



Neural mechanisms of self-generated thoughts elucidated by human intracranial EEG

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Abstract

Sharp-Wave Ripple (SWR) in the hippocampus, which is responsible for memory consolidation, has been reported in experimental animals, but its function during wakefulness has not been clear. We analyzed human intracranial electroencephalograms (iEEGs) for approximately 10 days, which were measured in epilepsy patients for preoperative evaluation, to investigate the relationship between the human hippocampal SWR and spontaneous thought states (Fig 1A). We found that the human SWR has a sleep-wake rhythm and that fluctuations during wakefulness are associated with mind-wandering.

Background & Results

The Sharp-Wave Ripple (SWR) is a synchronous neuronal activity observed in the hippocampus, which occurs frequently during sleep and play an important role in the memory consolidation. The SWR also occurs during wakefulness and tends to increase during immobility in animals. However, the relationship between SWR and the thought state during wakefulness has not been clear.

Human thought state changes significantly during daily life. Among these, the state of being unable to concentrate on the task at hand and thinking about something else, the so-called 'mind-wandering' (MW), a self-generated thought state, is known to occupy approximately 30% of the daily life. Here we hypothesized that human spontaneous thoughts are related to SWR. We recorded hippocampal iEEG from 10 epilepsy patients, while physical activity data (heart rate, skin conductance, acceleration and blood volume pulse wave) were simultaneously measured from a wearable device, and thought content was further assessed using 17

questions (Fig. 1A). SWR was detected from the hippocampal iEEG measured over a period of up to 10 days (Fig. 1B). Then, the frequency of SWR was averaged across all patients and diurnal variation was examined, showing that the SWR rate increased at night, decreased in the morning and decreased in line with the timing of eating. Generalized linear mixed-effects models explaining the variation in SWR frequency were then constructed from physical activity data and thought contents data, respectively. Each model explained significantly more than the random data in both cases, but the model using the thought contents was more accurate than the model using the physical activity data, and also showed that the MW contributed the most to SWR variability (Fig.1C).

Significance of the research and Future perspective

Self-generated spontaneous thoughts, such as mind-wandering, are estimated to account for 30% of human thought states and have been linked to creativity and mood disorders. However, the mechanism of how self-generated thoughts arise in daily life is not clear. By showing the relationship between SWR, which plays an important role in memory functions, and mind-wandering, our research has demonstrated the possibility of elucidating the mechanism of self-generated thought and its adjustment techniques. In the future, it is expected that the mechanism of self-generated thoughts and the higher cognitive functions such as creativity will be elucidated through the investigation on SWR and iEEG. SWR has also been reported to be associated with neuropsychiatric disorders such as epilepsy, memory impairment, dementia and schizophrenia; technology to control SWR is expected to lead to the treatment of these disorders.



Figure 1: Relationship Between SWR and Thought

A) Thought content was sampled through thought probes on a tablet from patients undergoing intracranial EEG recording. Simultaneously, physical activity was recorded and stored using a wearable device.

B) SWRs were detected from intracranial EEG recordings taken from the hippocampus. SWRs are characterized by a distinctive waveform comprising high-frequency ripples and sharp waves.

C) The coefficients of a generalized linear mixed-effects model to estimate SWR event rate based on responses to a 17-items questionnaire.

lwata, Takamitsu; Yanagisawa, Takufumi; Ikegaya, Yuji et al. Hippocampal sharp-wave ripples correlate with periods of naturally occurring self-generated thoughts in humans. Nature Communications. 2024, 15, 4078. doi: 10.1038/s41467-024-48367-1

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