Motor and Neural Adaptation during an Eight-Week Writing Training with the Non-Preferred Hand

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1 OBJECTIVES

Drawing on the work of Haken et al. (1985) and Hollerbachs oscillatory handwriting model (1981), Athenes et al. (2004) showed that graphomotor skills are governed by nonlinear dynamic coupling of two (nearly) orthogonal oscillators, measured as relative phase (RP). Other studies evaluated the degree of automaticity by means of kinematic parameters, e.g. the number of velocity inversions (NIV) per stroke (Mai and Marquardt, 1998). Electrophysiological and neuroimaging studies showed that motor training produced altered activity in task-related brain-areas, in both early and later stages (Patel et al., 2013; Bar and DeSouza, 2016). In the present study, we investigated the development of RP, velocity, and NIV of the letter “e” during eight weeks of training to write with the non-preferred hand, as well as changes in spectral maps of the cortex in three of the nine sessions. By applying an exploratory longitudinal single case study design to the task, we hope to gather new insights about individual motor and neural adaptation. We hypothesized that writing velocity and automaticity increase with training, while RP becomes more stable. Furthermore, subjects should show enhanced neural activity in task related regions. Areas disengaging in later stages could play a role during early learning.

2 METHODS

Five adult, right-handed participants performed eight weeks (3x30 minutes/week) of unsupervised differential training (Schöllhorn et al., 2015) to improve their left-handed writing. Motor adaptation was tested before the intervention and after every week (9 sessions). Subjects received eight sets of four letters on a screen placed in front of them. Every set was presented for 15 seconds and consisted of either one “e” or “m” and three random letters, which had to be written on a sheet of paper attached to a graphics tablet (Wacom Intous 3, 542*318mm, 2540 dpi, 200Hz). Kinematic data was recorded and kernel filtered with the software CS (Marquardt and Mai, 1994). All “e” were further analysed.

Average stroke velocity was calculated by CS. Corresponding NIV was calculated as an average of acceleration zero crossings of all vertical strokes of the letter. Mean values of velocity and NIV of every session were compared qualitatively. Continuous RP for was calculated with the Hilbert transform (Danna et al., 2012) and combined for early, mid, and late stages (three sessions each). As KS and Shapiro Wilk tests (Razali and Wah, 2011) showed that RP-data was not normally distributed, we compared the standard deviation (SD) of the stages.

For EEG acquisition, 19 electrodes were placed according to the international 10-20 system (Jasper, 1958), which recorded cortical activity at 1024 Hz (Brain Quick, Micromed; SystemPlus Evolution) for three conditions (rest 1, task, rest 2) during session 1, 5 and 9. Data was bandpass (0.8 Hz, 99 Hz) and notch filtered (50 Hz, 43 Hz) with the Matlab EEGLAB toolbox (Delorme and Makeig, 2004). Artifacts were removed by visual inspection and independent component analysis. We analysed theta (4-8 Hz) and gamma (30-99 Hz) bands by spectral mapping for every participant.

3 RESULTS

Individual mean velocity is plotted in fig. 1a for all sessions. Courses proceed differently and show fluctuations for every participant. One commonality was a decline of writing velocity after the first week for four subjects, which was followed by an increasing trend by three subjects.

The NIV-courses show fluctuations as well (fig. 1b). Three subjects had increased values even after eight weeks of training.

Fig. 1c presents the standard deviation of RP for every participant in the early, mid and late stage of

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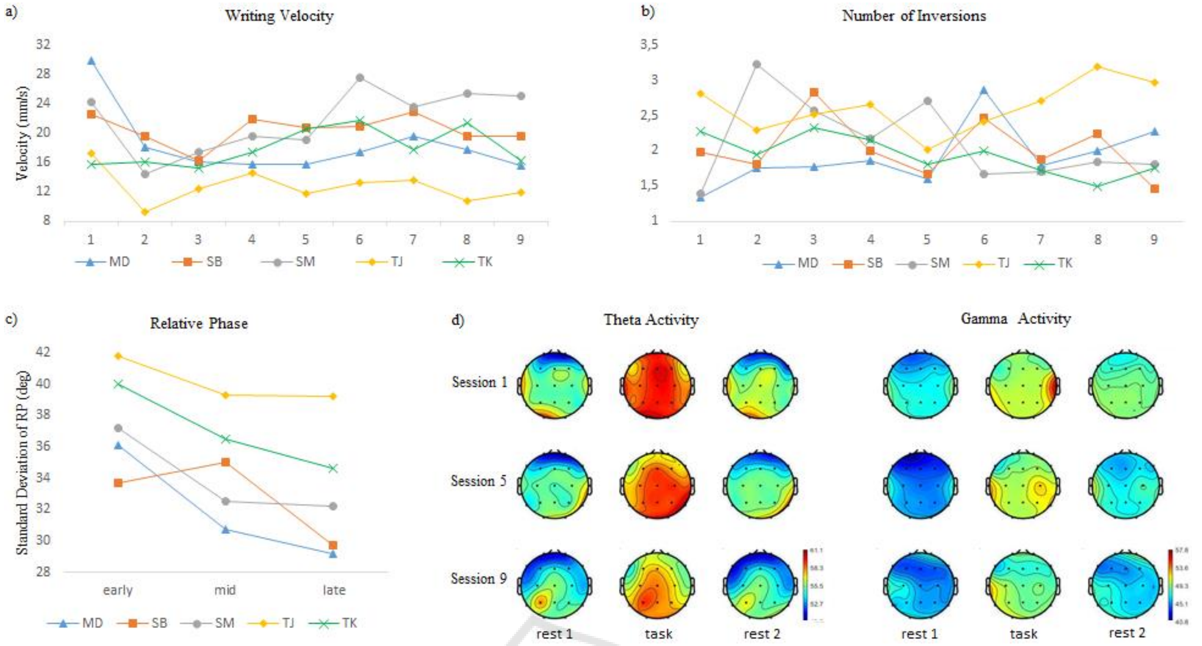

Figure 1: (a) Average writing velocity and (b) averaged NIV-values for the letter "e" for every subject on every session. (c) SD of relative phase for all five subjects during early, mid, and late stages of the intervention. (d) Spectral mapping of theta and gamma activity of subject TK in sessions 1,5 and 9. Blue = low, green = medium, red = high spectral power.

the intervention. It shows that the variation decreased. This was observed in the histograms (not presented here) as well, where distributions became narrower between 60° and 90°.

Cortical spectral activity of theta and gamma bands is presented for TK in fig. 1d. Three Subjects (SM, MD, TK) showed enhanced theta power under the task condition on the whole cortex. TK showed lower increases during later stages, especially in frontal areas. Frontal theta power increase was less for three other subjects in session 9. SB demonstrated increased theta power over the frontal lobes in sessions 1 and 5, as well as in parietal and occipital lobes in sessions 5 and 9. TJ showed increased power mainly on the right hemisphere during sessions 1 and 5, and reduced power in both lateral motor cortices in session 9.

Under rest 2 condition, four participants (MD, SB, SM, TJ) exhibited reduced theta activity over the frontal cortex during session 1, but not during other sessions. Slight increases in parietal and motor areas were found for four subjects (TK, MD, SM, SB) in session 5. TK matched baseline activity in rest 2 during session 9, while two participants showed regional decreases (SM frontal, TJ parietal and central), and two other participants increases (SB frontal, MD parietal and occipital).

With some exceptions gamma power of the whole cortex was enhanced in all subjects in the task condition. Exceptions were SB in session 1 (only parietal and occipital increase), SM in session 1 (only frontal increase) and TJ in sessions 5 and 9 (only parietal and occipital increase). Rest 2 gamma power remained above baseline for TK and SB in all three sessions and MD in session 9. It dropped below or at baseline for SM and TJ (and MD in session 1).

4 DISCUSSION

The time courses of NIV and velocity were unlike usual learning curves, which are often smoothed by averaging over many trials and subjects (Ritter and Schooler, 2002). This was unexpected, as we thought that a training-related increase of speed and decrease of NIV would be clearer. While TK and SM showed the tendency to increase writing speed during the intervention, we cannot distinguish between natural fluctuations and progress for MD, SB and TJ. The common decline from session 1 to 2 might reflect a shift from speed to shape constraints. Lower writing speed facilitates visual feedback for movement correction, which is utilized during early grapho-motor learning (Danna and Velay, 2015).

The number of velocity inversions can be seen as a marker for corrective movements (Mai and Marquardt, 1998). Higher Values indicate using more corrective movements which is associated with increased feedback control. SM and MD increased their NIV and therefore seemed to focus more on shape constraints during the intervention. TK and SB decreased their NIV and possibly relied less on feedback during later stages. The Variance in partly contradicting NIV and velocity values can be explained as subjects are seeking the optimal solution for a speed-accuracy trade-off during learning.

A clear progress was visible for RP, however. Lower SD indicates the formation of increasingly stable attractors, which supports the idea that writing can be modelled by updating RP, amplitude and frequency on a piecewise manner to spare neural resources (Andre et al., 2014). Semi-permanent stable RP would support automation as well. However, well learned letters exhibit more than one stable phase angle and are therefore not normally distributed. The transition between those angles is of special interest and can be further investigated by means of pattern or time series analyses.

We planned to reveal cortical adaptations by examining spectral maps for all participants. Perfetti et al. (2011) demonstrated that enhanced gamma activity in right parietal regions is associated with initial learning. We found that all subjects had increased power in this area, as well as in other areas in the task condition. Gamma activity remained enhanced shortly after the task, indicating that memory formation processes were still active. Increased activity over the whole cortex indicates engagement of a wide-spread network during graphomotor learning. High-density EEG could help localizing involved areas with a better resolution.

Wong et al. (2014) revealed that theta and gamma activities in the frontal cortex are having a negative relationship with task familiarity. In this line, we revealed lower frontal theta activities in session 9 for four subjects, while theta power was increased in other areas (especially occipital) during the task. This finding supports the idea that subjects need less attention with higher task familiarity.

Our aim was to gather insight about motor and neural parameters during eight weeks of learning. We found inter-individual differences for both, which could reflect using different strategies or learning with different speeds. Additionally, we discovered common features for RP as well as gamma and theta activities. Future studies could correlate behavioural with high-density EEG data (e.g. NIV with frontal activity) to reveal coherent adaptations or possible strategy-related differences in the neural network.

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