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Hypnotic suggestion alters the state of the motor cortex

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ABSTRACT

Hypnosis often leads people to obey a suggestion of movement and to lose perceived voluntariness. This inexplicable phenomenon suggests that the state of the motor system may be altered by hypnosis; however, objective evidence for this is still lacking. Thus, we used transcranial magnetic stimulation of the primary motor cortex (M1) to investigate how hypnosis, and a concurrent suggestion that increased motivation for a force exertion task, influenced the state of the motor system. As a result, corticospinal excitability was enhanced, producing increased force exertion, only when the task-motivating suggestion was provided during hypnotic induction, showing that the hypnotic suggestion actually altered the state of M1 and the resultant behavior.

1. Introduction

Hypnosis can be broadly defined as an altered state of consciousness by hypnotic induction or as a tool of responsiveness to specific suggestions following this induction (Kirsch et al., 2011). However, hypnosis is still an inexplicable phenomenon, even in this modern scientific era (Barabasz and Barabasz, 2008). Hypnotized people who demonstrate extraordinary obedience by producing movement in response to a suggestion, which is referred to as an ideomotor response, have reported subjective experiences of anomalous control (Haggard et al., 2004). Surprisingly, the influence of hypnotic suggestions on the motor system manifests as a more than 25% increase in maximal voluntary contraction (MVC) (Ikai and Steinhaus, 1961).

Meanwhile, the neuronal mechanisms of hypnosis are still unknown, but recent studies have begun to uncover how hypnosis alters brain states. Hypnotic induction has been shown to alter activity mainly in the default mode network (DMN); the degree of alteration is associated with the depth of hypnosis (Deeley et al., 2012; Lipari et al., 2012). In addition, when the intensity or unpleasantness of pain is altered by hypnotic suggestions, the activity of multiple brain regions, including the primary somatosensory area and/or anterior cingulate cortex (ACC), is modulated (Rainville et al., 1997; Hofbauer et al., 2001). With regard to the effect of hypnosis on motor function, Cojan et al. (2009) suggest that hypnosis mediates motor control by self-imagery-enhanced internal representation. In addition, hypnosis can facilitate the motor imagery of a new and simple finger movement (Müller et al., 2012). These previous results suggest possible hypnosis-induced alterations to the state of the motor system based on the neurocognitive model linking hypnosis with motor and/or attention control (Oakley, 1999); however, objective evidence for this hypothesis is still lacking. Thus, we used transcranial magnetic stimulation (TMS) of the primary motor cortex (M1) to investigate how hypnosis, and a concurrent suggestion that increased motivation for a simple handgrip contraction force exertion task, influenced the state of the motor system. Our present results demonstrated that the combination of hypnosis and task-motivation suggestions actually altered the state of M1 and the resultant behavior.

2. Material and methods

All procedures were executed in compliance with relevant laws and institutional guidelines, and were approved by the Human Research Ethics Committee of the Faculty of Sport Sciences, Waseda University. We obtained both written and oral informed consent from all participants.

2.1. Participants and procedure

The following three experimental conditions were employed: a hypnotic state was induced without any task-motivating suggestion [hypnotic induction (HI) condition], a suggestion that the right

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handgrip force would become stronger than usual was provided during a hypnotic state [task-motivating suggestions following hypnotic induction (TSH) condition], and only a suggestion was provided [task-motivating suggestions (TS) condition]. After providing both written and oral informed consent, 21 healthy college students (15 men and 6 women; mean age ± S.D. = 20.4 ± 1.4 years), with no history of neurological or other diseases were randomly assigned to one of the three experimental conditions (5 men and 2 women for each group). All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). We confirmed that there were no pregnant women among our participants to avoid the unknown risks of TMS to an unborn fetus.

Experiments were designed to examine the influence of hypnosis on the motor evoked potential (MEP) in the abductor pollicis brevis (APB) in response to TMS in a resting condition, during MVC, and at a moderate level of handgrip force (30% MVC). The experiments on MVC, 30% MVC, and MEP were performed separately: the order of MVC and MEP sessions was counterbalanced so that four of the participants in each group started with the MVC session and the other participants started with the MEP session. These sessions were spaced at least 20 min apart on the same day; the 30% MVC session was conducted at least 24 h after the other sessions. The results were obtained at the following three time points: before treatment (pre), immediately after treatment (post), and 7–8 min after treatment termination (recovery).

2.2. Force measurement

The force levels of MVC and 30% MVC were measured three times with a handgrip device (KFG-5-120-C1-16; Kyowa Electronic Instruments, Tokyo, Japan), with a 60-s interval between each measurement. For measurement of 30% MVC, the participants were asked to squeeze the handgrip force device with moderate strength at 30% MVC on the category-ratio scale [CR-10 scale (Borg, 1982)]. The peak force levels were quantified as MVC and 30% MVC.

2.3. TMS

Before MEP recording, the participants were asked to remove all metal objects (earrings, necklaces) and objects sensitive to magnetic fields (mobile phones, credit cards) as the rapid rate of change of current in the coil is capable of inducing a changing magnetic field. TMS was delivered using a transcranial magnetic stimulator (SMN-1200; Nihon Koden, Tokyo, Japan) with a figure-8 coil (7 cm inner diameter, 11 cm outer diameter; YM133B) composed of two loops. The participants lay comfortably in a reclining chair with their upper arm inclined at about 45° in front of the body with the aid of an armrest. The intersection of the coil was placed tangentially to the scalp with the handle pointing backward and laterally at a 45° angle away from the midline. The coil was positioned over the finger area of the left M1, which was determined by the lowest resting motor threshold (RMT) for the APB muscle in the right hand. MEPs in the APB muscle with peak-to-peak amplitude of greater than or equal to 50 μV were induced in at least 5 out of 10 trials when the participants were totally relaxed with their eyes closed, following a previous study (Rossini et al., 1994). The optimal scalp position of M1 was directly marked on the skin of the scalp with a black magic marker. The positioned coil was held by hand, and its position, with respect to the marks, was checked continuously to maintain consistent positioning throughout the experiment. The RMT had a range of 53–80% of the maximum stimulator output. Stimulus intensity was set at 110% of the RMT. Ten TMS stimuli were applied at an inter-stimulus interval of about 5–6 s. Surface electromyograms were obtained with bipolar, silver, surface electrodes (bandpass: 15–10 kHz). The peak-to-peak amplitude of the average MEP was calculated for each participant, the size of which reflects corticospinal excitability (Rothwell, 1971; Petersen et al., 2003).

2.4. Hypnotic suggestion

The hypnotic state was induced in reference to the previous study (Ikai and Steinhaus, 1961) by a hypnotist who was certified by both the National Guild of Hypnotists and the American Board of Hypnotherapy. In the preliminary screening, 21 participants with a score of 8 out of 12 on the Stanford Hypnotic Susceptibility Scale-Form C (Weitzenhoffer and Hilgard, 1962) were previously selected out of 27 healthy participants, who were highly susceptible individuals to hypnosis (Barabasz and Barabasz, 2008), and also homogeneous in terms of initial hypnotic susceptibility scores within each experimental group. During hypnotic induction, the participants were asked to fix their eyes on a clock and relax their muscles with various permissive and indirect (no specific) suggestions to induce relaxation while in a seated position. Around 8–10 min later, the depth of the hypnotic state was examined by determining the rigidity of the right arm because of the close relationship between hypnotic depth and motor response to specific suggestion following hypnotic induction (Oakley et al., 2007). If the arm did not bend significantly, the participant was considered prepared for "post" measurements (HI) or for task-motivating suggestion (TSH). The task-motivating suggestion was slowly provided two or three times for 4–5 min, as follows: "You are getting stronger and stronger, you can break all records, and nothing will hurt while you do it. I am going to test your grip strength again, and this time you can squeeze this handgrip device much more strongly than you did before." The duration of experimental manipulation in HI, TS, and TSH was 8–10 min, 4–5 min, and 11–15 min, respectively.

2.5. Data analysis

Data were analyzed using a two-factorial analysis of variance (ANOVA) [experimental conditions (HI, TS, or TSH) (3) × time points (the pre, post, or recovery) (3) repeated measurements], followed by the Dunnett's multiple comparison test. A difference among the three conditions was determined by a one-way ANOVA followed by a Bonferroni correction for multiple comparisons. If necessary, the Greenhouse–Geisser correction was applied to adjust for sphericity, changing the degrees of freedom using a correction coefficient epsilon. The effects were considered significant at $p < 0.05$.

3. Results

The results of the two-factorial ANOVA [three conditions (HI, TS, and TSH) × 3 measured time points (pre, post, and recovery)] showed that only the main effect of the measured points [$F_{(1.30,23.47)} = 6.08$; $p < 0.05$; Effect size: $\eta^2 = 0.25$] and the interaction between time and condition [$F_{(2.60,23.47)} = 6.63$; $p < 0.005$; effect size: $\eta^2 = 0.42$] on MEPs were significant, while the main effect of condition did not reach significance [$F_{(2,18)} = 0.08$; $p = 0.91$]. A post hoc analysis revealed a significant increase in MEPs from pre to post only during the TSH condition ($p < 0.001$; Fig. 1A and B). Furthermore, there were no significant differences in the pre MEP [$F_{(2,18)} = 0.44$; $p = 0.65$] and in the recovery MEP [$F_{(2,18)} = 5.16$; $p = 0.60$] among the three conditions (HI, TS, and TSH). The mean value of the time-averaged value of background EMG activity for 20 ms before TMS was below 1.5 μV, which was much lower than the amplitude of the MEP. As for the background EMG, two-factorial ANOVA revealed no significant main effects in the time-averaged value of background EMG activity for 20 ms before TMS among the measured points [$F_{(1.28,23.14)} = 1.64$; $p = 0.21$; effect size: $\eta^2 = 0.25$] and no significant interaction between them [$F_{(2.57,23.14)} = 1.78$; $p = 0.18$; effect size: $\eta^2 = 0.37$].