Electrocortical Activity Prior to Unpredictable Stimuli in Meditators and Nonmeditators

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Advanced meditators occasionally report experiences of timelessness, or states of awareness that seem to transcend the usual boundaries of the subjective present. This type of experience was investigated in eight experienced meditators and eight matched controls by measuring 32 channels of EEG before, during, and after exposure to unpredictable light and sound stimuli. The experiment postulated that if some aspect of consciousness extends beyond the present moment, then prestimulus electrocortical signals should differ depending on stimuli that were about to be selected by a truly random process, and that if such experiences were catalyzed through meditation practice, then prestimulus differences should be more apparent in meditators than in nonmeditators. Each of the 32 EEG channels was baseline adjusted on each trial by the electrical potential averaged between two- and one-second prestimulus, then for each channel the average potential was determined from one-second prestimulus to stimulus onset. The resulting means across subjects in each group were compared by stimulus type using randomized permutation procedures and corrected for multiple comparisons. Within the control group, no EEG channels showed significant prestimulus differences between light versus sound stimulus conditions, but within the meditator group five of 32 channels resulted in significant differences ($P < .05$, two tailed). Comparisons between control and meditator groups showed significant prestimulus differences prior to audio tone stimuli in 14 of 32 channels ($P < .05$, two tailed, of which eight channels were $P < .005$, two tailed). This outcome successfully replicates effects reported in earlier experiments, suggesting that sometimes the subjective sense of awareness extending into the future may be ontologically accurate.

Key words: Consciousness, time perception, anticipation, meditation, presentiment, prestimulus response

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INTRODUCTION

Across meditative traditions, advanced practitioners occasionally report "transcendental" states of deep absorption.[1,2] During such experiences, common distinctions–between subject and object, me and you, and past, present, and future–begin to diminish. With sufficient practice all distinctions are said to dissolve into an undifferentiated or nondual state of awareness, sometimes accompanied by an impression of timelessness or a vastly extended present moment.[3]

Conventional assumptions about the neuronal basis of consciousness and perception consider such time distortion experiences to be illusory.[4] Researchers have attempted to link meditation-related experiences of altered time to brain processes such as suppression of parietal lobe activity, enhanced theta-band activity, or increases in insula activity.[2,5-8] In addition, most models of time perception assume the existence of an objective time that is tracked by clock-like mechanisms in the brain.[9,10] The possibility that extended awareness experiences may reflect an ontological reality is rarely considered.

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However, there are good reasons to take exceptional subjective reports seriously, regardless of how challenging they may seem, when similar accounts have been recorded for millennia across cultures. For example, nondual awareness is similar to the subjective state called *samyama* in Patanjali's Yoga Sutras, a manuscript from the second century BC.[11,12] Patanjali wrote that those who achieve stability in *samyama* could experience extraordinary mental abilities, one of which was described as the ability to simultaneously perceive past, present, and future. Although it is imprudent to take ancient claims at face value, it is noteworthy that a growing body of empirical data shows that some advanced meditators have capacities once thought to be flatly impossible.[13] Examples include voluntary control of the autonomic nervous system, inhibition of the startle response, control of binocular rivalry and motion-induced blindness, control of pain, lucidity during sleep and dream states, and sustained selective attention.[14-20] As old assumptions yield to new data, some meditation researchers have proposed that what used to be regarded as ordinary "is increasingly coming to look like a form of arbitrary, culturally determined, developmental arrest."[21(p.69)]

The question examined in the present study focused on the ontological question of what advanced meditators reported millennia ago and continue to report today: can some aspect of consciousness extend through time? Extending into the past is trivial; we understand that as memory. But extending into the future is quite another matter–it questions conventional assumptions about the nature of causation. Despite such challenges, phenomena suggestive of time-reversed effects are not unknown in the psychological and neuroscience literature. The

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terms *precognition* or *presentiment* are occasionally used in apologetic tones, but more often one finds euphemisms such as "exceptional situational awareness,"[22] referring to the performance of jet fighter pilots who seem to respond faster in combat situations than they should be able to, "anticipatory systems,"[23] a phrase used to describe how organisms plan and carry out future behavior, and terms like "postdiction,"[24] "subjective antedating,"[25] "tape delay,"[26] and "referral backwards in time,"[27] all describing hypothetical mechanisms proposed to explain temporal anomalies suggestive of retrocausation. An example is the color phi effect, described by Dennett"[26]

> If two or more small [differently colored] spots separated by as much as 4 degrees of visual angle are briefly lit in rapid succession, a single spot will seem to move [from one location to the other]. What happened to the color of "the" spot as "it" moved? The answer . . . was striking: The [first colored] spot seems to begin moving and then change [to the other] color abruptly in the middle of its illusory passage towards the second location . . . (p. 5)

How are we able to perceive the second color spot *before* the second flash occurs? According to Dennett: "Unless there is precognition in the brain, the illusory content cannot be created until *after* some identification of the second spot occurs . . . ."[26(p.5)] That is, Dennett assumes that all neural events can be adequately explained via conventional causal processes, and thus the brain must have some sort of delay mechanism that fools us into seeing now what actually occurs later. But there is another possibility: the common sense notion of a unidirectional flow of time might be a façade, an approximation of a deeper reality in which both past and future influence the present. This idea might seem strange, but the concept of time-symmetry is embedded within many of the fundamental equations of classical and quantum physics, so this suggestion does not disobey known physics.[28] Fortunately, for our present purposes it is not necessary to take a diversion into mathematical physics to judge the credibility of meditators' claims of an extended awareness. Instead, we can devise an experiment to see if there are objective correlates to these subjective impressions.

Perhaps the first to suggest a neuroscientific approach to investigating the possibility of extended awareness was Good,[29] who in the 1960s recommended exposing subjects to flashes of light at random times while their EEG was recorded, and then analyzing the resulting signals prior to the flashes to see if the brain reacted to the upcoming stimuli. More than a half-century later Radin and Lobach[30] tested Good's idea, and they found positive evidence in support of what was dubbed a *presentiment* effect. Note that Good's concept did not imply conscious awareness of future events. Rather, it proposed that some aspect of consciousness, in the broadest sense of that term, was able to sense future events that could be detected through unconscious fluctuations in the autonomic or central nervous system. The same is assumed in the present experiment, that is, the term "extended awareness" does not require that meditators are consciously aware of future stimuli in the sense of their *knowing* what is about to unfold, but only that their meditative practice expands some aspect of their consciousness that is then reflected through their electrocortical activity. This is why the word "presentiment" is used for this type of experiment instead of the more common term "precognition." The latter suggests preknowing, whereas the former suggests presensing or prefeeling.

Of historical interest, Good's proposal presaged Walter and colleague's[31] description of contingent negative variation (CNV), one of several slow cortical potentials (SCP) now commonly used to study anticipatory effects in the brain. Walter also specifically recommended that SCPs might be an effective means for investigating presentiment.[32]

METHODS

Subjects

Sixteen subjects were recruited: eight advanced nondual meditation practitioners and eight nonmeditator controls matched by age, gender, handedness, income, and ethnicity. Eleven other subjects participated in the same experiment to pretest the design protocols, data recording, and analytical procedures, but they were not part of the subject pool specifically recruited for this experiment. Inclusion criteria for the meditators were (1) over 18 years of age, (2) able to read and write English, (3) right handed, (4) normal or corrected vision, (5) normal hearing in one or both ears, and (6) a minimum of 3,000 hours of an active nondual meditation practice (described below). Exclusion criteria were (1) use of antiseizure, antidepressant, antianxiety, or antipsychotic medications, (2) history of neurological injuries or illnesses, (3) a pacemaker, or (4) a hair style or facial piercings that might interfere with placement of the EEG electrodes. Control group subjects were required to have fewer than 100 lifetime hours of meditation practice of any type, no experience with nondual meditation, and no active meditation practice.

Meditators were specifically sought with experience in practicing a *nondual* form of meditation. Elements of nonduality can be found in many of the world's contemplative and philosophical traditions. These practices are perhaps best known in the West through the Dzogchen and Advaita forms of Zen meditation. They differ from concentrative and mindfulness forms of meditation, and indeed nondual practitioners often avoid terms such as "meditation" or "practice" (however, for expository ease we will continue to use those terms here). Nonduality practices may be described as a moment-to-moment awareness of the essentially unified nature of reality.[33]

The experiment was approved by the Institute of Noetic Sciences institutional review board, and all subjects read and signed an informed consent. Subjects were asked to fill out several questionnaires to assess differences in psychosocial variables and meditative practice. They included: (1) the Survey of Life Experiences scale,[34,35] which is a measure of response to everyday life stressors; (2) the Acceptance subscale of the Philadelphia Mindfulness Scale;[36] (3) the Subjective Happiness Scale;[37] (4) a Self-Transcendence Scale, a 10-item scale that measures behaviors and attitudes thought to reflect self-transcendence;[38] and (5) the Twenty Statements Test,[39] which is an open-ended self-report instrument that asks for twenty different answers to the question, "Who am I?" Responses to this question were coded based on four self-referential categories: (a) physical description (eg, woman), (b) social description (eg, grandparent), (c) reflective description (eg, generous), (d) spiritually oriented description (eg, child of God), plus a fifth coding scheme added for this study, (e) nondual concepts (eg, one with all, or simply, "I am"). Subjects' percentage of responses referring to nondual self-concepts was calculated to assess nondual self-concepts.

Materials

Stimulus presentations were controlled by a Windows XP computer running custom software written in Microsoft Visual Basic 6. Two stimuli were used: a light flash and an audio tone. A 250-millisecond light flash was provided by a pair of visual stimulator glasses (Model VSW-3, A/V Stim, San Rafael, CA). Three white light-emitting diodes (LEDs) were mounted in these glasses in front of each eye; one LED was positioned laterally toward the outside of the eye, a second was located near the bridge of the nose, and the third was above the eye. This arrangement produced an average illumination level of 3,850 lux about 1 cm from the pupil (light intensity measured with Model MS6610 Digital LuxMeter, Mastech, Hong Kong). The audio tone was a digitized noise burst provided over earphones (Jensen JB7 Earbuds, Spectra Merchandising International, Chicago, IL), and played by the stimulus computer. The audio stimulus envelope consisted of 100 milliseconds of silence followed by a 20-millisecond ramp up to a 70-dB noise burst for 250 milliseconds, with the noise consisting of approximately flat spectral power from 11 Hz to 5,000 Hz (sound levels measured with Sper Scientific Model 840028, Scottsdale, AZ).

Stimuli were selected with a truly random number generator (RNG), an electronic circuit accessed via the computer's serial port (model Orion, ICATT Interactive Media, Amsterdam, The Netherlands). The source of randomness in the Orion RNG is based on electron tunneling noise in Zener diodes. This RNG design has passed the DIEHARD randomness testing suite,[40] and the RNG used in this experiment was retested for proper operation prior to each test session. (An equal frequency test was used before each task to test for proper operation of the random number generator.)

A serial-port controlled electronic circuit (ADR-100, Ontrak Control Systems, Sudbury, Ontario, Canada) was used to mark the EEG record with a TTL signal at stimulus onset, and the same circuit simultaneously powered the LEDs in the visual stimulator glasses when the stimulus was randomly selected to be a light flash. (The ADR-100 circuit provided parallel control of the EEG marker and the power for the stimulus LEDs, so the two events occurred with no latency.)

EEG signals were acquired at 250 samples per second by a Net Amps 300 amplifier (Electrical Geodesics Inc. [EGI], Eugene, OR), an EGI 32 channel HydroCel™ Geodesic Sensor Net, and an Apple Macbook Pro computer running EGI's NetStation software (version 4.3.1). The electrode reference location was at the vertex. Electrode impedances were measured via a software function within the NetStation software. If necessary, electrodes were rewetted with EGI's electrolyte solution to drop impedance below the recommended levels for the Net Amps 300 (50 Kohms).

Procedure

Subjects were fitted with the EGI Sensor Net, visual stimulator glasses and earphones. They were told that the experiment would be conducted with eyes closed, in two sessions of about 15 minutes each, with a five-minute break between the sessions.

Each session consisted of two tasks, and each task of 50 repeated trials. Subjects were asked to conduct the first session in an ordinary state of awareness, and the second while maintaining a meditative state (or a rest state for the controls). The first task, referred to as "on demand," required subjects to press a button to start a trial using their right index finger (Figure 1A). Three seconds later the RNG randomly selected a stimulus and immediately presented it (less than 1-millisecond latency). There were four possible stimuli: a light flash, an audio tone, both light and audio, or blank (no stimulus). These stimuli were selected with a priori probabilities of .167, .167, .167, and .50, respectively.

The stimuli of interest in this study were the light flashes and audio tones because those events should elicit clear spatial dif-

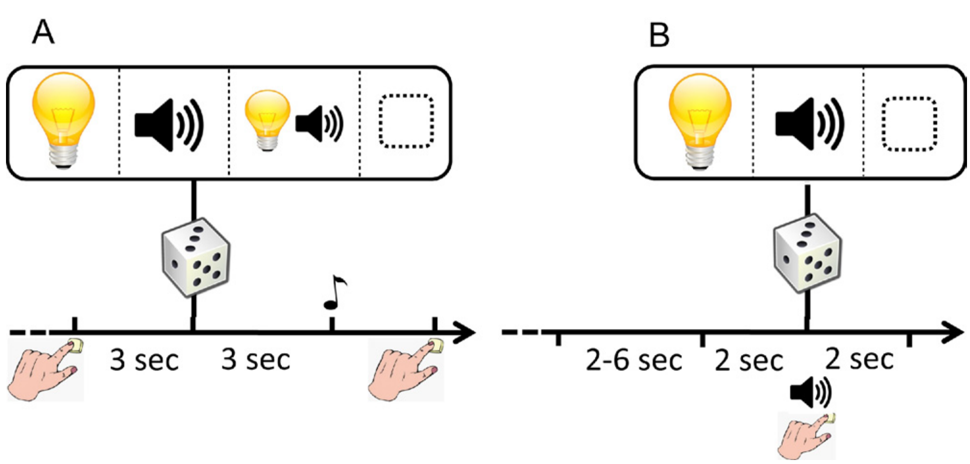

Figure 1. (A) In the "on-demand" task the subject pressed a button at will, then three seconds later a truly random process selected and presented one of four stimuli: a light flash, an audio tone, both light and audio, or nothing. Three seconds later a click tone signaled the subject to begin the next trial at will with a button press. (B) In the "free-running" task one of three stimuli appeared spontaneously without alerting cues: a light flash, an audio tone, or nothing. A button was to be pressed after an audio tone sounded. In this task both the interstimulus interval and there stimulus type were randomized. (Color version of figure is available online.)

ferences in poststimulus brain processing, and also because by design their a priori probabilities were identical. This latter feature was incorporated to reduce guessing behavior about which stimulus was likely to appear next. The other two stimuli (flash plus tone, and blank) were included as distracters to further reduce biasing effects due to development of subjective probabilities in serial tasks.

Three seconds after stimulus onset, a click tone signaled the subject to begin the next trial at will. After each group of 10 trials, a prerecorded audio clip announced the current trial number and reminded the subject to stay alert. An investigator read the instructions for this task aloud from a prepared script:

> Now we are going to begin a series of 50 six-second trials where you will see a light flash, hear an audio tone, both, or neither. You will press a button to begin each trial, and after you hear the click, please press the button again to start the next segment.

The second task involved a series of 50 "free-running" trials (Figure 1B). The subject began this task with a button press, then a random interstimulus interval (ISI) between 2 and 6 seconds was generated. (Using the Microsoft Visual Basic 6 pseudorandom algorithm reseeded by the computer's clock time at the beginning of each trial.) After the ISI, a two-second prestimulus period automatically began without cueing, followed by the RNG randomly selecting a light flash, an audio tone, or a blank stimulus (each with a priori $P = .33$), and then immediately presenting it. Two seconds poststimulus the next random ISI automatically began. The subject was instructed to press a button using the right index finger as fast as possible only after hearing an audio tone. After each group of 10 trials a prerecorded voice spoke the current trial number. This task was described as follows:

> Now, we will do a slightly different task. In this session, you may see a light flash or hear an audio tone. Please press the button *only* when you hear an audio tone. The trials will run automatically, so just press the button as soon as you hear an audio tone only.

After completing the on-demand and free-running tasks, the experimenter read the following to the meditators, which was developed in consultation with experienced nondual meditation practitioners:

> Now, with your eyes closed, we'd like to ask you to please rest in nondual awareness to the greatest extent you can. This may or may not be a shift from where you are right now, but please, for the next five minutes, bring your attention to your most basic awareness of what is. We may not be using the right words for you, but if you can, please settle your attention into the sense of wakefulness or awareness that many people speak of as nondual.

For control subjects, the same instructions were read except for the first line, which was revised as follows: "Now, with your eyes closed, we'd like to ask you to imagine that you are resting in a meditative state to the greatest extent you can." After the five-minute meditation/rest period, all subjects were asked to remain in a meditative or resting state while completing the same two tasks they completed in the first session.

EEG Analysis

EEG data from each session were exported in raw "binary simple" format by the NetStation Waveform Tools application and analyzed in MATLAB R2009a (The Mathworks, Natick, MA) using the EEGLAB software toolkit (version 9.0.3.4b, available from http://sccn.ucsd.edu/eeglab/).[41] Continuous EEG data were high-pass filtered above 0.5 Hz using a nonlinear causal elliptic filter (transition bandwidth 0.2 H, filter order 6) and low-pass filtered below 50 Hz also using a nonlinear causal elliptic filter (transition bandwidth one Hz, filter order 12). Causal filters were employed to ensure that the analyzed signals depended only upon past and present information.

Epochs time locked to the onset of light and audio stimuli were extracted from the filtered signals. The time window for each epoch was stimulus onset plus and minus three seconds. A standard EEGLAB artifact rejection menu item, "Automatic epoch rejection," was used to reject an entire epoch if any of the 32 channels in the epoch were identified as containing a potential artifact. All of the default parameters of this function were employed to eliminate post hoc data snooping and to facilitate independent replications of the analysis. (This function operates as follows, as summarized from the EEGLAB help feature for the function called pop_autorej:

> This function first finds large signal deviations anywhere within an epoch (default threshold 1,000 μV). This identifies potential artifacts from electrical surges or other unreasonably large amplitude events. Then in an iterative fashion it rejects data epochs containing values outside a given standard deviation (SD) threshold provided by the user (default five SD). In each iteration, if the percentage of epochs marked for rejection are fewer than "maxrej" (by default 5%), it rejects the above-threshold epochs and iterates. If the number of epochs marked for rejection is more than 5% of the total, it increases the sd threshold by .5 and iterates. When no more data epochs are found to exceed the current sd threshold, it lowers the threshold by .5 SD and continues to iterate until either no more epochs are rejected or until eight iterations have been performed.)

After extracting the relevant data epochs from the full EEG record, the EEGLAB artifact rejection routine removed between five and 31 epochs (mean = 15) out of the 200 trials contributed by each subject.

Based on the findings of previous experiments, the hypothesized prestimulus differential effects were expected to become maximally detectable during the one second that preceded the stimulus.[30,42-44] Thus, each EEG channel in each epoch that survived the artifact rejection procedure was baseline adjusted from two- to one-seconds prestimulus, and then for each electrode the average EEG signal was computed from one second prestimulus to stimulus onset. Finally, for each electrode these signals were averaged across all subjects per group according to stimulus type, and then compared. This analysis did not predict

Table 1. Subject Demographics and Responses to Questionnaires (Averages, Standard Deviations, and Two-Tailed *P* Values)

	Nondual Meditators	Nonmeditator Controls	*P* value
Male/female	7/1	7/1	—
Ethnicity	Caucasian	Caucasian	—
Age	60.6 (7.5)	57.3 (7.4)	.40
Income (higher = more income)	3.6 (1.1)	3.4 (1.3)	.68
Life Stress (higher = more stress)	56.1 (13.2)	58.5 (6.5)	.65
Acceptance (lower = more acceptance)	12.8 (4.23)	15.3 (5.3)	.32
Subjective happiness (higher = better)	26.1 (3.6)	23.1 (3.5)	.11
Self-transcendence (higher = more)	59.5 (7.4)	51.1 (9.7)	.07
Years of any meditation experience	29.3 (9.5)	2.75 (2.6)	.0003
Years of active nondual meditation practice	20.8 (11.2)	0	—
Percentage of nondual self-concepts	28% (29%)	0%	—

in advance precisely which brain areas were expected to show prestimulus differential effects, because unlike conventional forms of anticipation where specific cortical regions are known to become activated or inhibited in anticipation of known stimuli,[45,46] the present experiment ruled out ordinary forms of anticipation by design, so it was unknown which specific cortical regions might show the hypothesized prestimulus effects.

However, the experimental hypothesis did require that audio tones and light flashes would produce different poststimulus cortical behaviors. To confirm this, each electrode in each epoch was baseline-adjusted according to the average signal from one second prestimulus to stimulus onset, and then the average value of the poststimulus signal from 100 to 500 milliseconds was determined for each stimulus type and compared at each electrode site.

Statistical Analyses

Differences in EEG response to the two classes of stimuli were compared using a randomized permutation procedure in EEGLAB[47] (the *statcond* function), and all reported *P* values were adjusted for multiple comparisons across the 32 EEG channels using the EEGLAB implementation of the False Discovery Rate (FDR) procedure. FDR is less conservative than a Bonferroni correction, but it is also more appropriate for this type of data because of signal dependencies in proximal electrodes.[48,49] The raw EEG data and EEGLAB scripts used to conduct the principal analyses in this study are available from the corresponding author upon request.

RESULTS

Subjects

Meditators had an average of 20.8 years of active nondual practice; nonmediators had no active meditation practice (see Table 1). Meditators reported marginally higher levels of self-transcendence ($P = .07$, df = 7, two-tailed unpaired *t* test), but there were no differences in age or income, or in the life stress, acceptance, or subjective happiness scales. The lack of differences in the latter suggest that unlike mindfulness meditation, which has been shown to enhance positive functioning,[50] nondual meditation has a different goal, and as such, it may result in behavioral or subjective changes that are not captured by questions inquiring about stress and happiness. This conjecture is supported by subjects' responses to the Twenty Statements Test, which showed that 28% of meditators' responses referred to nondual self-concepts, whereas none of the nonmeditators' responses did.

Resting State Gamma

Previous studies have reported increases in EEG gamma frequencies in advanced meditators compared to nonmeditators,[1,51,52] and it has been proposed as an electrocortical correlate of sustained attention and conscious awareness. Consistent with those findings, the average of all 32 electrode sites showed a modest trend toward higher gamma activity (35-50 Hz) in the meditation versus control group ($P < .08$, two tailed) during the five-minute meditation/rest period between the two test sessions (see Figure 2). (This analysis excluded the first and last 20 seconds of the meditation period.)

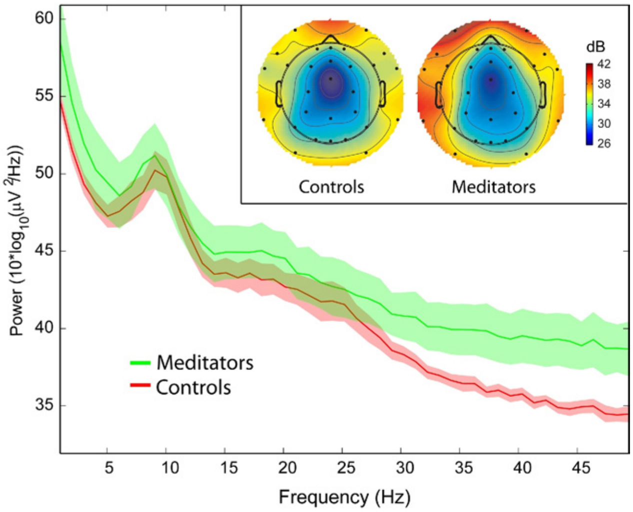

Figure 2. (Inset) Scalp maps showing spectral power scale in dB for the gamma (35-50 Hz) spectrum in the two groups during the five-minute meditation/rest period between test sessions. Small black dots in the scalp maps indicate electrode locations. Gamma activity averaged across all electrodes was modestly higher in the meditation versus control group ($P < .08$, two tailed). (Curves) Spectral power means and one standard error of the mean envelopes for a left inferior temporal electrode. Meditators showed consistently higher variability in spectral power than controls. (Color version of figure is available online.)

Poststimulus Response

To confirm that the audio tones and light flashes produced the expected poststimulus differences, electrocortical activity in all on-demand and free-running trials, ranging from 100 to 500 milliseconds poststimulus, was averaged per electrode and then compared between the two stimulus conditions both within and between groups. For the control group, nearly all of the 32 electrodes displayed significant differences in light versus audio tone stimuli, with statistical differences ranging from $P < .05$ to $P < .005$. For meditators, about half of the 32 electrodes showed significant differences ranging from $P < .05$ to $P < .005$ (Figure 3). This indicates as expected that the audio and light stimuli produced different patterns of cortical activity after exposure to the stimuli. Having found these poststimulus effects, we did not run further analysis on individual ERP peaks.

Prestimulus Effects

The extended awareness hypothesis predicted that electrocortical activity would differ before unpredictable audio versus light stimuli. Data pooled across all on-demand and free-running trials showed no significant differences within the control group for the two classes of stimuli, but in the meditation group five of 32 electrodes showed significant differences prior to light versus audio stimuli at $P < .05$, mostly over the right occipital region (Figure 4). When considering comparisons between groups, no differences were observed prior to light flashes, but before audio tones 15 of 32 electrode comparisons were significant at $P < .05$, of which eight were significant at $P < .005$, and distributed primarily over occipital, inferior parietal, and inferior right frontal regions. The group by stimulus type interaction indicated that five right occipital electrode sites showed significant differences at $P < .05$.

It is instructive to examine the time course of the prestimulus data for one electrode (right superior centroparietal) to see how the meditators' EEG signals differentiated before light flash versus audio tone stimuli. Figure 5 shows the mean and one standard error of the mean envelopes for audio and light stimuli, for the two groups, from two seconds prestimulus to one second poststimulus.

On-Demand versus Free-Running Task

Within the meditation group, comparison of cortical potentials between the on-demand versus free-running tasks showed that

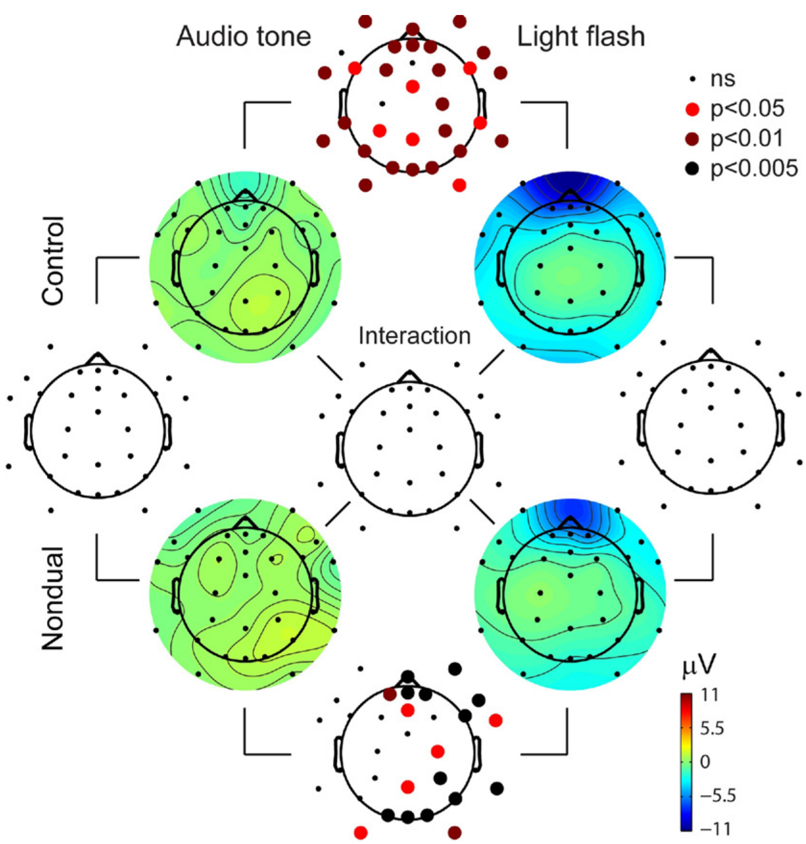

Figure 3. Cortical electrical potentials (color scale in microvolts) for the meditation and control groups, pooled across all trials, ranging from 100 to 500 millisecond poststimulus, and shown separately for audio tone and light flash stimuli. Statistical comparisons between stimuli are shown at each electrode site across groups, stimulus type, and interactions. This analysis shows no interaction effects, broadly distributed poststimulus cortical differences in the controls, and mostly right hemisphere cortical differences in the meditators. (Color version of figure is available online.)

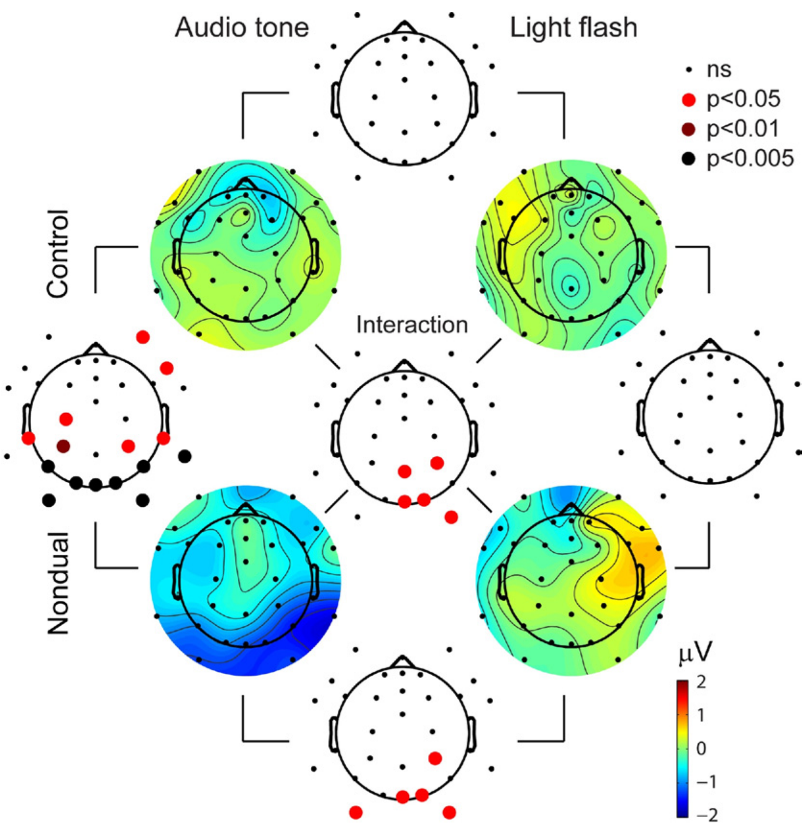

Figure 4. Average cortical electrical potentials (color scale in microvolts) pooled across all on-demand and free-running trials in the meditation and control groups, ranging from one second prestimulus to stimulus presentation, for all audio tone and light flash stimuli. The a priori probability of obtaining an audio or light stimulus was the same in both conditions; thus, under the null hypothesis there should be no prestimulus electrocortical potentials differences between the two stimulus types. Statistical comparisons between stimuli are shown at each electrode site across groups, stimulus type, and interactions, and are corrected for multiple comparisons. (Color version of figure is available online.)

the main prestimulus differences occurred in the free-running task (Figure 6). Figure 7 shows the time course of this effect at a right superior centroparietal electrode. This finding is noteworthy because tasks involving randomly selected stimuli with randomly timed interstimulus latencies effectively eliminate biases due to explicit or implicit guessing strategies, such as the gambler's fallacy.[53] This bolsters the likelihood that the observed outcome was not due to conventional forms of anticipation or subjective probability biases. To confirm this finding in future studies the comparison between the on-demand versus free-running tasks should ideally employ counterbalanced presentations.

Stimulus versus No Stimulus

For exploratory purposes we examined the audio versus blank (ie, no) stimulus and light versus blank stimulus comparisons across both the on-demand and free-running tasks. Significant differences were observed within the meditator group between audio versus blank stimuli, but not in the control group (Figure 8). For the light versus blank comparison no statistical differences were observed in either the controls or the meditators.

DISCUSSION

This experiment tested the ontological status of advanced meditators' reports of timeless awareness, or of an unusually spacious awareness that seems to extend through time. The results appear to support this claim. Is this interpretation justified?

Alternative Explanations

A number of conventional effects may mimic the observed outcomes. These include the presence of physical or probabilistic cues about the upcoming stimuli, use of inappropriate or ad hoc analytical methods, violation of statistical assumptions, result of an anticipatory strategy, or a statistical false positive.

Cues. Physical cues were avoided by randomly generating stimuli only after each prestimulus period had ended. This eliminated potential computer disk sounds or other noises that might have provided cues about the upcoming stimuli. Probabilistic cues were reduced through the use of a nondeterministic, noise-based RNG to select the stimuli, with replacement, and use of identical a priori probabilities for the two stimuli of principal interest. For the free-running task, the random ISI lengths were

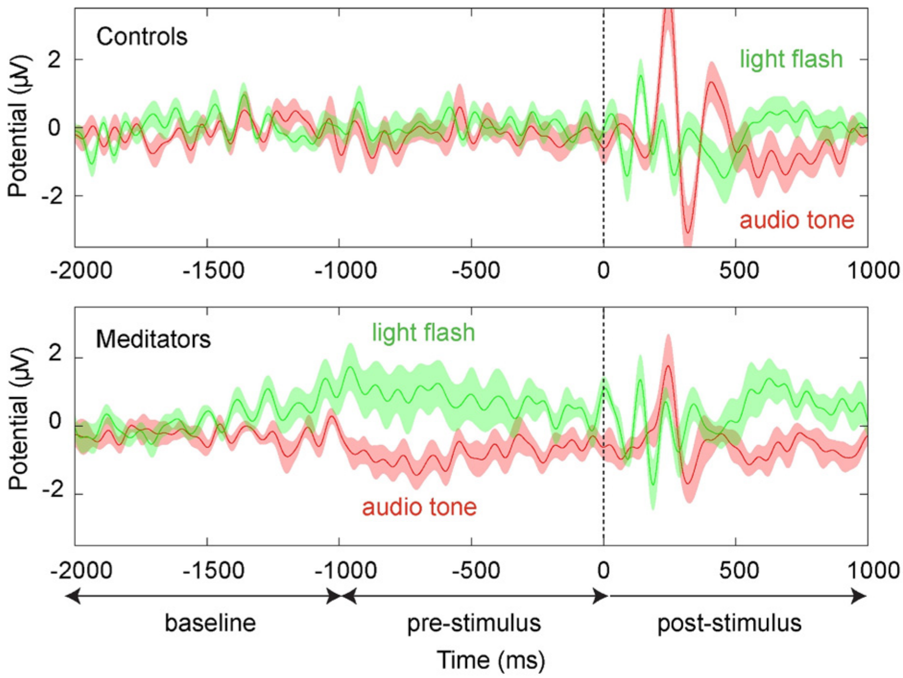

Figure 5. Mean potentials and one standard error of the mean envelopes for light and audio stimuli in all on-demand and free-running trials, shown by group, at a right superior centroparietal electrode, baseline adjusted from two- to one-second prestimulus. Time 0 is the moment of stimulus onset. For ease of visualization these data were smoothed with a 10-Hz high pass filter. (Color version of figure is available online.)

determined using a pseudorandom algorithm reseeded at the beginning of each test session, so the ISI and stimulus selection methods were independent.

Analytical methods. Data were intentionally analyzed using conventional tools and methods for studying event-related potentials. Just one minor change was introduced: instead of using prestimulus baselines averaged just prior to stimulus onset, EEG signals were conservatively adjusted with a baseline averaged from two-seconds to one-second prestimulus. To ensure that filtered prestimulus signals were not contaminated by future information, causal filters were employed. Potential low-frequency drifts or autocorrelations between successive EEG epochs were attenuated through use of a 0.5-Hz low-pass causal filter, and the epoch artifact rejection procedure used a standard EEGLAB function with all of the default options selected, specifically to avoid analyst selection biases or post hoc adjustments.

One might argue that blinded visual inspection is superior to an algorithmic artifact rejection procedure, but given the unusual nature of the hypothesis we felt that a completely automated method developed for conventional EEG processing was preferable. Besides avoiding the criticism that a novel technique had been developed for this application, it would also allow the analysis to be easily reproduced by other investigators.

We may also point out that the main differences observed in this study were primarily over occipital regions, and not over frontal regions where eye movements can distort EEG signals, or over temporal regions where muscle twitches can introduce artifacts.[54] This supported our decision to avoid more sophisticated data processing methods for removing artifacts, such as independent component analysis,[55] because those methods would have unnecessarily complicated the intentional transparency of our approach.

Statistical methods. Potential problems associated with violating assumptions of parametric statistics or alpha inflation due to multiple testing were avoided through use of nonparametric permutation techniques and FDR procedures. The possibility that the results were due to one or two outlier epochs or subjects is unlikely because permutation statistics are insensitive to distributional skew. The EEGLAB statistical functions used in the analysis were thoroughly tested using a separate Matlab script available from the corresponding author. Those tests, using random data with the same degree of freedom as the raw data and repeating the same test for the current analysis (including FDR correction), yielded false positive rates averaging 0.2%. In other words, it is likely that the effects observed in this study were genuine differences, and not false positives.

Anticipatory strategies. Could subjects have kept track of the various stimuli as they were presented, and then consciously or unconsciously used that information to outguess the upcoming stimuli? Or could the free-running task have introduced a sequential bias because a response was required after audio tones but not after light flashes? Such strategies might have introduced spurious results if dichotomous stimuli were selected without

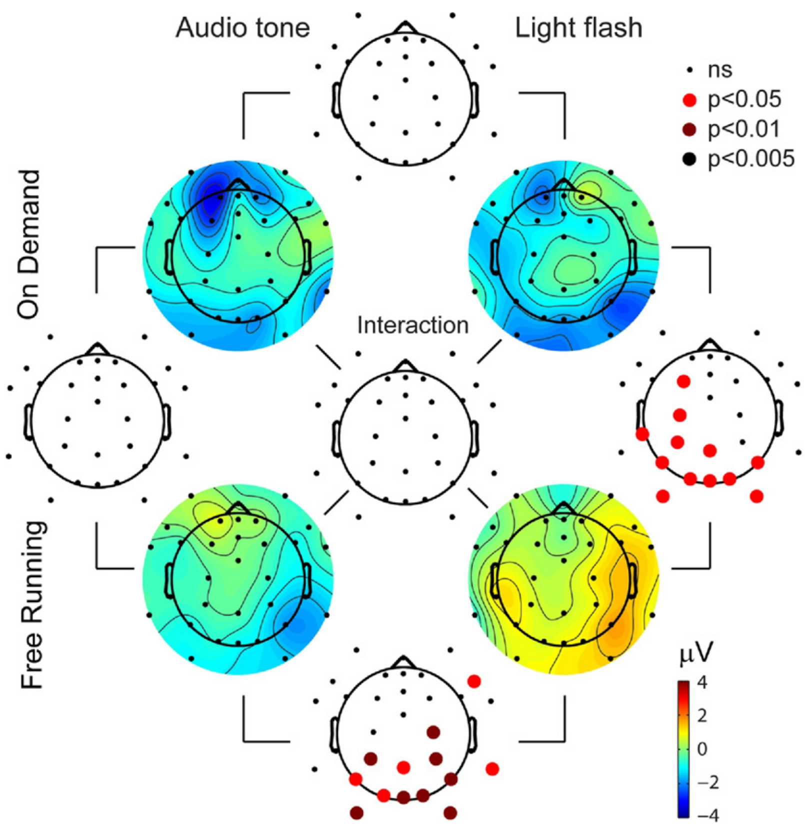

Figure 6. Comparison of electrocortical maps for on-demand versus free-running tasks in the meditation group. The principal differences occurred in the free-running task, suggesting that the observed prestimulus effect was not due to conventional forms of anticipation. (Color version of figure is available online.)

replacement, but this was not the case; multiple stimuli were selected with replacement, so attempts to consciously or unconsciously outguess the future stimuli would have been based on the gambler's fallacy. In addition, the free-running task (1) employed random interstimulus intervals, which reduced the potential influence of sequential biases, and (2) a third of the time the stimulus was neither a light flash or audio tone, but a silent period, which further reduced potential biases. If, however, the stimulus sequence was strongly autocorrelated by chance, or as the result of an intermittent failure of the RNG, this might have provided hints that an anticipatory strategy could have capitalized upon. To examine this possibility, we examined autocorrelations of all stimuli used in the experiment up to lag ± 100; no evidence of sequential structure was found that might have provided clues (autocorrelations ranged from a minimum of −.05 to a maximum of .05).

Replications. When confronted with experimental effects that appear to contradict long-held assumptions, a common first reaction is that the methodology must have been flawed. If subsequent analysis suggests that the methodology was sound, then the next assumption is that the results were a false positive, or a statistical fluke. Flaws and flukes do occur, so such explanations are not unreasonable. But they become progressively implausible when the reported results are viewed in context. In the present case, reports of perceptions that appear to transcend time can be found not just among advanced mediators, but in the general population across cultures and throughout history.[56,57] Scientists curious about these reports have conducted hundreds of laboratory experiments,[58] and a meta-analysis of 309 relevant studies appearing in English language journals between 1935 and 1987, conducted by 62 different investigators and over 50,000 subjects, provides strong evidence for the presence of some form of extended time perception in the general population.[59]

Of specific relevance are over three dozen previously reported presentiment experiments using designs similar to the one reported here, with similar outcomes. Earlier studies involved physiological variables such as skin conductance level,[42,43,60-62] nonspecific skin conductance response,[63,64] heart rate,[42,43,65-67] slow cortical potentials,[30,42-44,68,69] EEG-evoked potentials,[70,71] pupillary dilation,[72] and functional magnetic resonance imaging (fMRI) blood oxygenation measurements.[73] Stimuli in these studies included symbolic images, affective photographs, happy versus sad face cartoons, audio startle tones versus silence, and flashes of light versus no flash. In some studies subjects initiated fixed length trials, and in others stimuli appeared spontaneously at random times. No evidence for conventional anticipatory strategies or other artifacts have been identified in these studies.

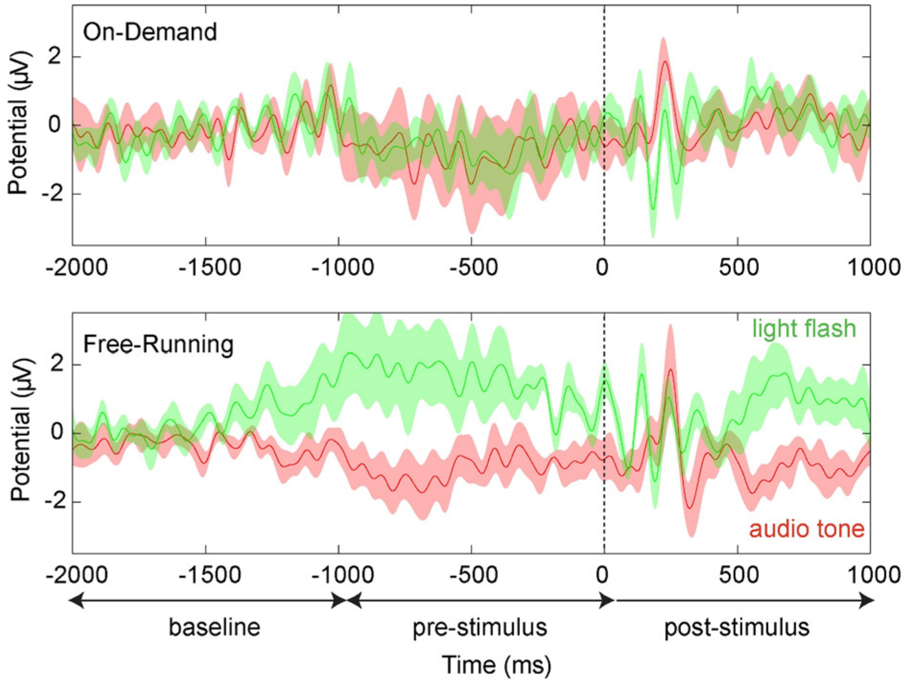

Figure 7. Mean event-related potentials and one standard error envelopes in the meditation group for light and audio stimuli in the on-demand and free-running tasks (right superior centroparietal electrode, baseline adjusted from two- to one-second prestimulus). Stimulus onset is at Time 0. For ease of visualization these data were smoothed with a 10-Hz highpass filter. (Color version of figure is available online.)

Gamma Frequency

The moderately increased gamma power in the meditators compared to the controls has been observed in previous electrocortical studies of meditation.[52,74] The increase in the present study was located primarily in frontal and left temporal regions, which may potentially be contaminated by high frequency muscle artifacts. The possibility of artifact was not evaluated in Lutz and colleague.,[52] but it was in Cahn and colleague.[74] using independent component analysis, and no evidence was found in those studies to support the muscle artifact idea. In any case, increased muscle tension seems unlikely to account for increased gamma because an important component of many sitting meditative practices involves attaining a state of profound mental and physical relaxation, and that in turn suggests a decrease in muscle tone rather than an increase.

Stimulus-Preceding Negativity (SPN)

SPN has been studied extensively as a cortical measure of anticipation.[46] SPN increases in anticipation of feedback of performance, of pleasant versus neutral pictures, of more relevant stimuli, from threat of noise or shock, and so forth. It also occurs more prominently before tasks requiring motor responses.[75] The prestimulus effects observed here are consistent with SPN effects in that the meditators showed greater negativity throughout the cortex in anticipation of an audio tone versus light flash, and in particular, they showed greater negativity prior to the audio tone in the free-running task, which required a motor response after the audio stimulus. However, the stimuli in this study were specifically designed to be unpredictable, and in the free-running task they occurred at unpredictable times. So SPN may be a marker not only for conventional forms of anticipation, but potentially for retrocausal forms as well.

A question that may arise from examination of Figure 4 is why prestimulus responses to audio tones occurred mainly over the occipital lobe given that the primary audio cortex is located in the temporal region. One possibility is that the audio tone stimulus in the free-running condition, which is where most of the prestimulus effects occurred, also required a motor response. Thus, what appeared as occipital activity may have been due to complex interactions between auditory and motor cortex activity, or to projections from deeper brain structures. Future research will be required to more closely examine this question.

Reactivity

Previous experiments indicate that the magnitudes of pre- and poststimulus responses may be correlated.[62] In practice, this means that to most efficiently detect prestimulus effects one should use stimuli that generate large poststimulus responses. This is why most presentiment experiments have used highly emotional versus calm images or startling versus silent stimuli, and also why–when autonomic measures such as skin conductance have been employed–meditators should be excluded as participants. That is, meditators tend to exhibit less reactivity to stress as compared to nonmeditators,[76-78] and thus they often produce constrained poststimulus responses.

Given this, one may wonder why the meditators showed superior prestimulus responses in the present study, but not the nonmeditators. Two speculations arise. First, unlike most previ-

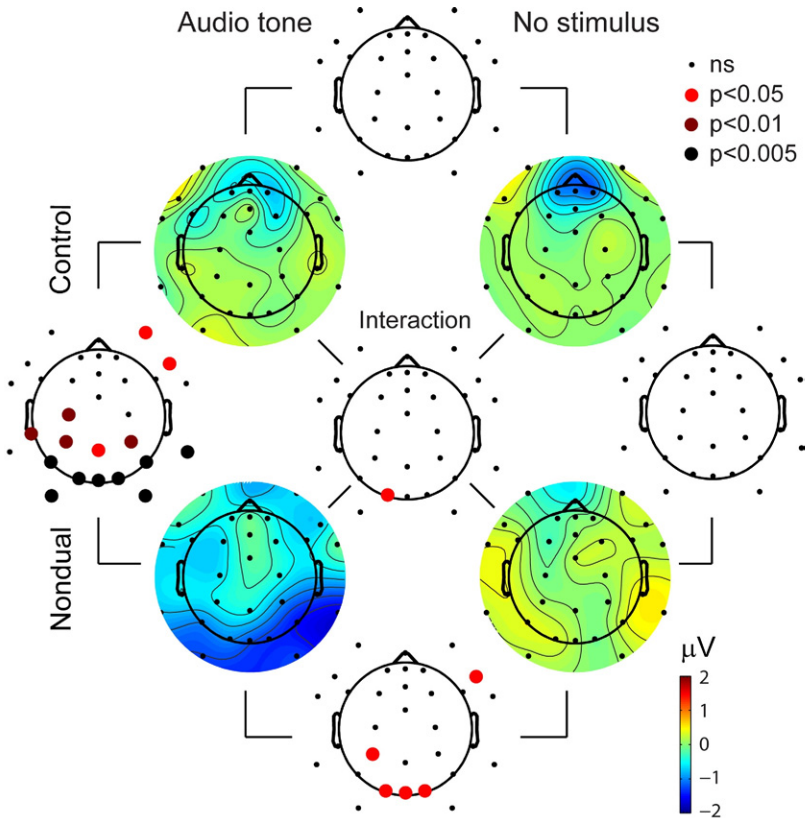

Figure 8. Electrocortical potentials and statistical comparisons one-second prestimulus for audio tone versus blank stimuli in the two groups, and pooled across both the on-demand and free-running tasks. (Color version of figure is available online.)

ous presentiment studies, the stimuli used here were neither emotionally charged nor especially startling. The use of mild stimuli was intentional because we did not want to shock the meditators out of their nondual awareness state, but perhaps what we gained in that group was at the expense of reducing prestimulus responses in the nonmeditators. Second, although meditative practice inhibits autonomic reactivity it also stimulates some aspects of central nervous system activity, for example, increased gamma band synchrony in the brain. This suggests that the physiological measurements one uses to detect a presentiment effect should be selected based on a subject's psychological trait and state, and also on idiosyncratic factors such as life experience and experience with meditation. Use of, say, skin conductance measures might be fine for young, naive subjects exposed to emotional versus calm images, but that same study design may not be appropriate for surgeons, jet fighter pilots, or advanced meditators.

Theoretical Considerations

Given the unconventional nature of the extended awareness hypothesis, but the use of a conventional experimental design to study it, one wonders whether similar presentiment effects may have been observed, inadvertently, in experiments conducted for entirely different purposes. This question was explored by Bierman,[79] who found three appropriate experiments using skin conductance measures. The first was a study on the speed with which fear arises in animal-phobic versus nonphobic subjects,[80] the second was concerned with the difference in anticipatory responses in the Iowa gambling task[81,82] and the third investigated the effect of emotional priming on the evaluation of Japanese characters.[83] For all three studies, Bierman asked an assistant blinded to the purpose of the task to measure skin conductance values from graphs appearing in those published reports, and upon analysis he found that the prestimulus baselines across these three studies revealed deviations that were significantly in agreement with the present results ($P < .003$).

Further evidence that apparent time-reversed effects may be pervasive but normally go unnoticed is provided by a series of nine experiments recently reported by Bem in the *Journal of Personality and Social Psychology*.[84] In those studies, involving more than a thousand subjects, Bem reversed the cause-and-effect sequence used to establish well-known phenomena such as the "mere exposure effect."[85] He obtained statistically significant evidence in eight of the nine experiments, indicating that sometimes effects precede their causes. There is also growing interest in the possibility of similar temporal anomalies in other cognitive and perceptive tasks, including bistable perception of ambiguous figures and decision making.[86,87]

Does perceiving the future, either consciously or unconsciously, imply a logical paradox that must surely be prohibited by one or more laws of physics? Until the beginning of the 20th century, this was a common assumption. But theories about the nature of time have evolved, and today discussions about counterintuitive aspects of time, including retrocausation, macroscopic time reversal, and time as an illusion sustained "by virtue of our thinking ourselves as separate from everything else,"[88(p.65)] regularly appear in the mainstream physics literature.[89-96]

In particular, the possibility that the future can influence the present is now taken seriously in discussions of the interpretation of quantum theory.[97,98] Given evidence suggesting that quantum effects can appear in macroscopic systems at room temperature,[99] including in organic systems such as photosynthesis,[100] it appears that physical explanations for presentiment effects may be emerging based on ideas from quantum biology. Awareness extending through time may be surprising but it is not prohibited; thus, based upon the accumulating empirical data it seems likely that this phenomenon, like many others once shrouded in mystery, may slowly be yielding to scientific investigation.

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