STEP IN TIME: CHANGES IN EEG COHERENCE DURING A TIME ESTIMATION TASK FOLLOWING QUADRATO MOTOR TRAINING

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Abstract

The aim of the current research was to examine change in EEG measures of local (power) and long-distance synchronization (coherence) during a time production (TP) task as a function of Quadrato Motor Training (QMT), a complex whole body movement technique performed in response to verbal commands. In order to determine whether the electrophysiological change was driven primarily by cognitive or motor aspects, we used two control groups: Verbal training (VT, identical cognitive task with verbal response); Simple Motor Training (SMT, identical motor task with reduced choice requirements). Eighteen female participants were tested for changes in alpha and theta power and coherence during a time production task, using a within-subject design. We found that changes in time production (slope and intercept) were correlated with frontal theta power and coherence changes. In addition, bilateral temporal theta coherence during the TP significantly increased following QMT, as compared to the SMT and VT groups.

We have previously reported a relationship between local synchronization measures (peak alpha frequency), time production, and movement (Glicksohn, Dotan Ben Soussan, Berkovich Ohana, Goldstein, & Donchin, 2010). In this paper, we expand our report to changes in theta (4-7 Hz) and alpha (8-13 Hz) power and coherence measures during a time production task, following motor training in comparison with two control groups. Studies examining EEG changes following motor training and studies examining the electrophysiological correlates of time production have focused on EEG measures, specifically on alpha power (for reviews see Crabbe & Dishman, 2004; Glicksohn, Berkovich Ohana, Balaban Dotan, Goldstein, & Donchin, 2009, respectively). Nevertheless, coherence, a long-distance synchronization measure, is also crucial for cognitive functions, such as attention, especially within the alpha and theta bands (Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007). In addition, it has been previously suggested by Neubauer and Fink (2003) that the electrophysiological correlates of cognitive performance are differently manifested depending on gender: while power may be an adequate measure for examining this relationship in males, it is the coupling of several brain areas assessed by EEG coherence which may be more suitable in females. Therefore, we focus on changes in both power and coherence following motor training during a time production task. We further examined whether changes in local and long-distance synchronization measures and changes in time production are related. We made three interrelated predictions regarding the benefits of motor training (i.e., benefits that should be found immediately subsequent to a period of motor training): (1) Changes in theta and alpha power (i.e., post – pre motor training) should be observed (2) increased theta and alpha coherence should be observed; and (3) increased theta and alpha coherence should be correlated with measures of the change in time production.

Method

Participants and Design

A total of 18 female students participated in the study; age ranging from 21-30 years. All were right-handed with no medical history that might affect their EEG. The experimental design is a simple pre-post single session of training, in which time production with online EEG was assessed both prior to and following the specific training. Participants were randomly assigned to one of three experimental groups: (1) Quadrato Motor training; (2) simple motor training and (3) verbal training.

Quadrato Motor Training (QMT)

The Quadrato Motor Training (see Glicksohn et al., 2009) by Patrizio Paoletti Foundation requires standing at one corner of a 0.5 m × 0.5 m square and making movements to different corners of the square in response to verbal instructions heard from an audio tape recording indicating the next corner to which the participant should move ("one four" means move from corner 1 to corner 4). There are 3 optional directions of movement, and the movement is always a step (essentially a whole body response). We used a specific sequence of movements that were dictated by the Paoletti Foundation, and we taped the instructions so that they would be consistent across subjects. Each movement can be forward, backward, left, right, or diagonal. At each corner, there are three possible directions to move (for example, from corner 1 the participant can move to corner 2, to corner 3 or to corner 4). The training thus consists of 12 possible movements (3 directions × 4 corners): 2 forward, 2 backward, 2 left, 2 right and 4 diagonals. The participant is required to move from one corner to another according to the number on the recording. For example, if the sequence required is 1, 2, 1, 2, 1, 2, 3, 2, 4, 3, 1…. this means moving to the first corner, then to the second, then back to the first, and so on. Our movement sequence comprised a total of 69 instructions, paced at a rate of 0.5 Hz, and was the same for all participants.

Simple Motor Training (SMT)

The Simple Motor training (SMT) group moved from corner to corner on the square in exactly the same manner as the QMT group, but their instructions were to move from corner one to corner two to corner three to corner four, and then begin again with corner one. Thus, the SMT subjects had no choice to make regarding direction of movement, but their movements were very similar to those of the QMT subjects. The SMT group thus provided a control of similar motor performance with minimal cognitive demands. This group practiced the task with the same audio tape as the Quadrato group. While the QMT group was told that each number represented a different corner of the square, the SMT group was simply told to begin at a certain corner and to continue to the next corner clockwise in response to the taped verbal instructions. That is, regardless of the number specified on the tape, they always moved from corner 1 to corner 2, from corner 2 to corner 3, from corner 3 to corner 4, and from corner 4 back to corner 1. Importantly, they were never instructed to associate the numbers with the corners in any way, so the numbers they heard on the tape did not represent a conflicting command and had no task-relevant meaning for them. For this group, each number spoken on the tape represented a command in which they knew they had to go to the next corner in their motor sequence. The training thus consisted of 4 possible movements – forward, right, backward and left – where the QMT subjects also made diagonal movements.

In all other respects, including speed and tempo, their movements were identical to those of the QMT group.

Verbal Training (VT)

The Verbal training group stood 1m in front of the square, but did not move on the corners of it. Instead, their instructions were to respond to the taped commands verbally by stating what direction of movement would be required in order to reach the corner specified by the command (thus, they had 3 possible directions of movement with verbal response). For a movement from corner 1 to corner 2, they were required to say “straight;” for a movement from corner 1 to corner 3, they were required to say “diagonal". The following is a list of all possible combinations and the appropriate response: 1-2, 4-3, “straight”; 2-1, 3-4, “back”; 1-3, 4-2, 3-1, 2-4, “diagonal”; 1-4, 2-3, “right”; 4-1, 3-2, “ left”.

Electrophysiological Measurements

EEG data were recorded at standard extended 10/20 positions with a 65-channel geodesic sensor net (Electrical Geodesics Inc., Eugene, USA), sampled at 500 Hz and referenced to the vertex (Cz) with analog 0.1-200 Hz band-pass filtering. The data were referenced offline to average reference. Sixteen non-overlapping, artifact-free epochs of 2.048 sec duration were extracted for further analysis. We chose to focus on bilateral frontal, central, temporal and parietal electrode sites (F3, F4, C3, C4, T7, T8, P5, P6). For coherence analysis we defined electrode ‘pairs of interest’ (POI) which is similar to the region of interest approach (Manganotti et al., 1998), prior to analyzing the data. Bilateral coherence analysis for left/right frontal, temporal, central and parietal (F3/F4, T7/T8, C3/C4, P5/P6) electrode pairs was also examined, as in previous motor-task studies (Shibata et al., 1998). Coherence values were transformed to a more normal distribution using Fisher's z transformation prior to averaging (Tucker, Roth & Bair, 1986).

Time Production

Four short durations of 4,8,16 and 32 seconds served for the task. The participant was required to remain with eyes closed while producing each of these target durations by pressing a finger button (Glicksohn, 1996). Each target interval was produced twice; the target durations being presented in a random order. Produced (P) and target durations (in sec) were log-transformed (to base 2), with required durations rendering a linear scale ranging between 2 and 5, with a midpoint of 3.5. Produced duration was then regressed on required duration.

Results

Time Production

Inspection of the individual psychophysical functions confirmed linearity for all participants, r^2 values ranging between 0.921 and 0.999 at pretest, and 0.930 and 0.999 at posttest. There were no significant changes in mean log(P), slope and intercept following training. Mean log (P) values ranged between 2.52 and 4.22 (M = 3.67) at test, and 2.46 and 4.34 (M = 3.59) at posttest. Mean slope at test was 0.94 and 0.96 at posttest. Mean intercept was 0.37 at test and 0.22 at posttest. We ran a Group × Training ANOVA, with repeated measures on the last factor, adopting the Greenhouse-Geisser criterion for both this analysis and the others reported in this paper. We examined r^2, mean log(P), slope and intercept measures separately. Although a Training main effect was not significant, a small increase was observed for slope in QMT, except for one participant, in contrast with VT which seemed to manifest the opposite pattern. SMT did not show any trend following training. See Figure1a.

EEG Power

We ran a Group × Training × Hemisphere (left, right) × Electrode Site (Frontal [F], Central [C], Temporal [T] and Parietal [P]) ANOVA on log-transformed power values for theta and alpha bands separately, with repeated measures on the last three factors. A significant Training main effect was found for both theta and alpha power [$F(1, 15) = 15.79$, MSE = 0.064, $p < 0.01$; $F(1, 15) = 6.82$, MSE = 0.169, $p < 0.05$], indicating that both theta and alpha power significantly decreased following training. In addition, a significant Training × Hemisphere interaction was found for theta power [$F(1, 15) = 5.70$, $MSE = 0.030$, $p < 0.05$], indicating that following training, the reduction in theta power was greater in the left hemisphere (average reduction of 0.16 and 0.07 in the left and right hemisphere respectively).

EEG Coherence

We ran a Group × Training × Hemisphere × Electrode Pair (F,C,T,P) ANOVA on the *z*-transformed coherence values, for theta and alpha frequency bands separately. A significant Training main effect was found for theta and alpha coherence [$F(1, 15) = 16.93$; $F(1, 15) = 7.31$, both at $p < 0.05$], indicating change in both bands following training. In addition, a significant Training × Group interaction was found for both bilateral *z*-transformed theta coherence and alpha coherence [$F(2, 15) = 7.01$, $MSE = 0.035$; $F(2, 15) = 11.65$, $MSE = 0.037$, both at $p < 0.01$]. A significant Training × Electrode Pair interaction was also found for both bilateral *z*-transformed theta and alpha coherence [$F(3, 45) = 5.13$, $MSE = 0.018$; $F(3, 45) = 7.50$, $MSE = 0.039$, both at $p < 0.05$]. Post hoc comparisons using the Bonferroni criterion indicated significant change in theta but not alpha coherence. Bilateral *z*-transformed temporal theta (T7-T8) coherence significantly increased in the QMT group [$t(5) = -5.26$, $p < 0.01$]. No significant changes were observed in the SMT and VT groups following training, indicating that QMT significantly increases temporal theta coherence in comparison to the SMT and VT groups (see Figure 1b).

Change in EEG and time production

Electrophysiological change was calculated for both local and long-distance synchronization measures, calculated by the subtraction of log-transformed power and *z*-transformed coherence before training from after training. Change in time production was calculated by the subtraction of slope, intercept and mean log(P) before training from after training. Change in mean log(P) was not correlated with either power or coherence. However, a positive correlation was found between change in slope and change in left frontal theta power ($r = 0.59$, $p < .05$, $n = 18$). A similar pattern was observed for left frontal alpha power, however it was not significant ($r = 0.46$, ns). In addition, a positive correlation between change in slope and change in bilateral frontal theta and alpha coherence was found ($r = 0.62$ and 0.47, respectively, both at $p < 0.05$, $n = 18$). This indicates that the greater the decrease in both local left theta power and bilateral frontal coherence, the smaller is the change in the slope of the psychophysical function (see Figure 1). As change in slope and intercept are negatively correlated, it is not surprising that the opposite pattern was observed for the intercept. A negative correlation was found between change in left frontal theta power and bilateral frontal theta coherence and change in intercept ($r = -0.50$ and - 0.59, respectively, both at $p < .05$, $n = 18$). A similar pattern of correlation between change in intercept was observed for left alpha power ($r = -0.50$, $p < 0.05$, $n = 18$) and bilateral frontal alpha coherence ($r = -0.44$, ns).

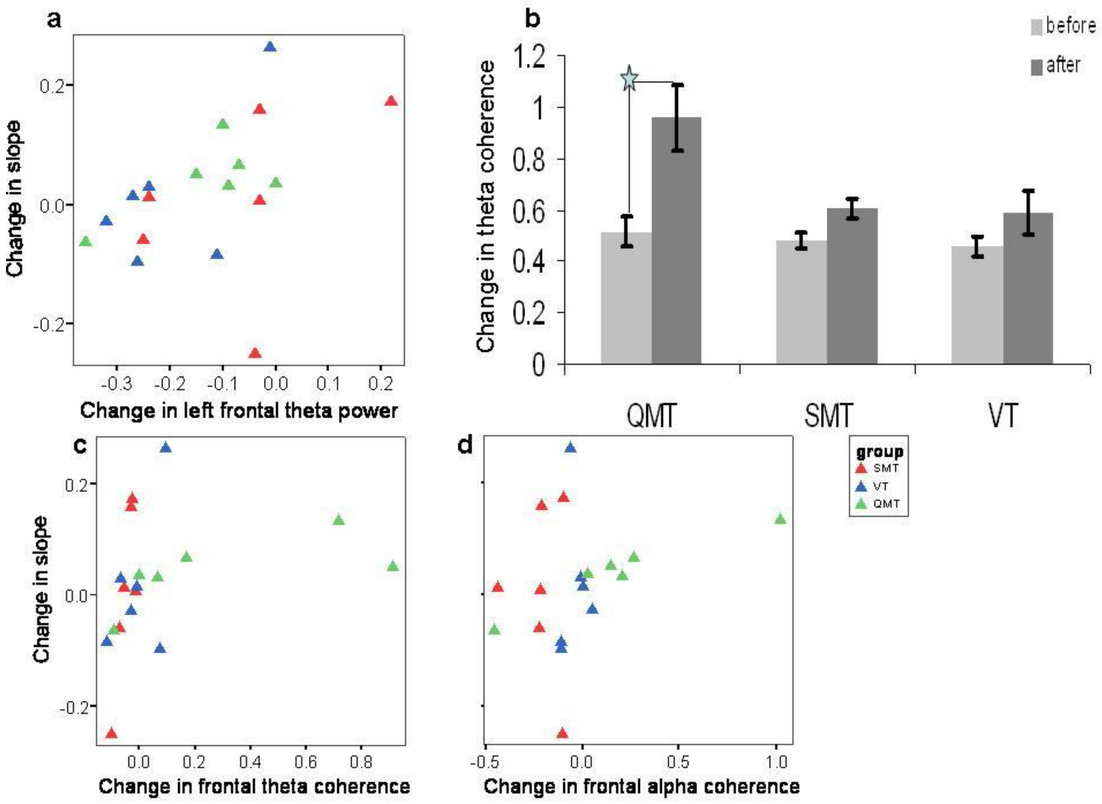

Figure 1. (a) Correlations between change in slope and change in log-transformed left frontal theta power. (b) *z*-transformed frontal theta coherence (mean ± SEM) as a function of Group and Training. Correlations between change in slope and change in: (c) *z*-transformed frontal theta coherence and (d) frontal alpha coherence.

Discussion

The aim of the current research was to examine change in EEG measures during a time production task as a function of Quadrato Motor Training (QMT), a complex whole body movement technique in response to verbal commands. We compared the effects of QMT to two control groups: While the QMT combines whole body motor response, the response of the verbal training (VT), representing the cognitive aspect of the training, was only verbal. The simple motor training (SMT), representing the motor aspect of the training consisted of whole body motor response as in the QMT, but with no choice in the direction of movement. We made three interrelated predictions regarding the benefits of motor training (i.e., benefits that should be found immediately subsequent to a period of motor training): (1) Changes in theta and alpha power should be observed (2) increased theta and alpha coherence should be observed; and (3) increased theta and alpha coherence should be correlated with measures of the change in time production.

Our central electrophysiological finding relates to the changes in coherence following whole body motor training. Bilateral temporal theta coherence, important for attention and movement (Anderson et al., 2000; Rubia, Taylor, Taylor & Sergeant 1999) significantly increased in the QMT group, in contrast to the VT and SMT groups (Figure 1b). This result supports previous claims that the QMT may increase attention by requiring the participant to focus on both sequence instructions and successive movement (Glicksohn et al., 2010). The fact that the QMT group increased theta coherence supports the importance of whole body training for cognitive improvement and electrophysiological change.

As there was a main effect of Training for both power and coherence, we further investigated the relationship between change in neuronal synchronization and change in time production following training. Left frontal theta power (Figure 1a) and bilateral frontal theta and alpha coherence were correlated with change in time production (Figures 1c and 1d). While previously EEG oscillations, specifically within the alpha band, were suggested as the 'physiological clock' (Glicksohn et al., 2009), our present results expand this view and show that changes in both alpha and theta oscillations are related to changes in time production as a result of training.

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