# Interaction of practice and fatigue effects in mental rotation

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**Introduction.** Mental fatigue is an ubiquitous phenomenon and a problem to many people [1]. Research of mental fatigue is complicated because of the multimodal nature of this phenomenon. Many confounding factors, such as individual differences in compensating strategies and practice effects hinder clearer findings [2]. Practice, habituation and fatigue effects occur simultaneously, making it hard to differentiate the influence of each of these processes. In our study we assessed the suitability of various measures for differentiating effects of practice and fatigue. We chose mental rotation task (MRT) for this goal, as this task is shown to have distinct learning effects and is suitable for testing the impact of different amount of mental load on performance [3]. The aim of our study was to investigate effects of practice and fatigue in a sustained mental rotation performance, comparing dynamics of speed and accuracy of performance, self-report ratings and cardiac measures.

**Methods. Participants.** 49 subjects (31 females; mean age = 20.73, SD = 0.7) took part in the study. All the participants filled in a questionnaire to screen out the possibility of substance abuse, chronic deficit of sleep, endocrinal illness, vision or hearing disorders, general health problems. The study was approved by the Lithuanian bioethics committee (approval No. 158200-13-579-174).

**Experimental task and stimuli.** Shepard and Metzler (1971) paradigm [4] was used for the investigation of mental rotation performance. Pairs of figures [5], rotated 90°, 135° or 180º to each other were presented to the subject. The participants were instructed to press one of two buttons, indicating if the two figures were identical or different. The participants performed four blocks of the task, each containing 400 pairs of figures (~ 20 min.). E-Prime 2.0 software and PST Serial Response Box (Psychology Software Tools (PST), Inc.) were used for stimuli presentation and data collection. The main outcome measures were the accuracy (percent of correct answers) and mean response time (RT) of correct answers.

**Subjective ratings.** Between the task blocks the subjects were asked to rate four aspects of their instantaneous subjective well-being and attitude (tiredness, task aversion, motivation and boredom), by means of a visual analogue scale (VAS).

**Cardiac measures.** Electrocardiogram (ECG) was monitored with PowerLab 3/80 polygraph and inspected offline using LabChart 7.3 software

(ADInstruments). Three disposable Ag–AgCl electrodes were used. The ECG signal was digitized at 1000 Hz and filtered with a 0.05 - 35 Hz band-pas filter. Two representative records of 90 s were selected from the rest-state (before and after MRT performance) and eight 5 min length records taken during MRT (1 from beginning and 1 from the end of each of the four MRT blocks) for HRV analysis. Main parameters analyzed were heart rate (HR), standard deviation of the RRIs (SDNN), square root of the mean squared successive heart period differences (RMSSD) and low frequency (LF) component ($0.04\ \text{Hz} \leq \text{LF} < 0.15\ \text{Hz}$) of HRV. The main cardiac data analysis was performed with Kubios HRV 2.0 software (University of Kuopio, Finland). HRV spectrum was calculated with FFT based Welch's periodogram method.

**Procedure.** All experimental sessions were started at the same time (between 14.00 and 15.00 h). The subjects performed a training session, consisting of 96 pairs of stimulus figures (~6 min.) several days before the main experiment and filled the questionnaire, controlling for inclusion criteriaDuring the main experimental session, participants were seated in an armchair in a soundproof, light-isolated chamber kept at a constant temperature (20 - 22° C), 80-83 cm from the computer monitor. After application of electrodes, the subjects performed four blocks of the experimental task (lasting ~ 1.5 h). The first block started with six pairs of figures to remember the task. The VAS scales were presented seven times during the experiment: 1) at the arrival to the laboratory, 2) before the first MRT block (after the preparatory procedures); 3) before the 2$^{nd}$ block, 4) before the 3$^{rd}$ block, 5) before the 4$^{th}$ block, 6) after the 4$^{th}$ block and 7) at the very end of procedures (after removal of electrodes etc.). Heart activity was monitored during the whole experiment session.

**Statistical analysis.** The statistical analysis was performed with the STATISTICA 8.0 software (StatSoft, Inc., USA). ANOVAs for repeated measures (RM-ANOVA) were used to evaluate effects of time on task (fatigue). Post hoc Tukey tests were used when appropriate. Effect sizes were evaluated by partial eta squared ($\eta^2$).

**Results. MRT performance.** Mean response times of MRT decreased from 1780 ms in the first block to 1512 ms in the fourth block (Fig. 1 a, $F(3, 1434) = 416.53$, $p < 0.001$, $\eta^2 = 0.47$). The percent of correct responses increased from 60.7 in the first block to 67.1 in the fourth block (Fig. 1 b, $F(3, 1428) = 63.98$, $p < 0.001$, $\eta^2 = 0.11$). Although the percentage of correct responses incresed from the 1$^{st}$ (60.7) to the 3$^{rd}$ block (68.9), the 3$^{rd}$ - 4$^{th}$ block difference is negative, showing a decreased accuracy of performance ($p < 0{,}01$, $\eta^2 = 0.02$).

**Subjective ratings.** During MRT, subjective fatigue ratings increased from 29.2% (before the first MRT block) to 57.3% (after the 4$^{th}$ block) (Fig. 2), with a significant time-on-task effect $F(4, 188) = 53.14$, $p < 0.001$, $\eta^2 = 0.53$). Aversion ratings increased from 22.9% to 39.7% ($F(4, 188) = 10{,}86$, $p < 0.001$, $\eta^2 = 0.19$). Motivation ratings decreased from 70.1% to 51.3%

(F (4, 188) = 10.24, $p < 0.001$, $\eta^2 = 0.18$). Boredom ratings increased from 23.3% to 43.7% (F (4, 188) = 15,88, $p < 0.001$, $\eta^2 = 0.25$).

a) b)

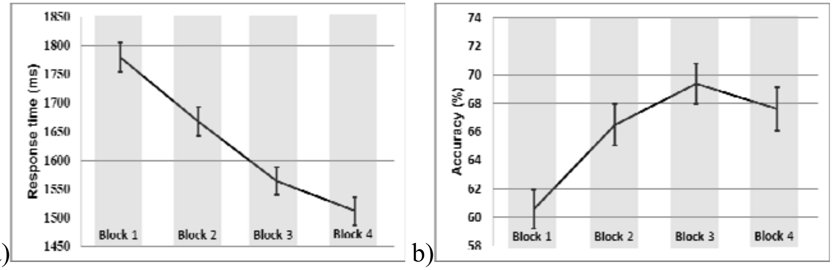


**Fig. 1.** Time-on-task effects in 4 blocks of MRT performance: a) mean response times, b) percent of correct responses. Vertical bars denote 95 % confidence intervals.

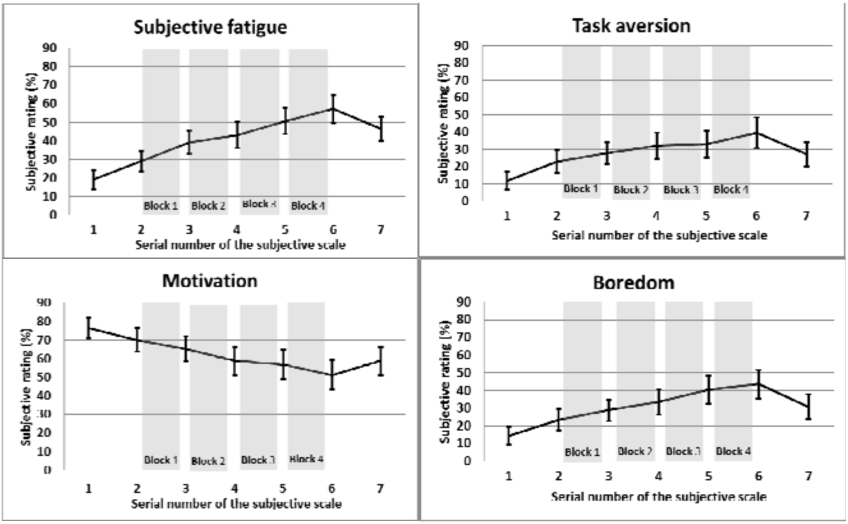


**Fig. 2.** Time-on-task changes of fatigue, task aversion, motivation and boredom subjective ratings. Vertical bars denote 95 % confidence intervals.

**Cardiac measures.** HR decreased from 81,14 bpm at the beginning of the first block to 77.25 bpm at the end of the fourth block (F (7, 273) = 22,51, $p < 0.001$, $\eta^2 = 0,37$), SDNN increased from 38.32 ms to 48.01 ms (F (7, 273) = 11,56, $p < 0.001$, $\eta^2 = 0.23$), RMSSD increased from 34.46 ms to 41.08 ms (F (7, 273) = 7,32, $p < 0.001$, $\eta^2 = 0.23$) and low frequency power of HRV increased from 548.29 $ms^2$/Hz to 1118.66 $ms^2$/Hz (F (7, 273) = 6,04, $p < 0.001$, $\eta^2 = 0.13$).

**Discussion.** The study compared performance-based, subjective and cardiac measures of the changing state of participants while they were performing 1.5 h duration MRT. With increasing time-on-task, mean RT tended to decrease and accuracy tended to increase, demonstrating a vivid practice effect, especially at the beginning of the task. At the end of the task, RT measures seemed to approach a plato and accuracy measures began to decrease, showing a possible growing effect of fatigue.

Decreasing HR and increasing HRV possibly also indicated a practice effect (the task becoming easier) or adaptation (stress reduction due to decreasing novelty of the task). Interestingly, LF component of HRV, usually associated with involvement of sympathetic branch of ANS, tended to increase with time-on-task, possibly demonstrating influence of fatigue [6].

Subjective ratings illustrated a growing influence of fatigue: the change of subjective fatigue showed the biggest effect size; task aversion, boredom and motivation changed the way, expected under the influence of fatigue. Interestingly, most of the ratings also significantly changed before the start of MRT and after the end of it, demonstrating a poor specificity of subjective ratings as measures of specifically *task-related* fatigue.

Usually it is hard to differentiate subtle effects of practice and fatigue as they co-occur and intertwine. The divergence of objective and subjective measures, found in the study, created an interesting possibility to assess the potential of different parameters for this goal.

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The study investigated interaction of practice and fatigue effects in a sustained mental rotation task. Dynamics of performance results, subjective ratings and cardiac measures were resgistered, while 49 subjects were performing a 1.5 h duration mental rotation task. Results helped to evaluate the complementary contribution of subjective and objective measures in differentiating subtle effects of practice and fatigue.