

TIME PRODUCTION AND PEAK ALPHA FREQUENCY: THE SEARCH CONTINUES

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Abstract

We recently reported that a left-right asymmetry index for peak alpha frequency (PAF) had a significant correlation with the mean log-transformed produced duration ($r = .36$, $n = 51$, $p < .01$) of individuals completing a time-production task with online EEG recording (Glicksohn et al., 2009). The sample in that study comprised 27 participants serving in a condition of restful wakefulness, and 24 participants participating in a session of motor training. In the present paper, we add to this data set a group of 47 meditators—31 long-term (LT), and 16 short-term (ST). For the LT meditators, we report that the left-right asymmetry index for PAF has a significant negative correlation with the mean log-transformed produced duration ($r = -.41$, $p < .05$), indicating a reversal in asymmetry. We discuss the relationship between PAF and time production, drawing implications for the rate of functioning of an internal clock.

Two collaborative studies are currently in progress, one concerned with meditation and the EEG, the other with motor training and the EEG. In both, participants complete a time-production task with online EEG recording, twice during a single session in the lab, in a pre-post design. Our previous report (Glicksohn et al., 2009) referred to the *control* conditions for these latter studies ($n = 51$). For the first ($n = 27$), this is the pre-post condition of restful wakefulness; for the second ($n = 24$), this is a pre-post session of motor training, based on the Quadrato Exercise, designed by the Patrizio Paoletti Foundation. One goal that we have set ourselves is to investigate the rate of functioning of the internal clock, relating EEG alpha and time production. We reported that a *left-right asymmetry* of the individual's *peak alpha frequency* (PAF) is correlated with produced duration. We now turn to the influence of meditation on both time production and PAF. Meditation, especially amongst individuals who are proficient in its practice, should result in a longer time production and a slowing down of the internal clock (Glicksohn, 2001b). With extended practice, what would be considered to be state effects would be transformed into trait effects (Cahn & Polich, 2006)—resulting in a clear distinction between long-term (LT) and short-term (ST) practitioners.

Method

Participants and Design

We focus on the data provided by a group of 47 right-handed meditators, 31 LT (23 practicing Vipassana, and 8 practicing TM; ranging in age between 22-73 years; $M = 45.2$ yrs) and 16 ST (ranging in age between 26-62 years; $M = 41.9$ yrs). LT meditators had between 2010-38,000 hours of practice; the range for ST was 54-1740 hours. A total of 11

meditators not further considered here include 1 reporting feeling sick after meditating in the lab, 4 reporting a history of depression, 3 reporting drug abuse, and 3 having a noisy EEG recording. Controls comprised the 27 individuals discussed in the previous report (1 of whom, being left-handed, was removed from the present data set) and an additional 4 older individuals. All controls were subsequently divided into 2 groups: An older group matching somewhat in age for LT ($n = 14$; $M = 43.6$ yrs), and a younger group matching somewhat in age for ST ($n = 16$; $M = 26.3$ yrs).

Time Production

Four short durations of 4, 8, 16 and 32 seconds served for the time-production (TP) task. The participant was required to remain with eyes closed while producing each of these target durations by pressing a finger button for the required period of time. Each target interval was produced twice, the target durations being presented in random order. The participants were subsequently requested to report on the strategy they adopted (all reported counting). Produced and target durations were log-transformed (to base 2), with required durations rendering thereby a linear scale ranging between 2 and 5, with a midpoint value of 3.5; produced duration was then regressed on required duration.

Electrophysiological Measurement

EEG was recorded using a 65-channel geodesic net (Electrical Geodesics Inc.) at a 500 Hz sampling rate, referenced to the vertex (Cz), with analog 0.1-200 Hz band-pass filtering. The data were subsequently referenced offline to average reference. EEG signals showing eye movements or muscular artifacts were manually excluded from the study. For each electrode, 16 non-overlapping, artifact-free epochs of 2.048 sec duration were extracted for further analysis, for each condition of the study: baseline, and during time production prior to either restful wakefulness or meditation, and baseline and during time production subsequently. For each epoch, the power spectral distribution was computed and grouped into the various frequency bands. In the present report, we focus on peak alpha frequency (PAF), at P3 and P4, the alpha band defined as ranging between 7.5-13 Hz.

Results

Time Production (TP)

For a minority of meditators ($n = 6$), some aberrant values were noted in their data, and these data points were dropped prior to running the individual regressions, as had previously been done for the controls (Glicksohn *et al.*, 2009). Inspection of the individual psychophysical functions subsequently confirmed linearity for all 77 participants (47 meditators and 30 controls), r^2 values ranging between 0.909 and 0.999 at test, and 0.919 and 0.999 at retest. Mean log-transformed produced duration (TP) ranged between 2.51 and 4.67 ($M = 3.71$) at test, and 2.53 and 4.63 ($M = 3.72$) at retest. Turning to the slope value, ranging between 0.72 and 1.22 ($M = 0.96$) at test, and ranging between 0.77 and 1.16 ($M = 0.97$) at retest, and the intercept value, ranging between -1.06 and 2.00 ($M = 0.36$) at test, and ranging between -1.06 and 1.69 ($M = 0.34$) at retest, we find them to be negatively correlated, at both test ($r = -0.64$, $p < .0001$) and retest ($r = -0.41$, $p < .0005$) as one would expect (Rule, 1993). Figure 1 presents test-retest data for these 3 indices, clearly supporting our choice of TP as the index worth further considering. We ran a Group (2 groups of meditators, 2 groups of controls) \times Condition (pre, post) analysis of variance (ANOVA) with repeated measures on the last factor for TP. Neither Group [$F(3,73) = 2.32$], Condition [$F(1,73) < 1$], nor their interaction [$F(3,73) < 1$] were significant. Thus, meditation did not result in a longer TP.

Peak alpha frequency (PAF)

We ran a Group \times Condition \times Task (baseline, TP) \times Hemisphere (left [L], right [R]) ANOVA with repeated measures on the last 3 factors for PAF. The main effect for Task

[$F(1,73) = 14.42$, $MSE = 0.15$, $p < .001$] indicated an increase in PAF during TP ($M = 10.19$), relative to baseline ($M = 10.07$), as one would expect (Osaka, 1984), with somewhat larger TP PAF values for controls (10.29 for the younger, and 10.42 for the older control group) than for meditators (9.71 for ST, and 10.03 for LT)— though the Group \times Task interaction was not significant [$F(3,73) = 2.14$]. Figure 2 presents test-retest data for PAF. We conducted a Group \times Hemisphere ANOVA with repeated measures on the last factor for PAF during meditation/relaxed wakefulness, finding no significant effects (all F -values < 1.8 , ns), with mean PAF values ranging between 10.10 and 10.26 for the control groups (relaxed wakefulness) and between 9.93 and 10.12 for the meditators (meditation).

Peak alpha frequency and Time Production

We previously showed that on employing *both* left TP PAF and right TP PAF in a multiple-regression analysis, with TP at test as dependent variable, it was their *joint* contribution that was substantial. For our LT meditators, we could replicate this finding [$F(2,28) = 2.86$, $MSE = 0.13$, $p = .07$; $R^2 = .17$], with intercept ($b = 3.43$, $p < .005$), left PAF ($b = -0.29$, $p < .05$) and right PAF ($b = 0.32$, $p < .05$) being significant. Note, however, that here the sign of the regression weights is reversed, indicating that it is an $R > L$ asymmetry in TP PAF that plays a pivotal role here for LT meditators. We find no such relationship for ST [$F(2,13) < 1.90$], nor for the controls either pooled [$F(2,27) < 1.50$], or viewed as separate groups [F -values < 2]. On computing a left-right asymmetry index for TP PAF, as in the previous report, we found that this index had a significant correlation with TP ($r = -.41$, $n = 31$, $p < .05$; see Fig. 3a) for the LT meditators, and nonsignificant values for the other 3 groups: ST ($r = .21$, $n = 16$), younger controls ($r = .39$, $n = 16$), older controls ($r = -.34$, $n = 14$). For comparison, in the previous report the correlation reported for all controls was positive ($r = .36$, $n = 51$, $p < .01$; see Fig 3b). Hence, there seems to be a change in asymmetry in TP PAF from $L > R$ to $R > L$ for LT practitioners of meditation.

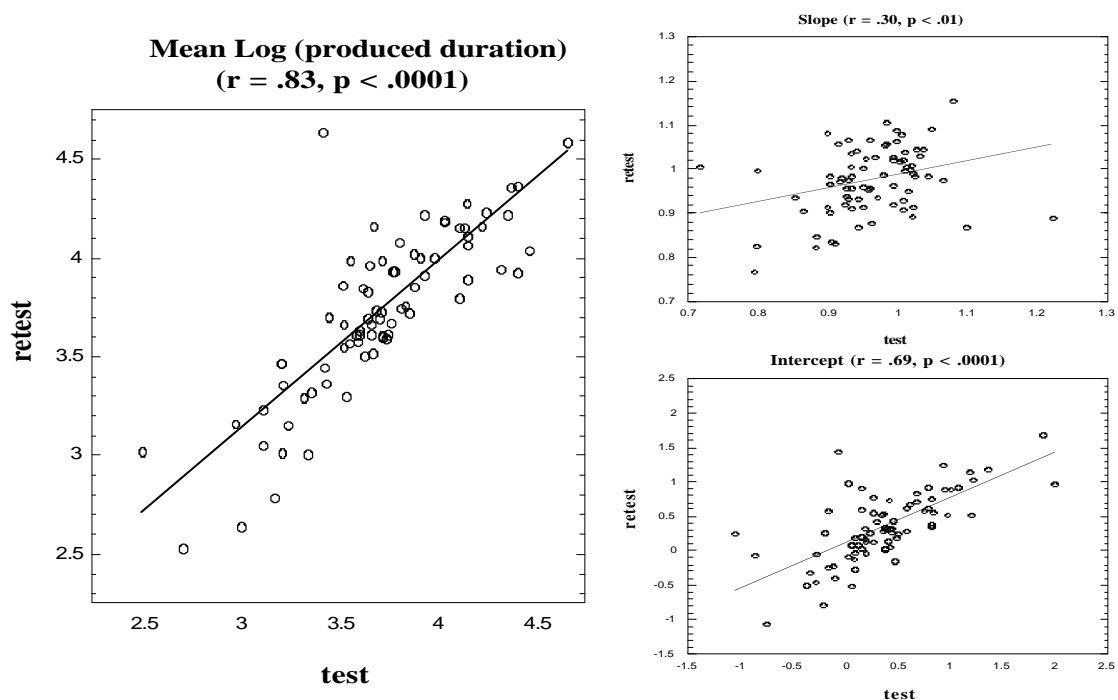


Figure 1. Test-retest data for produced duration

Discussion

Our choice of a time-production (TP) task was predicated on the fact that TP exhibits relatively high test-retest reliability (Brown, 1998, p. 610; see Fig. 1). However, high test-retest reliability is not necessarily an asset when one is investigating state-specific effects. Nevertheless, there is an increase in peak alpha frequency (PAF) during TP relative to baseline, and PAF itself exhibits relatively high test-retest reliability (Gasser *et al.*, 1991; see Fig. 2). Given that PAF, while being relatively stable, is also state-specific (Neuper *et al.*, 2005), and correlates with task performance (Angelakis *et al.*, 2004), it is the TP-PAF relationship that is the more promising avenue. Indeed, the TP task conducted with eyes closed can well be said to impose "...a more uniform level of alertness and mentation, and thus has a stabilizing effect on the EEG" (McEvoy *et al.*, 2000, p. 461).

LT meditators are expected to have lower PAF during baseline, relative to meditation (Aftanas & Golosheikin, 2003; Cahn & Polich, 2006). In the present study, baseline PAF for our LT meditators ($M = 10.04$ at baseline prior to meditation, and $M = 10.02$ at baseline subsequent to meditation) was indeed lower than that during meditation ($M = 10.12$), but clearly not to a significant degree (both t -values < 1). We stress that the prediction of longer TP *during* meditation (Glicksohn, 2001b) was not in fact investigated here (and is worthy of future study), primarily because of the disruptive effect on meditation of actually performing TP—a problem familiar to researchers studying altered states of consciousness (ASC), namely that the very act of data collection is inherently disruptive of whatever ASC is being explored (Glicksohn, 2001a, p. 350). What we have found, in continuing our investigation of the relationship between the asymmetry in TP PAF and TP, is that there seems to be a change in asymmetry in TP PAF from $L > R$ to $R > L$ for LT practitioners of meditation. Such a shift in asymmetry—a shift towards a right-hemisphere dominance—is one that has been predicted (but not actually found) for meditation (Pagano & Warrenburg, 1983, p. 171). It is a shift in PAF during TP, and not during meditation (meditation PAF values being quite similar to those of restful wakefulness) which is found, supporting a conclusion drawn by Travis and Arenander (2006, p. 1534) that the long-term effects of meditation practice "...on brain dynamics are more clearly evident during activity, rather than during meditation."

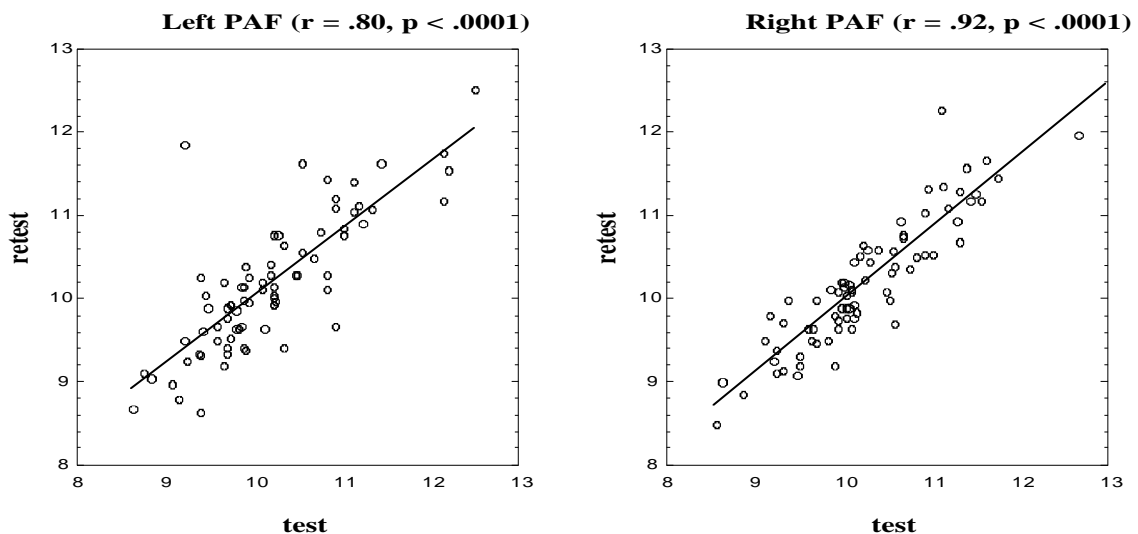


Figure 2. Test-retest data for peak alpha frequency (PAF)

The $R > L$ asymmetry in TP PAF found for LT meditators is intriguing, especially when viewed in the light of two recent studies indicating that Vipassana meditators had greater gray matter concentration in the *right* anterior insula, which is involved in interoceptive awareness (Hölzel *et al.*, 2008), and that participants having extensive Insight meditation experience, exhibited greater thickness of the prefrontal cortex and *right* anterior insula, cortical thickness being correlated with meditation experience (Lazar *et al.*, 2005). What does the $R > L$ asymmetry in TP PAF mean with respect to TP? From Figures 3a and 3b it is clear that when left PAF = right PAF, TP is certainly not veridical. For the LT meditators, as right PAF diverges from left PAF, the longer is the TP—in line with the hypothesis regarding the results of meditation on TP (note, however, that quite a number of LT meditators exhibit reversed asymmetry). For the controls, as left PAF diverges from right PAF, the longer is the TP (again, note the degree of individual variation here). Hence, the degree of hemispheric asymmetry in TP PAF (measured in Hz) is related to TP, hence to the basic rate of functioning of the internal clock. Clearly, much more work is needed here in understanding how these two temporal indices covary.

Finally, a comment regarding the investigation of LT practitioners of meditation: While non-EEG studies have not been restricted in the age range of the participants (e.g., Easterlin & Cardeña, 1998-99), previous EEG studies looking at LT (or, “experienced”, or “expert”) practitioners of meditation have employed samples somewhat restricted in age (i.e., up to the age of 45 yrs; Aftanas & Golosheikin, 2003). This might not be a necessity given the fact that fMRI studies have employed meditators ranging in age till 64 years (Brefczynski-Lewis *et al.*, 2007), having between 10,000-54,000 hours of practice. Furthermore, if extensive meditation does lead to greater cortical thickness, especially amongst older practitioners (Lazar *et al.*, 2005), then their inclusion is certainly more of an asset than a hindrance.

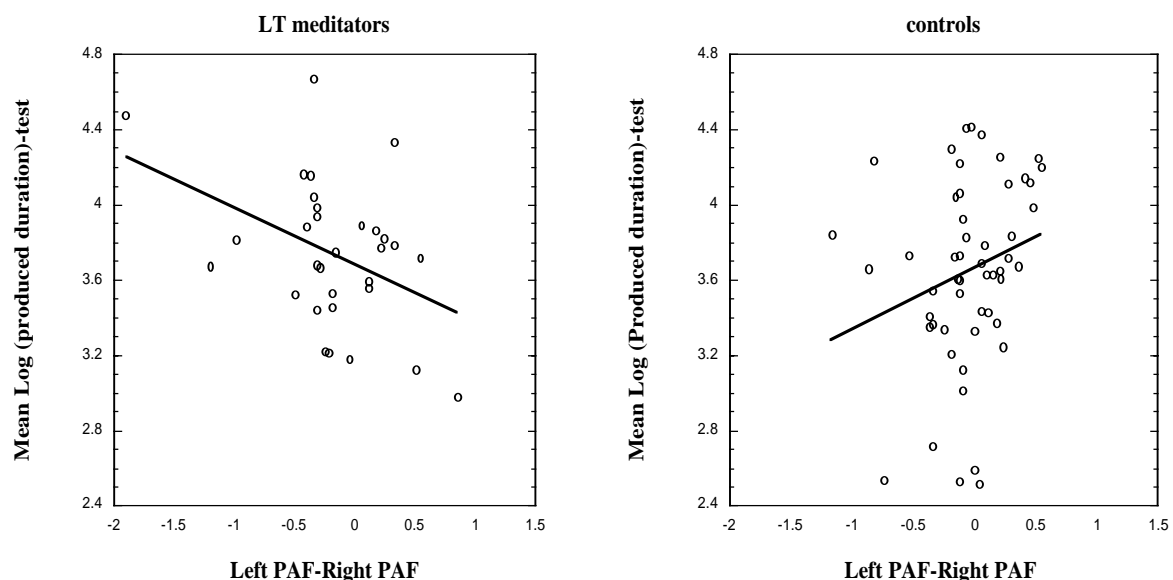


Figure 3. Produced duration correlated with PAF asymmetry: (a) for LT meditators; (b) for controls

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