Extracting Interaction Effect of Cognitive Task and Unwanted Cognitive Activity in Pre-Sleep Period

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***Abstract*—The difficulty of switching off unwanted pre-sleep cognitive activities always causes most people with insomnia unable to fall asleep. Previous studies suggested that manipulating pre-sleep thoughts with cognitive task could change sleep onset latency. The interaction effect of cognitive task and unwanted thoughts is a mixed effect in which each mechanism alone is not completely understood. The present study tries to explore the mixed effect and extract the single effect from it.**

Seven people with insomnia were investigated and the general cognitive task controlled internally by insomniacs themselves was replaced with an audio task in which the participants have to react distinctively to two different auditory stimuli. The reaction time for which reflected the interaction effect was recorded and then analyzed by the autocorrelation and partial autocorrelation method. A general decline tendency which is called decline effect was observed in the single effect and for most insomniacs the length of the decline effect was around 4 or 5 seconds. In addition, it indicated that such decline effect could be a potential candidate for investing the correlation between cognitive load and interaction effect.

Keywords-insomnia; cognitive; autocorrelation; partial autocorrelation

I. INTRODUCTION

The difficulty of switching off unwanted pre-sleep cognitive activities always causes most insomniacs unable to fall asleep [1-7]. In previous studies of insomnia, accumulated evidences suggest that the manipulation of pre-sleep thoughts with cognitive task such as mental arithmetic or imagery distraction could lead to sleep onset latency change [1, 8-12].

According to the account that the cognitive space is limited, the cognitive task will occupy sufficient cognitive space to keep the individual from re-engaging in the personally relevant negative intrusive thought. So, the adoption of a cognitive task can interrupt and suppress the unwanted thought [11, 13-16]. And then the problem of long sleep onset latency[17] will be solved for the maintenance of suppression for intrusive thought[15].

The maintenance of suppression suggests that there is continuous cognitive interaction between the cognitive task and the intrusive thought. That is to say, the repeated cognitive task is needed to maintain the continuous suppress effect. The cognitive interaction effect at one time point will decay but not vanish immediately. This indicates that the current cognitive interaction effect will mix with the previous effects. So, it is the complex mixed effect that has impact on intrusive thought. The previous cognitive interaction effect which mixes with current effect is called decline effect. Accordingly, detecting cognitive interaction dynamically in real-time and extracting the mixed effect and decline effect are likely to be crucial to understanding the cognitive interaction and suppression of the unwanted thought for the insomnias in pre-sleep period.

Therefore, in the present study we will use an audio cognitive task to manipulate pre-sleep cognitive activities by which the insomniacs can make behavioral response as the stimuli presented and the behavioral response magnitude (such as reaction time) can be recorded.

This task is chosen for two main reasons. Primarily, it's a valid behavioral dynamic measurement of subjective information in real-time and easy to distinguish sleep and pre-sleep. So it is often used to detect cognitive processing in sleep onset[18-25]. Secondly, though the internal control strategy such as mental arithmetic or imagery distraction is replaced by the external control strategy such as audio task, the external task will also interact with pre-sleep unwanted thought, and the cognitive space occupation hypothesis would be satisfied. So the interaction information will be included in the behavioral magnitude. By repeated measuring, series of interaction data can be easily got.

For the decline effect, the data of behavioral response time-series is dependent. By calculating the values of autocorrelations and partial autocorrelations we can assess

the value of the dependency. And based on the changes of dependency, we try to evaluate decline effect and mixed effect in this paper.

II. METHOD

A. Participants

The volunteers were recruited from Central China Normal University and they all described their sleep quality as "poor". The criterion for inclusion in this study was a total score of more than seven on the Pittsburg Sleep Quality Index (PSQI)[26, 27]. After PSQI approval and informed written consent, seven volunteers who had not received pharmacologic sleep aids were enrolled.

B. Procedures

All participants spent four consecutive nights, each night held one session in a sound proof sleep room with air-conditioned. And the first night was considered as adaptation period. Each subject was asked to come to the sleeping room one hour earlier before their bedtime routine.

For the first night after informed written consent, the participants received the instruction on the experimental procedures. They were asked to perform a sound discrimination task in which there were two short audio stimuli. One was clearly such as dropping water, the other was relaxing. When they heard the clear tone they should click the right button of a mouse and the relaxing one with the left button.

The intensity of the tone was, prior to the beginning of sleep testing session, adjusted to the lowest level that subjects could consistently register while awake. The inter-stimulus interval (ISI) (see Figure 1 a) was constant during the same testing session in order to satisfy with time series analysis. During the first two night testing session, ISI was 2 seconds and 3, 4 or 5 seconds was chosen in following days. Matlab7.0 with a psychtoolbox3.0[28] was used to generate audio tone and record the timing of both the tone and the mouse-click responses.

The formal test session was begun when insomniacs reported sleepy. Insomniacs were then placed in the dark sleep room and instructed to fall asleep. There were powered speakers and a mouse connected with the computer which was outside the testing room (see Figure 1 b). The testing was over when subject consecutively lost responses in 30 min. After testing session, a subjective assessment of sleep quality was made. Insomniacs were interviewed to report their subjective sleep quality.

C. Data Coding

The insomniacs' behavioral response magnitude of reaction time in the same testing session is approximately time series if the stimuli were set to occur in constant intervals. Then we used xn to represent the observation value in the data

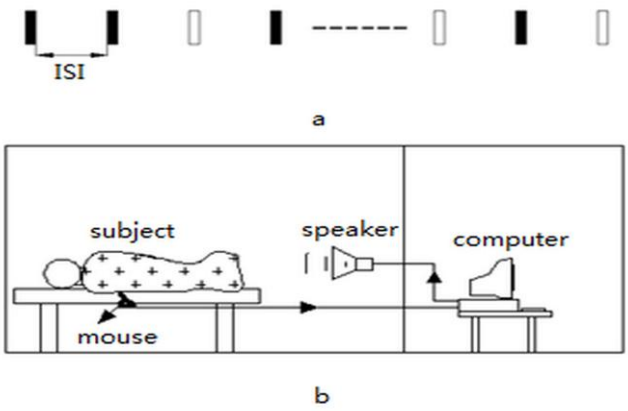


Figure 1. ISI and testing devices. (a) The inter-stimulus interval (ISI) was constant during the same testing session in order to satisfy with time series analysis. During the first two night testing session, ISI was 2 seconds and 3, 4 or 5 seconds was chosen in following days.(b) There were powered speakers and a mouse connected with the computer which was outside the testing room.

TABLE I. STIMULI RESPONSE CODING

Stimuli	Correct response	No response	False response
Signal A	x_n	∞	$-x_n$
Signal B	x_n	∞	$-x_n$

Set of time series of behavioral response. The subscript n represents the number of stimuli occurring order.

There are three kinds of behavioral responses when an alternative stimulus is presented such as correct response, false response, and no response. In order to facilitate the analysis following, three kinds of responses are coding as following: correct response coding positive, false response coding negative and no response coding ∞ (shown in table 1).

Then, the reciprocal of behavioral responses is calculated, we get table 2. Based on the new coding shown in table 2, all the behavioral response data in a testing session can be used to analysis. All the data for each participant were assessed with Eviews 6.0.

TABLE II. Stimuli response coding

Stimuli	**response**	**No response**	**False response**
Signal A	$\frac{1}{x_n}$	0	$-\frac{1}{x_n}$
Signal B	$\frac{1}{x_n}$	0	$-\frac{1}{x_n}$

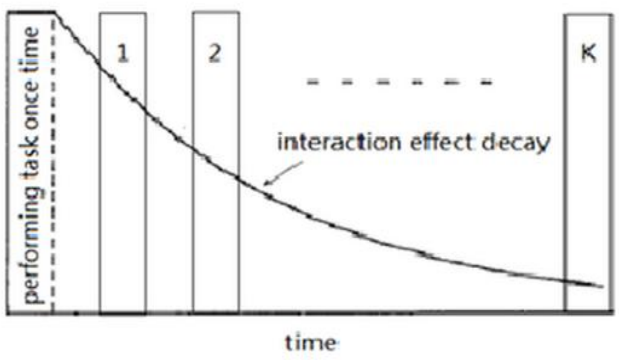


Figure 2. Decline time of interaction. The numbers 1, 2, 3…n present stimuli in turn. So, the length of the decline time of interaction can be approximately represented as k×ISI if the interaction decrease to zero near k stimuli presented time point.

D. Algorithms of Extracting Decline Effect

In the sound discrimination task, ISI is constant during the same testing session. We assign number 1, 2, 3…n to the presented stimuli in turn. So, the length of the decline time of interaction can be approximately represented as k×ISI if the interaction decrease to zero near k stimuli presented time point (See fig 2). Then, the behavioral response for first stimulus will affect subsequently behavior such as response for stimulus 2, 3 until K.

Based on the observations transformation time-series data (written as yn) above (see table 3 row 1), these relationship can be listed in row 1. Similarly, this relationship exists among data y2，y3，y4……，yk＋1 (see table 3 row 2). And by analogy same relationship is among other rows data listed in table 3.

In other words, column 1 affects each column subsequently. It indicates that column 1 correlate with column 2，3 till k and this correlation relationship is represent with values of autocorrelations.

For example, for Lag 1, the second observation is paired with the first; the third observation is paired with the second, and so on, until the last observation is paired with the second from the last observation.

TABLE III. AUTOCORRELATIONS AND PARTIAL AUTOCORRELATION

Time	**Lag**				
		1	2	…	k-1
1	Y_1	Y_2	Y_3	…	Y_k
2	Y_2	Y_3	Y_4	…	Y_{k+1}
⋮	⋮	⋮	⋮	⋮	⋮
n	Y_n	Y_{n+1}	Y_{n+2}	…	Y_{n+k-1}

If we now calculate the correlation between these paired observations, we will have calculated the Lag 1 autocorrelation. We should note that anyone of the autocorrelation of paired observations include all the interaction effect between them. Such as autocorrelation coefficient of lag 2 contains first and second time response interaction effect. In other words, autocorrelation coefficient of lag 2 reflects the mixed effect of first and second time response interaction effect. It imply that autocorrelation coefficient reflect the mixed effect of all interaction of current and before.

For autocorrelation of paired observations include all the interaction effect, and then excluding interaction effect except paired observations we will get the interaction decline effect. This pure interaction effect can be got by partial autocorrelation.

III. RESULT

A. Participant Characteristics

The subjects comprised 5 females and 2 males, with a mean age of 19.14 years (SD=0.69). The average PSQI global score was 8.86 (SD=0.9). During the test sessions, all subjects fell asleep except one subject in one session. This session was excluded from later analysis. The mean sleep onset latency was 8.31minutes (SD=4.61).

B. The Reciprocal of Reaction Time Time-Series

Based on data transformation of table 1 and table 2, we get reciprocal time-series of reaction time (See fig 3). It shows two morphological stages in reciprocal time-series. During the stage B, the subjects make no response to any audio stimuli. The data collected in this stage will not be analyzed. Only the data collected in stage A is used to analysis.

Generally, 50 or more observations data provide reasonably accurate estimates in time series analysis of single subject[29-31]. The data being discussed later are satisfied with this condition.

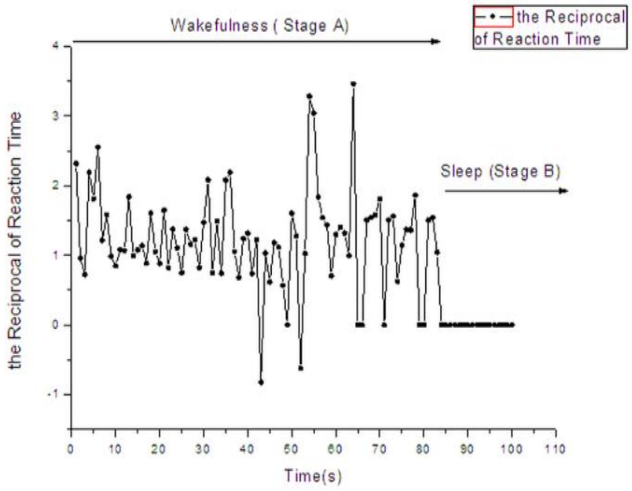
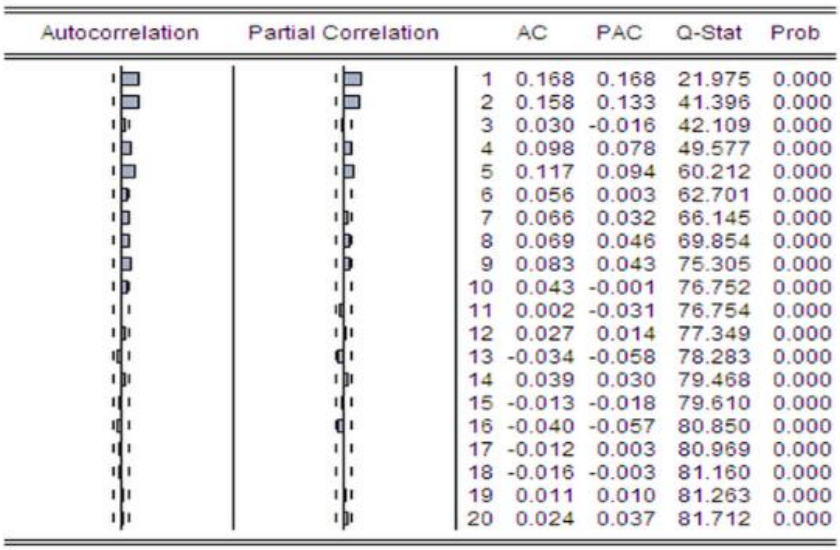


Figure 3. reciprocal time-series of reaction time. It shows two morphological stages in reciprocal time-series. The data collected in stage A is used to analysis. While during the stage B, the subjects make no response to any audio stimuli. So, the data collected there will not be analyzed.

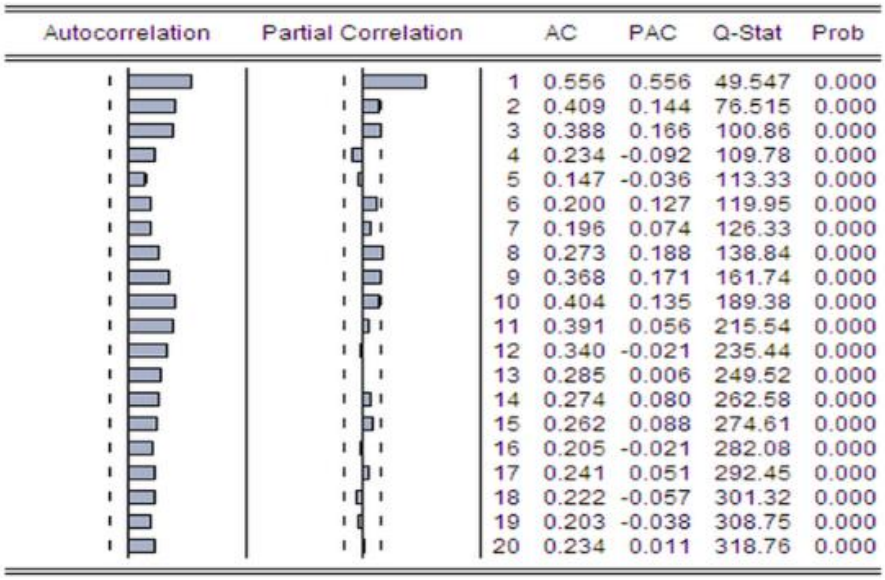
C. Autocorrelation and Partial Autocorrelation of the Reciprocal of Reaction Time Time-Series

Fig.4, fig.5 and fig.6 show the autocorrelation and partial autocorrelation of an insomniac's reciprocal of reaction time series with ISI equaled to 2, 4 and 5 seconds in different testing days.



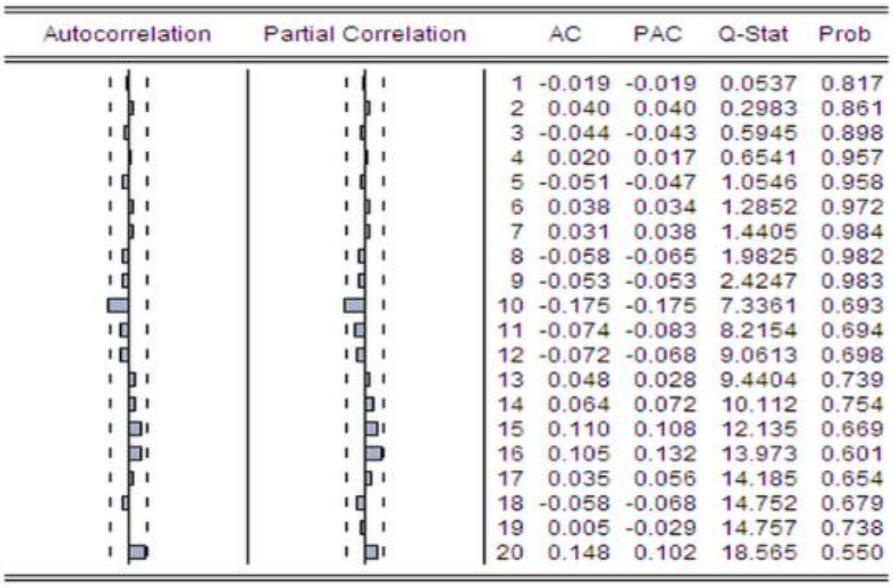
Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.168	0.168	21.975	0.000
		2	0.158	0.133	41.396	0.000
		3	0.030	-0.016	42.109	0.000
		4	0.098	0.078	49.577	0.000
		5	0.117	0.094	60.212	0.000
		6	0.056	0.003	62.701	0.000
		7	0.066	0.032	66.145	0.000
		8	0.069	0.046	69.854	0.000
		9	0.083	0.043	75.305	0.000
		10	0.043	-0.001	76.752	0.000
		11	0.002	-0.031	76.754	0.000
		12	0.027	0.014	77.349	0.000
		13	-0.034	-0.058	78.283	0.000
		14	0.039	0.030	79.468	0.000
		15	-0.013	-0.018	79.610	0.000
		16	-0.040	-0.057	80.850	0.000
		17	-0.012	0.003	80.969	0.000
		18	-0.016	-0.003	81.160	0.000
		19	0.011	0.010	81.263	0.000
		20	0.024	0.037	81.712	0.000

Figure 4. Autocorrelation and Partial Correlation. The autocorrelation and partial autocorrelation of an insomniac's reciprocal of reaction time series with ISI equaled to 2 seconds in different testing days.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.556	0.556	49.547	0.000
		2	0.409	0.144	76.515	0.000
		3	0.388	0.166	100.86	0.000
		4	0.234	-0.092	109.78	0.000
		5	0.147	-0.036	113.33	0.000
		6	0.200	0.127	119.95	0.000
		7	0.196	0.074	126.33	0.000
		8	0.273	0.188	138.84	0.000
		9	0.368	0.171	161.74	0.000
		10	0.404	0.135	189.38	0.000
		11	0.391	0.056	215.54	0.000
		12	0.340	-0.021	235.44	0.000
		13	0.285	0.006	249.52	0.000
		14	0.274	0.080	262.58	0.000
		15	0.262	0.088	274.61	0.000
		16	0.205	-0.021	282.08	0.000
		17	0.241	0.051	292.45	0.000
		18	0.222	-0.057	301.32	0.000
		19	0.203	-0.038	308.75	0.000
		20	0.234	0.011	318.76	0.000

Figure 5. Autocorrelation and Partial Correlation. The autocorrelation and partial autocorrelation of an insomniac's reciprocal of reaction time series with ISI equaled to 4 seconds in different testing days.



	AC	PAC	Q-Stat	Prob
1	-0.019	-0.019	0.0537	0.817
2	0.040	0.040	0.2983	0.861
3	-0.044	-0.043	0.5945	0.898
4	0.020	0.017	0.6541	0.957
5	-0.051	-0.047	1.0546	0.958
6	0.038	0.034	1.2852	0.972
7	0.031	0.038	1.4405	0.984
8	-0.058	-0.065	1.9825	0.982
9	-0.053	-0.053	2.4247	0.983
10	-0.175	-0.175	7.3361	0.693
11	-0.074	-0.083	8.2154	0.694
12	-0.072	-0.068	9.0613	0.698
13	0.048	0.028	9.4404	0.739
14	0.064	0.072	10.112	0.754
15	0.110	0.108	12.135	0.669
16	0.105	0.132	13.973	0.601
17	0.035	0.056	14.185	0.654
18	-0.058	-0.068	14.752	0.679
19	0.005	-0.029	14.757	0.738
20	0.148	0.102	18.565	0.550

Figure 6. Autocorrelation and Partial Correlation. The autocorrelation and partial autocorrelation of an insomniac's reciprocal of reaction time series with ISI equaled to 5 seconds in different testing days.

IV. DISCUSSION

Based on the behavioral responses, sleep was defined as failure to respond to the faint auditory cue and the criterion for wakefulness is cognitive response to external stimulation[21]. In our experiment, the subject was asked to make behavioral response to audio stimuli. So, the behavioral criterion of the sleep was adopted. Based on this criterion, the brain was in sleep state during phased B. And data of phase A reflected the cognitive interaction between cognitive tasks and unwanted thought.

Unwanted thought interacts with cognitive task, which will induce series of psychological effect having effect on the processing of falling asleep. For this interaction effect will not vanish immediately, the currently interaction effect will be hand on step by step until it decrease to zero level.

For the decline effect, the reciprocal time-series of reaction time will dependent. And the autocorrelation coefficient and partial autocorrelation coefficient all present the link among series of behavioral responses.

In our task, ISI is constant during the same testing session. So, the length of decline time can be approximately represented as k×ISI if the interaction reduces to zero near k stimuli presented time point (See fig 2).

The result shows that partial autocorrelation coefficient reduce slowly until zero and has a small correlation at lag 3. It indicates that interaction effect reduces slowly until zero and the length of the declined tendency of interaction effect is less

Than 3 times ISI. For this test session, the ISI is 2 second, and then the interaction effect reduces to zero between the 4 and 6 seconds.

To test this prediction, in subsequent test session next day, the ISI is 4 seconds. For interaction effect reduces to near zero, and then the partial autocorrelation will be zero at lag 2. Surely as we expect, partial autocorrelation coefficient near zero lag 2(see fig 5). The same results are all yield in other insomniacs. Its shows that partial autocorrelation is reasonable in extracting decline effect.

Use this method, we invested the decline time of different insomniacs and found difference between them. This phenomenon may indicate that there are differences within insomniacs and another factor correlation with cognitive interaction effect. Obviously it needs new research design and intensive investigation which is beyond this paper.

In summary, we used a behavioral response task manipulated by computer to replace self-manipulating task to detect interaction effect between cognitive task and unwanted thought. And the reaction time time-series was got, which reflects changes of cognitive interaction. We proposed that the interaction effect will mix together for decline effect. Autocorrelation and partial autocorrelation analysis in time series method was adopted to extract mixed effect and decline effect. Such extracting is a potential candidate for investing correlation between cognitive load and interaction effect. And further test is necessary in subsequently studies.

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