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Sleep restriction and strategy choice in cooperation and coordination games

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ABSTRACT

This study explores how sleepiness affects decision-making in social dilemma and coordination games. Using laboratory experiments, we find that sleep-restricted pairs of individuals are more likely to play Nash strategies compared to well-rested groups.

1. Introduction

There are many situations in which individuals make decisions autonomously but coordination is advantageous, such as with social-dilemmas (e.g., providing public goods). Other examples include situations in which players mutually prefer to coordinate on a strategy, but would incur significant losses if cooperation could not be assured (e.g., bank runs). Social scientists often rely on game-theoretic paradigms like the Prisoner's Dilemma (PD), Stag-hunt (SH), or assurance games to analyze how groups make such strategic decisions. Whether players use sophisticated inductive strategies or less cognitive-demanding heuristics has been a topic of recent research (Schneider and Leland, 2015). In this paper we explore how sleepiness – which can impact a person's cognitive state – affects decision-making in social dilemma and coordination games. Previous research suggests that more sleepy individuals will rely relatively less on deliberative thought processes in social interactions (Dickinson and McElroy, 2017).

Our study builds off Schneider and Leland (2015) that questions whether a "simple" heuristic – called reference-dependent maximin (RDM) – predicts behavior better than the Nash equilibrium in two-player static games. They find support for their hypotheses and show that RDM predicts pair-level behavior better than Nash in PD, SH and Battle of the Sexes (BOS) games. We use the same portfolio of games as Schneider and Leland, but in our experiment the participants' sleep state is experimentally varied using a validated one-week sleep manipulation protocol. As such, our data set involves choices in these games from participants in an objective well-rested (WR) or sleep-restricted (SR) state.

We find that in coordination games (SH and BOS), groups with more SR players are more likely to play a Nash equilibrium compared to groups with more WR players. We find no significant effect of SR on the likelihood of groups playing the RDM strategy in any of the games we consider (PD, SH, BOS).

2. Experimental design and sleep protocol

We use the same eight matrix games as reported in Schneider and Leland (2015) except that we multiply all payoffs by 10. The games include two PDs, three SHs and three BOS. While the PD games each have one unique Nash equilibrium in pure strategies (we do not consider mixed-strategy equilibria), the coordination games each have two Nash equilibria. All eight games have one unique RDM strategy, which roughly involves deviating from the reference maximin strategy when the possible gains outweigh potential losses.

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Table 1
Player payoffs and percentage of group decisions for each game.

PD

(30,30) 26%	(0,50) 26%
(50,0) 22%	(20,20)* 25%

(80,80)* 33%	(0,100) 26%
(100,0) 21%	(20,20) 21%

SH

(80,80)* 88%	(20,21) 8%
(21,20) 3%	(21,21) 1%

(80,80) 45%	(20,79) 25%
(79,20) 19%	(79,79)* 11%

(80,80) 63%	(20,21) 2%
(79,20)* 33%	(79,21) 2%

BOS

(100,90)* 91%	(10,10) 2%
(20,90) 7%	(20,100) 1%

(100,20) 30%	(10,10)* 42%
(20,20) 10%	(20,100) 18%

(100,90) 27%	(10,10) 5%
(90,90)* 59%	(90,100) 9%

We started with an online screening survey to identify young adults without self-reported sleep disorders, significant risk of major depressive or anxiety disorder, or extreme diurnal preferences that might confound the sleep manipulation protocol with circadian influences. The survey was sent to a randomly drawn set of undergraduates at Appalachian State University. From the viable population, we *ex ante* randomly assigned participants to the full-week SR (5–6 hrs/night attempted sleep) or WR (8–9 hrs/night attempted sleep) condition prior to sending recruitment invitations.[1]

The experiment was conducted over two sessions: In Session 1 the participants completed self-reports on habitual sleep and current mood, were given sleep diaries to complete daily, and assigned a wrist-worn accelerometer (a research-grade actigraphy device) to passively but objectively measure nightly sleep levels for the next week. One week later the participants returned to the lab for decision tasks (Session 2). Mixed cohorts (WR and SR participants) of up to 20 participants were recruited, and participants were randomly paired-together for each of the eight games (a "strangers" matching protocol). Subjects also completed a number of other tasks (discussed later).

In total, 279 participants were recruited into the study, 258 showed up for Session 1, and 233 completed both sessions.[2] We document the validity of the protocol elsewhere.[3] SR participants slept significantly less each night and had higher self-reported sleepiness during Session 2 compared to WR participants.

3. Results

Following Schneider and Leland (2015) we report the percentage of trials each strategy set is chosen in each game (Table 1). In the Table, Nash equilibria are indicated by shaded cells and the RDM strategy set is indicated by an asterisk. Note that while Schneider and Leland find the RDM strategy to be the most frequently played in all eight games, we find this strategy played most often in only five out of eight games (62.5%).

To investigate how sleep affects strategies we estimate a series of regression models. Each observation in our data set is for a pair of subjects, and the dependent variable is binary and equals one if the pair chooses a given strategy. Following Schneider and Leland (2015) we consider both Nash and RDM strategy sets. The regression models take the following form

$$Y_p = \alpha + \beta_1 SR_p + \beta_2 Epworth_p + \beta_3 SVO_p + \beta_4 Wins_p + \beta_5 CRT_p + \beta_6 Female_p + \beta_7 Backup_p + \gamma Game + \varepsilon_p$$

where the subscript p denotes pairs, $SR \in [0,1,2]$ is the number in the pair who are in the sleep-restricted protocol, *SVO* is the pair's average score from the social value orientation instrument (Murphy et al., 2011), *Wins* is the pair's average number of wins in a set of race games (capturing inductive abilities), *CRT* is the pair's average number of correct answers to the expanded cognitive reflection task (Primi et al., 2016), *Epworth* is the pair's average score from the chronic daytime sleepiness measure elicited in Session 1 (Johns, 1991), *Female* is the number of females, *Backup* is a dummy variable that equals one if a backup subject was used, and *Game* is a vector of dummies for each game.

The model is estimated using a logit specification, and we use inverse probability weights that account for sample selection due to attrition (i.e., those that do not complete Session 2). Only subject pairs considered minimally compliant with the prescribed sleep condition are included in the analysis.

We start by analyzing Nash equilibrium outcomes (if chosen strategy is Nash then $Y = 1$, otherwise $Y = 0$).

The second column in Table 2 reports estimates for the model including all eight games (game fixed effects are not reported).

Table 2
Sleep restriction and the likelihood of playing Nash.

	All 8 Games	PD	(SH & BOS)	SH	BOS
SR	0.212*	−0.076	0.284**	0.296*	0.274
	(0.119)	(0.231)	(0.123)	(0.179)	(0.179)
Epworth	0.000	0.002	−0.003	0.014	−0.017
	(0.039)	(0.058)	(0.039)	(0.064)	(0.046)
SVO	0.006	−0.014	0.011	0.036***	−0.018*
	(0.007)	(0.024)	(0.008)	(0.013)	(0.009)
Wins	−0.078	0.111	−0.139*	−0.137	−0.132
	(0.056)	(0.073)	(0.072)	(0.098)	(0.094)
CRT	0.023	0.078	0.007	−0.041	0.064
	(0.061)	(0.176)	(0.067)	(0.121)	(0.089)
Female	−0.166	−0.199	−0.168	−0.294	−0.022
	(0.174)	(0.267)	(0.219)	(0.277)	(0.241)
Backup	0.010	0.227	−0.040	−0.437	0.406
	(0.302)	(0.662)	(0.287)	(0.340)	(0.457)
Constant	−0.845	−1.027	2.248***	1.782*	3.125
	(0.583)	(1.070)	(0.726)	(0.951)	(0.855)
n	812	203	609	306	303
χ^2	2543.59	19.38	840.14	45.34	102.32

Notes: Standard errors (parentheses) are robust and clustered at the session level, and *,**,*** indicate significance at the 0.10, 0.05 and 0.01 levels respectively.

[1] These sleep levels are considered insufficient (SR) or sufficient (WR) for young adults (see https://www.sleepfoundation.org/ and https://www.cdc.gov/sleep/index.html).

[2] Some subjects (9 in total) did not return for Session 2. To ensure an even number, some pairs include a 'backup' player who did not take part in the sleep protocol.

[3] https://ideas.repec.org/p/apl/wpaper/21-08.html

Table 3
Sleep restriction and the likelihood of playing Nash in coordination games.

	SH UL	SH DR	BOS UL	BOS DR
SR	0.312*	−0.0895	0.0581	0.548**
	(0.163)	(0.246)	(0.179)	(0.240)
Epworth	−0.0398	0.231**	−0.0246	0.00389
	(0.0737)	(0.109)	(0.0590)	(0.0790)
SVO	0.0421***	−0.0247	−0.0152	−0.0111
	(0.0111)	(0.0357)	(0.0124)	(0.0235)
Wins	−0.151*	0.0329	−0.0778	−0.152
	(0.0916)	(0.203)	(0.126)	(0.124)
CRT	0.0169	−0.246	0.107	−0.0629
	(0.141)	(0.255)	(0.152)	(0.174)
Female	−0.209	−0.361	−0.0783	0.0987
	(0.289)	(0.449)	(0.289)	(0.392)
Backup	−0.471	0.126	−0.376	1.318**
	(0.314)	(1.142)	(0.522)	(0.672)
Constant	1.734*	−4.852***	2.900***	−4.238***
	(0.922)	(1.551)	(0.975)	(1.017)
n	306	306	303	303
χ^2	102.14	58.76	205.33	107.51

The coefficient on SR is positive and weakly significant ($p = 0.073$), indicating that the more sleep-restricted subjects in the pair the more likely they play a Nash equilibrium. When segmenting by game type, we see that SR has no significant impact in PD games, but is positive and significant ($p = 0.021$) in coordination games. The effect of SR is weakly significant when focusing on SH games ($p = 0.098$), but is insignificant in BOS.[4]

The six coordination games each have two Nash equilibria (up-left, down-right in Table 1). In the SH games the up-left equilibrium is *payoff dominant* and the down-right equilibrium is *less risky*. In the BOS games, up-left is the equilibrium preferred by the row player and down-right is the equilibrium preferred by the column player. To investigate the impact of SR on the choice of Nash equilibria in coordination games, we run separate models for each equilibrium (Table 3).

In SH games, we see that more SR players leads to a higher likelihood of playing the payoff-dominant Nash equilibrium ($p = 0.056$), but no impact on choosing the less-risky Nash equilibrium. The results suggest that SR is positively correlated with choosing a Nash equilibrium that yields relatively high payoffs over other strategy sets in games of assurance.

In BOS games, SR has a positive and significant impact on pairs playing the Nash equilibrium that is preferred by the column player ($p = 0.023$).

To explore whether SR is correlated with playing the RDM heuristic, we estimate the same functional forms as in Table 2 with RDM as the dependent variable. For all models, SR has no significant impact on the likelihood of playing the RDM strategy (Table 4). However, daytime sleepiness (Epworth score) decreases the likelihood of playing RDM in the pooled data, which suggests sleepier pairs play alternative strategies to RDM.

Table 4
Sleep restriction and the likelihood of playing RDM.

	All 8 Games	PD	(SH & BOS)	SH	BOS
SR	−0.216	−0.129	−0.252	−0.0427	−0.418
	(0.187)	(0.288)	(0.201)	(0.202)	(0.259)
Epworth	−0.0636**	−0.195**	−0.0154	−0.0159	−0.0158
	(0.0322)	(0.0778)	(0.0385)	(0.0480)	(0.0499)
SVO	−0.00183	0.000929	−0.00442	−0.0187*	0.00806
	(0.00623)	(0.0181)	(0.00750)	(0.0111)	(0.0132)
Wins	0.170***	0.194***	0.165**	0.115	0.204*
	(0.0450)	(0.0724)	(0.0672)	(0.104)	(0.110)
CRT	−0.0739	0.0367	−0.123	−0.187	−0.0530
	(0.0806)	(0.104)	(0.0889)	(0.162)	(0.114)
Female	−0.0160	0.125	−0.0570	−0.109	−0.00345
	(0.212)	(0.292)	(0.285)	(0.354)	(0.311)
Backup	−0.165	−0.277	−0.229	0.0582	−0.460
	(0.391)	(0.716)	(0.423)	(0.483)	(0.473)
Constant	−0.670	−0.425	2.199***	2.850***	1.956***
	(0.432)	(0.980)	(0.541)	(0.649)	(0.668)
n	812	203	609	306	303
χ^2	384.69	19.13	177.32	180.66	99.32

4. Conclusion

Our exploratory study shows that sleep restriction increases Nash equilibria play in some key coordination games compared to being well rested. As the Nash strategies in these games require less deliberation than the RDM heuristic, our findings are consistent with previous research indicating that sleep restriction promotes the use of simpler or less cognitively demanding thought processes (Dickinson and McElroy, 2019). Future research could examine how sleep impacts decision making across a wider variety of noncooperative games in order to strengthen or clarify this finding.

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[4] Given that multiple hypothesis tests can lead to an increase in Type I errors, the reported p-values should be interpreted with caution.