The association between REM sleep and decision-making: supporting evidences

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Abstract:

Studies suggest that REM sleep is important for the maintenance of prefrontal cortex functioning. Therefore, reducing REM sleep may have an impact on cognitive functions such as impulse control and decision-making processes. This study examined the association between impulsiveness and sensation seeking personality traits, REM sleep and performance on a decision-making computer task following a habitual night of sleep and a partial sleep deprivation (PSD) condition with advanced wake-up time. Eighteen young adults participated in two experimental conditions: a control (habitual bedtime and wake time) and a 50% PSD with an advanced wake time. Impulsiveness and sensation seeking personality traits were measured with a personality inventory (NEO-PI-3), sleep was assessed using standard polysomnography and the Iowa Gambling Task (IGT) was completed at noon following each sleep condition. Results showed that when sleep deprived, participants choose more often to play riskier decks of cards during the last half of the IGT. Results also showed that REM sleep duration and REM sleep deprivation were associated with riskier decisions on the IGT. Moreover, impulsiveness was associated with riskier decisions after a normal night of sleep. These findings suggest that REM sleep duration and impulsiveness are important factors to consider while investigating decision-making processes under conditions of uncertainty and risk.

Keywords: REM sleep deprivation | Impulsivity | Decision-making

Article:

1. Introduction

Decision-making processes may lead to risk-taking behaviors, which can have various negative consequences (e.g. reckless driving, drug use, unsafe sexual practices) [8]. Although underlying mechanisms are numerous and are still not fully understood, we now know that some individuals may have personality traits that predispose them to taking risks [31]. For example, impulsiveness and sensation seeking personality traits have been associated with risk-taking behaviors such as gambling [31]. Conversely, it has been shown that situational factors, such as sleep deprivation, may also lead to riskier decisions [19, 29]. It is well known that the prefrontal cortex region is a major center of executive control such as planning, inhibition control, and decision-making [29]. Most studies support that the frontal lobes are distinctly fragile to sleep loss [29]. However, decision-making process is a very complex system with many components, which may be affected differently by sleep loss.

Recent studies have shown that cognitive functions involving emotional processing, such as emotionally-based decisions, are impaired after sleep deprivation [1, 30]. For example, sleep loss negatively impact mood and emotional functioning, and these changes may then have negative impacts on risk assessment, feelings of trust, and impulsive decision-making [18]. Furthermore, studies have shown that being exposed to a potential gain or reward, rather than a potential loss, when sleep deprived, leads to riskier decision-making [19, 28]. It has been shown that in the context of sleep deprivation, the connectivity between the amygdala and the medial prefrontal cortex is attenuated to give way to a predominant connectivity between the amygdala and the brain stem structures (locus coeruleus and midbrain) involved in more automatic responses of the brain [30]. This new pathway is believed to result in a loss of control from the prefrontal lobe, down to the limbic system, resulting in an extreme sensitivity of the amygdala to emotional stimuli [30]. Recent humans and animals research suggest that REM sleep may be of particular importance for the emotional processing [24]. For example, Goldstein and Walker [15] observed that REM sleep contribute to resetting functions within key brainstem, limbic, and prefrontal brain regions, in order to restore optimal emotional reactivity for the upcoming day, and thus possibly impacting risk assessment. Also, many brain structures involved in the “emotional brain”, including the amygdala, the cingulate cortex and the prefrontal cortex, are selectively activated or deactivated during REM sleep [21]. Research have also showed that REM sleep play an important role in the regulation of particular neural pathways involved in the processing of fear, danger or threat, key components in risk-assessment, and thus in decision-making processes [5, 14, 25, 30].

Over the years, most of the sleep deprivation studies on emotional processing and decision-making have used total sleep deprivation settings (not sleeping at all), which does not represent what is most commonly found in normal populations [13]. On the other hand, studies using partial sleep deprivation (PSD) settings (cutting off only a part of the night) have shown mixed results, as changes in decision-making processes are not always found [13, 26]. This may be in part due to the lack of sensitivity of some tests to the effect of PSD. Moreover, given the link between REM sleep, prefrontal cortex and the limbic system, different PSD protocols could lead to mixed results on decision-making, depending on their impact on REM sleep. The Iowa Gambling Task (IGT) is one of the most well-known tasks used to assess decision-making in research, but also in clinical settings [7]. For instance, several studies involving participants with ventromedial prefrontal cortex lesions, a region sensitive to sleep loss, noted a tendency to make riskier decisions on the IGT compared to control subjects [7]. The objective of this study was to explore the possible associations between personality traits (impulsiveness, sensation seeking), REM sleep duration, and the performance on the IGT following a habitual sleep night (control condition) and a PSD condition with an advanced wake time (experimental condition), thus significantly reducing REM sleep duration.

2. Material and methods

2.1. Participants

Eighteen participants (12 men, 6 women) aged 18 to 33 years (mean age 23 ± 4 years) completed all conditions and measurements. They were all non-smokers, and weight stable (±4 kg) for 6 months prior to the study. Participants were excluded if they had heart problems, diabetes and were taking medication that could affect sleep. All participants were not shift workers and did not take regular daytime naps. They reported having habitual sleep durations of 7 to 9h per night, which was confirmed with accelerometry (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA, USA) and sleep diary monitoring for two weeks prior to the experiment. We also excluded individuals with extreme morning or evening chronotype according to the Morningness-Eveningness Questionnaire [17]. Only women taking monophasic combined estrogen-progesterone birth control were recruited, in order to control for sex-steroid hormones effects on sleep parameters [2]. The Université du Québec en Outaouais and the University of Ottawa ethics committees approved all procedures. Written informed consent was obtained from all participants.

2.2. Procedures and measures

The present analyses are part of a larger study which aimed to investigate the effects of 50% sleep restriction combined with alteration in sleep timing on energy balance. For the description of the full study procedure and measurements, see McNeil et al. [23]. This study follows a randomized crossover design that included three experimental conditions: a control condition with an habitual bedtime and wake-up time, a 50% sleep restriction with an habitual bedtime and advanced wake time, and a 50% sleep restriction with a delayed bedtime and habitual wake-up time. The prescribed bedtimes and wake times for each condition were based on the two weeks of accelerometry and sleep diaries monitoring prior to the experiment. Hence, the timing of all measurements was different for each participant, but were standardized across conditions and tailored for each participant. The three experimental conditions were randomly assigned to each participant, and at least 7 days separated each condition.

Before the first experimental condition, all participants had a first meeting, followed by an habituation night in the laboratory. During this first meeting, they completed the NEO-PI-3 in order to evaluate personality traits. The NEO-PI-3 [22] is a personality test consisting of 240 statements divided into five dimensions (Neuroticism, Extraversion, Openness, Agreeableness, Conscientiousness), which are then divided into six facets of different personality traits. For the present study, the impulsiveness and sensation seeking facets were used since they have been previously associated with risk-taking behaviors [31]. Following this habituation night in the lab, all participants were given an accelerometer and a sleep diary to measure habitual sleep-wake patterns under free-living conditions for 2 weeks.

For each experimental condition, participants arrived three hours before the usual bedtime to set up the electrodes for the polysomnography recording. Participants were asked to not consume alcohol or exercise for at least 24h, or consume caffeinated products after 12PM (noon), prior to each experimental condition. Sleep was measured with EEG (C3, C4, O1, O2, F3 and F4), EMG (bipolar submental), and EOG on a Medipalm 22 with the Pursuit Advanced Sleep Software (Braebon Medical Corporation, Kanata, Ontario, Canada). Polysomnography recordings were scored independently by 2 judges according to the AASM (American Association of Sleep Medicine, 2007 AASM criteria [4] using 30-s epochs; discrepancies were resolved by mutual agreement.

To assess decision-making, all participants performed the IGT on a computer at 12PM following the control and the 50% sleep restriction with advanced wake time conditions. Two equivalent versions were used in a counterbalanced manner during the study (positions of the decks were different on the screen between versions) as a way to avoid a learning effect [19]. Therefore, the IGT was not administered after the 50% sleep restriction with delayed bedtime condition because it was hypothesized *a priori* that the sleep restriction with an advanced wake time condition would lead to a greater reduction in REM sleep duration [15]. The IGT is a computer-based task that assess decision-making [10]. The present study used the modified version of the IGT described in Cauffman et al. [10]. Participants were asked to choose to play or pass four randomly pre-selected decks of cards. In other words, the subjects could not choose freely between the different decks but could only decide to draw a card or not from one deck at a time. Of the four decks of cards, two were advantageous (small amounts of money but long terms gains), and two were disadvantageous and more risky (large amounts of money but long terms losses). When a deck was played, participants either received or lost money (monetary gain was fictional only). When participants passed, they lost nothing, but also gained nothing. Participants had 120 attempts to gain as much money as possible. In order to address the evolutionary nature of the task, these attempts are divided into 6 blocks of 20 trials each. Usually, participants adjust their answers as feedback is received across the different blocks. They gradually learn, as they gain experience, which decks are more or less risky [7]. Consequently, performance on the last blocks of the IGT has been considered as the best indicator of decision-making under risk, whereas the first blocks has been associated with more ambiguous decision-making [7].

2.3. Data analysis

To assess the performance on the IGT, the three primary outcomes described by Cauffman et al. [10] were used in the analyses: the percentage of disadvantageous decks (%Disadvantageous) chosen by each participant, the percentage of advantageous decks (%Advantageous) chosen, and the net score (%Advantageous minus %Disadvantageous). The analyses were first conducted on the 120 trials (global performance) and, then, on the trials of the second half (last 3 blocks) of the task [7]. We conducted paired-sample t-tests to assess differences in sleep measurements and in the IGT outcomes. The Wilcoxon signed-rank test was used for non-normally distributed data according to the Shapiro Wilk test. Since significant differences were obtained with %Disadvantageous on the second half of the task, multiple linear regression models were computed to explore the unique contribution of the personality traits and REM sleep duration to the %Disadvantageous for each sleep condition separately. Given the large number of evidences of gender and age differences in sleep and decision-making, it would be important to consider those variables in the analyses. However, given the small sample size of this study, it was not possible to compare men and women or to divide the participants in different age groups. Therefore, gender and age were added as control variables in the regression models. Finally, since an association was found between REM sleep duration and %Disadvantageous in both sleep conditions, a simple Pearson correlation analysis was calculated between Delta REM sleep duration (PSD minus control) and Delta %Disadvantageous (PSD minus control) in order to verify if changes in REM sleep duration are associated with changes in %Disadvantageous. All statistical analyses were conducted using SPSS (version 23.0; SPSS Inc., Chicago, IL). All assumptions were considered, and variables were analysed accordingly. Differences with *p* values <.05 were considered statistically significant.

3. Results

Descriptive characteristics are presented in Table 1. Additional descriptive data on the in-laboratory sleep and energy balance parameters assessed during each condition can be found in McNeil et al. [23]. As expected, participants slept significantly less in the PSD condition, which impacted significantly the absolute and relative amount of the sleep stages compared to the control condition (see Table 1). In sum, all absolute amounts of sleep stages were significantly reduced, since the total sleep duration was cut by half a night. The relative amounts of each sleep stage showed that the advanced wake time condition successfully reduced the amount of REM sleep, as it was intended.

Table 1. Descriptive data: sleep parameters and performance on the Iowa Gambling task during each session (n=18)

	Control	**PSD with advanced wake time**	**Comparison test**	
	Mean ± SD	***Mean ± SD***	***t value***	***p value***
Sleep parameters				
Sleep duration (min)	463.01 ± 29.81	229.26 ± 16.68	45.69	<.001*
N1 (min)	17.76 ± 9.34	6.88 ± 3.68	5.39	<.001*
N2 (min)	245.34 ± 35.28	112.99 ± 28.96	18.94	<.001*
N3 (min)	91.50 ± 31.98	75.75 ± 33.81	2.81	.01*
REM (min)	108.41 ± 23.81	33.63 ± 7.34	14.75	<.001
Sleep efficiency (%)	94.62 ± 3.48	92.85 ± 4.47	*n.a.*	.09
N1 (%)	3.67 ± 1.85	2.88 ± 1.47	1.74	.10
N2 (%)	51.11 ± 7.01	47.63 ± 12.48	1.51	.15
N3 (%)	19.06 ± 6.60	31.79 ± 14.16	-5.34	<.001*
REM (%)	22.57 ± 4.65	14.16 ± 2.92	8.30	<.001*
IGT				
Advantageous (%)	80.66 ± 15.48	84.51 ± 10.33	-1.06	.31
Disadvantageous (%)	69.97 ± 19.40	75.71 ± 15.76	-1.50	.15
Net score (%)	8.00 ± 20.57	7.13 ± 15.06	*n.a.*	.78

Notes: t values are available only for normally distributed data; IGT, Iowa Gambling task; PSD, partial sleep deprivation; SD, standard deviation ; N1-N3 (min), absolute amount of non-REM sleep stages; N1-N3 (%), relative amount of non-REM sleep stages; REM, rapid eye movement; Advantageous (%), percentage of advantageous decks chosen by each participant; Net score (%), Advantageous – Disadvantageous; Sleep efficiency is calculated as [(sleep time/time in bed)*100].

No differences in global performances on the IGT were noted between conditions. On the other hand, further analyses on the trials of the last 3 blocks revealed a significant tendency to choose more disadvantageous decks after the PSD condition compared to the control condition ($Z = -2.08$, $p = .038$; see Fig. 1).

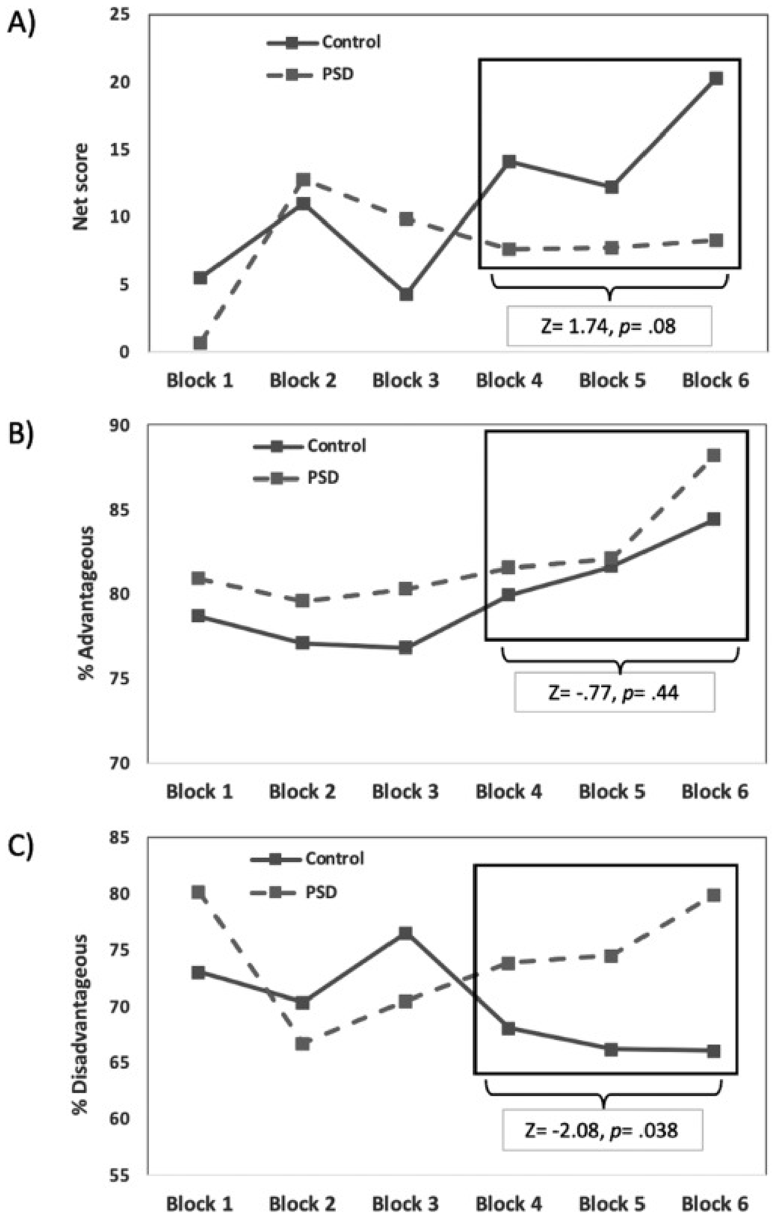

Fig. 1. Results for the Wilcoxon signed-rank test conducted on the trials of the second half (last 3 blocks) of the IGT between the control and PSD conditions for each outcome: (A) Net score, %Advantageous minus %Disadvantageous; (B) %Advantageous, the percentage of advantageous decks chosen; (C) %Disadvantageous, the percentage of disadvantageous decks chosen.

Results from the multiple regression models are presented in Table 2. For the control condition, results showed that impulsiveness and REM sleep duration collectively explained 71% of the variance of %Disadvantageous (p<.001). For the PSD session, results showed that the model explained significantly 46.2% of the variance of %Disadvantageous (p=.02). However, it was not possible to determine the exact contribution of each variable, but Age and REM sleep duration both shows strong tendencies. Post-hoc analysis showed that changes in REM sleep duration were significantly associated with changes in %Disadvantageous between sleep conditions (r = -.49, p = .04), suggesting that a higher decrease in REM sleep duration was associated with a higher tendency to play riskier decks (see Fig. 2).

Table 2. Results from the multiple linear regression models presenting the associations between each predictor with Disadvantageous% during both sleep conditions.

	Control				PSD with advance waketime			
	β	*95% CI*	*SE*	*p value*	*β*	*95% CI*	*SE*	*p value*
Impulsiveness	.43	[.32, 1.93]	.37	.01*	.24	[-.35, 1.38]	.40	.22
Sensation seeking	.04	[-.81, 1.00]	.41	.82	.33	[-.28, 1.67]	.45	.15
REM	-.59	[-.73, -.23]	.12	.001*	-.38	[-1.69, .07]	.40	.07
Age	.28	[-.12, 2.93]	.70	.07	.39	[-.07, 3.30]	.77	.06
Gender	.19	[-6.86, 21.93]	6.60	.28	.11	[-11.92,18.82]	7.05	.63

Notes: Disadvantageous%, percentage of disadvantageous decks chosen by each participant; PSD, sleep deprivation; REM%, relative amount of REM sleep for each condition; CI, confidence interval; SE, standard error

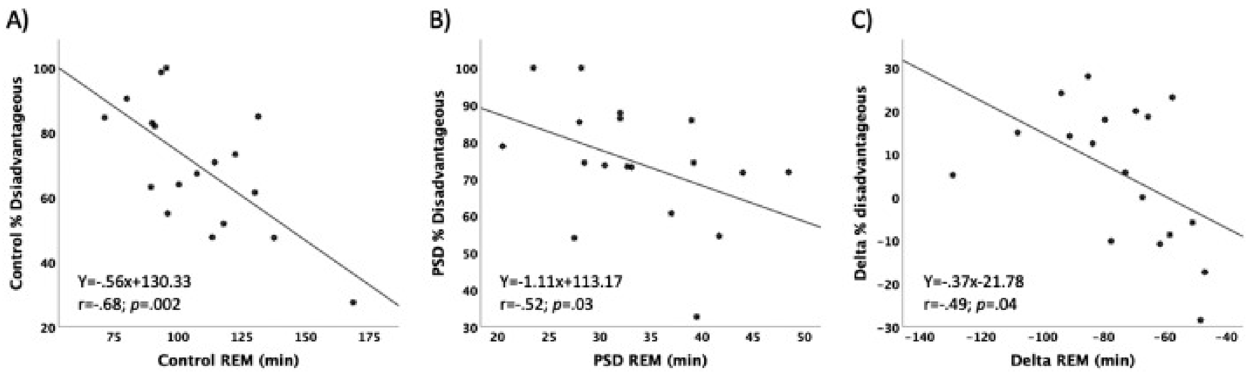

Fig. 2. Relation between the % of disadvantageous deck chosen and the amount of REM sleep for the control and PSD condition (A and B) and the differences between conditions (C) (Delta REM = PSD minus control, Delta %Disadvantageous = PSD minus control). Linear regression equation and Pearson correlation coefficient are presented in each scatter plot.

4. Discussion

The objective of this study was to explore the possible associations between personality traits, REM sleep, and decision-making. Our results showed that when partially sleep-deprived, participants choose more often to play riskier decks of cards during the last half of the IGT, revealing a difficulty in decision-making under conditions of uncertainty. More interestingly, our results suggest that there is a relationship between REM sleep and the decision-making processes measured by the IGT.

It is already documented that risk-taking behaviors are more prominent in sleep deprivation conditions [29], but the implication of REM sleep has thus far been less clear. In our study, sleep loss did not result in any changes in the primary outcomes on the IGT. That was partly expected, since studies using PSD settings have frequently shown mixed results [13, 26]. However, more specific analyses on the last half of the task, which have previously been associated with decisions under risk [6], revealed that participants tended to choose a greater proportion of disadvantageous decks after sleep loss, compared to a normal night of sleep. Interestingly, the amount of REM sleep reduction was associated with a proportional increase in riskier decisions on the IGT. Our results thus seem to support the hypothesis that REM sleep may be important for maintaining cognitive functions that are closely related to the prefrontal lobes, a region involved in decision-making [15]. Our results are also consistent with previous studies showing that participants with ventromedial prefrontal cortex lesions, choose more disadvantageous decks, have difficulties in weighting reward and punishment contingencies, and are more inclined to take risks in their daily lives [3]. Moreover, our results are in accordance with functional neuroimaging studies showing a decrease in the functional connectivity between different mesolimbic and striatal structures of the reward system, and the prefrontal cortex after sleep deprivation that impairs emotion management, reward, and punishment analysis [15, 16, 28, 30]. Finally, REM sleep behavior disorder patients, who are presenting REM sleep disruptions, show a similar pattern of response as our participants on the IGT [12], reinforcing the idea that the physiology of REM sleep contributes to the decision-making processes under risk.

Over the years, human and animal research has shed more light on the role of sleep, and more specifically REM sleep, in decision-making processes. Many studies are supporting the role of REM sleep in the regulation of the emotional and motivational states associated with the reward system, which are in turn associated with decision-making and risk-taking behaviors [16, 19, 20, 28]. For example, Liu et al. [20] showed that sleep deprivation induce sucrose seeking and consumption but not food intake, suggesting a selective increase in the motivational component of the reward system. The authors also showed that sleep deprivation impairs the glutamate release of the medial prefrontal cortex to the nucleus accumbens, which is an important region for the emotional and motivational response to reward [20]. Other studies have confirmed that the brain glutamatergic system plays an important role in animal fear and human anxiety, both of which are closely associated with the decision-making process. For example, a study showed an alteration in the glutamate level in the cortico-limbic circuit after sleep deprivation, which was associated with reduced fear-like behaviors and increased risk-taking behaviors in rats [11]. These authors found an inverse relationship between glutamate levels in the medial prefrontal cortex and risk-taking behavior. Results of our study are very much in line with these studies and contibute to the hypothesis that REM sleep plays a significant role in risk-taking behaviors.

On another note, our study also show that specific personality traits may contribute to altered decision-making under risk, but only when well rested. More precisely, our results showed that having a higher impulsiveness personality trait (higher tendency to make impulsive decisions) was associated with riskier decisions on the IGT after a normal night of sleep. These results suggest that personality traits could have different impacts on behaviors based on current sleep debt. For example, it is possible that under optimal sleep conditions, personality traits may influence behaviors and decision-making processes, but following sleep deprivation, other factors (such as frontal lobes dysfunctions) may become more prominent and have stronger effects in directing those behaviors and mental processes [18, 28].

The performance on the IGT has been previously associated with age and gender, risky behaviors being more prominent in younger men [10, 27]. Considering the fact that our study included a relatively small homogenous sample of young (18 to 33 years old), healthy adults, mostly men (12 men and 6 women), and with a high sleep efficiency (≥85%), it is not surprising that we did not find any significant associations between age, gender and the IGT outcomes. On the other hand, despite the fact that our sample was small, results are showing strong associations between the amount of REM sleep and people's performance on the IGT. This suggest consistent patterns in all participants, both men and women, across conditions. However, further studies are needed to replicate our results with a broader population, including both men and women of different age group.

In conclusion, these findings suggest that REM sleep duration and impulsiveness personality trait are important factors to consider while investigating risky decision-making. For instance, adolescents are more prone to making riskier decisions but may also be more prone to be REM sleep deprived, as they tend to have a delay in their circadian rhythms, but still need to wake early to go to school [9]. Therefore, adolescents may experience frequent REM sleep deprivation, which may lead to the adoption of more frequent and/or riskier behaviors. Additional studies are needed to assess this hypothesis, given the implications that the current findings may have on adolescent's propensity towards risk-taking behaviors. Understanding underlying mechanism to decision-making may help prevent negative consequences such as reckless driving, drug uses and unsafe sexual practices. Thus, by exploring the possible implications of personality traits and REM sleep in this process, our study helps understand the complex interactions that guide every choice we make.

Author contributions

J-FB**,** JM, GF and ÉD formulated the research questions and designed the study. J-FB and JM carried out the experiment. J-FB analyzed the data. J-FB, JM and GF wrote the manuscript and all authors approved the submitted version.

Jean-François Brunet: Conceptualization, Project administration, Investigation, Formal analysis, Writing - review & editing. **Jessica McNeil:** Conceptualization, Project administration, Investigation. **Éric Doucet:** Conceptualization. **Geneviève Forest:** Conceptualization, Project administration, Investigation, Writing - review & editing.

Declaration of Competing Interests

The authors of this paper declare no conflict of interest.

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