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High neuroticism is associated with reduced negative affect following sleep deprivation☆

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ABSTRACT

The aim was to investigate how neuroticism moderates the affective consequences of personalized mild-moderate partial sleep deprivation. A total of 52 healthy subjects aged 18–35 years completed the NEO PI-3 at baseline, before they completed an 11-day study protocol. After maintaining habitual sleep for seven days, the participants were asked to sleep 2 h less than their average sleep duration, the last three nights of the study protocol. Sleep patterns were observed using actigraphs and sleep diaries. The participants completed the PANAS questionnaire measuring positive and negative affect at 9 am (±90 min) at day 1, 4, 8 (habitual sleep), 9 and 11 (partial sleep deprived). We found that participants with higher scores on neuroticism experienced a decrease in negative affect following sleep deprivation. Participants with lower scores on neuroticism experienced an increase in negative affect after sleep deprivation. Positive affect was reduced following sleep deprivation, regardless of scores on neuroticism.

1. Introduction

Sufficient sleep is crucial for brain health, cardiovascular health and prospective of a long life (Fernandez-Mendoza et al., 2020). Sleep loss greatly impacts all levels of emotional processing, from immediate affective responses to more complex socio-emotional functioning (Ben Simon et al., 2020). Still, many adults report not getting enough sleep and often going to bed later than intended (Kroese et al., 2014; Nauts et al., 2019). Prior studies in healthy participants show that partial sleep deprivation reduces positive affect, but seem to have no influence on negative affect (e.g. Lo et al., 2016; Saksvik-Lehouillier et al., 2020; Talbot et al., 2010). However, there seem to be biological based individual differences in habitual sleep length (Aeschbach et al., 2003). We therefore need to take an individualistic approach to examining the effect of sleep deprivation on affect, considering individual differences in personality as well as habitual sleep timing and sleep duration.

Recently, there has been an increased interest in delineating phenotypical frameworks for improved understanding of mental disorders (Conway & Simms, 2020). Vulnerability to sleep restriction seem to have trait-like qualities, where the participants show the same degree of vulnerability to sleep restriction regardless of the duration and manner of the restriction (Rupp et al., 2012). Personality profiles, representing phenotypical expression of inherited dispositions, are potential targets for interventions (Clark et al., 2020). High scores on neuroticism represent a general increased risk for developing common mental disorders (Kotov et al., 2010; Ormel et al., 2013).

Because of its link to mental and physical health, neuroticism is important to consider in a public health context. Accordingly, research focusing on how the mechanisms in neuroticism are linked to mental and physical disorders is requested (Lahey, 2009). High scores on neuroticism were associated with poor sleep hygiene and poor subjective sleep quality, pronounced daytime sleepiness (Cheng et al., 2012; Duggan et al., 2014; Gray & Watson, 2002; Williams & Moroz, 2009). Recent findings indicate that the relationship between neuroticism and

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sleep is not limited to subjective reports, but extends to objective measures (Sutin et al., 2020). Neuroticism also predicts changes in insomnia symptoms among shift workers over a six-month period (Larsgård & Saksvik-Lehouillier, 2016). In addition, insomnia seems to be a mediator between neuroticism and development of anxiety and depression (Sørengaard et al., 2019).

Most of the prior research on the role of personality in sleep deprivation is limited by small sample sizes and few as well as suboptimal measures of personality traits. There is a need for research using comprehensive, gold-standard, validated measures of personality traits. Moreover, sleep deprivation studies have typically been performed in laboratories, with low ecological validity, and without considering individual differences in sleep habits and sleep needs. Some diary studies of naturalistic sleep and personality, has however, recently been conducted (Hisler et al., 2018), but in this study sleep was measured only subjectively. Although rarely used, naturalistic at-home sleep experiments using actigraphy to monitor sleep is considered superior to lab experiments in many settings due to the increased ecological validity (Lowe et al., 2017). We have recently developed a protocol for a sleep deprivation study which can be performed in the participants' homes, calculating sleep deprivation conditions based on individual, habitual sleep using actigraphy in combination with self-report measures (Saksvik-Lehouillier et al., 2020). In this study, we leverage this protocol to test how neuroticism is associated with affective changes after individually calculated mild-moderate partial sleep deprivation.

2. Method

2.1. Design and participants

A within-group multiple baseline experimental design was applied. A total of 59 healthy subjects aged 18–35 years were recruited through a convenience sample. Participants were recruited through social media, in lectures, and information was given on bulletin boards throughout campus. Four participants had to be excluded due to technical issues with the actigraphy measuring their sleep and/or compliance with sleep deprivation ($n = 3$) and one due to illness. Another three participants were excluded because they failed to comply with the sleep deprivation protocol of sleeping for 90 min less than they usually do during all three days of the sleep deprivation condition. Thus, 52 individuals comprised the final sample. Of these, 41 (78.8%) were female, and the mean age was 22.58 years (SD = 3.06).

2.2. Procedure and study design

Participants took part in an 11-day study protocol where they slept at home, and sleep patterns were observed using actigraphs and sleep diaries. They visited the university for testing at five occasions, the first three visits during normal sleep, and the last two during partial sleep deprivation; on day 1 (visit 1), day 3 (visit 2), day 7 (visit 3), day 8 (visit 4) and day 10 (visit 5). At visit 1 the participants provided their informed consent, completed baseline questionnaires, and underwent testing. After maintaining habitual sleep for seven days, the participants were asked to sleep 2 h less than their average sleep duration, the last three nights of the study protocol. The participants completed the PANAS questionnaire during the testing at campus measuring positive and negative affect at 9 am (±90 min) at visit 1–3 (habitual sleep), and at visit 4 and 5 (short sleep).

The study was approved by the Regional Medical and Health Research Ethics in Central Norway (REK number 2017/85) and was performed in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

3. Instruments

3.1. Sleep recording

A wrist-worn actigraph (Actiwatch Spectrum Pro, Philips Respironics, USA) was used to record information about the participants sleep and activity during the day. Data was collected in 15-second epochs, with a medium sensitivity threshold of 40 activity counts. Rest intervals were set using the RISE procedure (Follesø, Austad, Olsen, & Saksvik-Lehouillier, 2021), a procedure that incorporates raw actigraphic data with algorithm analyses and sleep diary data. The participants also kept a sleep diary; a modified version of the one published by Morin (Morin, 1993).

3.2. Affect

The participants' mood was assessed using the PANAS-SF (Watson et al., 1988a, 1988b). This is the short form of the PANAS, and is a valid tool in measuring mood states (Thompson, 2007). It includes the items determined, attentive, alert, inspired and active, which constitute the positive affect factor. Afraid, nervous, upset, ashamed and hostile constitutes the negative affect factor.

3.3. Personality

To measure personality we used the NEO Personality Inventory-3 (NEO-PI-3), which assesses the five personality traits of the Five Factor Model (Costa & McCrae, 2013) (neuroticism, extraversion, openness to experience, agreeableness and conscientiousness). These domains are further subdivided into six facets. The NEO-PI-3 is established as one of the most widely used instruments for the assessment of personality and is considered a valid and reliable instrument (Egger et al., 2003; Martin & Martín-Sánchez, 2012; McCrae & Costa, 2010; Yoon et al., 2002).

3.4. Other measures

Several health and sleep variables were measured in the baseline questionnaire. These included Insomnia Severity Index, Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale, Hospital Anxiety and Depression Scale, Fatigue Severity Scale, Diurnal Scale, Brief Pain Inventory, Behavioral Rating Inventory of Executive Function – Adults (BRIEF) and Metacognition Questionnaire. The participants also completed a cognitive performance test, the Conners' Continuous Performance test (CCPT; Conners, Epstein, Angold, & Klaric, 2003) at all visits before completing the PANAS. We report all manipulations, measures, and exclusions in these studies.

3.5. Statistical analyses

Statistical power was calculated post hoc using the software G*Power3 (Faul, Erdfelder, Lang, & Buchner, 2007). The analysis included observed effect size (η_p^2) for the respective analysis, and all results indicated statistical power exceeding 0.80. All analyses were performed in SPSS v25. First, we performed a correlation analysis with demographic variables, neuroticism, sleep variables and affect variables on baseline. To examine how neuroticism influenced the change in negative and positive affect at the five visits, we performed two sets of repeated measures ANCOVAs. Three neuroticism sub-groups were created: participants with scores within 0.5 standard deviation from the mean was allocated to the middle group, and those scoring below and higher than this in the low and high neuroticism group respectively. Time was included as a fixed factor. Neuroticism was inserted as a between subject factor. Assumptions of sphericity was tested using Mauchley's test for all rANOVAS, and in case of violated assumptions the F tests were corrected using the Greenhouse-Geisser method (Greenhouse & Geisser, 1959). Significant main or interaction effects were further investigated using polynomial trend analyses.

4. Results

Mean and standard deviations for all variables are presented in Table 1. In addition, Table 1 shows correlations between neuroticism, baseline sleep and affect variables. Higher scores on neuroticism was positively correlated with more negative affect (0.48), higher insomnia scores (0.50), higher score on Pittsburgh Sleep Quality index (low value indicates good sleep quality) (0.32) and higher fatigue scores (0.50). There were no statistically significant correlations between neuroticism and the demographic variables, positive affect, daytime sleepiness, nor the actigraphy measures. Neuroticism had a negative, although non-significant correlation with actigraphy measured sleep efficiency ($r = -0.23$, $p = .107$).

In Table 2 we show mean scores on actigraphy and sleep diary measured total sleep time, actigraphy measured sleep efficiency and subjective sleep quality for the habitual sleep period and the sleep deprived period. This is shown across the different groups of low, medium and high neuroticism scores. We analyzed differences between the low, medium and high groups in all variables using one-way ANOVA, but no significant differences appeared.

The assumption of Sphericity was violated in the analyses of negative affect with neuroticism, as a between subjects' factor. The Greenhouse-Geisser method was therefore used for correction for these analyses. The main effect of time was not significant (F (2.93, 143.61) = 0.95, $p = .44$, $\eta_p^2 = 0.02$). There was a significant interaction effect between negative affect and neuroticism on time F (2.83, 141) = 2.80, $p < .001$ $\eta_p^2 = 0.059$. This effect was linear, showing that in the high neuroticism group, negative affect was reduced following partial sleep deprivation, while in the low neuroticism group negative affect increased after partial sleep deprivation F (5.86, 143.61) = 3.01, $p = .009$, $\eta_p^2 = 0.109$ (see Fig. 1).

The main effect for positive affect was significant as reported in our previous article (Saksvik-Lehouillier et al., 2020). There was no significant interaction effect between neuroticism and positive affect on time F (7.156, 175.31) = 1.63, $p = .126$, $\eta_p^2 = 0.063$.

Table 3 shows mean scores and standard deviations of negative and positive affect across the five visits (visit 1–3 at baseline and visit 4 and 5 during the sleep deprived condition), for the three different neuroticism groups. The participants with low and medium scores on neuroticism had significantly lower negative affect scores at visit 1 and 2, compared to those with high neuroticism scores. For visit 3 there was a significant difference in negative affect scores between those with low neuroticism and high neuroticism. There were no significant differences in negative affect score at visit 4 and 5 nor positive affect score at visit 1–5 between the neuroticism groups.

5. Discussion

In this study, we found that healthy young adults with high neuroticism scores experienced decreased negative affect following three days of mild-moderate sleep deprivation. Low scores on neuroticism were associated with the opposite, i.e. an increase in negative affect after sleep deprivation. Positive affect was reduced following sleep deprivation, regardless of scores on neuroticism. The scores on negative affect were higher at baseline for those with high scores on neuroticism compared to those with low scores, but the scores were similar after the sleep deprivation. Negative affect at baseline showed an association with more fatigue and insomnia symptoms. Both sleep problems (Harvey, 2009) and neuroticism (Ormel et al., 2013) are associated with transdiagnostic psychopathology. Our findings suggest that neuroticism moderates the negative implications of partial sleep deprivation on negative affect.

The finding that individuals with high scores on neuroticism experience reduced negative affect after sleep deprivation is counterintuitive considering the known link between neuroticism and poor health (Kotov et al., 2010; Lahey, 2009; Ormel et al., 2013) and poor sleep (Cheng et al., 2012; Duggan et al., 2014; Gray & Watson, 2002; Williams & Moroz, 2009). Our results also show that a higher neuroticism score was associated with higher negative affect scores, fatigue, and poorer sleep during habitual sleep (baseline). From this one might have expected that individuals with high scores on neuroticism would be more vulnerable to the negative effects of sleep deprivation than those with low scores on neuroticism. The paradoxical reduction in negative affect in the high neuroticism group after sleep deprivation may indicate that different mechanisms are in play in the context of such transient life stressors than those related to more longer-term vulnerability.

One explanation for our results may be that individuals with high neuroticism have lower/more pessimistic expectations of their own reactions to the sleep deprivation at baseline, and that their actual experience therefore was perceived as less negative, or even *better than expected*. It is well known that individuals with high scores on neuroticism have more negative self-expectations and viewpoints in general compared to those with low neuroticism scores (Thomson, 2016). One could also hypothesize that this tendency for negative and stringent self-expectations (Thomson, 2016), combined with a high sensitivity to risk (Oehler & Wedlich, 2018), can result in an hyperactive monitoring system in the brain (Olsen et al., 2018) which provide high anxiety and negative affect in this group of individuals. It may be possible that this monitoring system breaks down when faced with sleep deprivation, with the consequence that the individual perceives the world as less distressing or negative. This is however, just one out of many possible explanations that we did not examine in the present study. Future studies should examine discrepancy between expected and actual effect of partial sleep deprivation on affect.

Another explanation, also not investigated in the present study, may

Table 1
Baseline measures of neuroticism affect, sleep, and demographic characteristics of the sample measured at visit 1 (n = 47–52).

	Mean (SD)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1.Gender	41 (78.8%) females	–											
2.Age	22.58 (3.06)	0.08	–										
3.Neuroticism	48.08 (10.97)	0.22	−0.15	–									
4.NA	13.98 (3.81)	−0.03	−0.01	0.49**	–								
5.PA	26.78 (5.88)	0.04	−0.14	−0.03	0.11	–							
6.ESS	7.51 (3.47)	−0.21	−0.10	0.14	0.14	−0.03	–						
7.PSQI	3.25 (2.05)	−0.01	0.00	0.30*	0.13	−0.07	0.10	–					
8.ISI	5.76 (3.65)	−0.03	−0.03	0.48**	0.32*	−0.15	0.21	0.70**	–				
9.FSS	3.91 (1.01)	0.03	−0.10	0.50**	0.50**	0.20	0.08	0.21	0.46**	–			
10. A total sleep time	451 (69)	0.00	−0.13	−0.11	−0.01	0.11	−0.05	0.01	−0.01	0.11	–		
11.A midpoint sleep	4.03 AM (1.06)	0.21	0.06	0.09	−0.06	−0.10	0.09	0.09	0.19	0.17	0.27	–	
12.A sleep efficiency	87.16 (5.23)	−0.17	0.07	−0.23	0.00	0.21	−0.01	−0.22	−0.15	−0.06	0.41**	−0.17	–

Note. $*p < .05$; $**p < .001$; NA = negative affect; PA = positive affect, ESS = Epworth sleepiness scale; PSQI = Pittsburgh sleep quality index – low score indicates good sleep; ISI = insomnia severity index; FSS = fatigue severity scale; A = actigraphy.

Table 2
Average actigraphy and sleep diary measured sleep variables.

	Habitual sleep period			Sleep deprived		
	Low N ($n = 16$)	Medium N ($n = 23$)	High N ($n = 13$)	Low N ($n = 16$)	Medium N ($n = 23$)	High N ($n = 13$)
Sleep duration actigraphy (min)	440 (40.29)	429 (41.21)	438 (44.82)	293 (43.19)	299 (46.50)	310 (39.14)
Sleep duration sleep diary (min)	444 (36.77)	449 (43.11)	466 (47.53)	310 (39.85)	313 (43.49)	321 (40.05)
Sleep efficiency actigraphy (%)	87.77 (3.87)	86.98 (39.14)	85.56 (4.41)	87.55 (5.81)	86.72 (5.81)	86.52 (5.24)
Subjective sleep quality (1–5)	3.66 (0.58)	3.42 (0.59)	3.57 (0.56)	4.29 (0.15)	4.04 (0.13)	3.77 (0.19)

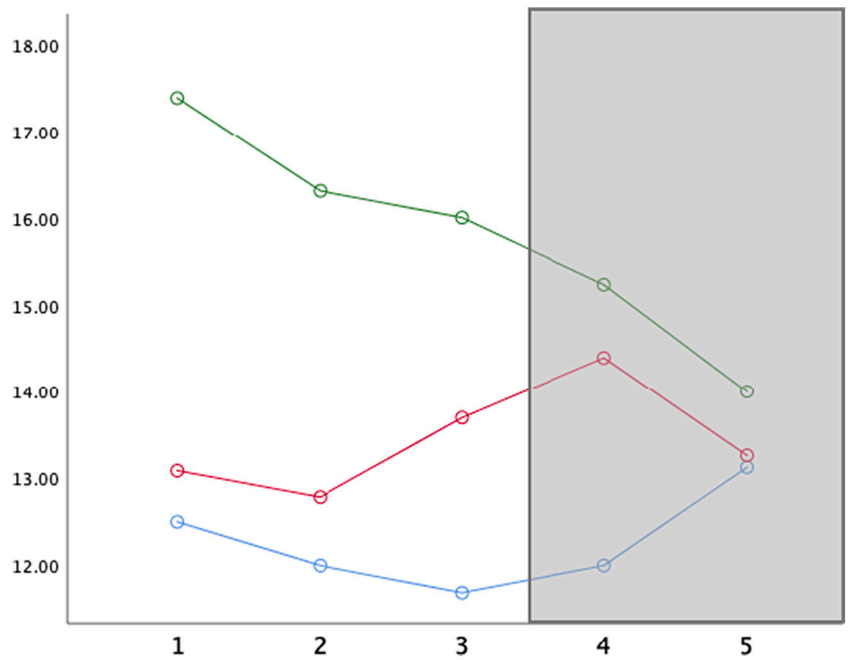

Fig. 1. Change in negative affect divided by scores on neuroticism (green line = high neuroticism, red line = medium neuroticism, blue line = low neuroticism). Note: Numbers on the x-axis represent the five different visits, visit 4 and 5 was during the sleep deprived condition (marked with gray background). Numbers in the y-axis represent scores on negative affect. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Mean (SD) for positive and negative affect.

	Low N ($n = 16$)	Medium N ($n = 23$)	High N ($n = 13$)
Negative affect visit 1	12.50 (2.47)**	13.09 (2.84)*	17.38 (4.71)**
Negative affect visit 2	12.00 (2.89)*	12.78 (2.43)*	16.31 (4.63)*
Negative affect visit 3	11.69 (3.42)*	13.70 (4.23)	16.00 (3.70)*
Negative affect visit 4	12.00 (2.63)	14.39 (4.06)	15.23 (4.71)
Negative affect visit 5	13.13 (3.57)	13.26 (2.73)	14.00 (2.71)
Positive affect visit 1	27.19 (5.99)	26.93 (6.42)	27.00 (5.14)
Positive affect visit 2	23.75 (6.68)	26.17 (8.14)	22.15 (6.24)
Positive affect visit 3	22.56 (5.45)	23.39 (6.66)	21.62 (6.09)
Positive affect visit 4	18.31 (4.81)	19.91 (5.73)	19.83 (6.05)
Positive affect visit 5	17.00 (4.26)	19.30 (7.40)	18.67 (5.99)

* $p < .05$.
** $p < .001$.

be that partial sleep deprivation actually helps reduce negative affect for individuals with high scores on neuroticism. A total of 50% of patients achieve a symptom reduction in depression when experiencing total or partial sleep deprivation (Boland et al., 2017). However, this antidepressant effect does not maintain over time for 80% of the responders. We still lack critical knowledge about the complex mechanisms of the antidepressant effect of sleep deprivation. One step towards revealing this is to investigate how partial sleep deprivation influence affect differently among healthy individuals with different phenotypic background, which we have done in our study. In line with the above-mentioned research and our results, one could speculate if depressed individuals with high scores on neuroticism could be among those who would show a more long-term benefit from sleep deprivation treatment of depression.

One may assume that individuals with high scores on neuroticism may have more dysfunctional sleep compared to those with low neuroticism scores, due to the associations between neuroticism and several aspects of poor sleep reported in previous studies (Cheng et al., 2012; Duggan et al., 2014; Gray & Watson, 2002; Williams & Moroz, 2009). Hence, the shortened sleep we imposed to our participants in the present study, may be experienced as better than dysfunctional sleep for the individuals with high neuroticism scores. However, we did not detect any differences in sleep efficiency or subjective sleep quality between the three neuroticism groups in either the habitual or sleep deprived period in the present study. Still, individuals with low neuroticism scores may be more used to poor sleep than those with high neuroticism scores, which may not be detected in the sleep variables themselves, but in the affective consequences of poor sleep. Sleep restriction in itself is an often used intervention to improve poor sleep (Maurer et al., 2018).

The participants with low scores on neuroticism had somewhat lower scores on negative affect after sleep deprivation compared to those with high scores on neuroticism. The reduction in negative affect among those with high scores on neuroticism was evident all through the study, also before the sleep deprivation. Thus, the effect of reduced negative affect may have been a consequence of participation in the study, or a regression towards the mean. Still, this explanation is delimited as the decrease seemed to be larger after sleep deprivation and as we also noticed a reduction in positive affect throughout the study for the total sample.

Neuroticism scores did not influence positive affect after sleep deprivation. Positive affect decreased for the total sample, and the tendency was evident regardless of neuroticism score. Neuroticism is more strongly related to negative than to positive affect (Langvik et al., 2016), and this could explain why neuroticism only influenced the change in negative, not positive, affect after sleep deprivation.

6. Strengths and limitations

Our study utilized a new, comprehensive design incorporating individual differences in habitual sleep as well as multiple baseline and ecological validity as the participants could sleep at home. This is a strength with the study. The sample size was somewhat modest, which may represent a limitation with the present study, still it was larger than what is seen in other studies investigating the role of personality traits in sleep deprivation.

Measuring personality traits and affect with the same method (questionnaires) may lead to common method bias (Podsakoff et al., 2003). However, we used comprehensive and validated methods to measure the variables included, and the NEO PI-3 consisting of 240 questions to measure personality, which represent a strength (Costa & McCrae, 2013).

7. Conclusion

In this study, we found that high scores on neuroticism seems to buffer against the negative effects of partial sleep deprivation on negative affect, and that neuroticism do not influence the decline in positive affect following partial sleep deprivation. Further research is needed to look deeper into the mechanisms behind the role of personality traits in vulnerability to sleep deprivation. We need to know more about how the brain reacts to partial sleep deprivation in different individuals and how this affect individuals throughout the day outside a laboratory setting for example in a normal workday. Our findings could serve as a promising starting point for new research exploring how neuroticism is linked to sleep and affect through emotion regulation.

CRediT authorship contribution statement

Ingvild Saksvik-Lehouillier: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Eva Langvik:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Simen Berg Saksvik:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **Håvard Kallestad:** Conceptualization, Writing – original draft, Writing – review & editing. **Hanna Størksen Follesø:** Investigation, Validation, Data curation. **Sigrun Borgen Austad:** Investigation, Validation, Data curation, Writing – review & editing. **Johanna Dahlberg:** Conceptualization, Investigation, Data curation, Writing – review & editing. **Heidi Ringen:** Conceptualization, Investigation, Data curation, Writing – review & editing. **Tiril Tanum:** Conceptualization, Investigation, Data curation, Writing – review & editing. **Torhild Anita Sørengaard:** Investigation, Data curation, Writing – review & editing. **Håvard Rudi Karlsen:** Formal analysis, Writing – review & editing. **Trine Smedbøl:** Conceptualization, Investigation, Data curation, Writing – review & editing. **Alexander Olsen:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Project administration.

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