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Boosting Human Learning by Hypnosis

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Human learning and memory depend on multiple cognitive systems related to dissociable brain structures. These systems interact not only in cooperative but also sometimes competitive ways in optimizing performance. Previous studies showed that manipulations reducing the engagement of frontal lobe–mediated explicit attentional processes could lead to improved performance in striatum-related procedural learning. In our study, hypnosis was used as a tool to reduce the competition between these 2 systems. We compared learning in hypnosis and in the alert state and found that hypnosis boosted striatum-dependent sequence learning. Since frontal lobe–dependent processes are primarily affected by hypnosis, this finding could be attributed to the disruption of the explicit attentional processes. Our result sheds light not only on the competitive nature of brain systems in cognitive processes but also could have important implications for training and rehabilitation programs, especially for developing new methods to improve human learning and memory performance.

Keywords: functional connectivity, hypnosis, memory systems, prefrontal cortex, sequence learning, striatum

Introduction

Human learning and memory rely upon multiple cognitive systems related to separable brain structures. These systems interact in cooperative and sometimes competitive ways in optimizing memory and information processing performance (Poldrack et al. 2001; Poldrack and Packard 2003; Brown and Robertson 2007). Support for the competitive nature of memory systems comes from studies showing interactions between explicit/hypothesis-testing and implicit/procedural systems (Ashby et al. 1998; Poldrack and Packard 2003; Daw et al. 2005; Seger and Cincotta 2005; Filoteo et al. 2010). The former is often characterized by voluntary mechanisms relying more on attentional resources, and thought to be mediated by frontal and medial temporal lobe (MTL) structures, while the latter relies more on automatic, nonconscious processes mediated primarily by striatum. Manipulations reducing the engagement of the explicit, hypothesis-testing system, such as a demanding secondary task (Foerde et al. 2006; Fu and Anderson 2008; Filoteo et al. 2010), a distractor task inserted between the learning sessions (Brown and Robertson 2007), or neuropharmacological blockage (Frank et al. 2006) had no effect or even led to performance improvements in striatum-dependent learning tasks. In a recent study, Galea et al. (2010) also found improvements in procedural learning after the disruption of the dorsolateral prefrontal cortex (PFC) using theta burst stimulation. In contrast, strengthening the reliance on explicit hypothesis-testing processes resulted in impaired procedural learning (Howard DV and Howard JH 2001; Fletcher et al. 2005) with greater PFC activity during the acquisition (Fletcher et al. 2005).

As rapid and reversible changes of cognitive processing are encountered in hypnosis, this phenomenon is an excellent tool of research in the cognitive neurosciences (Raz and Shapiro 2002; Egner et al. 2005). Regarding the neural background of hypnosis, studies demonstrated that people (especially with high susceptibility) show decreased performance on some frontal lobe–related tasks in hypnosis (Kaiser et al. 1997; Kallio et al. 2001; Wagstaff et al. 2007). More recent studies suggest reduced functional brain connectivity between cortical areas in hypnosis, and this is especially typical for frontal areas (Fingelkurts et al. 2007; Oakley and Halligan 2009). Hypnosis temporarily disconnects certain frontal areas from the anterior cingular cortex and other brain areas, disturbing the frontal attentional control and executive system (Kaiser et al. 1997; Egner et al. 2005; Gruzelier 2006).

In our experiment, we used hypnosis as a tool to reduce the competition between frontal lobe–related explicit hypothesis testing and striatum-related procedural-based systems. In order to measure procedural learning in the hypnotic and alert states, we administered a motor sequence acquisition test, which is based on statistical learning mechanisms (Howard JH Jr and Howard DV 1997; Janacsek et al. Forthcoming; Perruchet and Pacton 2006). This fundamental learning mechanism underlies not only motor but also cognitive and social skills (Lieberman 2000; Ullman 2004; Kaufman et al. 2010; Nemeth et al. 2011; Romano Bergstrom et al. 2011); it is therefore an important aspect of life from infancy to old age. Sequence learning is essential for learning languages and operating appliances, such as, for example, computers and musical instruments (Howard et al. 2004; Romano et al. 2010). Social skills appear in compound behaviors realized in proper sequences activated under appropriate circumstances. Most models and empirical studies of sequence learning highlight the role of the basal ganglia (Hikosaka et al. 1999, 2002; Keele et al. 2003; Kincses et al. 2008; Dennis and Cabeza 2010; Rieckmann et al. 2010).

The main question of the study was how the disruption of frontal lobe functions by hypnosis affects performance in procedural-based sequence learning. Sequence learning was measured by the Alternating Serial Reaction Time (ASRT) task (Howard JH Jr and Howard DV 1997) on highly hypnotizable young adults. Participants performed the ASRT task both in waking alert and hypnotic state. In addition, executive functions were assessed by the Wisconsin Card Sorting Test (WCST) (Heaton et al. 1993; Anokhin et al. 2010) and Verbal Fluency Task (Spreen and Strauss 1991) in order to investigate the possible interactions between frontal lobe functions and the effect of hypnosis on sequence learning.

Materials and Methods

Participants

Fourteen healthy right-handed students from the University of Szeged participated in the experiment (12 females; mean age: 22.70, SD: 1.70; mean years of education: 15.50, SD: 1.58). All participants provided signed informed consent. They received no financial compensation for participating in the study. The study was approved by the Psychology Ethics Committee at the University of Szeged, Institute of Psychology.

Participants were selected from a pool of pretested subjects, on the basis of their hypnotic susceptibility. Hypnotizability was measured using the Hungarian version of the Harvard Group Scale of Hypnotic Susceptibility: Form A (HGSHS:A, Shor et al. 1962). Scoring procedure was based on the original English version (scores ranging from 0 to 12). Similarly to previous studies (Kallio et al. 2001; Halsband 2006), we defined high hypnotizability as having 8 or higher score on the HGSHS:A. The mean hypnotizability score of the participants was 9.07 (SD = 0.997; range from 8 to 12).

Tasks

Sequence Learning Task

The ASRT task is a widely used paradigm measuring implicit sequence learning in cognitive neuroscience (Song et al. 2007; Nemeth and Janacsek 2011). In this task, stimuli appear in 1 of 4 empty circles on the screen and participants are required to press the corresponding key (Y, C, B, or M on Hungarian keyboard) as quickly and accurately as possible. Participants are told that stimuli appear randomly, but, in fact, stimuli delivered in a random order (low predictability) alternate with the same stimulus items, which, however, follow a regular presentation order (high predictability). RTs to the high predictability stimuli become shorter than to the low predictability items as participants (implicitly) learn the hidden sequence.

The current ASRT task consisted of 1 practice block with random stimuli and 15 blocks with the alternating pattern described above. The latter blocks consisted of 85 key presses—the first 5 button pressings were random for practice purposes, then an 8-element alternating sequence (e.g., 2r1r3r4r, where numbers represent specific stimuli and r represents a random stimulus) was repeated 10 times. The response to stimulus interval was 120 ms. Participants were given different sequences in the 2 conditions (see below), in order to eliminate intersession learning effects.

Fluency Task

In this task, participants are instructed to produce as many words belonging to the same category (animals and supermarket) as possible in 60 s, without repetitions, synonyms, or generated forms of the same word (Spreen and Strauss 1991). The average number of correct words was used as the performance score. Higher score reflects better frontal lobe functions (Baldo et al. 2006).

The WCST

This task is one of the most specific tests of prefrontal functions (Heaton et al. 1993; Anokhin et al. 2010). Participants are required to derive a correct card-sorting rule based on a trial-by-trial feedback. As the rule changes without warning, the participant has to modify the previously learned response strategy on the basis of the feedback information. A key indicator of cognitive flexibility is the number of perseverative errors that occur when the participant persists in using the old strategy despite the negative feedback. A lower number of perseverative errors indicate better frontal lobe functions.

Design and Procedure

All tests were conducted on an individual basis. Participants performed the ASRT task in both the alert waking and the hypnotic state, with the same standard instructions. The order of the 2 conditions was counterbalanced across participants. The delay between the 2 sessions was 30 days. Fluency and WCST task was administered once, in a third session in alert state. Two participants did not take part in the third session due to time schedule problems.

A skilled hypnotist therapist (the author, Z.A.K.), who has extensive experience with hypnosis, tape recorded the induction, instructions, and dehypnotizing phases (similar to the study of Szendi et al. 2009). This recording was played to each participant. The type of hypnosis induction, similarly to that of the hypnotizability scale, was essentially relaxational.

The induction took approximately 14 min. After the induction, the hypnosis session began. When participants had completed half of the ASRT task, we played an approximately 30-s long induction in order to maintain their hypnotic state (in the wake condition, subjects had a 30-s rest). In the hypnosis condition, after the task had ended, the dehypnosis instruction was played.

Statistical Analysis

As there is a fixed sequence in the ASRT with alternating random elements (e.g., 2r3r1r4r), some triplets or runs of 3 events occur more frequently than others. For example, following the illustration above, triplets such as 2_**3**, 3_**1**, 1_**4**, 4_**2** occur more often because the third element (bold numbers) could be both derived from the sequence as well as from a random element. In contrast, triplets such as 4_**1**, 4_**4** would occur infrequently because, in this case, the third element could only come from the random stimuli. Following previous studies (e.g., Howard et al. 2004; Song et al. 2007), we refer to the former as high-frequency triplets and the latter as low-frequency triplets. Because of this difference in the occurrence frequencies of certain triplets, after observing two stimuli, a certain third stimulus can be expected with 62.5% of probability (for example, 22*3* is five times more probable than 22*1* or 22*2* or 22*4*). In our analysis, we determined for each stimulus whether it was a more or less probable continuation for the previous 2 stimuli. Participants gave faster responses to the more probable than to the less probable stimuli, thus revealing sequence learning in the ASRT paradigm (Howard et al. 2004; Song et al. 2007). In addition, general skill learning can be observed in the ASRT task in the overall increase of the response speed, irrespective of the triplet type. Thus, we were able to separately measure sequence-specific and general skill learning in the ASRT task.

Similar to previous studies (e.g., Howard et al. 2004; Song et al. 2007; Nemeth et al. 2010), 2 kinds of low-frequency triplets were eliminated; repetitions (e.g., 222, 333) and trills (e.g., 212, 343). Repetitions and trills were low frequency for all participants, and participants often show preexisting response tendencies to them (Howard et al. 2004; Soetens et al. 2004). By eliminating these triplets, we could ascertain that any high- versus low-frequency differences were due to learning and not to preexisting tendencies.

Since the participants' accuracy remained very high throughout the test (as is typical, the average was more than 92% for both conditions; Howard JH Jr and Howard DV 1997; Nemeth et al. 2010), we focused on RT for the analyses reported. We calculated medians for correct responses only, separately for high- and low-frequency triplets, and for each participant and each third of the stimulus blocks (1–5, 6–10, and 11–15). To compare sequence learning between hypnosis and alert condition, and between groups with high- and low-executive functions, we conducted repeated measures and mixed design analyses of variance (ANOVAs) with Fisher's Least Significant Difference Test (LSD) post hoc tests. We reported the relevant effect sizes: η_p^2 for main effects and interactions, and Cohen's *d* measures for post hoc tests.

Results and Discussion

A repeated measures ANOVA was conducted with TRIPLET (2: high vs. low), BLOCK (3: 1–5, 6–10, and 11–15), and CONDITION (2: alert and hypnosis) as within-subjects factors. In this ANOVA, a significant main effect of TRIPLET reflects sequence-specific learning, which can increase with practice (TRIPLET × BLOCK interaction), while a significant TRIPLET × CONDITION interaction indicate differences in sequence-specific learning between the hypnosis and alert conditions.

ANOVA revealed significant sequence-specific learning (main effect of TRIPLET: $F_{1,13} = 16.21$, $P = 0.001$, $\eta_p^2 = 0.55$),

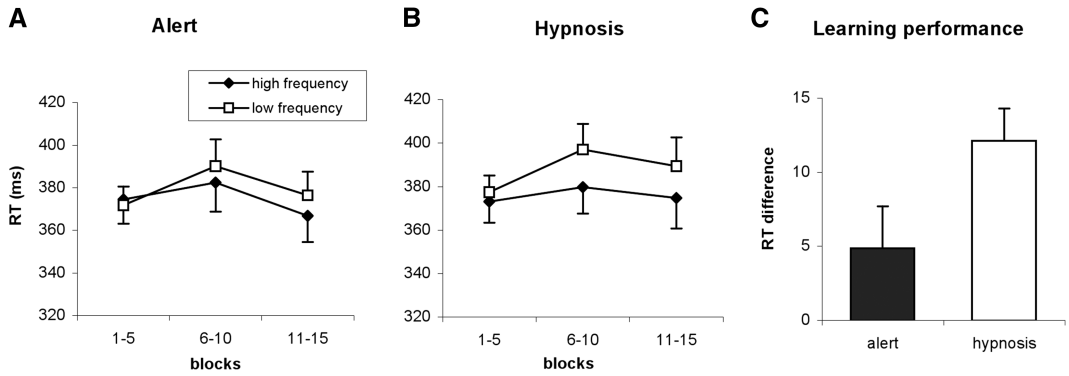

Figure 1. Sequence learning across blocks is plotted for waking alert (*A*) and hypnotic state (*B*), separately. Sequence learning performance (measured by the reaction time differences between high- and low-predictability events) was higher in the hypnotic state compared with the waking alert condition (*C*). Error bars represent standard error of mean.

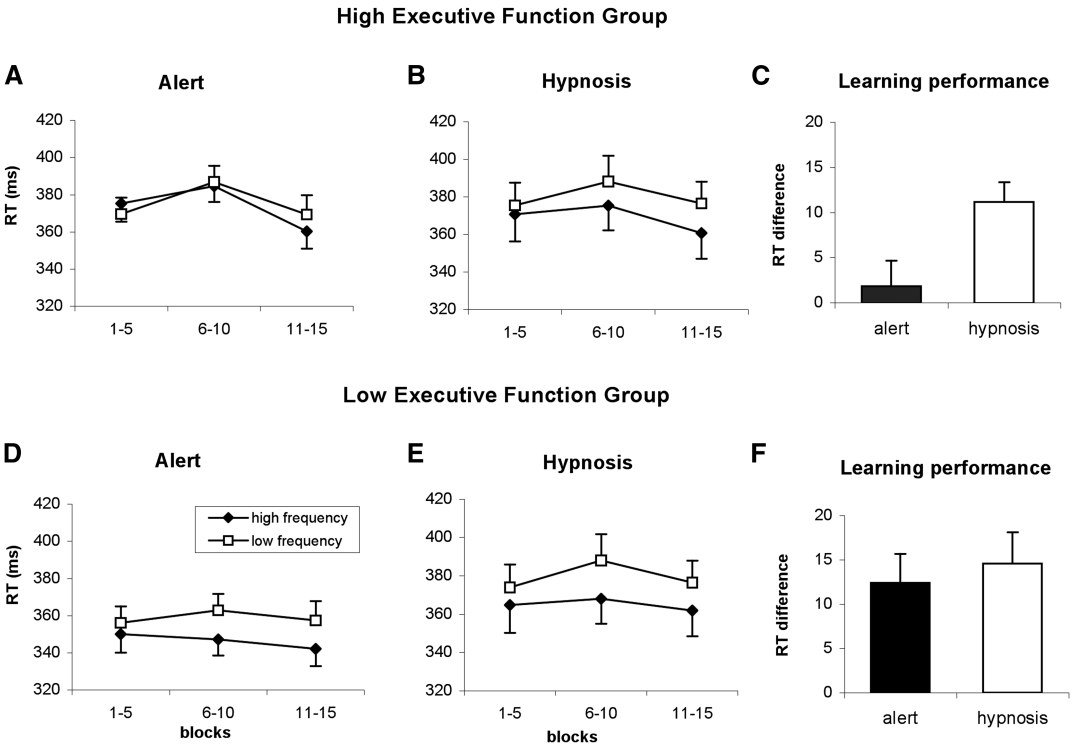

Figure 2. Relationship between high versus low executive functions and the effect of hypnosis on sequence learning. Sequence learning across blocks for the high executive function group in waking alert (*A*) and hypnotic state (*B*), as well as sequence learning across blocks for the low executive function group in waking alert (*D*) and hypnotic state (*E*) is plotted. Participants with high executive functions showed smaller sequence-specific learning (measured by reaction time differences between high and low probability events) in the alert state compared with the hypnosis condition (*C*), while participants with lower executive functions showed similar extent of sequence learning in the waking alert and hypnotic state (*F*). Error bars represent standard error of mean.

which increased with practice (TRIPLET × BLOCK interaction: $F_{2,26}$ = 9.36, P = 0.001, η_p^2 = 0.42). The 2 states differed significantly from each other (TRIPLET × CONDITION interaction: $F_{1,13}$ = 7.08, P = 0.02, η_p^2 = 0.35): sequence learning was 2.5-times higher under hypnosis than in the waking alert state (Fig. 1). Independently from sequence learning, general RT decreased with practice (main effect of BLOCK: $F_{2,26}$ = 4.93, P = 0.034, η_p^2 = 0.27). Other main effects and interactions were not significant (all Ps > 0.34), thus the general RT was similar in the waking alert and hypnotic state (main effect of CONDITION: $F_{1,13}$ = 0.12, P = 0.73, η_p^2 = 0.009). In addition, the rate of sequence learning process was also similar between the 2 conditions (TRIPLET × BLOCK × CONDITION: $F_{2,26}$ = 0.42, P = 0.63, η_p^2 = 0.03). Thus, hypnosis affected only sequence-specific learning (the difference between RTs for low- and high-probability events) and not the general RT. As we used a within-subject design with 2 learning sessions, a further analysis was conducted to test the possible effect of whether hypnosis was in the first or in the second session, and ANOVA revealed no order effect on sequence learning.

To calculate a composite score for executive function, first, we transformed measures of fluency task and WCST into z-scores. Then, we averaged these 2 transformed data into a composite score. Based on the median of this composite measure, we assigned half of the participants to the higher and other half to the lower executive function group. To compare

sequence learning between the high and the low executive function groups, in the alert and the hypnosis conditions (see Fig. 2), a mixed design ANOVA was conducted with TRIPLET (2: high vs. low), BLOCK (3: 1–5, 6–10, and 11–15), and CONDITION (2: alert and hypnosis) as within-subjects factors and GROUP (2: high vs. low executive function) as a between-subject factor.

The general RT was similar in the 2 groups (main effect of GROUP: $F_{1,10} = 1.5$, $P = 0.25$, $\eta_p^2 = 0.13$), and it was not affected differently by the 2 conditions (CONDITION × GROUP interaction: $F_{1,10} = 0.71$, $P = 0.42$, $\eta_p^2 = 0.07$). The TRIPLET × CONDITION interaction almost reached the significance ($F_{1,10} = 4.5$, $P = 0.06$, $\eta_p^2 = 0.31$) replicating that participants exhibited greater sequence learning under the hypnosis condition compared with the waking alert condition. The overall sequence learning was similar in the high and low executive function groups (TRIPLET × GROUP: $F_{1,10} = 3.07$, $P = 0.11$, $\eta_p^2 = 0.24$). Although the TRIPLET × CONDITION × GROUP interaction did not reach significance ($F_{1,10} = 1.72$, $P = 0.219$, $\eta_p^2 = 0.15$), the LSD post hoc tests revealed that participants with higher executive functions showed smaller sequence learning in the waking alert state compared with the hypnotic condition (Fig. 2*C*; $P = 0.03$, $d = 0.94$), while participants with lower executive functions showed similar extent of sequence learning (Fig. 2*E*; $P = 0.58$, $d = 0.25$). In addition, the learning performance of the high executive function group was significantly smaller compared with the low executive function group in the waking alert state ($P = 0.04$, $d = 1.31$), while it was similar in the hypnotic state ($P = 0.51$, $d = 0.396$).

Taken together, we found enhanced sequence learning performance in hypnosis. Our results provide support for the idea that learning and memory processes may not only involve the engagement of specific neuroplastic mechanisms but may also rely upon the disengagement of interacting systems (Brown and Robertson 2007, p. 149). Our finding is in line with previous studies demonstrating that manipulations reducing the reliance on frontal lobe–dependent processes improved procedural based learning performance (e.g., Filoteo et al. 2010; Galea et al. 2010).

The improved sequence learning in hypnosis could be attributed to the disruption of attentional control and executive system (Kaiser et al. 1997; Kallio et al. 2001; Wagstaff et al. 2007), by weakening the engagement of the frontal lobe and/or the interconnectivity between related brain areas (Egner et al. 2005; Gruzelier 2006; Fingelkurts et al. 2007; Oakley and Halligan 2009). This could diminish the competition between 2 fundamentally incompatible modes of learning: 1) PFC/MTL–mediated hypothesis-testing attention-dependent processes versus 2) basal ganglia–dependent procedural learning (Ashby et al. 1998; Poldrack et al. 2001; Filoteo et al. 2010; Henke 2010). Reducing the reliance on executive hypothesis-testing processes could have improved sequence learning capacity by heightening the sensitivity to statistical probabilities, which is essential for automatic procedural mechanisms (Daw et al. 2005; Janacsek et al. Forthcoming). This interpretation is consistent with the result that participants with better executive functions showed decreased sequence learning in the waking alert condition compared with the participants with lower executive functions, suggesting that in the alert state relying more on attentional processes prevented the learning of statistical contingencies to a greater extent (Fletcher et al. 2005). In the hypnotic state, participants with higher executive functions shifted from relying on frontal lobe–related attentional processes to automatic procedural-based mechanisms, resulting in enhanced sequence learning. However, future neuroimaging studies need to corroborate these results, providing direct evidence for the underlying brain systems.

In sum, we found that hypnosis substantially boosted procedural-based sequence learning. This result sheds light not only on the competitive nature of brain systems in cognitive processes but also could have important implications for training and rehabilitation programs, especially for developing new methods to improve human skill learning.

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