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Research Report

Neural effect of mental fatigue on physical fatigue: A magnetoencephalography study

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ABSTRACT

We sought to clarify the neural effect of mental fatigue on physical fatigue using magnetoencephalography (MEG) and classical conditioning techniques. Eleven right-handed volunteers participated in this study. On the first day, participants performed fatigue-inducing maximum handgrip trials for 10 min; metronome sounds were started 5 min after the beginning of the trials. We used metronome sounds as conditioned stimuli and maximum handgrip trials as unconditioned stimuli to cause physical fatigue. On the next day, MEG recordings during the imagery of maximum grips of the right hand guided by the metronome sounds were performed for 10 min just before (control session) and after (mental fatigue session) a 30-min fatigue-inducing mental task session. In the right anterior cingulate cortex (Brodmann's area 23), the alpha-band event-related synchronization of the mental fatigue session relative to the control session within the time window of 500–600 ms after the onset of handgrip cue sounds was identified. We demonstrated that mental fatigue suppresses activities in the right anterior cingulate cortex during physical fatigue.

1. Introduction

Fatigue, which can be primarily classified into mental and physical fatigue, is best defined as a condition or phenomenon of declined ability and efficiency of mental and/or physical activities caused by excessive mental or physical activities, or illness; fatigue is often accompanied by peculiar sense of discomfort, desire to rest, and reduced motivation, referred to as fatigue sensation (translated from Japanese into English by M.T.) (Kitani et al., 2011). It was reported in human studies that mental fatigue impairs physical activity, and this decreased performance is not caused by cardiorespiratory or muscular mechanisms (Marcora et al., 2009; Pageaux et al., in press), suggesting the neural impact of mental fatigue on physical fatigue. However, the neural mechanism of impaired physical performance induced by mental fatigue has not been clarified.

In addition to its high temporal resolution, magnetoencephalography (MEG) can measure brain activity using time-frequency analyses (Stam, 2010). Oscillatory brain rhythms are considered to originate from synchronous synaptic activities of a large number of neurons (Brookes et al., 2011). Synchronization of neural networks may reflect integration of information processing, and such synchronization processes

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can be evaluated using MEG time-frequency analyses; multiple, broadly distributed, and continuously interacting dynamic neural networks are achievable through the synchronization of oscillations at particular time-frequency bands (Varela et al., 2001). In particular, alterations of alpha-frequency band (8–13 Hz) power were reported to be associated with fatigue in the central nervous system (Shigihara et al., 2013a; Ishii et al., 2013; Tanaka et al., in press). The alterations of the MEG alpha power densities in some brain regions induced by mental fatigue when performing physical trials under the condition of physical fatigue may provide valuable clues to identifying the neural effect of mental fatigue on physical fatigue. However, because physical trials cause a lot of electromagnetic noise, it is difficult to evaluate neural activities when participants perform physical tasks. Recently, we performed a neuroimaging study of classical conditioning of physical fatigue (Tanaka et al., 2013). In this study, metronome sounds were used as conditioned stimuli and physical trials were used as unconditioned stimuli to cause physical fatigue. Participants underwent MEG measurements during the imagery of maximum handgrips guided by metronome sounds for 10 min. Thereafter, fatigue-inducing physical trials were performed for 10 min; metronome sounds were started 5 min after the beginning of the task trials. The next day, neural activities during the imagery of maximum handgrips guided by metronome sounds for 10 min were measured using MEG. The level of physical fatigue sensation caused by listening to the metronome sounds on the second day was higher relative to the first day and the MEG recordings and evaluations were successfully performed. These findings suggest that classical conditioning of physical fatigue took place, and the neural activities related to the physical trials under the condition of physical fatigue could be evaluated using the MEG and classical conditioning techniques. The aim of the present study was to identify the neural effect of mental fatigue on physical fatigue using these techniques.

2. Results

To assess changes in subjective levels of right- and left-hand fatigue after a fatigue-inducing mental task session, comparisons of fatigue scores between the control and mental fatigue sessions were performed. The level of subjective fatigue of the right hand during the MEG recording was not altered after the mental fatigue-inducing mental trials (Fig. 1A). Similarly, the level of subjective fatigue of the left hand during the MEG recording was not altered after the mental fatigue-inducing mental trials (Fig. 1B).

To assess changes in subjective levels of general fatigue after the fatigue-inducing mental task session, comparisons of fatigue scores between the control and mental fatigue sessions were performed. The level of subjective general fatigue during the MEG recording was significantly increased after the mental fatigue-inducing mental trials (Fig. 2).

To identify the brain region affected by mental fatigue during physical fatigue, the increased and decreased oscillatory powers, that is, event-related synchronization (ERS) and event-related desynchronization (ERD), respectively, for the alpha-frequency band in the mental fatigue session relative to the control session within the time window of 0–1000 ms (every 100 ms) were evaluated. Results are shown in Table 1 and Fig. 3. Among the entire brain regions within the time windows of 0–1000 ms (every 100 ms), only the right anterior cingulate cortex (Brodmann's area 23) within the time window of 500–600 ms showed a significant ERS ($P<0.05$, corrected for multiple comparisons). No brain regions showed a significant ERD within the time window assessed.

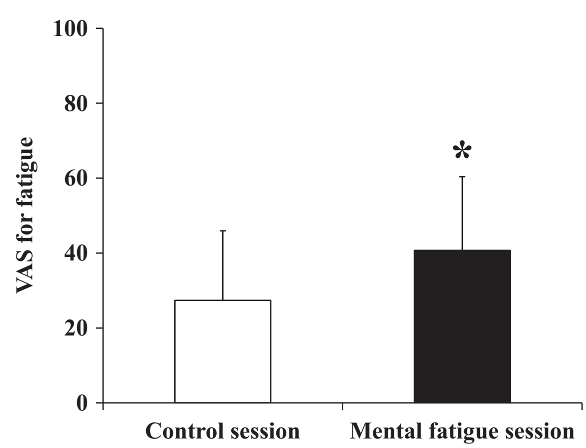

Fig. 2 – Visual analog scale (VAS) values for general fatigue in the control (open columns) and mental fatigue (closed columns) sessions. Data are presented as mean and SD. *$P<0.05$, significant difference (paired t-test).

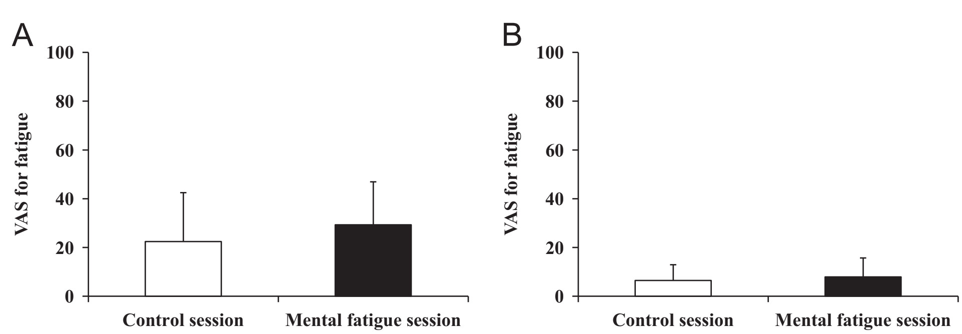

Fig. 1 – Visual analog scale (VAS) values of right (A) and left (B) hands for fatigue in the control (open columns) and mental fatigue (closed columns) sessions. Data are presented as mean and SD.