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Individual differences in ERPs during mental rotation of characters: Lateralization, and performance level

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ABSTRACT

The cognitive process of imaging an object turning around is called mental rotation. Many studies have been put forward analyzing mental rotation by means of event-related potentials (ERPs). Event-related potentials (ERPs) were measured during mental rotation of characters in a sample ($N = 82$) with a sufficient size to obtain even small effects. A bilateral ERP amplitude modulation as a function of angular displacement was observed at parietal leads without any lateralization. Sex had no effect on mental rotation of characters, neither with respect to performance nor with respect to brain potentials. When the sample was split into groups of high- and low-performers, however, the results indicated (a) in line with the idea of neural efficiency substantially larger amplitudes for low-performers; (b) that the smaller amplitudes of the high-performers involved larger parietal networks; and (c) a left-parietal disengagement of neural activity for high-performers but a right-parietal disengagement for low-performers. The latter finding became evident through an analysis of internal consistencies of ERP amplitudes across conditions and performance levels, showing that internal consistencies were reduced at all three leads in the high-performance group for the biggest rotation angle, relative the other conditions and the low-performing group.

1. Introduction

The cognitive process of imagining an object turning around is called mental rotation (Shepard & Metzler, 1971). A growing body of evidence suggests that mental rotation is a cognitive process localized in the parietal cortex (e.g. Jordan, Heinze, Lutz, Kanowski, & Jäncke, 2001; Schöning et al., 2007) operating in a continuous, analogous way (Heil, Bajric, Rösler, & Hennighausen, 1997). Many studies have been put forward analyzing mental rotation by means of event-related potentials (ERPs; see e.g. Heil & Rolke, 2002; Jansen-Osmann & Heil, 2007a; Johnson, McKenzie, & Hamm, 2002). The primary finding has been that mental rotation tasks are accompanied by a positivity 300–700 ms after stimulus presentation located at parietal electrodes. The amplitude of this positivity is a monotonic function of the amount of rotation performed (for a summary, see Heil, 2002). Thus, the stimulus-evoked positivity becomes relatively more negative with increasing angular disparities from the upright (Wijers, Otten, Feenstra, Mulder, & Mulder, 1989). Therefore, Wijers and colleagues (1989) suggested that the decrease of the positivity is caused by an increase of a slow negativity that should be understood as a direct electrophysiological correlate of the mental rotation process itself. This idea was validated in a large number of studies, suggesting that the ERP effect observed during mental rotation indeed is highly specific (Heil, 2002).

Additionally, in line with studies using brain imaging methods with high spatial resolution such as fMRI, ERP studies with mental rotation of *characters* consistently revealed two findings: In contrast to mental rotation of three-dimensional figures (Peters et al., 1995; Vandenberg & Kuse, 1978), mental rotation of characters does *not* evoke substantial sex differences, neither in performance (Jansen-Osmann & Heil, 2007b) nor in brain activation (e.g., Heil & Jansen-Osmann, 2007). Second, mental rotation of characters is usually accompanied by a bilateral activation of the parietal cortex *with no reliable hemispheric asymmetry* (e.g., Jordan et al., 2001). These two findings, however, are based on the absence of significant effects (of sex or of hemisphere, respectively) and thus, both suffer from the problem of small sample sizes usually found in neuroscientific studies, and as a consequence, a large Type-II-error. Thus, this study aims to investigate (i) hemispheric lateralization

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during mental rotation of characters with a sufficient power. Given a sample size of $N = 82$, power calculation shows that an effect size of $d = 0.3$ (i.e., a small effect as defined by Cohen, 1977) can be detected with a level of $\alpha = \beta = .10$. Additionally, we investigated (ii) the effect of the performance level on the ERPs during mental rotation, also with emphasize on the putative performance-related differences in the reliability (internal consistency) of ERP measures. Both of these questions have not been examined so far. The measure of internal consistency may be relevant with respect to differences in performance. Internal consistencies in ERPs increase, if neural activity is relatively similar across conditions. It is likely that especially persons with low mental rotation abilities show increased internal consistencies, since neural networks underlying mental rotation maybe more, or even fully demanded at lower rotation angles, than in persons with better mental rotation abilities.

A number of fMRI studies suggest that not sex but interindividual performance differences might determine either the amount of the symmetrical parietal brain activation (see, e.g., Tagaris et al., 1996) or the lateralization of the parietal activation (e.g., Unterrainer, Wranek, Staffen, Gruber, & Ladurner, 2000). No study has yet assessed the influence of interindividual performance differences on ERPs during mental rotation of characters.

2. Methods

2.1. Participants

In all, 82 healthy adults participated in the study. The age of the participants was 22.71 (2.02), ranging from 19 to 28 years of age. There were 55 female and 27 male participants. The mean (school) education of the participants was 13 till 15 years. There was difference between low- and high-performers or between the sexes. All subjects had normal or corrected to normal vision. Participants were recruited by newspaper announcements. The study was approved by decision of the Ethics committee of the University of Münster.

2.2. Materials and procedure

In each trial, one of the letters F, P, R, and L was presented in their normal or mirror-image version at either 30°, 90°, or 150° clockwise or counterclockwise from the vertical upright on a computer screen. The letters had a height of 3.2 cm, subtending 2.28° of visual angle. Each trial began with the presentation of a fixation point in the center of the computer monitor. One second later, a letter was presented in the center of the screen and remained visible until a button press response. Participants pressed the left or right mouse button depending on whether the letter was normal or mirror-reversed. The letter was then replaced by a "+" or "−" for 500 ms indicating the correctness of the response. Participants were instructed to respond as fast as possible, but accuracy was stressed in the instruction. Trials were separated by randomly varying intervals of 1–3 s. Letters were presented in blocks of 48 trials each. Each combination of orientation, version and letter occurred eight times resulting in 384 experimental trials. To familiarize participants with the task, 48 unrecorded practice trials were added. The procedure lasted about 30 min.

2.3. EEG recording and analysis

During the task the EEG was recorded from 32 EEG electrodes (Ag/AgCl) (Fpz, Fp1, Fp2, Fz, F3, F4, F7, F8, FCz, FC3, FC4, FC5, FC6, Cz, C3, C4, C7, C8, Pz, P3, P4, P7, P8, Oz, O1, O2, M1, M2), two lateral and four vertical EOG electrodes with a sampling rate of 500 Hz. Cz was used as primary reference. The filter bandwidth was set from DC to 80 Hz. Impedances were kept below 5 kΩ. The EEG was digitally filtered using a 0.10 Hz high-pass and 20 Hz low-pass filter. From the EEG recordings, stimulus-locked ERPs were computed based on correct responses only, beginning 200 ms before and ending 700 ms after stimulus presentation. Effects of neural activity, i.e. inversions of polarity stemming from movements of the eyeball (ocular artifacts) were corrected with the Gratton–Coles–Algorithm using the EOG data (Gratton, Coles, & Donchin, 1983), followed by a baseline correction (−200 ms to −0 ms). Remaining artifacts were rejected using an amplitude criterion of ± 80 μV followed by re-referencing all data to linked-mastoids. Artifact detection was made by algorithm, but subsequently visually inspected before discarding the epochs. From the edited set of raw data, we extracted ERPs by averaging single trials with correct responses separately for participants, electrodes and experimental conditions. ERP maps are given twice: (i) under linked-mastoids referenciation and (ii) using CSD transformation allowing a reference-free evaluation and hence a less biased scalp topography (Nunez et al., 1997; Perrin, Pernier, Bertrand, & Echallier, 1989). The CSD transform replaces the potential at each electrode with the current source density, thus eliminating the reference potential. The algorithm applies the spherical Laplace operator to the potential distribution on the surface of the head. Since the potential distribution is only known for the electrodes used, the procedure of spherical spline interpolation is employed to calculate the continuous potential distribution. The exact mathematical procedure is explained in detail in Perrin et al. (1989).

2.4. Statistical analysis

For the ERPs, the average amplitude of the epoch 300–700 ms after letter presentation (Heil & Rolke, 2002; Jansen-Osmann & Heil, 2007a) was used as dependent variable, referenced to a pre-stimulus baseline of 200 ms duration. In accordance with the literature, ERPs were quantified at electrodes P3, Pz and P4 (e.g. Heil & Rolke, 2002; Jansen-Osmann & Heil, 2007a). For statistical analysis amplitudes were subjected to a repeated measure ANOVA with the within-subject factors "electrode" and "angular displacement". Between-subject factors were "sex" or "performance level", i.e. high- versus low-performers. The latter was constructed on the basis of a median split derived from the mean error rate averaged across rotation angle. Since "parity" (normal versus mirror-reversed) had no effect on ERPs, data are presented averaged across this factor. In addition to these ANOVAs we calculated split-half reliabilities of the ERP amplitudes across experimental conditions, relevant electrodes (P3, Pz, P4) and performance groups. Split-half reliabilities were calculated using odd and even trials numbers. Only correct trials were used for all statistical analyses.

3. Results

3.1. Behavioral data

Only trials with correct responses were used for reaction time (RT) analyses. Prior to the analysis, RT data were trimmed. RTs more than two standard deviations above or below the mean per condition and per participant were excluded (4.3% of the data). A main effect of "angular displacement" was obtained ($F(2,160) = 232.02$; $p < .001$), showing that RTs increased with increasing angular displacement (30°: 621 ± 15; 90°: 690 ± 18; 150°: 803 ± 24). We obtained neither a main effect of "sex" nor an interaction of "angular displacement" and "sex" (all $Fs < 1$; $p > .3$).