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Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts

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Abstract

Prompted reports of recall of spontaneous, conscious experiences were collected in a no-input, no-task, no-response paradigm (30 random prompts to each of 13 healthy volunteers). The mentation reports were classified into visual imagery and abstract thought. Spontaneous 19-channel brain electric activity (EEG) was continuously recorded, viewed as series of momentary spatial distributions (maps) of the brain electric field and segmented into microstates, i.e. into time segments characterized by quasi-stable landscapes of potential distribution maps which showed varying durations in the sub-second range. Microstate segmentation used a data-driven strategy. Different microstates, i.e. different brain electric landscapes must have been generated by activity of different neural assemblies and therefore are hypothesized to constitute different functions. The two types of reported experiences were associated with significantly different microstates (mean duration 121 ms) immediately preceding the prompts; these microstates showed, across subjects, for abstract thought (compared to visual imagery) a shift of the electric gravity center to the left and a clockwise rotation of the field axis. Contrariwise, the microstates 2 s before the prompt did not differ between the two types of experiences. The results support the hypothesis that different microstates of the brain as recognized in its electric field implement different conscious, reportable mind states, i.e. different classes (types) of thoughts (mentations); thus, the microstates might be candidates for the 'atoms of thought'. © 1998 Elsevier Science B.V.

Keywords: Microstates of brain electric field; Conscious experiences; Visual imagery; Abstract thought; Mode of cognition; Spontaneous mentation

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1. Introduction

Brain electric field recording allows the monitoring of brain work continually and non-invasively with that very high time resolution which is needed to study cognitive–emotional processes. At each time instant, the data yield a map of the potential distribution on the head surface (Lehmann, 1971). Thus, brain activity can be visualized as a series of momentary brain electric field maps. An instantaneous map reflects the sum of all momentarily active brain processes, superficial and deep (Smith et al., 1983). If the map's spatial configuration (the momentary landscape) changes, different neural elements must have become active. It appears reasonable to assume that different sets of active neural elements perform different functions.

Using data-driven analysis strategies we found that the changes of the spatial configuration of the brain field are discontinuous; they occur in a step-wise fashion. Accordingly, the continuous stream of maps of momentary electric field potential distributions can be segmented into time epochs of varying durations in the sub-second range during which the field shows a near-stable landscape (Lehmann and Skrandies, 1980; Lehmann, 1984). These epochs of quasi-stable field landscape were called microstates and were observed with very different analysis approaches and experimental conditions during event-related brain activity (Lehmann and Skrandies, 1980; Brandeis and Lehmann, 1989; Michel et al., 1992; Brandeis et al., 1995; Pascual-Marqui et al., 1995; Koenig and Lehmann, 1996; Fallgatter et al., 1997; Kondakor et al., 1997; Pegna et al., in press) as well as during spontaneous brain activity (Lehmann, 1984; Lehmann et al., 1987; Merrin et al., 1990; Strik and Lehmann, 1993; Wackermann et al., 1993; Koukkou et al., 1994; Kinoshita et al., 1995).

It thus appears that continuous brain electric activity consists of a concatenation of building blocks, the microstates, which are defined by their quasi-stable field landscapes and which are suggested to incorporate different modes, contents or steps of information processing. This raises the suggestion that the subjective experience of what William James called the 'stream of consciousness' actually consists of discernible elements. Of course it is clear that this stream of consciousness over time carries varying contents as has been studied repeatedly (see Pope and Singer, 1978). During free-floating, no-task conditions (so-called day dreaming), experiences of visual imagery are frequent and reports of subjective experiences involving visual imagery are easy to distinguish from reports of non-imaginal thoughts which concern abstract topics such as planning (Foulkes and Fleisher, 1975; Lehmann et al., 1995). The PET cerebral correlate of visual imagery was also reported to differ from that of non-imaginal thinking (Goldenberg et al., 1989).

The brain mechanisms of visual imagery were the topic of many studies (see Pylyshyn, 1981; Paivio, 1986; Kunzendorf and Sheikh, 1990; Kosslyn, 1994). Early general hypotheses on right hemispheric specialization for visual imagery, typically based on EEG power measurements (for a very critical overview see Ehrlichman and Barrett, 1983) were replaced by proposals that different modes of visual imagery utilize different brain mechanisms involving not solely the occipital regions (Roland and Friberg, 1985; Petsche et al., 1992) and involved left- as well as right-predominant mechanisms. Input-driven imagery tasks were reported to cause left-sided occipital event-related potential maxima (Farah et al., 1989), similar to PET studies where task solution or attention to images caused stronger left-sided activity, but instruction-less or memory-based imagery was more right-sided (e.g. Goldenberg et al., 1987; Kosslyn et al., 1995). Mental rotation, a particularly well studied imagery operation, typically showed a right-hemisphere preponderance (e.g. Papanicolaou et al., 1987; Corballis and Sergent, 1989; Pegna et al., in press), similar to other examined imagery conditions (e.g. Sergent, 1989) and to task-free visual input event-related potentials (Mecacci et al., 1990).

Investigations of the microstate structure of event-related potential map series lead to the identification of certain microstates with certain processing steps (e.g. by Brandeis and Lehmann, 1989, subjective visual contours; Brandeis et al., 1995, congruent vs. incongruent sentence endings;

Koenig and Lehmann, 1995, reading of abstract vs. imagery words; Koenig and Lehmann, 1996, reading of verbs vs. nouns; Pegna et al., in press, mental rotation).

The topic of the present article is the functional significance of different types of brain electric microstates during spontaneous, 'free-running' brain activity. A no-task, no-input, no-response paradigm was chosen in order to avoid overlays of potentially influential brain subroutines that are necessary for continual remembering of and attending to a task, task execution and preparation and implementation of motor acts (Antrobus, 1987) and in order to examine mind states as such without externally driven representations of information. Hence, the article examines the concept that spontaneous, conscious states of the mind experienced as recallable thoughts can be described as physical states of the brain.

The present study presents evidence suggesting that two specific, spontaneous, conscious mind states are associated with two different classes of brain microstates that are defined in the brain electric field. In our no-input, no-task, no-response paradigm, subjects (when hearing a random prompt) reported recall of their immediately preceding spontaneous, conscious, unconstrained, private experiences. The reports were classified into experiences involving visual imagery or abstract thinking. An earlier analysis which used the entire 2-s epochs before the prompts showed that the two classes of subjective reports were associated with different locations of frequency domain EEG source models (Lehmann et al., 1993). The present analysis shows that the two mentation classes were associated with two different classes of brief brain electric field microstates immediately before the prompt signal, but not 2 s earlier.

2. Methods

2.1. Subjects

Thirteen male volunteer subjects participated, recruited from the students at Zurich University by an advertisement. They had a mean age of 26 years (S.D. 3.8, range 21–36). The subjects were sequentially accepted into the study without prescreening for EEG patterns. Smokers and persons with a history of drug use, neurological or psychiatric disease and on current medication were not accepted.

The analysis reported here concerns the placebo data set of a double blind, placebo-controlled study on single dose effects of 5 mg Diazepam (Valium® Roche), 600 mg Pyritinol (Encephabol® Merck) and the placebo orally taken in capsules 30 min before recording started. The treatment sequence was pseudo-randomized across subjects (predecided sequences unknown to experimenter and subjects). Each subject thus participated in three sessions that were done at intervals of at least 1 week. The study design had been accepted by the ethics committee of the hospital.

The subjects were informed about the experimental design and gave their formal consent; they received a small financial recompensation. The subjects had to be fluent German speakers and right-handed; the latter was checked with the 'Edinburgh Handedness Inventory'; no subject had left-handed immediate family members.

2.2. Procedure

All recordings were done in the afternoon, conducted by the same female experimenter (B.H.).

The subject was instructed that he was going to hear prompt tones at irregular intervals and that after each prompt tone he was expected to report, without further interrogation or questioning, in approx. 3–6 sentences 'what went through his mind just before the prompt occurred'. The subject was also informed that he had the right to refuse the report without giving a reason, but that in such a case he should say whether he could not recall any experience or whether he did not wish to report it.

At 19 scalp sites, gold cup GRASS electrodes were attached with GRASS EC2 paste, using the '10/20 positions' Fp1/2, F7/8, F3/4, Fz, T3/4, C3/4, Cz, T5/6, P3/4, Pz and O1/2. Recording reference was Cz. All impedances were below 5 kΩ. The subject was seated in a comfortable chair in a sound-proof and temperature-controlled Faraday chamber, with communication to the experimenter by intercom. The chamber was dark and the subject was instructed to keep his eyes closed during the entire session. The recording was started 5 min after 'lights out'.

At the beginning, the subject was familiarized with the procedure in habituation runs; he was presented five prompt signals; his reports were collected but the data were not used. Then the recording started. The amplified and analog/digital converted EEG was monitored continuously on a computer screen. The prompt signal (a gentle tone) was presented through a loudspeaker. The prompt also set a time mark in the digitized recording. At minimum intervals of 2-min and 20-s, a prompt was presented if the last 20 s were without obvious artifacts in the on-line monitored EEG. There were 30 prompts during the recording session; the duration of the session was approx. 90 min.

The 19-channel-EEG data and the prompt marks were recorded using a Brain Atlas (BioLogic) system with a band-pass filter of 1–30 Hz and an analog/digital conversion rate of 128 samples per second. Off-line, the 2-s EEG epoch immediately preceding each prompt was marked for further analysis and carefully screened for muscle-, eye- and movement-artifacts. The accepted epochs were band-passed digitally to 2–15 Hz.

The subjects' verbal reports were recorded on an audio tape and transcribed off-line.

2.3. Material

Of the total of 390 prompt cases, 53 could not be used because of audio recording problems (2), EEG recording errors (6), refusal of the subject to give a report (5), no recall of any content (11), or artifacts (muscle, movement, eye movement) detected during the off-line screening (29); 337 cases remained.

2.4. Rating of the reports

Two blind, independent raters classified the transcribed reports as 'visual imagery' (e.g.: a beach scene with palm trees and the blue ocean) or as 'abstract thought' (e.g.: thinking about the connotations of the word 'belief'). If neither rating was judged to be acceptable, the report was classified as 'no decision'. Of all 337 cases, the raters agreed in 233 cases; Cohn's kappa between the raters was 0.85 for the two mentation classes used in this study, visual imagery and abstract thought. There were 38 agreement cases for 'no decision'. The 104 disagreement cases were reconsidered in a consensus rating; 29 were rated as visual imagery, 8 as abstract thought and 69 as 'no decision' (including 'no agreement').

2.5. Occurrence frequencies of visual imagery and abstract thought

Between 22 and 30 prompt cases (mean 25.9) were available from each subject for rating and EEG analysis. One-hundred and forty-six, i.e. approx. 43% of all cases were rated as visual imagery (mean over subjects 11.2 ± 3.1, range 6–16) and 84, i.e. approx. 25% as abstract thought (mean over subjects 6.5 ± 2.9, range 3–12). This difference of occurrence frequency between thought classes was significant over subjects. From each subject, six or more cases rated as visual imagery and three or more rated as abstract thought were available. Approximately 32% (107; 8.2 ± 2.6 per subject) of all cases were rated as 'no decision' (rated 'not convincing' as visual imagery nor abstract thought).

2.6. Segmentation of the EEG epochs into brain electric microstates

The artifact-free 2-s EEG epochs immediately before the occurrence of each prompt were segmented into brain microstates. The segmentation procedure views the brain field data as a series of momentary field maps. For the present analysis, the electrode positions were schematically arranged into a regular grid pattern and interelectrode distances in the grid were used as measuring units (Fig. 1).

A microstate is defined as a time segment during which the momentary field maps display a quasi-stable landscape. For the segmentation of spontaneous data, only the configuration of the

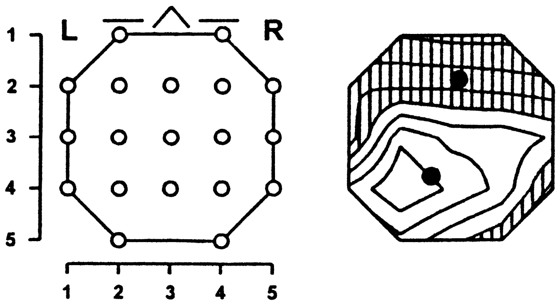

Fig. 1. Left: schematic of the 19-channel array of electrodes (open elements), with row and column numbers. Head seen from above, nose up. Right: assessment of map landscape by centroid locations: a sample map with isopotential lines and with the locations of the positive and negative area centroids (black dots). White area positive, hatched negative referred to the momentary mean, i.e. the average reference.

map landscape is considered; the polarity of the landscape is disregarded, following the approaches for estimates of spectral power and coherence in frequency domain analyses. This sequential, space-oriented segmentation procedure (Lehmann, 1984; Lehmann et al., 1987; Strik and Lehmann, 1993; Wackermann et al., 1993) is briefly reviewed in the following: The electric strength of each map was computed ('Global Field Power', Lehmann and Skrandies, 1980) using the spatial S.D. of all momentary voltages. In order to analyze data with an optimal signal-to-noise ratio, the maps at times of maximal Global Field Power were selected for further analysis. (The maps at times of maximal Global Field Power are representative for the data epochs, Lehmann et al., 1987). Each map landscape was described (example in Fig. 1; see also Appendix in Wackermann et al., 1993) by the two locations of the points of gravity (centroids) of the map area with positive and of the map area with negative potentials; before doing this, the maps were re-calculated against the average reference (removal of spatial DC offset), i.e. against the mean of all momentary potential values in the map.

For segmentation of a data epoch into microstates (illustrated in Fig. 2), the pair of centroid locations of the first map of the sequence of the selected maps was retrieved. Circular spatial windows of individually determined optimal size were set up around both centroids; this optimal size of the spatial window was determined individually for each data epoch (Strik and Lehmann, 1993), giving equal weight to the two competing goals of the segmentation procedure: recognition of similarity and of dissimilarity between successive maps. The pair of centroids of the next map was

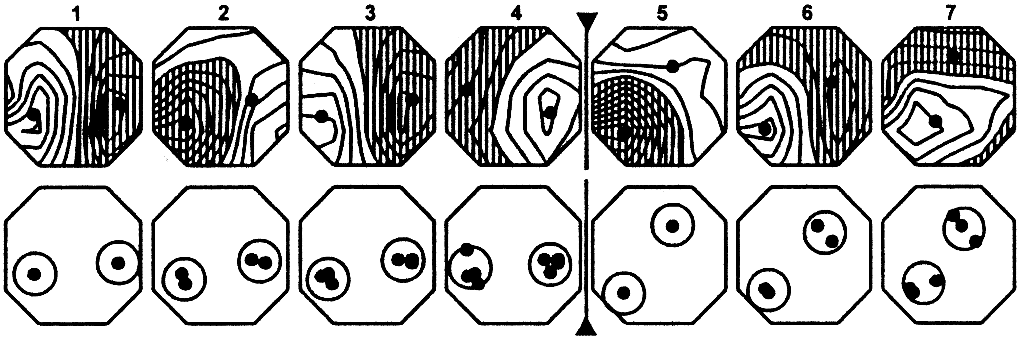

Fig. 2. Segmentation of a map series into microstates. A sequence of momentary isopotential line maps at seven successive time points of maximal global field power (approx. 50 ms interval between maps) is shown in the upper row (white positive, hatched negative referred to the average reference). Black dots mark the centroid locations. The lower row shows only the centroid locations and the spatial windows. The accommodation of the centroids of successive maps into the windows set around the centroids of map #1 is achieved by horizontal and vertical translations of the spatial windows. This process is terminated by map #5 whose centroids cannot anymore be accommodated by window translations without loosing an earlier centroid. Thus, the microstate consisting of maps #1 through #4 is terminated and a new one begins at the vertical line. Note that only the map's landscape is important, whereas polarity is disregarded.

retrieved. Using a minimum absolute sum-of-distance criterion, each of the next map's centroids was assigned to the nearest window area (disregarding polarity). The spatial windows were translated horizontally and vertically in order to accommodate the new pair of centroids while maintaining the previous centroid within the window. If this was possible, the centroid pair was accepted. If accommodation was not possible without excluding an earlier member centroid from the window areas, a new microstate was started.

For each microstate, the locations of all member centroids were averaged for each of the two windows. These mean locations will be called 'window locations'. In this way, the spatial configuration of the map of a microstate is described in the present analysis by four values: the coordinate values of the microstate's two window locations on the anterior–posterior and on the left–right axis of the head.

For each subject and each of the two report classes, the mean descriptor of all microstates was computed using a permutation algorithm. This is necessary because of the following problem: when averaging the two window locations 1 and 2 of two microstates A and B, two combinations are possible, 1A + 2A and 1B + 2B, or the permutated combinations 1A + 2B and 2A + 1B. When averaging N cases, there are 2^{N-1} possible combinations. The desired optimal solution is defined by the minimal sum of the S.D. of the two window location means.

2.7. Data transformation and statistics

The four Cartesian coordinate values of the mean numerical map descriptors of the microstates for each subject and both report classes were transformed into the four corresponding polar coordinate values: the location of the electric gravity center on the (1) anterior–posterior axis; (2) on the left–right axis of the head (the electric gravity center is the mean of the two window locations); (3) the distance between the two window locations; and (4) the clockwise angle formed by the left–right axis and the line connecting the two window locations. This description of the field distribution by polar coordinates was chosen because it is suitable for physiological interpretations.

The present article analyzes the last and the first microstate of the 2-s analysis epoch that immediately preceded the prompt. Since the microstate segmentation was started 2 s before the random prompt, the last microstate before the prompt was randomly truncated.

Repeated measures MANOVA, ANOVA and paired post-hoc t-tests were used for statistics. Double-ended P-values are reported unless noted.

3. Results

The mean values of the spatial parameters of the microstates associated with the two classes of subjective reports are illustrated in Fig. 3, in the right panel for the last microstates before the prompt and at the left for the earliest microstates of the 2-s epochs before the prompt (numerical values in Table 1).

For the last microstates before the prompt, the four landscape-describing microstate parameters (angle, distance between window locations, gravity center location on the left–right axis and gravity center location on the anterior–posterior axis) showed a significant overall difference between the report classes of visual imagery and abstract thought in a repeated measure MANOVA (Wilk's $\lambda = 0.225$, Rao's $R = 7.749$, d.f. = 4,9, $P = 0.006$).

On the other hand, the landscape parameters of the earliest microstates in the 2-s data epochs before the prompts were not significantly different between the two report classes (MANOVA $P > 0.40$).

Post-hoc paired t-tests of the four microstate parameters of the last pre-prompt microstate showed that the angle of the field orientation was the prime cause of the overall difference between the microstates of the two report classes: the 86° mean angle for visual imagery cases and the 100° mean angle (a clock-wise rotation) for abstract thought cases differed at $P = 0.010$ over subjects (d.f. = 12).

The location of the electric gravity center was

Table 1
Spatial configuration parameters (polar coordinates) of the first and last microstates, for visual imagery and abstract thought classes; means (over subjects) and standard error (S.E.) are tabulated (illustrated in Fig. 3)

	First microstate			Last microstate		
	(Imagery)	(Abstract)	Difference	(Imagery)	(Abstract)	Difference
Angle (degrees):						
Mean	88.60	85.40	3.20	86.08	100.11	−14.04
S.E.	5.47	9.96	13.89	3.83	6.20	4.60
P-value			n.s.			0.010
Distance between window locations (E.D.)						
Mean	2.070	1.890	0.180	2.019	1.872	0.147
S.E.	0.071	0.095	0.097	0.091	0.097	0.108
P-value			n.s.			n.s.
Electric gravity center on left–right axis (electrode column numbers)						
Mean	3.030	3.009	0.021	3.034	2.973	0.061
S.E.	0.018	0.028	0.028	0.021	0.032	0.030
P-value			n.s.			**0.068**
Electric gravity center on anterior–posterior axis (electrode row numbers)						
Mean	3.126	3.148	−0.022	3.152	3.113	0.038
S.E.	0.039	0.036	0.032	0.033	0.032	0.030
P-value			n.s.			n.s.

Angle is in degrees; with the head seen from above, the convention is clockwise for increasing angles: the 0° line is a vector from right to left (positive at left), hence 90° is sagittal from posterior to anterior.
Distance between window locations is given in electrode distances (E.D.) and locations of the electric gravity center is in column and row numbers of the schematic array in Fig. 1.
Double-ended *t*-test *P*-values (< 0.10) for the significances of the differences of the values between thought classes are listed also.

more to the right for visual imagery than for abstract thought cases (hypothesis-testing single-ended $P = 0.034$).

The more posterior location in the sagittal direction for visual imagery cases and their larger distance between the microstate window locations reached only $P = 0.23$ and $P = 0.20$, respectively.

Since the analyzed data was the placebo data set of a study that included single-doses of two drugs, we examined the question whether there was a significant drug condition effect on the observed difference of the last microstate between visual imagery and abstract thought cases. A repeated measure 2-factor (class × drug condition) ANOVA showed a significant report class effect ($F = 6.59$, d.f. = 1,12, $P < 0.025$), but no drug effect and no interaction.

The mean durations of the last microstate (across subjects) was 121.3 ms; 126.4 (S.D. = 18.5) ms for the visual imagery reports and 116.3 (S.D. = 29.8) ms for the abstract thought reports; the S.D. of the difference across subjects was 32.6 ms, i.e. the difference was not significant.

The mean individual window size (across subjects) of the analysis epochs did not differ between report classes (visual imagery 0.47 E.D., S.D. = 0.17; abstract thought 0.48 E.D., S.D. = 0.15).

4. Discussion

The two classes of recalled, spontaneous, subjective experiences distinguished, across subjects, between two different classes of the brief, brain electric microstates that were observed immedi-

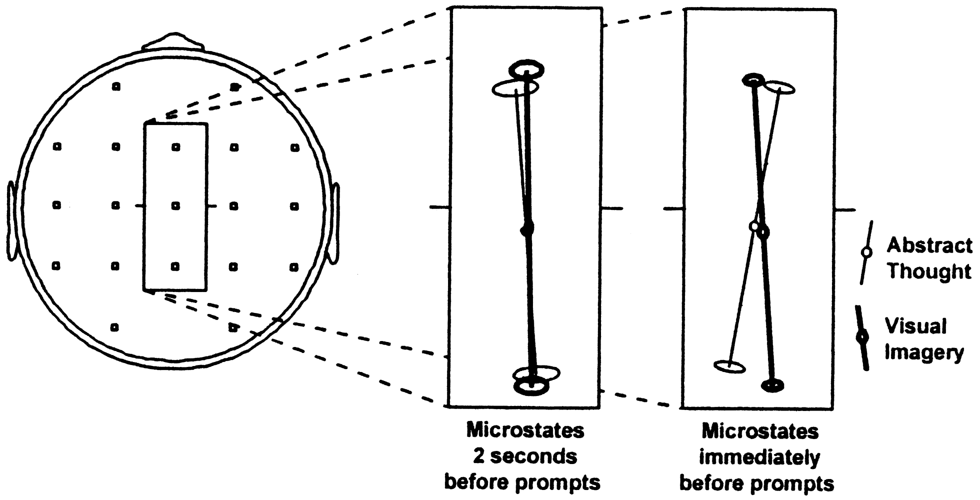

Fig. 3. The mean parameters (and standard errors) of the maps (across subjects, $N = 13$) of the last microstates immediately before the prompts (right) and of the earliest microstates in the 2-s analysis epochs before the prompts (left), for the cases associated with reports rated as visual imagery (heavy lines) and as abstract thought (thin lines). Straight lines indicate the angle of orientation of the electric fields; their lengths indicate the distances between window locations; the very small ellipsoids at the line centers are formed by 1 S.E. around the electric gravity centers; the ellipsoids around the ends of the lines are formed by 1 S.E. of the distance between window locations and 1 S.E. of the angle of orientation. Head seen from above, left ear left. Electrode positions indicated by small dots in the head schematic (see also Fig. 1) where the rectangle marks the area used for the two enlarged displays. The numerical values are reported in Table 1.

ately before the recall prompt. This distinction did not exist 2 s before the prompt signal. The microstates were defined by their mapped, brain electric landscapes. Different landscapes of the potential distributions must have been generated by geometrically different active neural populations. Thus, the subjective mentation classes of ‘visual imagery’ vs. ‘abstract thought’ correspond to the activity of two different neuronal assemblies and therefore are not only post-hoc, social labeling conventions for the reporting of mentations. The observation held over subjects, i.e. the two classes of mental experiences were incorporated by different neuronal assemblies which had common spatial features across subjects. This communality is of particular interest because it has been argued repeatedly that strategies for information processing might show basic inter-individual differences because their development is driven by personal experiences. The communality of the characteristics over subjects also weighs in for the biological constituency of the two types of experiences and against social labeling conventions.

The utilized polar descriptors of the configuration of the brain electric fields of the microstates bear some physiological interpretation: The orientation of the field map indicates the net geometry of its sources in the brain. The observed difference in field orientation angle between the microstates of the two mentation classes shows that different sets of neural elements were active in the two conditions because the active elements must have had different orientations, but asymmetric hemispheric involvement cannot be deduced from the angles. On the other hand, the location of the electric gravity center of the microstate is a conservative estimate of the mean location of all momentarily active processes: the gravity center’s location on the scalp is perpendicularly over the mean location of all active processes in the brain. There was a difference in gravity center location across subjects, more to the right and posterior for visual imagery than abstract thought. The near-midline locations for both types of experiences strongly support the common assumption of widely distributed, bilateral activity, but the hypothesized preponderance of right-sided brain activity for task-free, spontaneous visual imagery (see Introduction) is supported by our results (single-ended $P < 0.035$). As to the anterior–posterior dimension, our results only weakly support the general notion that the point of gravity of the imagery-producing brain activity is more posterior than that producing abstract thought (single-ended $P = 0.114$), but the locations near the anterior–posterior midpoint agree with distributed activity where anterior regions also participate (see Introduction). We note that, as only male subjects were investigated, the conclusions can only be drawn on male brain function.

The relationship between the class of 'what just went through one's mind' and different brain electric microstates did not hold for the brain microstates 2 s before the prompt. This suggests that working memory update, occurring stepwise as suggested by the possibility to segment brain electric activity into microstates, has a rapid, basic cadence.

The last microstates which were randomly truncated by the prompts and which showed the relation with class of conscious mentation had a mean duration of 121 ms across subjects and mentation classes. This result suggests that approx. 120 ms of near-stable brain activity on the average suffices for a conscious experience. This mean duration is in the time range of 100 ms that was postulated by Newell (1992) for 'elementary deliberations' and it is not much shorter than the times needed or available to change or bridge perceptual input organization or attention (Michaels and Turvey, 1979; DiLollo, 1980; Reeves and Sperling, 1986; Posner et al., 1987; Motter, 1994). However, it is appreciably shorter than the minimal time of approx. 500 ms postulated for conscious perception of intracerebral, electric stimulations (Libet, 1982).

The present analysis did not examine the intermediate microstates between the last and the first microstate of the 2-s period. Some support for the above hypothesized unique identification of the last microstate ('the atom of thought') with the content of working memory comes from our used strategy of microstate parsing which implies that the next to the last microstate must have been different from the last one. However, more involved hypotheses are conceivable and might be considered in future studies: (1) instead of the single, last microstate, the basic, hypothesized brain–mind unit might be a brief sequence of microstates (a 'thought molecule') that follows some syntax. As the next to the last microstate is different from the last one and because transitions between microstates obey weak constraints (Wackermann et al., 1993), for a given last microstate, the next to the last microstates are expected to belong to several classes and accordingly, the putative microstate molecules for a given class of experiences would belong to a complex family. Another hypothesis (2) is that the last microstate is implemented in consciousness because it actually re-occurred within a limited, brief time window, i.e. that mirroring within constrained time might be a pre-requisite in addition to the mirroring in brain space at each time moment that is provided by the brain's multiple representation areas. Both, the molecule as well as the time window would have to be very short in duration, in order to make conscious decisions possible that are useful in real life.

Our results suggest that the seemingly continuous stream of consciousness consists of separable building blocks which follow each other rapidly and which implement different, identifiable mental modes, actions or functions. How then is it that one readily refers to the continuum of consciousness and does not think of breaks? Disregarding the possible theory of an integrating process that is not represented in the electric field (the so-called 'homunculus regression'), we have the following two comments: Firstly, self-observation does not always support the impression of a continuous process: the famous 'sudden ideas' that one might chance upon while having idle thoughts are examples. Secondly, sudden changes in a sequence of thoughts are not necessarily experienced as interruption; for instance, watching a movie might take the viewer through a lifetime within 2 h without producing the impression of having witnessed disconnected bits and pieces; in other words, man might have learned in earliest childhood that the discontinuity of conscious mentation is coexistent with the continuity of being oneself.

In discussions about dream recall it was argued that the subjective experiences that were reported after prompt signals might actually have been induced by the prompts, i.e. that they occurred after the prompts. If this were so in our experiment, the results would indicate that the momentary brain electric microstate immediately before the prompt crucially influenced the type of thought generated by the prompt and that the microstate 2 s earlier did not and that this followed common rules across subjects. In fact, the microstate immediately before a stimulus influences post-stimulus microstates (Kondakor et al., 1997) and thereby might exert influence on thought types following the general rules of state-dependent information processing (see e.g. Koukkou and Lehmann, 1983). Although the hypothesis of prompt-produced thoughts is interesting, we do not think it is reasonable; everyday experience supports the view that if someone is asked about an immediately preceding externally generated experience, he/she is more likely than not to recall this experience; it appears convincing that the same holds for internally generated experiences. However, if the criticism were justified, the relationship between prompted microstate and subjective mentation class shown in our data would still hold, but it would be based on an unlikely mechanism; one would have to ascribe an extremely powerful processing–determining influence to the last pre-prompt microstate.

The rating procedure used in this study relied on the assessment of the reports by two raters. Distinguishing between ‘visual imagery type experiences’ and ‘abstract thought type experiences’ was done in remarkable agreement by the raters. The decision-making criteria used by our raters might involve certain idiosyncratic features. At any rate, the observed communality in the electric measurements across subjects is an exterior reference that validated the internal consistency of the raters’ criteria. Others thought classes such as pleasant and unpleasant experiences, or normal, reality-referred and schizophrenic, reality-remote thoughts will be examined in future studies.

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