagnated (or by some accounts declined) in recent years[25]. Simply put, many people may not contribute their time, money and energy to social causes because they are too tired to do so.

From a theoretical perspective, our results point to the importance of a broader set of motivational inputs that are important for prosocial behaviour than have previously been noted. The extant literature has focused almost exclusively on motivation towards a domain-specific act (for example, one's interest in politics) that governs one's decision to engage in that area (for example, voting). Our results suggest that a broader, more generalized set of motivations (that is, sleepiness) matter for civic participation. Future work would do well to try and break apart the mechanisms between these relationships, acknowledging the inherent difficulties in performing causal mediation analyses[52].

From a policy perspective, our results suggest that interventions affecting individuals' levels of sleep may have broader consequences than has been previously acknowledged. Not only may behavioural interventions—for example, at the workplace or targeting parents with infants—that promote sleep enhance productivity and health[53–56] but they may also help to increase dismally low and unequal levels of social capital, cohesion or engagement. As policymakers consider whether to intervene to help remediate troubling sleep trends, they should realize that a lack of sleep threatens

not only health, productivity and educational success but also threatens to break apart fragile social connections that form the bedrock of society.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Code availability

The replication code that produced this report is available in the Supplementary Information Appendix. The replication code for the Add Health study cannot be shared as we 'cannot move files or data in or out of the [computing environment]' that houses the Add Health data/code (per Duke University's PRDN data sharing terms).

Data availability

The following restrictions apply to data in studies 1 and 2: the Add Health (restricted) data set used in study 1, the SOEP data in study 1 and the Catalist data used in study 2 are proprietary and cannot be shared by the authors. For information about how to access the Add Health restricted-use data, see www.cpc.unc.edu/projects/addhealth/documentation/restricteduse. The SOEP data are available after registration with the DIW Berlin, see www.diw.de/en/diw_02.c.222829.en/access.html. Catalist is a subscription-based service; for information about contracting with Catalist, see catalist.us/products/data-subscriptions. The data that support the findings of study 3 are available from the corresponding author on request.

Received: 19 February 2018; Accepted: 25 January 2019;
Published online: 4 March 2019

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Acknowledgements

J.B.H. thanks the NSF for its support (no. SES-1657821). J.P.S. thanks the Yale CSAP. We are also grateful for the helpful feedback from V. Arceneaux, P. Aronow, E. Busby, J. Clinton, R. Enos, B. Fraga, A. Gerber, S. Hill, G. Huber, J. Kalla, L. Keele, M. Kryger, T. Mendelberg, M. Meredith, D. Mutz, J. Nagler, S. Nuamah, D. Rand, M. Rangel, R. Tituinik and audiences at the APSA/MPSA meetings and at Princeton, Yale and BYU. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

Author contributions

J.B.H. and J.P.S. contributed to the observational, natural experimental and experimental analyses and write-up. D.L.D. contributed to the experimental design, analysis and write-up.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41562-019-0543-4.

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Our web collection on statistics for biologists may be useful.

Software and code

Policy information about availability of computer code

Data collection	Experimental data from study 3 was collected using Qualtrics. The voter file data from study 2 was collected from Catalist. The data from study 1 were taken from Add Health and the SOEP.
Data analysis	All analyses were conducted in Stata and R.

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The data that support the findings of study 3 is available from the corresponding author upon request. Note, however, the following restrictions to data in studies 1 and 2: the Add Health (restricted) dataset used in study 1, the SOEP data in study 1, and the Catalist data used in study 2 are proprietary and cannot be shared by

the authors. For information about how to access the Add Health restricted-use data, see www.cpc.unc.edu/projects/addhealth/documentation/restricteduse. The SOEP data are available after registration with the DIW Berlin, see www.diw.de/en/diw_02.c.222829.en/access.html. Catalist is a subscription-based service; for information about contracting with Catalist, see catalist.us/products/data-subscriptions.

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This article provides evidence from an observational study, a natural experiment, and a randomized experiment showing that insufficient sleep reduces prosocial behaviors such as voter turnout, donating to a charity, and signing petitions.
Research sample	We use multiple datasets, including data from Add Health, the German SOEP, proprietary voter file data, and an original experiment run among MTurk workers.
Sampling strategy	Our sample sizes in studies 1 and 2 are determined by the survey designers (study 1) and the number of zipcodes around the time-zone boundary cutoff. For study 3, we ran a pilot study that helped us create power calculations to obtain a sufficient sample size (which we did) for our experiment.
Data collection	The only data collection we engaged in was the two-wave MTurk study, wherein we administered two surveys to workers. The first measured baseline characteristics. The second measured our civic engagement outcomes.
Timing	Data was collected in early 2018.
Data exclusions	No data were excluded.
Non-participation	In our experimental study, between wave 1 and wave 2, we lost roughly 400 individuals due to attrition. The number of types of people who attrited were similar across the treatment and control group, making it unlikely that this would bias our estimates.
Randomization	In our experimental study, subjects were randomized at the individual level to treatment or control. The other two studies had no randomization component.

Reporting for specific materials, systems and methods

Materials & experimental systems

n/a	Involved in the study
☒	☐ Unique biological materials
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology
☒	☐ Animals and other organisms
☐	☒ Human research participants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics	Study 1: the add health data is a representative sample of the cohort of middle/high school students starting in 1994-1995; the SOEP is a representative survey of all adults in Germany; Study 2: Voter file data contains a 1% sample of every adult registered to vote in the United States; Study 3: contains Mturk workers who were 58.2% female, with a mean age of 36 (range: 18-85).
Recruitment	For study 3 (the only study with subject recruitment), we recruited MTurk workers through the standard protocol. We filtered based on quality of respondent. Otherwise, all workers were allowed to participate.