Mindfulness and Asynchronous Neurofeedback: Coping with Mind Wandering

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Abstract. Mindfulness has taken over the past 25 years a status of autonomous paradigm in some medical and psychotherapeutic disciplines that have generated a pervasive interest about its clinical applications and the nourishment of the individual well-being. This tendency coexists with a technological direction that in recent years has enabled the development of personal and portable devices for EEG neurofeedback (already used to support the treatment of ADHD, DOC, autism, depression, anxiety disorders, etc.) easily usable in real life situations by the individual. We will discuss the pros and cons about the convergence between these two trends through the results of an 11 month autoetnographic study and the analysis of the data gathered during the long period usage of a personal meditation neurofeedback device.

Keywords: Mindfulness · MBSR · Neurofeedback · EEG · Quantified Self

1 Introduction

Technological advances in wearable and ubiquitous technologies have recently opened new opportunities for Quantified Self (QS). These systems aim to leverage sensors and mobile devices for collecting personal information in order to trigger self-reflection and enhance self-knowledge.

To this aim, we carried out an 11 month autoethnography, monitoring the daily session of meditation and the "quality" of this session in relationship with different intervening variables. The results of the study are somehow interesting: asynchronous neurofeedback could be considered a facilitator to overcome the notorious difficult start and continuity in mindfulness meditation and represent a valuable tool. The paper is structured as follow. Section 2 describe the present status of mindfulness in clinical and non clinical setting. Section 3 present the basic functioning and application of Neurofeedback. Section 4 describe the relationship between mindfulness, EEG and Mind Wandering. Section 5 presents the most relevant related work in relation of mindfulness and EEG/Neurofeedback. Section 6 describes the setting of our research while provides a picture of the practice of autoethnography both in anthropology and in Human-Computer Interaction. Section 7 describes results and future directions of the work. Section 8 draw some conclusions.

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2 Mindfulness Today

The term Mindfulness is the English translation of the word "Sati" in Pali language, which means "mindfulness" or "bare attention." According to the definition of Jon Kabat-Zinn, Mindfulness means "paying attention in a particular way: on purpose, in the present moment and in a non-judgmental way." It is a question of voluntarily directing attention to what is occurring in your body and around ourself, moment by moment, listening more accurately to our personal experience, and observing it for what it is, not evaluating or criticizing it. The practice of this particular "attitude of mind", that can also be defined "awareness", is derived from the Theravada Buddhism, one of the two main currents of Buddhist thought, spread from 2500 years in South Asia and Southeast Europe, especially in Burma, Cambodia, Laos, Sri Lanka and Thailand, both in the monastic and secular ambience. The use, by the western medicine, of the Mindfulness for the promotion of health is a relatively recent acquisition, which began in the 70s in the United States. The Mindfulness is a form of meditation, so it requires time, energy, determination, firmness and discipline. From the point of view of involved mental processes it is embodied in paying attention, into the present moment, to four factors: the body, the sensory perceptions (physiological, physical and psychological belonging to the large domains of the pleasant, unpleasant, mixed and neutral), the mental formations (eg. anger, sorrow or compassion) and the objects of mind (every mental formation has an object, being angry with someone and for something, etc …). The observation of these elements of subjective experience takes place in a state of genuine non-reactive calm, in which you accept what is seen for what it is, allowing change to happen naturally, without obstruct or promote them and avoiding the usual resistance or the usual judgment that cause further suffering. The primary applications have been and still remain in the clinic area: the pioneering work of Jon Kabat-Zinn, professor of medicine at the University of Massachusetts had a very wide following both in the field of medicine and in the field of psychotherapy. The backbone of the applications is based on in the liberating power of awareness. More recently, however, these applications have been extended to the field of education and organizational domain as a proposal of a real healthier and aware lifestyle. One of the most important aspects of the Mindfulness practice is to devote himself with a constant and regular commitment over time. The suggestion that is given in all of Mindfulness training is to practice, if possible, every day, even if only for ten minutes. An indication that may sound rigid and restrictive, but whose meaning is to be found in the trust about the utility of the practice: awareness is a quality potentially present in each of us that can be reinforced through constant training; the more we exercise to be present, the more awareness grows over time. And the experience itself is the strongest confirmation of this simple mechanism. However, just the constancy of practice become from the beginning of the training one of the most difficult obstacles to overcome for almost all the practitioners; a rock which often recurs over and over again, cyclically, also over the years, even in the most experienced meditators. We collect a lot of evidence of this difficulty in our courses, and our own experience is punctuated occasionally by moments when the commitment vacillate. A strong base of the mindfulness approach is the close and organic connection with the scientific thought and the research: it is born indeed from

personalities who are scientists, researchers, clinicians, and from the beginning has developed both from the field of practical experimentation, as from rigorous scientific research seeking to verify the actual effectiveness and operational mechanisms. Today, research on various issues related to the perspective of mindfulness are expanding exponentially, with several hundred research papers published each year in leading scientific journals.

3 Neurofeedback

Neurons of our brain constantly generate electrical activity recordable through electrodes placed on the scalp. The types of brain waves measured at a given time depends on the state in which the brain is. This can range from numbness and drowsiness up to a state of extreme focus and concentration. When we are involved in different activities, the electrical activity change. We mainly refers to 5 rhythms (or waves) brain: Delta, Theta, Alpha, Beta and Gamma. These rhythms differ in several aspects: the amplitude or voltage (measured in microvolt) and the frequency, defined as the number of cycles per second, measured in Hertz (Hz). Depending on their frequency we can have "slow" waves and " fast" waves. In particular the prevalence of certain brain waves show some types of mental states:

- Delta 1–4 Hz: sleep, intuition, unconscious thought
- Theta 4–8 Hz: sub-conscious thought, insight, meditative
- Alpha 8–12 Hz: neutral, peaceful, relaxed state
- Beta 15–21 Hz: being present, sustained attention, focusing,
- Gamma 33–64 Hz: integrative thinking, creativity, learning.

The nervous system works best when it is able to be flexible and change functioning even during a single activity, passing from moments of concentration to moments of thoughtfulness or creativity. However sometimes some imbalances are generated causing the preponderance of one rhythm limiting so the flexibility of CNS functioning. Therefore, as for the car gears, each band has a function and is not in itself positive or negative.

Neurofeedback is a tool through which an individual learns to change the amplitude, frequency and consistency of the electrophysiological aspects of his brain. Through neurofeedback, which allows real-time display on the monitor of a computer, of its own electroencephalographic activity, the brain is trained to produce brain waves into specific widths and in specific locations: providing immediate feedback to the brain about their operation, he becomes able to re-educate himself, until reaching the desired activity pattern. The purpose of the neurofeedback training is to teach the individual how to feel specific states of cortical activation and how to achieve these states voluntarily. Through neurofeedback training, in fact, the individual becomes aware of the different EEG states (EEG is a well-established, non-invasive, harmless method of recording the electrical activity of groups of brain cells) and becomes able to produce them when required. Many studies and research on neurofeedback have attested its effectiveness in the treatment of many clinical conditions, such as ADHD, epilepsy, anxiety, depression, chronic fatigue

syndrome, fibromyalgia, sleep disturbance, Tourette's syndrome, obsessive-compulsive disorder. The neurofeedback was also used to increase cognitive performance, in the music domain, with athletes, with business executives, and for the cognitive improvement and increase of memory in normal college students.

The practice of mindfulness was associated with a neurophysiological mechanism involving the alpha rhythm and that would be connected to our attentional capacity.

Alpha waves have moderate amplitude and average "speed". Their presence, evident especially in the back of the brain, is associated with the closing of the eyes (Alpha Blocking) and state of calm, relaxation, daydreaming (even in full wakefulness). It is interesting to note that those who pray or meditate, instinctively close their eyes, as if unconsciously wanted to achieve an "Alpha state".

3.1 Muse

Novice meditators usually struggle with two issues: knowing whether they are "doing it right," and staying motivated. Muse addresses these issues by providing real-time "state of mind" feedback, providing an engaging motivational framework. Muse is based on electroencephalography (EEG) technology and could be considered a technological advance over earlier versions of EEG neurofeedback technologies. Muse is at present the most versatile and easy-to-use EEG system available for individual use. It is designed as a personal meditation assistant. It can pair with any tablet or smartphone and operate with the Muse application, which trains the user in meditation exercises and records EEG data. Muse is also used in hospitals, clinics, and universities as a research tool. Institutions currently using Muse in research include Harvard, Stanford, MIT, Mayo Clinic, NYU, McMaster University, University of Toronto, University College London, and many others. This device uses two channels on the left and two on the right, so it is ideal for exploring hemispheric asymmetries. Muse has two micro-USB ports on the back of the ear pods where two auxiliary electrodes can be attached. These electrodes can be used to measure EMG, ECG, or EEG on other areas of the head or body. It has been tested against industry standard EEG systems including the Brain Vision actiCHamp system and the g.Tec g.USBamp system. Muse achieves comparable performance in voltage trace comparisons and in patterns of total and hemispheric power. The product is also an open platform: anyone can record raw data and anyone can build their own application. EEG data can be also recorded with MuseLab, MusePlayer, or via the third-party mobile application MuseMonitor (for Android and iOS).

4 Mind Wandering

Mind wandering is our daily and ordinary being distract from what we are doing: the daydreaming, the fantasies about the future, trying to anticipate something that we are going to do, the reliving of past scenes, the interior monologue, the imaginary conversation with someone. Mind wandering is therefore our mental life, the "movie" that flows in the head when we are not focused with our senses in a task which fully engages our attention. According to recent studies, nearly half of our mental life when we are

awake is spent in a state of mind wandering, which involves the brain regions of the Default Mode Network (DMN), composed of some very large brain nodes, as such as the medial prefrontal cortex, posterior cingulate cortex and the inferior parietal and temporal cortices. Understanding the cognitive mechanisms and the neural basis of mind wandering can also help us understand how mindfulness work, because the mental training that takes place during the practice is basically a method to decrease the mind wandering. In people who are more mindful, and which are either for personal attitude or because they train through the techniques of mindfulness meditation, we experience less brain activity in the Default Mode Network (DMN). That's why understanding the mind wandering helps to better understand mindfulness: one is the opposite of the other. Mindfulness is the tendency to focus while mind wandering is the tendency to get distracted. Neuroscience in recent years have given a valuable contribution to the understanding of the neural mechanisms involved in the mind wandering and the role of the Default Mode Network (DMN). Its specificity and its relationship with the mind wandering allowed to identify the DMN as separate from the other, both functionally and structurally.

5 Related Work

Quantified Self applications aim at increasing individuals' self-knowledge by collecting a variety of personal data [1, 2]. Recently, the range of information detectable by such applications has widely increased [3, 4]. Moreover, new techniques for collecting data needing self-reporting [5], mining and structuring information [6, 7], as well as displaying it in meaningful visualizations [8–10] have been experimented to get "naive" users closer to the activity of self-monitoring [11, 12], as well as lead to new opportunities for designing self-tracking devices [13, 14]. Finally, new design techniques to allow a serendipitous navigation through data [15], as well as gamification methods [16–19] have been employed to increase users' intrinsic motivation [20], or drive individuals toward a change in their behavior [21], foreseeing the use of game elements in self-tracking domain [22].

Among these recent advancements in the Quantified Self context, an important element is represented by the possibility of tracking aspects related to the human cognition [23], such as attention [24], reading activities [25], and memories [26]. Progress in the development of wearables is now allowing to detect and track also more complex mind-related states, like meditative states, and more precisely mindfulness states. For such states, changes in the central system have been found as the most reliable indicator [27]: these changes can be commonly tracked in lab environment with EEG using electrodes placed on the scalp.

Different studies correlated neural activities with mindfulness states [28, 29], showing, for example, an EEG lowering (lowering the alpha rhythms and appearing of theta waves) during meditation [30–35]. For example, studies with mediation masters pointed that they experience a series of EEG changes during meditation, from appearance of alpha waves, their increase in amplitude, and then decrease of their frequency, to the appearance of theta waves [28]. The lowering of the alpha rhythm has been linked

to increase in internal attention, and the increase in the theta band to relaxation, indicating that EEG measures correlates with the subjective experience of mindfulness [27].

Now, less obtrusive EEGs allow to monitor such states also outside the laboratory context. Self-monitoring one's attention is a key ability for mindfulness meditation: tracking and feeding information back about brain waves can support meditative states. This form of training is precisely provided by neurofeedback. It has been highlighted that neurofeedback can be effective in attention deficit disorder [30], epilepsy [36], learning disabilities [37] and autism spectrum disorders [38], and precisely meditation [28].

Different research successfully experimented neurofeedback as a support to mediation and mindfulness. Sensorium [39] is a neurofeedback environment that enable individuals to experience their brain waves and heart rate in the form of sounds and light effects. MeditAid [27] uses an aural neurofeedback to help users in mindfulness practices, by feeding brain activity data back through binaural bits: a user study showing that users were able to achieve a deeper level of meditation by using the system. Finally, RelaWorld [40] is a neuroadaptive virtual reality meditation system that combines virtual reality with neurofeedback to provide a tool for supporting meditation.

6 Study Outline

In our research, we recorded through a Muse device 9900 min (165 h) of meditation divided into 220 meditation sessions of 45 min over a period of 11 months. The practice of meditation adopted has always been the same: a sequence of Seated Meditation with attention to Breath, Body, Sounds, and Thoughts.

The aim was to understand how a neurofeedback device might improve adherence to daily practice or not considering the resistance that every meditator meets in the effort to keep the practice consistent over time, and if some sort of synchronous (during practice) or asynchronous (after practice) feedback could have an effect on the practice in terms of quantity or quality.

The measurements were made all by the same subject, an instructor of Mindful Based Interventionts (MBI's) with 10 years of practice. It was therefore chosen an approach based on Autoethnographic Method.

6.1 The Autoethnographic Method

Autoethnography requires that we observe ourselves observing, that we interrogate what we think and believe, and that we challenge our own assumptions, asking over and over if we have penetrated as many layers of our own defenses, fears, and insecurities as our project requires. Good autoethnography completely dissolves any idea of distance, doesn't produce 'findings', isn't generalizable, and only has credibility when is self-reflexive.

When it is done well, we can learn previously unspoken, unknown things. Autoethnography has been employed in HCI for evaluating technologies and gaining empathy with users of various types of devices [40]. It has been used in autobiographical design

as a design research method that "drawing on extensive, genuine usage by those creating or building the system" allows designers "to uncover detailed, subtle understandings that they likely wouldn't have found with other user-centered design techniques because they might seem unremarkable". The recent popularity of this kind of self-study has to be retraced to the need of finding less-demanding techniques than traditional ethnographic methods, which are very expensive in terms of time and costs. Typically, ethnography will take place over a period of several months with at least the same amount of time spent in analysis and interpretations of the observations. So they can be inscribed in those approaches called as "rapid ethnography", which aims to understand users and their environments in a shortened timeframe. By using this method we tried to overcome the difficulties in observing users in private setting, such as during meditation, gathering a variety of data that would have been impossible to collect otherwise.

6.2 Ethnographic Setting

In the light of the aspects identified above and the chosen autoethnography methodology, we choose for a 11 month period of self-observation wearing the Muse Device during each seated meditation.

The considered measures has been:

- Length and percentage of estimated (from the meditator) concentrative time on each session
- Length and percentage of concentrative time of each session measured by Muse device
- Number of attention drop (mind wandering activation) counted by Muse device
- Notation by the meditator through self report for each session of thoughts, body sensation, pleasant/unpleasant quality of the experience
- Notation by the meditator through self report for each session of the subjective perception of time
- Time of day in which the meditation was made
- Notation of the amount of sleep each day.

7 Results

The first result that shall be highlighted is that there was an almost immediate abandonment of the synchronous feedback deemed distracting instead of easing. This is probably due to the advanced level of the practitioner. Advancing in the meditation practice, there is less and less need to have a guiding voice that appeals to notice any form mind wandering. The feedback of Muse does just that, it signals the loss of focus in a way that however is itself a disruptive stimulus. Very useful appears instead to the expert meditator the presence of the asynchronous feedback, meaning the tracking of the session available after each session.

Another interesting finding relates to the estimate by the meditator of concentrative capacity during the session. This estimate is pretty accurate but suffers from a kind of *recency* effect. In particular, if we consider only the last 15 min of the EEG registration

(about one third of the session) the accuracy of the estimate has an error that varies around ±5%. If we consider the whole session the error compared to the value recorded by Muse varies around ±16%. Another aspect of estimation particularly interesting and logged during sessions regards the perception of perceived length of the session. All sessions last 45 min but at the same time the perception of time is highly variable. This is a well known phenomenon to all meditators, some sessions can "fly" while others seems to "never end". In our meditations we asked to sign the practice as "normal", "short" or "long" and what has been highlighted is that there is a close correlation between perception of time and concentrative capacity within the session. So practices that have achieved a high score in terms of maintaining the attentional focus were also the ones most often signed as "short" on the contrary those who have recorded more distractions and therefore a lower quality on attentional capacity are those that were signed more as "long." This data tells us that with the growth of the attention decreases the sense of boredom, so we can infer that the sense of boredom, a feeling often very unpleasant, is heavily based on scarce attentional capacity.

Finally we should highlight two more evidences. The first one is that the "quality" of the meditation measured through the attentional capacity (not activation of the mind wandering) strongly dependent on the amount of sleep in the previous night. The focus of activity requires a certain amount of energy. It is common that meditators especially in early stages feel very tired after meditation practices. This energy must be available. When the amount of sleep in not sufficient the energy deficit is immediately evidenced by a decreased attentional ability, from increased distractibility and a consequent feeling that the practice is more difficult and more boring. Less clear is rather the relationship with the time of day. The data in this study tell us that there are two times of the day in which the attentional capacity is systematically better: it is late morning (around 11:00) and late afternoon (around 17.00). The data have been recorded on a large number of sessions but only on one meditator so this result is obviously not generalizable. We can however suppose some causes for this. The first could be related to the distance from the meal times, particularly breakfast and lunch. It's possible that during digestion the ability to mobilize energies (also mental energies) is compromised and as such the attentional capacity would be reduced. Or it could be a simple cyclical trend linked to the personal metabolism of the meditator. Finally could be considered some aspects of greater complexity linked to changes in blood glucose or fat metabolism throughout the day. The "worst" sessions with less attentional capacity were those measured on the evening. Likely this is due to the contemporary occurrence of two conditions: the fatigue due to the day activities and the condition of digestion in place after dinner.

We were not able to highlight any aspect or any correlation between the content emerged during the sessions, both physical (pain, tension, etc.), both of mental type (thoughts, images, etc.) and the quality of the session as measured by Muse. One hypothesis could have build about a possible correlation between unpleasant feelings and content and a high score in terms of attention drop. Indeed, the data analysis did not produce such evidence.

7.1 Discussion and Further Research

The appearance of non-acceptance of the synchronous feedback from the practitioner is not generalizable, although noting the activation of mind wandering is an autonomous capacity that develops with practice and which therefore does not require in advanced phases any external feedback. To develop this autonomous capacity is actually the essence of the practice. However, to make this a generalizable insight, synchronous feedback should be tested with a sample of different meditators with different experience levels to assess if indeed there is an inverse correlation between level of experience and appreciation of the synchronous feedback.

Also about the ability to estimate the quality of the session the result does not appear generalizable. It is not possible to say how much this accuracy in estimating is a personal expression of a good awareness of the meditator involved or dependent on the experience level of the same. Again should be necessary to repeat the study with a larger sample that includes different practitioners with different levels of experience.

About the "short" perception of time in direct correlation with the degree of attentional capacity expressed in the session this only confirms a phenomenon known and widely documented in the literature. What future research could instead target is on one side, which are the unpleasant mental states connected in a large sample with the length of the session perception (boredom, restlessness, irritation, etc.) and on the other, in what amount these states may be present in clinical situations where there is a fundamental attention deficit. It is on the other hand known how this kind of unpleasant sensations are present in syndromes involving attention deficit such as ADHD (attention deficit hyperactivity disorder). Also the ability to focus as element strongly dependent from the mental energy represents a confirmation of a wel known fact in the literature. More interesting seems the relationship with the hour of the day but it was not possible to determine the origin. It is possible that aspects related to the digestion process are interfering with the mobilization of energy necessary to feed up the attentional capacity. However this is only an hypothesis that requires a thorough study on the relationship between attention and specific components of the meal (sugars, fats, proteins, etc.) in a sample on which assess the attention capacity in a laboratory setting.

Finally, our study did not reveal anything significant about the relationship between emerging content during sessions (or at least pleasant/unpleasant feeling) and the number of attention drop and mind wandering activation. A research of particular interest in this regard would require evidence from large numbers and big data from a worldwide network. Some experiments have been attempted to do so by platforms such as Dreamboard on dreams, an interesting variation would bring this same logic of distributed collection on the domain of meditative content.

8 Conclusions

The suggestion that is given in all Mindfulness training is to practice, if possible, every day, even if only for ten minutes. An indication that may sound rigid and restrictive, but whose meaning is to be found in the trust about the utility of the practice: awareness is a quality potentially present in each of us that can be reinforced through constant

training; the more we exercise to be present, the more awareness grows over time. And the experience itself is the strongest confirmation of this simple mechanism. However, just the constancy of practice become from the beginning of the training one of the most difficult obstacles to overcome for almost all the practitioners; a rock which often recurs over and over again, cyclically, also over the years, even in the most experienced meditators.

These difficulties take the form of resistances. We can talk about internal resistance when they come by the individual himself (*I can not stand the boredom, I am not able, I feel pain, I can not sit still, I do not experience the benefits*). We can talk about external resistances if the individual attributes his difficulties with practice to external causes (*not enough time, I do not have a suitable space, I don't have a place to be alone, there are too many distractions*). The role of the asynchronous neurofeedback helps to overcome at least in part this resistance, especially on the meditator in the early stages of practice, when the value of repeatability and consistency has not yet grasped. This is similar with what happens using a fitness tracker: the neurofeedaback provides personal data relating to the practice which allow to derive some personal evidence. For example it is difficult to meditate after a big meal or it is easier when you are rested. This allows to make the sessions more concentrative, making the duration perceptually faster, experiencing less boredom or restlessness or other unpleasant sensations creating that wealth meditation amount that at some point will become a critical mass capable of perpetuating itself even in difficult times, which necessarily will come. We can consider neurofeedback a facilitator to overcome the initial obstacle of practice continuity and as such has a big impact for beginners. However, there is a risk: to transform the mediation practice into a performance, in a target score to reach or to improve. This approach would lead away from the deep intention inborn with mindfulness meditation and as such should always avoided carefully.

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