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Progressive practice promotes motor learning and repeated transient increases in corticospinal excitability across multiple days

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ABSTRACT

Background: A session of motor skill learning is accompanied by transient increases in corticospinal excitability(CSE), which are thought to reflect acute changes in neuronal connectivity associated with improvements in sensorimotor performance. Factors influencing changes in excitability and motor skill with continued practice remain however to be elucidated.
Objective/Hypothesis: Here we investigate the hypothesis that progressive motor practice during consecutive days can induce repeated transient increases in corticospinal excitability and promote motor skill learning.
Methods: Changes in motor performance and CSE were assessed during 4 consecutive days of skill learning and 8 days after the last practice session. CSE was assessed as area under recruitment curves(RC) using transcranial magnetic stimulation(TMS). Two groups of participants($n = 12$) practiced a visuomotor tracking-task with task difficulty progressively increased with individual proficiency(PPG) or with the same task level throughout all 4 days(NPPG).
Results: Progressive practice resulted in superior motor learning compared to NPPG($p < 0.001$). Whereas NPPG displayed increased CSE following only the first day of practice($p < 0.001$), progressive motor practice was accompanied by increases in CSE on both the first and the final session of motor practice($p = 0.006$). Eight days after ended practice, the groups showed similar CSE, but PPG maintained superior performance at a skilled task level and transfer task performance($p < 0.005$,$p = 0.029$).
Conclusion: The results demonstrate that progressive practice promotes both motor learning and repeated increases in CSE across multiple days. While changes in CSE did not relate to learning our results suggest that they signify successful training. Progressive practice is thus important for optimizing neurorehabilitation and motor practice protocols in general.

Introduction

Motor skill learning describes the process of improving skilled motor performance through practice and repetition independent of maturation processes. In humans, both a single session [1,2] and several weeks [1] of visuomotor skill learning is accompanied by increased amplitude of motor evoked potentials (MEP) when measured with TMS, commonly taken as a measurement of corticospinal excitability (CSE) [2]. While this has been demonstrated in a number of studies, the key factors driving changes in corticospinal excitability accompanying motor skill learning are still poorly understood.

Changes in CSE accompanying a single session of motor skill practice are transient [3,4] and have been suggested to depend on down-regulation of intracortical GABAergic inhibition, unmasking excitatory networks [5,6] permitting increased excitatory transmission in the primary motor cortex likely through early LTP-like processes [7,8]. In contrast, increased corticospinal excitability

Abbreviations: AURC, Area under recruitment curve; CSE, Corticospinal excitability; NPPG, Non-progressive practice group; PPG, Progressive practice group; RC, Recruitment curve; ToT, Time on target.

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and cortical representation accompanying extended practice across multiple days reflect a structural reorganization of M1 dependent on posttranslational processes [9,10]. Early work has suggested an interdependent nature of these short and long-term changes in CSE [4,11], but it remains elusive how within-session changes in CSE evolve longitudinally with daily sessions of motor practice and how these changes relate to the motor practice protocol.

Both changes in CSE excitability [2] and cortical representation [12,13] have been suggested to relate to the active process of learning rather than the level of performance or mere use. This is supported by findings demonstrating continued skill development despite an attenuation of CSE after 2 weeks of visuomotor practice [1] and work demonstrating that the first, but not the fifth day of practice is accompanied by increases in CSE [14]. However, contrasting findings from cross-sectional studies have demonstrated expanded corticospinal representation and CSE in proficient athletes [15,16], musicians [17] and braille readers [18] compared to novices. We speculate that these apparently contrasting findings may be related to the progressive nature of deliberate practice leading to high skill proficiency in experts [19] and that the changes in CSE accompany the learning process prior to skill automatization.

Here, we hypothesize that sustained challenge during motor practice across several days can promote motor skill learning and lead to repeated transient increases in corticospinal excitability. Detailed knowledge of which aspects of motor practice protocols are decisive for skill learning and the underlying plastic changes is highly important in order to qualify practice in neurorehabilitation training and motor practice in general. Consequently, we explore whether individually tailored progression of motor practice across four consequent days promotes motor skill learning and corticospinal plasticity compared to non-progressive motor practice.

Methods

Participants and ethics approval

After receiving written and verbal information about the experiment, twenty-four able-bodied, male subjects between the ages of 18–29 years (mean 22.8 ± 2.5) gave their written informed consent prior to testing. All subjects were right-handed according to the Edinburgh Handedness Inventory (mean 92.29 ± 8.35) [20], naive to the motor task and uninformed of the hypothesis of the study. The experiments were approved by the local ethics committee of the capital region of Denmark (hs:h-2-2011-032) and all experimental procedures were carried out in accordance with the Helsinki Declaration (1964).

Experimental design

Subjects practiced a visuomotor accuracy-tracking task with either fixed or progressively increasing task difficulty during a 4-day intervention. Electrophysiological measurements were obtained prior to and following daily motor practice. These measurements encompassed peripheral nerve electrical stimulation and single-pulse TMS of the left hemisphere primary motor cortex with the aim of establishing recruitment curves (RC) to assess corticospinal excitability. Within and between-session changes in CSE were compared between the groups to explore the effect of the progressive practice protocol. Within session effects were analyzed by comparison of measurements obtained before vs. after motor practice and longer-lasting effects were analyzed by comparison of measurements obtained before motor practice on day 1 and 4 (D1 and D4). Eight days after the intervention CSE and retention of motor learning was tested (D12). On D4 and D12 motor performance was additionally tested in a transfer motor task. An overview of the behavioral and electrophysiological tests on the different test days is illustrated in Fig. 1.

Screening

Prior to participation in the main experiment, subjects participated in a screening procedure with the aim of familiarizing subjects to TMS, screen for TMS contraindications and to obtain baseline measures in order to match intervention groups. Subjects were matched pairwise by age, baseline motor performance, TMS resting motor threshold (rMT), and performance in neuropsychological tests of spatial working memory and sustained visual attention (CANTAB, RVP and SWM test, Cambridge Cognition Ltd, UK). Following this procedure, subjects were randomly assigned to either a progressive (PPG) or a non-progressive practice (NPPG) group. Information of age, handedness, baseline motor performance and electrophysiological measures are presented in Table 1.

No subjects had any history of neurological illness, showed any contraindications to TMS or reported any discomfort to TMS. Accordingly, all subjects were included in the subsequent main experiment.

Design of main experiment

The main experiment involved behavioral and electrophysiological testing procedures and practice of the visuomotor tracking task 30 min per day for 4 consecutive days. All subjects returned after 8 days of detraining for a long-term retention test of performance and corticospinal excitability. Each practice session was conducted at the same time of the day and consisted of 30 min of accuracy-tracking divided into blocks of 20 trials with their dominant right hand. All practice blocks were interspaced with 1 min of rest to diminish fatigue.

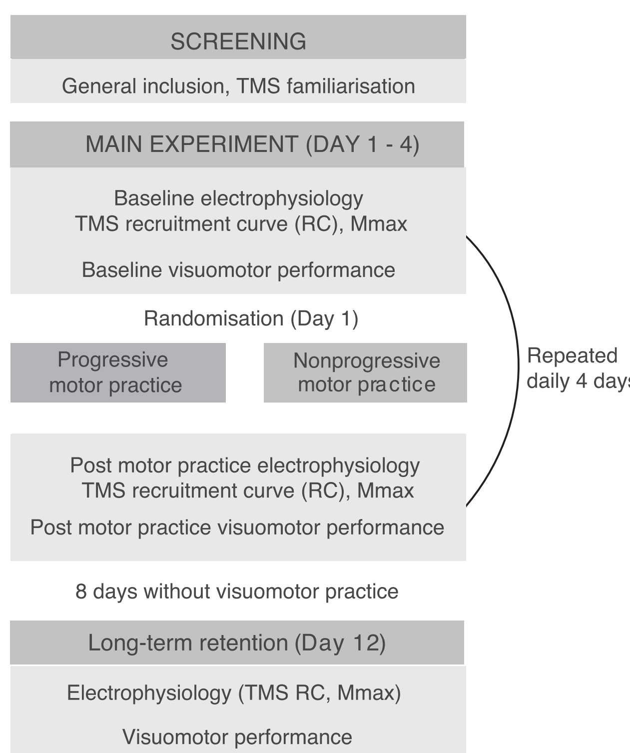

Fig. 1. Flow chart of experimental design.

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