

TIME PRODUCTION, PEAK ALPHA FREQUENCY, AND SEX DIFFERENCES:

THE PLOT THICKENS

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Abstract

We propose a novel way of computing the change in size of a subjective time unit (S), based on a ratio score of produced durations, and investigate how this S-ratio changes as a function of Quadrato motor training, Vipassana meditation and a control condition of restful wakefulness, using different participants for each condition. The similar trend for both peak alpha frequency (PAF) and the S-ratio following motor training is summarized by their significant correlation of 0.57. We discuss the relationship between PAF, time production, and movement, drawing implications for the rate of functioning of an internal clock.

The task of time production perhaps best reflects the speed or rate of functioning of an internal clock (Baudouin *et al.*, 2006). If the required duration is 10 sec, individual A might produce a duration of 8 sec, individual B one of 10 sec and individual C one of 12 sec — though for all three individuals, produced duration is subjectively viewed as lasting 10 sec. Individual B exhibits veridical time perception (i.e., produced duration = required duration; 1 subjective second = 1 sec). Individual A would be viewed as having a faster internal clock (with each subjective second lasting 0.8 sec), and individual C would be viewed as having a slower internal clock (with each subjective second lasting 1.2 sec). If these same individuals are consistent (i.e., their clock speed is consistent), and they are asked to produce durations of 4, 6, 8, 10, 12, 14 and 16 sec, say, then a psychophysical function can be easily derived for each individual (with slopes being 0.8, 1.0 and 1.2, respectively). This is the case, whether the data are consistent with a linear function (Allan, 1979) as here, or with a power function (which can be subsequently linearized using a log-log plot). This is also the case whether the individual employs chronometric counting (Bizo *et al.*, 2006; Brown *et al.*, 1995) or not.

Our data are drawn from two current studies using the same procedure for time production with online EEG recording (Glicksohn *et al.*, 2009a, 2009b). The online EEG enables us to provide a different indicator of internal clock speed, namely peak alpha frequency (PAF). The longer the produced duration (individual C), the slower the internal clock — and “if the alpha rhythm drives the internal clock, alpha frequency should decrease as time productions increase” (Adam *et al.*, 1971, p. 134) — hence the decrease in PAF (Coffin & Ganz, 1977). We contrast the data for males and females, given that males make relatively longer time productions (Block *et al.*, 2000, p. 1341; Zakay & Block, 1997, p. 13).

Our main goal, however, is to bridge between psychophysical and chronometric-counting approaches, assuming that while longer produced durations could be indicative of the fact that the internal clock is “...producing pulses at a considerably decreased rate”

(Binkofski & Block, 1996, p. 491), it is more likely “when humans are required to produce an integer number of seconds they count up to that integer value....” (Wearden, 1991, p. 71). The power function relating produced duration (T) to required duration (D) is given by:

$$T = aD^\beta \text{ subsequently linearized as } \log(T) = \log(a) + \beta \log(D) = \alpha + \beta \log(D) \quad (1).$$

If the individual’s time production is veridical, then $\alpha = 0$, and $\beta = 1$. When $\alpha \neq 0$, there is a consistent bias in producing durations; when $\beta \neq 1$, then the untransformed data are not consistent with a linear function. The multiplicative model for produced duration is given by the product of the number of subjective units (n) and the size of the subjective unit (S):

$$T = nS, \text{ which after log transformation gives } \log(T) = \log(n) + \log(S) \quad (2).$$

If chronometric counting is employed, then the multiplicative function is a simple linear and additive function of the number of required counts (Killeen, 1992); nevertheless, it is convenient to employ the log transformation so that we can work with the same data on the same scale, with these two models. Note that the model in equation (2) is a special case of that in equation (1), where $n = D$, $\beta = 1$, and $a = S$. Given n (and T), we easily solve for S . As we shall show in this paper, by focusing on S using a pre-post design, we can explore to what degree the change in size of S is related to experimental condition and gender.

Method

Participants and Design

Complete data were obtained from a total of 74 individuals (with age ranging between 19 and 50; mean age = 30.8 years), who served in two separate studies, each having a pre-post design. Time production with online EEG was assessed both prior to (pre) and following (post) a specific experimental session.

In the first study, conducted by the second author, a total of 22 participants (6 males and 16 females) completed a Quadrato Motor Training (QMT) session. The QMT, developed by the Patrizio Paoletti Foundation, involves standing within a 0.5 m \times 0.5 m square and making a movement to different corners of the square in response to taped verbal instructions ("1"-“4”), indicating the next corner to which the participant should move. Movements are forward, backward, left, right, or diagonal, while keeping the eyes focused straight ahead, hands loose at the side of the body, and beginning all movements with the leg closest to the center of the square. 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. A movement sequence comprised a total of 69 instructions, paced at a rate of 0.5 Hz, and was constant for all participants.

In the second study, conducted by the third author, a total of 26 participants (22 males and 6 females) having prior experience with meditation completed a Vipassana meditative session, and a further 26 participants (14 males and 12 females) served as controls, in a “restful-wakefulness” session.

Time Production

Four short durations of 4, 8, 16 and 32 seconds served for the time-production 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 (73 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 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 (Hagemann, 2004). Sixteen non-overlapping, artifact-free epochs of 2.048 sec duration were extracted for further analysis, for each condition of the study: during time production prior either to restful wakefulness, Vipassana meditation or QMT, and during time production subsequently. We focus on PAF during time production, averaged for P3 and P4, the alpha band defined as ranging between 7.5-13 Hz.

Results

Time Production

Inspection of the individual psychophysical functions confirmed linearity for all 74 participants, r^2 values ranging between 0.937 and 0.999 at pretest, and 0.914 and 0.999 at posttest. Mean log (T) ranged between 2.51 and 4.41 ($M = 3.65$) at test, and 2.46 and 4.34 ($M = 3.63$) at posttest. If the participant employs chronometric counting, then mean log (T) = 3.5 (i.e., midpoint value) + mean log (S). Hence, we can easily derive S for both pre and post experimental session. This value ranges between 0.50 and 1.88 ($M = 1.16$) sec at pretest, and 0.49 and 1.82 ($M = 1.15$) sec at posttest. We propose that a change in size of S (either a shortening or a lengthening) is best captured by computing the ratio of S_{post} to S_{pre} . As Figure 1a indicates, this S -ratio is quite symmetric, ranging between 0.714 and 1.425, with a mean of 0.998.

Peak alpha frequency (PAF)

We ran a Sex \times Condition (pre, post) ANOVA on PAF. The two main effects [$F(1,72) = 4.23$ and 7.55 , respectively, $p < .05$], and not the interaction, were significant, and this additive model is depicted in Figure 1b. Clearly, females have higher PAF than males, and PAF becomes slower following the experimental condition. There may, however, be one complication here in that on running a Group \times Sex ANOVA on age, the two main effects [$F(1,72) = 3.41$ and 7.07 , respectively, $p < .05$], and not the interaction, were significant, indicating that our males were older than the females, and that our meditators were older than the other two groups. Would age and mean PAF (i.e., the mean of the pre and post values for PAF) be therefore correlated? Hardly: Their correlation is -0.02 . Are age and S -ratio correlated? A correlation of -0.03 is reassuring.

Peak alpha frequency and Time Production

We computed the correlation between mean PAF and the S -ratio, for each experimental condition. These were -0.056 for the control condition, -0.115 for meditation and 0.566 ($p < .01$) for QMT, the latter being depicted in Figure 1c. The correlation between the S -ratio and mean PAF for QMT may be different for males ($r = -0.20$, ns) and for females ($r = 0.66$, $p < .005$), though this is arguably due to the difference in n for each group. Focusing therefore just on the females, we find that the S -ratio is correlated with PAF at both pretest and posttest ($r = 0.64$ and 0.63 , respectively, $p < .01$), further justifying our focus on mean PAF.

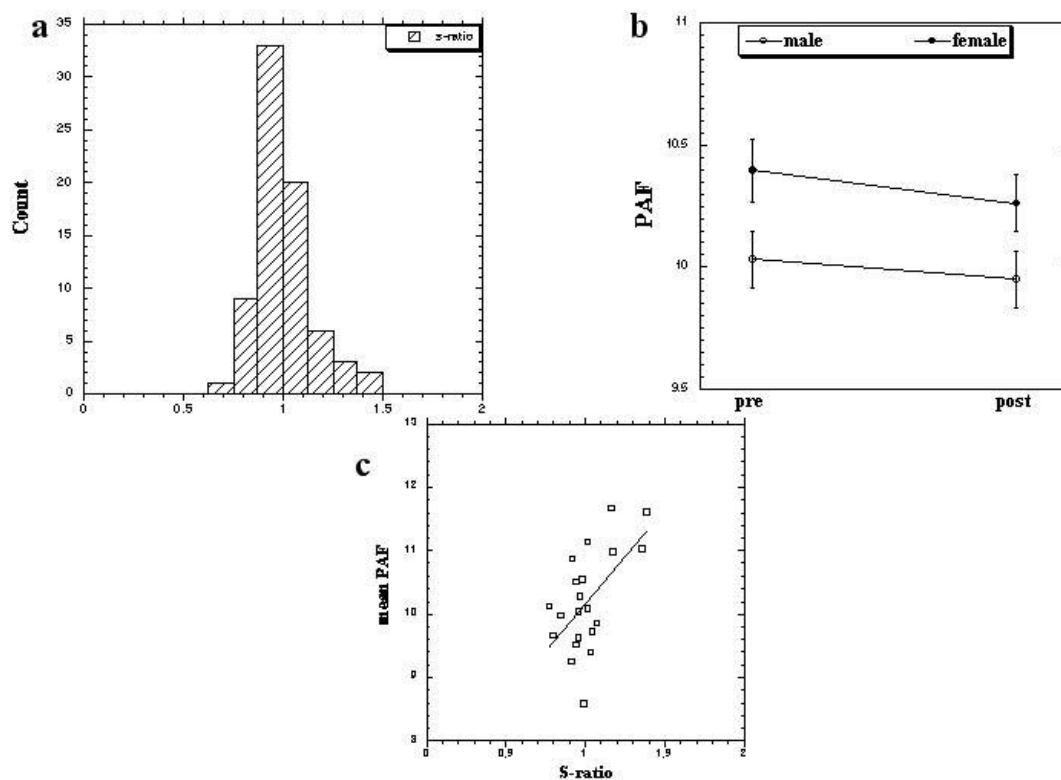


Figure 1. Basic Findings: (a) Distribution of the S -ratio; (b) Change (pre, post) in PAF as a function of Sex; (c) Correlation of mean PAF and S -ratio for QMT

Discussion

When requested to generate a duration of, say, 10 sec, but with no other instruction — especially no instruction explicitly prohibiting the use of chronometric counting (see, e.g., Noulhiane *et al.*, 2007)—it is common to find that one counts up to 10, before responding manually. As Fetterman and Killeen (1990, p. 766) note, “The ubiquity of the practice calls into question experimental psychologists’ attempts to prevent or interfere with subjects’ counting strategies as a means of eliciting ‘uncontaminated’ temporal judgments”. Counting is beneficial, the produced duration being both more accurate and less variable than one generated otherwise (Grondin *et al.*, 1999; Hinton *et al.*, 2004; Wearden & Lejeune, 2008). Some researchers actively invite their participants to engage in chronometric counting, because this is a simple strategy for participants to employ (Coelho *et al.*, 2004; Mimura *et al.*, 2000) and because this enables uniform task performance of all participants in the study (Gironell *et al.*, 2005; Miró *et al.*, 2003; Myers & Tilley, 2003).

Our participants reported counting. While the S -ratio was not related to mean PAF for the controls or for the meditators, it was quite substantially correlated for those engaged in the

QMT. This positive correlation is, however, counterintuitive. For what is suggested here is that the higher the *S*-ratio (i.e., a lengthening of the subjective time unit), the higher is the PAF (i.e., the faster the internal clock, if PAF is indeed indicative of this)—which is clearly inconsistent. There may, however, be a solution to this quagmire. Note that in completing the QMT, our participants had to be intensely focused on the sequence of instructions and on their successive movements. Pockett (2003, p. 63) has recently suggested that when one is “actively engaged in the external world” (as these participants had to be) then “time slows down” (i.e., higher *S*-ratio). Hence, the *positive* correlation found for these two indices for QMT might well be consistent. As usual, it is perhaps best to reserve judgment until more data are collected.

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