Can hyper-synchrony in meditation lead to seizures? Similarities in meditative and epileptic brain states

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ABSTRACT

Meditation is used worldwide by millions of people for relaxation and stress relief. Given sufficient practice, meditators may also experience a variety of altered states of consciousness. These states can lead to a variety of unusual experiences, including physical, emotional and psychic disturbances. This paper highlights the correspondences between brain states associated with these experiences and the symptoms and neurophysiology of epileptic simple partial seizures. Seizures, like meditation practice, can result in both positive and negative experiences. The neurophysiology and chemistry underlying simple partial seizures are characterised by a high degree of excitability and high levels of neuronal synchrony in gamma-band brain activity. Following a survey of the literature that shows that meditation practice is also linked to high power gamma activity, an account of how meditation could cause such activity is provided. This paper discusses the diagnostic challenges for the claim that meditation practices lead to brain states similar to those found in epileptic seizures, and seeks to develop our understanding of the range of pathological and non-pathological states that result from a hyper-excited and hyper-synchronous brain.

Keywords: meditation, epilepsy, seizures

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INTRODUCTION: THE BASIS OF A LINK BETWEEN MEDITATION AND EPILEPSY

The practices of altering brain activity with the range of techniques known as meditation have been performed for thousands of years. Interest in meditation and related mindfulness practices has rapidly increased in recent years, in part due to the mounting evidence that such practices can improve psychological well-being [1], and may be helpful in treating clinical problems such as depression, anxiety and chronic pain [2–4]. However, there has been controversy about the link between meditation practice and the neurological disorder of epilepsy [5,6]. Some have suggested that brain states induced by meditation could be conducive to triggering seizures in epileptics [7] or could trigger epilepsy with patients with no known history or risk factors for epilepsy [6]. In contrast, it has also been argued that there is no evidence that meditation can increase risk of epilepsy, and that meditation can be used as a safe and effective treatment for some forms of epilepsy [8,9]. This paper will examine the hypothesis that meditation could lead to seizures in non-epileptics, though it appears that if meditation can trigger seizures with non-epileptics then it would be likely to increase risk of seizures in epileptics.

Meditation is difficult to define but can be described as a deliberate practice of inducing and regulating brain states due to their perceived positive qualities, primarily through the deliberate control of attention. These states may involve a sense of calm and tranquillity, with the relative absence of discursive thinking, and an increase in positive emotions such as love or compassion. With sufficient skill, such states can be induced, stabilized and maintained for long periods of time, typically periods of 15-60 minutes. In some meditation traditions there is a focus on achieving transient “peak” experiences of transcendental states of consciousness, which may involve a radically altered sense of self and reality, and extreme emotional states of bliss, ecstasy and joy. These ecstatic states may be so rare and powerful as to be life changing [10].

Defining epilepsy is also challenging, given the diversity of causes, brain areas affected and corresponding range of symptoms [11]. One recent attempt at a general definition is that an epileptic disorder is characterized by the presence of epileptic seizures along with “an enduring disturbance of the brain that increases the likelihood of future seizures” [12]. An epileptic seizure is defined as “a transient occurrence of signs and/or symptoms due to abnormal excessive or synchronous neuronal activity in the brain” [12]. When seizures persist for a long period (such as five minutes or more) they are termed “status epilepticus”. It should be noted that the occurrence of an epileptic seizure does not mean someone has an epileptic disorder, as seizures can be induced from other causes (e.g., overdoses of recreational drugs).

Epileptic seizures are most commonly associated with generalised seizures, during which the firing rates of populations of neurons become highly synchronised, and excessively high neuronal synchrony spreads out of control across the brain, leading to the loss of consciousness and tonic-clonic convulsions (historically known as grand mal epilepsy). However, there are many types of seizures, which can lead to a huge variety of symptoms depending on the locus, type and spread of seizure-related brain activity, and consequentially the clinical severity varies enormously. Epileptic seizures are not necessarily uncontrollable; epileptics report the ability to wilfully stop the emergence of some seizures once warnings signs are recognised, and there are cases where epileptic seizures can be deliberately induced just by thinking about previous experiences of them [13].

A class of seizures less severe than tonic-clonic seizures are partial seizures, which are sub-divided into complex and simple types. Complex partial seizures involve a loss or significant impairment of awareness, whereas simple partial seizures can alter consciousness without its loss, with memory of the episode fully preserved. They are also typically of shorter duration (i.e., approximately 5-30 seconds vs. 30-120 seconds). Both can lead to an assortment of motor, sensory, autonomic (both parasympathetic and sympathetic) and psychic (cognitive and emotional) symptoms depending on seizure focus. Common motor symptoms are jerking, spasms and posturing, with complex partial seizures associated with automatisms such as chewing or lip smacking when consciousness is impaired. Sensory symptoms might include tingling sensations in the body, light flashes or buzzing sounds, and less commonly more complex structured hallucinations, which are more typically associated with complex partial seizures. Automatic symptoms include changes in heart rate and breathing patterns. Psychic symptoms include distorted perception of body size, altered sense of self and reality, and extreme emotional states. Simple partial seizures can be highly localised and not show signs of spreading propagation, but can lead to propagation outside of their initial focal area, triggering complex partial seizures, in which case the manifestation of the simple partial seizure is called an aura.

In advancing the claim that meditation can cause seizures, it is important to clarify what kind of seizures. An issue that has hampered previous debate has been the implication that meditation could induce tonic-clonic seizures. For example, scepticism was expressed in the following quote: “The experience of meditation is one of peaceful relaxation and well-being that is in contrast to the painful wild seizures of an epileptic ‘storm’” [9]. However, a recent survey [6] suggests that there is little to no evidence that meditation has precipitated generalized tonic-clonic seizures in epileptics or non-epileptics. In regard to less severe seizure types, there are long standing claims of a link between religious and mystical experiences and temporal lobe epilepsy [14,15]. In development of this idea, Persinger [16] argued that meditation could lead to “complex partial epileptic-like signs”, and found such signs were more likely in a survey of Transcendental Meditation practitioners compared with controls.

Persinger’s research suffers from a liberal interpretation of epileptic-like symptoms, which include visual and auditory hallucinations which plausibly could be caused by epileptiform activity, and other phenomena which are unlikely to be of epileptic origin, such as writing (“keeping notes about personal thoughts”) and “profound experiences from reading or reciting poetry and prose”[16]. Scepticism has also been expressed [6] on claims based on EEG records of meditators purportedly showing complex partial seizures indicative of temporal lobe epilepsy [17], as such EEGs have been argued to not match the typical electrophysiological profile of spatiotemporally evolving and spreading pattern of activity which characterises a complex partial seizure [6].

Furthermore, in the literature on first person accounts of meditation experiences, reports that point towards the occurrence of complex partial seizures are very rare, such as a transient loss of consciousness or lack of memory of an event. However, limited evidence for a link between meditation and complex partial seizures does not preclude a link between meditation and simple partial seizures. Simple partial seizures can be focal without spreading propagation, and can be very difficult to detect in the scalp EEG due to the limited amount of neuronal tissue or the depth of the activity. For example, one study [18] found that only 20% of a variety of simple partial seizures could be detected on the scalp EEG. This factor makes it technically difficult to determine whether epileptic brain states can occur during meditation, and could contribute to the limited neurophysiological evidence for a link.

Much of the previous debate on the link between meditation and epilepsy has focused on whether meditation could cause seizures or reduce risk of seizures (particularly tonic-clonic and complex partial seizures) in those with an existing epileptic disorder [6,8,9]. The current work looks to find supporting evidence of the hypothesis that meditation can lead to seizures by scrutiny of meditation practitioners and meditation techniques. In the next section, which discusses "Unusual experiences in meditation", new lines of behavioural evidence consistent with the claim that meditation could cause simple partial seizures are discussed. This evidence suggests that meditators do report symptoms consistent with the occurrence of simple partial seizures, though these symptoms are rarely interpreted as such.

It has been speculated that there are close correspondences between the neuronal environment found in meditation and in epilepsy [19,20]. Building on suggestions that high synchrony brain activity may be important in understanding the link [7,21], the subsequent section, titled "High neuronal synchrony and excitability in epilepsy and meditation", surveys the emerging literature on the role of high frequency neuronal oscillations in meditation and in epilepsy. In moving beyond just pointing out possible similarities, the next section titled "How meditation practices could lead to high neuronal synchrony", provides a further novel contribution to the meditation-epilepsy debate by specifying how particular meditation techniques at particular points in practices might give rise to brain states similar to those seen in simple partial epileptic seizures.

In the final section, titled "Challenges for understanding the link between meditation and epilepsy", testable predictions that follow from this account are discussed in more detail, along with complications and difficulties which need to be considered when evaluating the claim that meditation can lead to simple partial seizures. In the absence of direct evidence, one response to the debate is discussed, which is to consider brain states occurring in some meditation practices and brain states occurring in some epileptic seizures (such as simple partial seizures) as instances of a general class of brain states, both characterised by high neuronal synchrony and excitability (high neuron firing rates).

UNUSUAL EXPERIENCES IN MEDITATION

Unusual experiences in meditation are widely, if anecdotally, reported and are described in traditional manuals, though it is likely that negative experiences are underrepresented due to a focus on beneficial aspects of meditation in meditation traditions. On initial inspection, these reports appear to match the range of motor, sensory and psychic symptoms associated with simple partial seizures. Unusual activity in meditation practice is commonly understood by meditation teachers as resulting from spiritual awakening, internalised stresses and psychological issues being worked out, or a release of spiritual or psychophysiological "energy", and is often seen as a positive sign of a deepening meditation practice and increased concentration ability. These symptoms and causes have been described as "unstressing" from a Transcendental Meditation perspective in the following way: "Unstressing takes the form during meditation of completely involuntary, unintended, and spontaneous muscular-skeletal movements and proprioceptive sensations: momentary or repeated twitches, spasms, gasps, tingling, tics, jerking, swaying, pains, shaking, aches, internal pressures, headaches, weeping, laughter, etc… The experience covers the range from extreme pleasure to acute distress" [22].

The clearest reports of events that may reflect seizure activity come from intensive meditation retreats, where practitioners may meditate between 5-15 hours per day, often for periods of up to seven or ten days, or in some cases three months or more. Similar reports to the Transcendental Meditation concept of "unstressing" are found in other meditation practices. In the Japanese Zen Buddhist tradition, unusual experiences which are deemed negative are called "makyo" (literally: a world of the devils), which can present as "emotional swings from vacant feelings to bliss, unusual body sensations, misperceptions (illusions), and hallucinations" [23]. A Zen teacher [24] teaching American college students meditation found they reported "hallucinoid feelings, muscle tension, sexual excitement, and intense sadness". Detailed accounts are found in a study which describes interviews conducted on Westerners on a three month Buddhist meditation retreat, with 80% reporting unusual experiences [25]. A control group who received the same instructions but meditated much less and outside of the silent retreat environment (1-2 vs. 12-15 hours a day) reported much fewer unusual experiences. These unusual experiences comprised a wide variety of motor, somatic, visual, psychic and emotional phenomena. Bodily experiences included tingling, twitching, shaking, involuntary arm movements, facial contortions and ticks, drooling, unilateral bodily movements of body and head ("body pulls to the left", "head feels tilted"), and alterations of somatic perception which included floating, increased or decreased bodily or limb awareness, out of body experiences, and body size alterations ("limbs and body huge and bulbous"), along with time distortions. Visual hallucinations included snow or spots of light, flashes of light and colour, and bright white light. Subjects also reported a wide variety of emotional disturbances, with experiences of extreme negative (anger, fear, sadness) and extreme positive emotional states (bliss, joy, rapture). Students also reported a strong relationship between their perceived intensity of concentration and the frequency of unusual experiences.

Another way in which unusual experiences in meditation have been discussed, which may provide a further tentative pointer to a link between seizures and meditation states, come from traditional texts on meditation from Hindu and Buddhist sources. They describe "siddhis" or "powers" [26], which are paranormal abilities attained through advanced meditation practice, often seen as signs of progress by meditation teachers. These include altered perceptions of body size (shrinking or enlarging), visions, out of body experiences, precognition, mind reading and controlling the mind of others, and experiences of past lives. The experiences of psychic powers in meditation may be indicative of psychosis, which itself could be linked to seizures, or result directly from psychic seizures [27], particularly of temporal lobe origin [28]. For example, experiences of precognition may be linked to ictal prescience, the subjective feeling of knowing what will happen in the future [29]; out of body experiences have a neurophysiological basis [30]; and memories of past lives may result from erroneous recollection and experiences of déjà vu resulting from ictal activity [31].

Many of these unusual experiences that arise from meditation practice appear to occur as side-effects from the practice, though may be seen as ultimately beneficial even when having a negative character. Experiences of more positive states are more directly associated with the purpose of meditation, such as the experience of bliss, joy and rapture [25], and ecstatic states of cosmic unity [32]. As noted earlier, it is often assumed that epilepsy triggers undesirable mental and physical states which have little in common with the positive experiences of meditation. While epileptic seizures are normally described to have a negative character, there are rare cases of a sub-type of simple partial seizures, in what has been called Dostoevsky epilepsy [33], due to his vivid writing about them. These seizures have been termed ecstatic [13,34], and are associated with feelings of intense joy, pleasure (in some cases sexual) and contentment, which may be linked to religious or mystical interpretations in some patients. When preceding complex partial seizures, they are described as ecstatic auras. Patients with ecstatic seizures often report inducing them deliberately due to their positive nature [13,34]; half of the 10 patients in one study [13] were able to induce such seizures by deep concentration and remembering previous incidences. The correspondences between religious experience and ecstatic epilepsy has been previously highlighted [15] but also disputed [35].

In the descriptions of these positive and negative unusual experiences, there appears a reasonable match with the range of symptoms associated with simple partial seizures. In the next section, we discuss the neurophysiology of epilepsy and of meditation, in order to develop an account of how these unusual experiences and altered states of consciousness may occur during meditation practice.

HIGH NEURONAL SYNCHRONY AND EXCITABILITY IN EPILEPSY AND MEDITATION

Neuronal synchrony is a necessary part of normal brain function, involved in short-scale and large-scale integration of activity across diverse brain areas. High frequency synchrony has been found to be important for sub-serving complex cognitive processes in normal populations [36], such as top-down attention [37], perceptual binding [38], and working memory [39]. These high frequency oscillations are referred to as gamma activity, particularly around 40 Hz, though what is classified as gamma varies across individual studies, with the gamma band including activity that can range from 20-30 Hz to 200 Hz.

Abnormally low or high levels of gamma power have been linked with neurological and neuropsychiatric disorders [40] such as schizophrenia [41]. High gamma power has been associated with the positive symptoms of schizophrenia, such as hallucinations [42], and first-episode psychosis [43]. Epilepsy, however, is most commonly associated with abnormal levels of synchronous brain activity, activity that is too high in power and too long lasting. Only relatively recently has the importance of gamma range activity in epileptic seizures been understood [44,45], due to previous limitations in analysis technique, as gamma-band activity is undetectable by eye on non-digital EEG recordings, and is co-present with other non-neural sources of gamma in an EEG, such as movement artefacts and EMG contamination, which have high power in the upper gamma range (i.e., 80 Hz - 200 Hz).

Current models of epilepsy treat it as resulting from an imbalance between excitatory glutamate and inhibitory GABA systems [46], leading to a brain environment of excess excitation, and the triggering of gamma oscillations linked to this hyper-excitation. For example, dopamine antagonists, which are known to modulate these systems and reduce excitability, have been shown to stop seizures, while dopamine agonists can encourage hyper-excitation triggering seizures [47], and are associated with increased gamma power [48]. High power and high frequency gamma oscillations may be localised to the seizure focus [49] or can lead to the spreading neuronal hyper-synchrony seen in epileptogenesis.

This prevalence of gamma-band activity may provide a crucial link to meditation and neurological disorders. Electrophysiological studies of meditation practice have found that meditation practices are typically associated with changes in synchronous activity in lower frequency alpha, beta and theta bands in scalp recorded EEG [50]. These differences can be observed during meditation states (state-based), or can be found in changes to baseline levels of synchrony when not meditating, indicating that meditation practice can induce long lasting or perhaps even permanent (trait-based) levels of synchrony outside of meditation practice [50]. An increasing number of studies are revealing high power gamma linked to meditation practice. Such findings were previously limited due to methodological issues in studying gamma activity, which means that, where reported at all, analysis was often limited to lower frequency gamma-band ranges, particularly around 40 Hz, where gamma activity is commonly found to be strongest.

Recordings of high power gamma levels in meditators have been found in a variety of meditation practices. A concentration based breathing meditation practice from the yoga tradition was led to biphasic high gamma activity in experienced practitioners [51], where the pattern of spike trains was noted to be almost identical to those involved in epileptic seizures. Similar findings of increased state-based and trait-based gamma was reported in advanced practitioners in the Theravada Buddhist meditation tradition (associated with Buddhism in South-East Asia) [52], with trait-based gamma power co-varying with years of practice. Regardless of practice level, state-based increases in posterior gamma were found in mindfulness meditation [53], along with trait-based increases in more advanced meditators. Studies of highly experienced meditators in Tibetan Buddhist traditions showed pronounced gamma power during meditation states [54]. These individuals also scored higher than controls in baseline activity when not meditating, an increase that correlated with lifetime hours of practice. Note that contrary to this line of evidence, a longitudinal study of intermediate meditators in a three month Tibetan Buddhist meditation retreat (primarily using a breath-based concentration practice) found no evidence for state or trait-based changes in gamma power over that time period [55].

On a more individual basis, the level of gamma activity has been found to distinguish meditative states in an advanced meditator from the Tibetan tradition [56]. Early investigations of advanced meditators before the development of modern EEG analysis techniques (whose results have to be taken with caution) also observed evidence for transient bursts of high power gamma activity in advanced Transcendental Meditation practitioners [32], which was linked to subjective reports of transcendent states of consciousness. In experienced yogic meditators, increases in gamma power were found during meditation, with one case of a sudden and short lasting widespread doubling of gamma power linked to a subjective report of the peak of an ecstatic experience [57].

HOW MEDITATION PRACTICES COULD LEAD TO HIGH NEURONAL SYNCHRONY

Due to the limited number of studies and the variety of different meditation techniques that have been investigated in the literature (often a single study per technique or practice group), it is difficult to determine on the available evidence how particular meditation practices induce particular brain states such as high power gamma activity. However, one interpretation is that increased gamma power in meditation practice results from concentrated states of enhanced sensory or present moment awareness, particularly in skilled practitioners, where there is limited involvement of narrative or default mode processing [53]. An additional possibility is that high power localised gamma activity would be associated with neural circuits involved in the objects of working memory and attention [52]. These objects can involve focusing on somatosensory experiences of the breath, a visual image or a sound, or attention to introspective and interoceptive states, such as feelings of compassion.

Traditional models of meditation describe progressive stages of meditation associated with increased levels of concentration [59] which are similar to trance states [60]. These descriptions have considerable overlap across traditions [60], but some of the most detailed accounts are found in Theravada Buddhism [61]. These accounts describe an important first stage of concentration practice that is beyond the range of most beginners called “access concentration”. This is a highly concentrated state where external and internal distractions are reduced and have limited effect on sustained focus on objects of concentration. Practices leading to access concentration typically involve extended use of simple working memory tasks such as counting each breath or repeating a word or phrase. Following access concentration, experiences of exhilaration, euphoria, physical excitement and rapture are described to develop and persist, and with practice can be stabilised, leading to progressively increased levels of peace, calm and tranquillity. These pleasurable states can be sustained by focusing on the pleasant sensations themselves, and without continuing focus on the initial object used to develop access concentration.

One speculative account [62] with limited support from a neuroimaging study [63], is that these progressive states of meditation involve self-stimulation of reward systems, with the excitement and euphoric phase associated with release of dopamine and noradrenaline, and the more calm and blissful states associated with activation of opioid and serotonergic systems. Supporting evidence for this idea comes from research showing meditation can lead to ventral striatum dopamine release [64], and the finding of elevated levels of serotonin in long term meditators [65]. In the case of this study of an experienced practitioner going through advanced-level progressive states of meditation [63], high gamma power levels were reported in the state associated with increased euphoria and potentially elevated levels of excitatory neurotransmitters. However, detailed EEG and fMRI analysis was not reported, due to the presence of excessive muscular tension and head movements specific to this stage, symptoms which may have been caused by epileptiform activity and excessive gamma power.

The claim that excitatory neurotransmitters are released in meditative concentration states fits studies showing that dopamine and glutamate is released through the maintenance of attention in working memory tasks [66,67], via afferents to working memory circuits in the pre-frontal cortex. The activation of the unusually long lasting working memory circuits involved in concentrated states could lead to high levels of these neurotransmitters, hyper-excitability of the brain, and correspondingly high levels of neuronal synchrony, particularly in the gamma-band. One possibility to consider is whether sustained high levels of excitation and synchrony in upper frequency ranges could be considered a form of simple partial status epilepticus [68].

Studies of highly experienced meditators reveal the occurrence of “steady state” high gamma power during meditation, while at the same time appearing to avoid undesirable states associated with high synchrony in upper frequency ranges in epileptic seizures. A study of advanced Tibetan meditators [54] reported finding the highest ever recorded endogenous gamma activity in healthy subjects (according to the authors), pointing out such levels are more typically associated with epilepsy. While it is interesting to note that the report of the time it took to shift to the advanced states of meditation with the Tibetan monks (15-30 seconds) fits the temporal profile of a simple partial seizure, these monks were able to maintain such states for long time periods and exit at will.

The characterisation of a meditative state as being epileptiform based on the definition supplied earlier is that neuronal synchrony should be abnormally high and excessive [12]. In one sense the advanced meditative states associated with high power gamma activity could be considered abnormal. They are typically beyond the reach of beginners due to the level of meditation training required; the Tibetan monks in one study had 10,000-50,000 hours of practice over a range of 15-40 years [54]. However, in these studies the states of meditators showing high power gamma seem inappropriate to be described as dysfunctional, as such states were associated with subjective reports of calm, bliss or ecstasy. While the levels of gamma could be described as excessive, since the normal range of cognitive functioning does not require such high levels of gamma power, high levels of gamma synchrony may be functionally necessary for skilled execution of particular meditation practices.

Over a lifetime of practice, advanced meditators presumably develop great skill in controlling brain activity to induce, maintain and end meditative states. However, in some instances, lack of experience and control in managing hyper-excitable brain states could lead to more widespread activity, especially when concentration states are continually maintained in the presence of initially limited focal epileptiform activity. This combination of potentially excessive levels of power in high frequency ranges with high levels of excitatory neurotransmitters would be a conducive environment for the emergence of even higher frequency epileptiform activity and the occurrence of simple partial seizures; a related observation has been made previously, based on high synchrony in low frequency bands [20]. Given enough practice, meditators may ultimately develop skill in down-regulating the excitatory brain activity as working memory circuits that triggered excessive activity are disengaged and inhibitory systems are activated, leading to power reductions in high frequency brain activity. This account is consistent with anecdotal reports from teachers that describe unusual experiences as most commonly following the intense concentration states in access concentration [69]. A further factor in the development of such states is that individuals or meditation traditions may see symptoms of possible epileptiform phenomena as signs of meditation ability. Though these side effects are typically not sought after in themselves, the likelihood of such events may inadvertently be increased due to attempts to replicate those highly concentrated states, akin to a form of biofeedback.

CHALLENGES FOR UNDERSTANDING THE LINK BETWEEN MEDITATION AND EPILEPSY

The link between meditative states and epileptic seizures is necessarily speculative given the current absence of direct evidence from EEG recordings, but the account provided here gives directions to where confirmatory evidence could be found. As suggested above, meditation-induced epileptiform brain states should be most likely with intermediate meditators, especially in contexts of intensive practice. This group should have sufficient amounts of practice to reach more advanced meditative states but lack the skill in systematically inducing and controlling such states. Supporting evidence could be found in analysis of detailed subjective reports of meditators undergoing such practices, though these evidence sources are currently very limited.

A basic prediction is that evidence for simple partial seizures should be more likely in intermediate meditators, who could be classified as having a serious meditation practice for six months or greater, which may involve an hour or more of meditation per day. Further, seizure-associated symptoms should be directly linked to intensity of practice, with such symptoms more likely during retreats where meditation skill and momentum is significantly enhanced in a short space of time.

While the link between meditation practices and synchrony in different frequency ranges is not fully understood, it is hypothesised that hyper-synchronous epileptiform activity would be more likely with meditation practices involving (or following) concentration and focused attention. Anecdotal reports also suggest that unusual experiences are more likely with breath-based concentration states. Furthermore, the account suggested here predicts that epileptiform activity should be more probable at specific points within a meditation session, where there has been sufficient time to develop high synchrony and highly excited brain states, but before the emergence of more calming states that lead to inhibition. While such states may be more likely in intermediate level meditators, they still may be found in more advanced meditators [63].

Based on the suggestions outlined here, direct evidence that meditation can lead to seizures is needed from the use of standard clinical video/EEG techniques in order to show epileptiform discharges (as has been previously suggested [6]), such as sharp waves or spike-and-wave complexes. However, detecting epileptiform activity associated with simple partial seizures at the scalp is problematic, with the likelihood of detection depending on the depth and extent of ictal discharges [18]. This makes falsification of the hypothesis that particular meditation practices can cause simple partial seizures difficult without the use of intracranial recordings.

Existing electrophysiological studies of meditators (which have not been designed to detect seizures) have so far provided limited direct support for the account outlined here. One issue is the use of beginner or highly advanced subject groups. A further limitation in the available meditation research is that high gamma power is often not analysed, particularly upper gamma activity (i.e., > 50 Hz) in the range that has been linked to seizures, due to contamination of non-neural sources and movement artefacts. This is problematic for our understanding of such phenomena, especially given that muscular artefacts may themselves have a seizure-related origin. As described earlier, there is one study which found spike trains indicative of ictal discharge (paroxysmal gamma waves) during breath meditation [51], but further EEG evidence is clearly necessary.

Another prediction is that symptoms of epileptiform activity should be linked to the neural circuits involved in specific meditation practices that induce hyper-synchrony and hyper-excitability. Concentration practices are associated with activation of fronto-parietal networks involved in internalized attention, with breath focused practices additionally involving paralimbic areas such as the anterior cingulate and the insula, and emotion based practices involving frontal-limbic networks [70]. Though evidence for the occurrence of simple partial seizures would not necessarily be limited to those circuits, presentation of symptoms should be similar to what is known from studies of epileptics with epileptic foci in those regions. For example of one such link, it has been hypothesised that ecstatic seizures are connected to focal seizure activity in the anterior insula cortex [34], an area known to be involved in breath meditation [71,72].

A challenge to the present account is that very commonly reported signs of simple partial seizures and auras, such as unusual noxious or burning smells, metallic tastes, epigastric rising and déjà vu, appear to be comparatively less frequently reported by meditators. Other more severe autonomic symptoms such as incontinence and vomiting are even rarer. If meditation can lead to brain activity similar to what is seen in simple partial seizures, a further important outstanding question is why there is no clear evidence for generalization to complex partial seizures. However, epileptic and non-epileptic seizures have a wide-ranging aetiology. While a general account has been provided of how excessive neuronal synchrony could lead to epileptiform activity in meditators, specific causes may differ from typically encountered epileptic syndromes and correspondingly lead to different foci, therefore close correspondence with meditation-induced states might not always be expected. Another significant issue for the account provided here is that there are considerable diagnostic challenges in determining whether symptoms reflect simple partial seizures, mimicking psychogenic seizures, and symptoms which reflect psychogenic non-seizure related causes. For example, hallucinatory, illusional, and delusional symptoms could reflect pre-existing or undiagnosed psychiatric disorders, and factors such as psycho-social stressors, such as lack of sleep (common on meditation retreats), may influence presentation of symptoms. A further issue here is discriminating between symptoms of psychosis and epilepsy. In some cases a diagnosis of psychosis may be more clinically appropriate than seizure, especially when unusual experiences apparently triggered by meditation persist outside of meditation practice. Given that psychosis has also been associated with high gamma synchrony [42,43], further assessment of the link between meditation practices and psychosis deserves more careful consideration in future.

An additional complicating factor is that meditation is an unusual activity atypical of everyday life, characterised by co-presence of a high level of alertness and deep relaxation, normally performed while seated or lying down, with eyes closed and attention focused on interoception and meta-cognitive states. This would affect the presentation and subjective experience of preictal, ictal and postictal states compared their more typical presentation in awake and active epileptic populations. Another issue is how unusual symptoms may relate to autonomic nervous system dysfunction, such as panic attacks, which can be hard to distinguish from simple partial seizures [73]. Furthermore, some meditation practices involve unusual breathing patterns leading to hyperventilation. Here the clinical picture is complicated, as autonomic response (such as changes in breathing rate and rhythm) may result from seizure activity, but hyperventilation can make seizures more likely in epileptics [74]. In this case, unusual breathing during meditation leading to hyperventilation may increase cortical excitability and gamma activity [75], thus exacerbating the likelihood for seizures.

This paper has provided supporting evidence for the claim that meditation may lead to seizures but in doing so raises some definitional issues. Defining what is a seizure is notoriously difficult [12], particularly when we consider cases where epileptic seizures can be controlled and induced voluntarily, and can have a positive character. One perspective is to consider that if meditation can bring about pathological states which fit the profile of a seizure, then similar practices with similar neurological underpinnings that have a positive character may also appropriately be termed a form of seizure, or status epilepticus if such states are long lasting. In highlighting these correspondences, the goal is not "pathologize" the practice of meditation, but to gain insight into non-pathological and pathological brain states and the controlled and uncontrolled transitions between. While some religious or mystical experiences induced by meditative practices may be classified as pathological from a medical perspective, in some cultures such experiences may be taken to be a normal and healthy part of psychological development.

A further question is what constitutes the dividing line between epileptic and non-epileptic brain activity, and if there are any unique characteristics which allow distinguishing a meditative “seizure” from an epileptic seizure. An alternative to the question of whether meditation can induce epileptic seizures is to consider broadly the neurophysiology and behavioural effects of brain states with higher than normal excitability and synchrony. While this paper has focused on epilepsy, as noted earlier, hyper-excitability and hyper-synchrony is found in other neuropsychiatric disorders [40], such as psychosis, which may also have a relationship to the unusual experiences of meditators. Consequently, the correspondences between meditation and epilepsy might be better seen as resulting from such states being sub-types of a more general class of brain states characterised by hyper-excitation and hyper-synchrony. Recognition of these possible overlaps and relationships may further our understanding of these states and their positive and negative behavioural correlates more generally.

Due to the continued popularity of meditation worldwide, more practitioners may come across unusual experiences in meditation, either as side effects or where altered states of consciousness are sought after for their own sake. It is therefore important that unusual experiences in meditation are better understood by clinicians and within meditation communities, especially given the potential physical and mental health hazards of deliberate induction of potentially epileptic-level brain activity. On a more positive note, given that advanced meditators appear to have the ability to induce and control such states, meditation might have potential in the management and treatment of clinical disorders involving excessive excitability and synchrony.

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