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Explicitness of Task Instructions Supports Motor Learning and Modulates Engagement of Attentional Brain Networks

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Abstract Motor learning is a complex cognitive and motor process underlying neurorehabilitation. Cognitive (e.g., attentional) engagement is important for motor learning, especially early in the learning process. In this study, we investigated if task instructions enforcing the underlying task rule of a virtual sailing task modulate attentional engagement and motor learning. Our results suggest that enforcing the rule of a motor task using explicit knowledge or visual cues enhances motor learning compared with no enforcement of task rules. Further, training with visual cues may support early visuo-attentional engagement.

1 Introduction

Motor learning is a complex cognitive and motor process leading to behavioral and neural changes (i.e., brain plasticity) underlying neurorehabilitation. Fitts proposed three delimited phases of motor learning: the *cognitive, associative,* and *autonomous* phase [1]. In the earlier cognitive and associative phases—where task rules are discovered and appropriate sequences of actions determined and refined—attentional engagement is essential for motor learning, e.g., to focus on relevant stimuli (selective visual attention) and to generate selective and controlled responses (executive attention).

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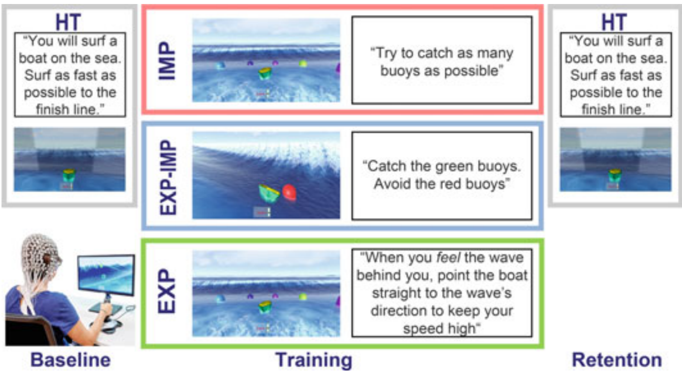

Fig. 1 Experimental protocol and task instruction types used

In line with this, studies have shown that enforcing task rules during training—e.g., using visual cues and/or explicit knowledge—is associated with increased automaticity of movements, enhanced goal-action coupling [2], and inhibition of self-related (internal) distractors [3, 4]. However, to date, less is known about the effect of enforcing task rules on the attentional engagement during motor learning.

Yet, a better understanding of the influence of task rule enforcement on attentional engagement during motor learning may help to design more efficient training paradigms, namely for neurorehabilitation. For example, explicit knowledge about the task rule could be provided during training, depending on the attentional deficits after stroke, to optimally support motor recovery.

Therefore, the goal of this study was to investigate the influence of different task instructions types that vary in the degree of explicitness of the task rules during training on motor learning and attentional brain networks (i.e., reflected in alpha-band cortical activity [3, 5]) using electroencephalography (EEG).

2 Methods

2.1 *Experimental Setup and Participants*

Thirty-six healthy naïve volunteers (41.67% women; $\mu_{age} = 27.9$ years, $\sigma_{age} = 6.64$ years; gender and age balanced across groups, $p > 0.05$) performed a virtual sailing game developed in Unity (*Unity Technologies, USA*) using a Logitech joystick (*Logitech, Switzerland*) (see Fig. 1). The height and position of the chin rest, chair, joystick, and computer screen were controlled across participants and adapted accordingly for left-handers. Participants' neural activity was recorded using a 256-channel Hydrogel cap and EGI Net Amps amplifier (*Electric Geodesics, USA*). EEG data and Unity PC were synchronized via a parallel port.

2.2 Virtual Sailing Task and Instructions

The task of the participants was to sail a boat on a wavy sea in a virtual environment using the joystick (i.e., *Horizon Task, HT*). Wave height, frequency, and direction were controlled across participants. The boat would tilt forward and accelerate if two conditions were met: (1) a wave as high as the boat height reached the back part of the boat (i.e., *sailable wave* onset); and (2) the participant aligned the front of the boat perpendicular to the wave rim (i.e., the *underlying task rule*). The goal was to sail 36 sailable waves as fast as possible to a finish line. Participants performed the HT task at baseline and retention (Fig. 1).

Participants were randomly assigned to one of three training groups that used three different *task instruction types* (Fig. 1):

(1) *Implicit Task Instruction (IMP)*: Single floating buoys appeared at random locations over an imaginary semi-circumference of radius 25 m.u. (*maritime units*) spanning from -90° to 90° relative to the advancing direction of the wave, centred 40 m.u. ahead of the boat in the wave direction. Participants were instructed to "*Try to catch as many buoys as possible*". Thus, participants were disclosed no explicit information about the underlying task rule; they were just compelled to explore it.

(2) *Explicit Task Instruction (EXP)*: Buoys were placed as in IMP. Participants were instructed: "*When you feel the wave behind you, point the boat straight to the wave direction to keep your speed high*". Thus, the underlying task rule to succeed was disclosed.

(3) *Explicit-Implicit Task Instruction (EXP-IMP):* Visual cues, i.e., green "Go" buoys and red "No-Go" buoys, were placed ahead at 10 m.u. distance on the perpendicular to the wave rim. Participants were explicitly instructed to "*catch the green buoys*" and to "*avoid the red buoys*" to experience *catching* and *missing* a wave, respectively.

2.3 Data Collection and Analysis

The distance sailed towards the finish line during the wave propulsion time (i.e., [+150 ms, 3.44 s] from sailable wave onset) was computed. The distance improvement (Retention-Baseline) for *hit* waves (i.e., that resulted in a sustained speed increase) was used to assess participants' ability to sail longer distances on waves as an effect of Task Instruction Type (tested using Kruskal-Wallis and corrected Mann-Whitney tests, $\alpha < 0.05$).

EEG data were pre-processed (i.e., artefact channel removal, 0.1–40 Hz band-pass filtering, and eye-artefact correction) using the Automagic toolbox for EEGLab, resulting in the inclusion of a total of 186 electrodes in the analysis. Temporal-Spectral Evolution (*TSE*) [6] of the alpha-band (7–15 Hz) signal reflecting alpha

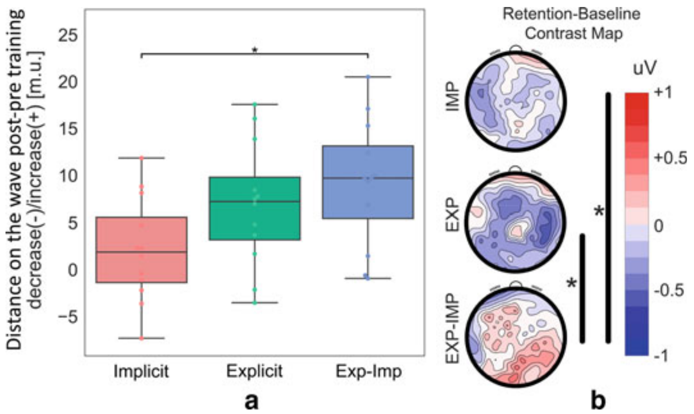

Fig. 2 Behavioral (**a**) and electrophysiological (**b**) results. Scalp maps (**b**) depict retention-baseline contrast map changes of alpha wave strength in micro-volts for each task instruction type. *($p <$ 0.05)

wave strength was extracted for the time window [−1 s, +1 s] from sailable wave onset across all electrodes and averaged per participant, Trial Type (*Hit/Missed* wave), and Phase (*Baseline/Retention*) using EEGLab. *Contrast map*s were computed as the TSE difference between trial types, characterizing the learning of the HT as the *neural-attentional distance* between hit and missed waves. To test if alpha TSE in the contrast maps is modulated across Task Instruction Type and Phase, a mixed-measures topographic ANOVA was performed (TANOVA, [7]). Alpha TSE in time intervals showing significant interactions was compared via corrected post-hoc pairwise comparisons between Task Instruction Type and baseline-normalized (i.e., Retention-Baseline) contrast maps (t-maps, [7], Fig. 2b).

3 Results

3.1 Enforcing Task Rule Supports Motor Learning

Task Instruction Type had a significant effect on the distance sailed ($p = 0.03$, Fig. 2a): Participants in the EXP-IMP ($p = 0.02$) group improved more than participants in IMP group. The improvement marginally differed between the EXP and IMP groups ($p = 0.09$).

3.2 Visual Cueing Supports Attentional Engagement

Alpha TSE difference in the contrast maps −50 to 350 ms relative to sailable wave onset evolved significantly differently depending on the Task Instruction Type (TANOVA, Task Instruction Type × Phase, $p = 0.007$). Group EXP-IMP showed more occipital and frontal alpha wave strength after training than the EXP group ($p = 0.006$, Fig. 2b) and a trend for more parieto-occipital alpha wave strength than the IMP group ($p = 0.07$, Fig. 2b). Participants in EXP and IMP groups only showed a statistical trend for a significant difference ($p = 0.12$; IMP > EXP, Fig. 2b).

4 Conclusion

Our findings suggest superior motor learning linked to training with explicit knowledge about the task rules (EXP) and with visual cues enforcing these rules (EXP-IMP) compared with training without any enforcement of the task rules (IMP). Our neurophysiological results show that training with visual cues (EXP-IMP) enhanced alpha wave strength over parieto-occipital and frontal areas compared with the other task instruction types. Since it is generally acknowledged that alpha wave strength is linked with cortical inhibition [5], our finding on an enhanced alpha wave strength in EXP-IMP versus EXP and IMP may reflect a lower engagement of attentional brain networks after training with visual cues. Even though participants in the EXP and EXP-IMP groups improved their motor performance, training with visual cues (EXP-IMP) may be associated with cognitive facilitation, namely a lower engagement of selective visual (occipital) and executive (frontal) attentional brain networks after training [3–6]. Our results suggest that training parameters such as task instructions indeed modulate the attentional engagement during motor learning and may be an important factor to consider in neurorehabilitation. Studies with larger samples may further explore the effect of training parameters on cognitive processes during motor learning.

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