Visualising the Meditating Mind: The Aesthetics of Brainwawe Data

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Abstract

Meditation is an ancient Eastern practice, which is receiving renewed popularity as a secular approach to health and well-being. Recent advances in commercial EEG sensor technology provide opportunities for visualising biological brainwave data by artists and designers, outside the fields of neuroscience and psychiatry. We chart the creative development of an aesthetic visualisation, *Narcissus Brainwave* that aims to provide insight into the shifting states of mind during the practice of meditation, informed by a series of user studies with meditators and non-meditators. Interestingly, assumptions we made from the interpretation of brainwave sensor data about when a meditative state was achieved did not always resonate with how meditators understood the quality of their inner meditation experience. This may be due in part to the limitations of a single electrode EEG device. Issues also arose related to personal preferences and cultural conventions for interpreting the meaning of the Buddhist-inspired visual symbols representing our model of meditation. Our study has revealed some of the challenges of visualising the meditating mind and creating meaningful aesthetic visualisations with commercial devices.

Keywords

Biological Data, Brainwaves, EEG, Meditation, Mindfulness,Visualisation

Introduction

Meditation is an ancient Eastern practice, now recognised as leading to benefits in health and wellbeing (Kabat-Zinn 1998, Keng 2011, Greenberg 2012). Despite the rising popularity of secular meditation in the West, novice and experienced meditators can struggle to maintain a regular practice. One of the issues facing meditators is that they may not know whether they have successfully entered into a state of meditation during their practice. In order to address this difficulty, this research aims to provide tools to visualise the participants' biological brainwave data during meditation to help them practice. It is based on the assumption that when the mind enters a meditative state it has specific patterns of brainwave data that can be visualised as unique patterns. Scientific studies of the brainwave activity of experienced meditators suggest that this is the case (e.g., Fell et al., 2010).

This project aspires to go beyond traditional graphical presentations of biological brainwave data common in the sciences to the application of aesthetic approaches to data visualisation. Artists and designers are beginning to create visual works depicting the activity of the brain, with new opportunities arising from the recent introduction of commercial electroencephalogram (EEG) devices. We created a custom- built software program, entitled *Narcissus Brainwave* that uses symbols from Buddhist mandalas to visualise different brainwave states in meditation, and brainwave data from the Neurosky Mindwave device.

The focus of this paper is not on the technical development of *Narcissus Brainwave*; instead we explore the challenges in designing aesthetic visualisations using biological data captured from commercial brainwave sensors. Our objectives were to reflect the qualities of the inner experience of meditation, and to evoke similar qualities in the viewer. Towards that end, we developed dynamically changing visual designs that aimed to depict the meditating mind and to resonate with meditators' interpretations of their inner meditation experience. However, as we will see in this paper, this is not as straightforward as it seems.

In this paper, we first briefly describe the historical background of meditation and mindfulness. Then the use of EEGs for visualising brainwave activity to capture data is discussed through reference to key scientific and artistic studies. We illustrate and explain the visual design and interactive behavior of the aesthetic visualisation tool, *Narcissus Brainwave*, followed by a description of the underlying model of meditation. The

development of the software program that generates the visualisation is described in terms of the series of user studies conducted to understand the nature of visualising biological brainwave data in meditation and how the data from the studies informed design choices for the tool. Finally, our paper concludes with a discussion of the key challenges we encountered in aesthetic visual design for representing the meditating mind and creating meaningful aesthetic visualisations with commercial devices.

Literature Review

Meditation and Mindfulness

Meditation has been an integral part of pan-Buddhist Asian cultures for the past 2,500 years (Otani, 2003, p. 97). It is utilised by various religious and spiritual groups throughout the world, in particular by Buddhist monks for spiritual training. Meditation is thought to be a useful skill to learn and use to discipline and heal the mind and spirit. Buddhist meditation encompasses a variety of meditation techniques that aim to develop concentration, tranquillity, and insight (Fernando 2010). More generally, meditation is considered a form of mental training. The word *meditate* stems from Latin *meditatum*; to ponder. Meditation promotes concentration and relaxation, to help manage emotional states through focussed attention.

Increasingly, around the world non -Buddhists are adopting Buddhist meditation techniques; these techniques are progressively used by psychologists and psychiatrists to help alleviate a variety of health conditions such as chronic pain, anxiety and depression, sleep apnea and stress management (Gotink, Chu et al. 2015). Currently, the most widely researched is the secular form: mindfulness meditation (Kabat-Zinn 1998, Hofmann 2010).

Measuring Brainwave Data in Meditation

EEGs capture biological data from, and record, the electrical activity of the brain. An EEG measures the way brain cells communicate by producing electrical signals. In 1924 Hans Berger recorded the first human brain activity with an EEG (Collura 1993). The EEG was adopted by clinicians and scientists to observe brain wave patterns. Human brainwaves have been classified into five types: Gamma, Beta, Alpha, Theta, Delta.

The change of consciousness through meditation is recognisable by its brainwave status. Brainwave readings taken during a normal day and during normal activities show the beta brainwave status to be dominant (Teplan, 2002, p. 3). Alpha brainwave activity is induced by closing the eyes and by relaxation. It is diminished by eye opening or by mental activity such as thinking or calculating. When people close their eyes, their brainwave pattern significantly changes from beta into alpha waves (Teplan 2002, p. 3). The most dominant effect in the majority of studies on meditation is a state-related slowing of the alpha brainwave rhythm in combination with an increase in the alpha brainwave amplitude (Fell et al., 2010, p. 220).

Researchers have found that low amplitude alpha brainwaves may reflect stressed states. Unpleasant acoustic stimuli reduced the amplitude of low alpha brainwaves by approximately 20% (Nishifuji et al., 2010). A similar observation was made in our preliminary study, where decreased amplitudes of alpha brainwaves took place at times of external distraction such as an unpleasant sound.

The key scientific findings we applied in the design of our visualisation tool were the increase in alpha brainwaves during relaxation and meditation, both in terms of a slowing down or decrease in frequency, and an increase in amplitude. In a study of mindfulness meditation, alpha brainwaves have been linked to an increase in internal attention and an increase in theta brainwaves to relaxation (Haupt and Fell 2007). We used this distinction between relaxation and meditation as a key parameter in our model of meditation, by employing the ratio between alpha and theta brainwaves as a threshold indicator between calculated states of relaxation and meditation.

Artistic Visualisation of Brainwave Data

Although historically, EEG devices were used in psychiatry and neuroscience, these devices are now being employed by artists and designers to visualise brainwave data. Currently, there are only a few examples of artistic visualisations of brainwave activity related to meditation. We discuss three projects that use bespoke software programs and commercial EEG headsets to visualise brainwave data in meditation, and focus on the aesthetic aspects of the artistic works.

Andreas Borg's *Alhambra Mandalas* (2012) is an artistic visualization developed using Islamic patterns found in the Alhambra castle in Granada, Spain. Similar to Narcissus Brainwave, the work was inspired

by the idea of mandala patterns, which are created when the user achieves a specific state of mindfulness meditation. Users can interact with the artwork by wearing a Neurosky Mindwave headset. The result is a continuously evolving tapestry varying according to the values of brainwave data. The parameters used are raw signals of brainwaves and attention and meditation values provided by the Neurosky device. It creates symmetrical patterns depending on the values of brainwave status. Whilst the artwork is visually sophisticated, it does not include any user evaluation nor provide users with insight into their meditation practice.

Visualise Your Mind (2015) created by Zhepeng Rui is an example of a visualisation that represents participants' brainwaves in meditation using the Neurosky Mindwave headset. It has a Mind Painting feature, which creates unique abstract paintings in real-time based on brainwave data. The colours of the seven chakra centres were used to convey different states of meditation. Whilst the coloured lines are aesthetically pleasing and convey some level of abstract information about the nature of brainwave activity recorded by the Neurosky headset, they fall short of providing more precise and insightful information about the nature and quality of meditation. More details of this work can be found at de Bérigny et al. (2016).

George Khut's *Behind Your Eyes, Between Your Ears* (2015) is an example of the use of visual and sonic representation of brainwaves in meditation. This artistic work invites a participant to sit down, put on a wireless Muse EEG sensor and relax in meditation. Changes in the amplitude of alpha brainwave activity recorded from four electrodes along the front and side of the participant's head, are used to modulate sound textures and layers of graphics. The work aims to help the user to enter into a meditative state, and to explore and reflect on their ability to sense and then move voluntarily between these two states. Participants interact with the work with their eyes closed in meditation, whilst observers can watch a video of the participant overlaid with the graphics being modulated by their alpha brainwave activity. The visual material references "photographic idioms from sci-fi, to 70's aura-photography and 19th Century spiritualist imaging" (Khut, 2015) and provides observers with some indication of the meditator's state of mind, but in a non-didactic, evocative manner.

All three examples discussed above illustrate the variety of approaches to using brainwave data to generate artistic visualisations. They reveal to various degrees through abstract patterns, the ever-changing mental activity of the mind, and offer new ways of understanding and influencing states of consciousness through the application of aesthetic strategies. Now we turn to the development of our aesthetic visualization tool, *Narcissus Brainwave*, where we explore some of the challenges of visualising the meditating mind.

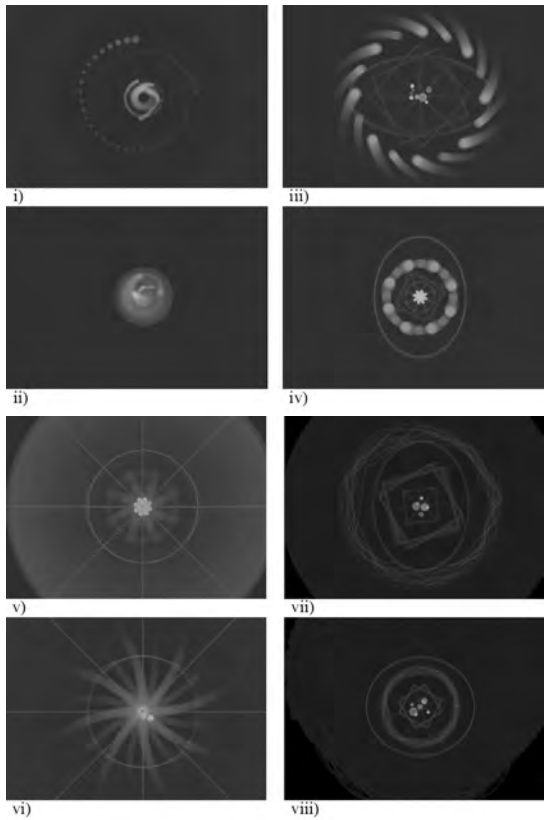

Figure 1 The visual patterns related to each stage of the meditation model

Developing Narcissus Brainwave

Narcissus Brainwave is an aesthetic visualisation, allowing users to observe their brainwave data in different states. It is composed of a custom-built software program, implemented in Processing (processing.org) that takes EEG data and creates a dynamically changing visualisation. We used the Neurosky Mindwave

headset, a commercially available non-invasive type of brainwave sensor that is attached to the forehead and ear of the user and wirelessly transmits raw EEG data to a computer.

In this section, we first present and explain the visual design based on the Buddhist Mandala symbology. The underlying model of meditation is then introduced. This is followed by the key phases of development of the visualisation tool through a series of user studies, including how the model of meditation was modified as a result of the findings from the user studies. The technical description of the visualisation tool and development process is limited to providing sufficient information in order to comprehend the model of meditation and the design of the visualisation tool.

The Buddhist Mandala Symbology

Symbols derived from Buddhist mandalas were chosen as the primary visual metaphor to visualise dynamic changes in brainwave activity during meditation. The third author who was responsible for the technical development of this tool has a Korean cultural background, where Buddhism is the primary spiritual practice. The word Mandala in Sanskrit means circle. Mandalas and circles symbolise the cycle of life (Laine 2009). Even though not all mandalas are circular, they are traditionally symmetrical, and believed to inform the wisdom behind sacred geometry. Traditionally, Mandalas are circular diagrams enclosing a square, which are used to 'support of an act of spiritual concentration' (Stutley and Stutley 1977). The circle represents unity and the square the essence of Buddha. Mandalas are also used as images for reflection in meditation. Mandalas in Eastern traditions are believed to represent the cosmos, the universe, and people, in which bodily, psychological and spiritual aspects are represented. This signifies the journey of the individual toward wholeness (O'Nuallain 2009).

Tibetan monks spend approximately two weeks creating sand Mandalas from grains of coloured sand, whilst the act of destroying the mandalas takes only a few minutes. Monks divide the Mandala circle into eight parts and sweep the grains of the Mandala toward the centre. The coloured sands is swept away and destroyed. The process of creation and destruction of the Mandala ceremony illustrates that all form is impermanent, by highlighting the Buddhist concepts of non-attachment. This ritual symbolic practice underlies the visual design and dynamic behavior of Narcissus Brainwave.

The Visual Design of Narcissus Brainwave

The model of meditation was translated into a specific visual design, incorporating the visual metaphor of the Buddhist mandala. The key stages and rules of the visualisation are illustrated and explained below, with reference to Figure 1.

Normal Status During normal status (non-meditation-like status), as complex brainwave activity was observed, this was illustrated in the design by circles moving in a spiral towards the centre at a fast pace (see Figure 1 (i)). The amplitudes of each type of brainwave are displayed as a distance from the centre. Each colour represents each brainwave (blue: theta, red: low alpha, green: high alpha, purple: low beta, dark purple: high beta, yellow: low gamma (see Figure 1 (ii)). This visual appears when the EEG sensor receives over the threshold amplitude of theta brainwave.

Meditation Status As the user gets into a continuous meditation state, shapes begin to appear. Fast orbiting patterns morph into a slower paced mandala pattern (see Figure 1 (iii)). The rotational speed of all elements slows down to reflect the calm state of the mind in meditation. When the outer circles are red, they represent a low alpha brainwave. When the alpha brainwave frequency increases to high alpha range, the red circles change into green circles. The size of the pattern is determined by the ratio between alpha brainwave and theta brainwave. If the alpha amplitude is registered higher than the theta, the mandala patterns are larger than if the inverse occurs. The brainwave signals (excluding alpha and theta) are visualized as circles inside the large square. The smaller circles' size and colour are dependent on the amplitude of brainwave data. Another square was added that rotates at a different speed from the first square to develop more dynamic visuals.

Deep Meditation Status There is a significant parameter, sustainability. When meditation status is sustained without any distraction, the sustainability value will be increased. If the sustainability value exceeds a certain level, the lotus appears in the centre (see Figure 1 (iv)). This lotus state expresses a deep meditation status. The size of the lotus changes in proportion to the time in which this deeper status is maintained. The colour of the lotus changes, depending on the amplitude of brainwaves in each frame (low beta, high beta, low gamma and mid gamma). The lotus

colour appears followed by a gradient colour from the highest brainwave to the lowest. Eight circles between the outer red (low alpha) or green (high alpha) circles were added to create a more circular image.

Distraction Status Distraction causes the Mandala pattern to move back to the normal brainwave status. The mandala breaks into eight divisions indicated by blue lines emerging from the centre (see Figure 1 (vi)). The whole pattern shrinks down to the centre and expands outward with a blue hue (see Figure 1 (v)) - this symbolises the dissolution of the Tibetan sand Mandala at completion.

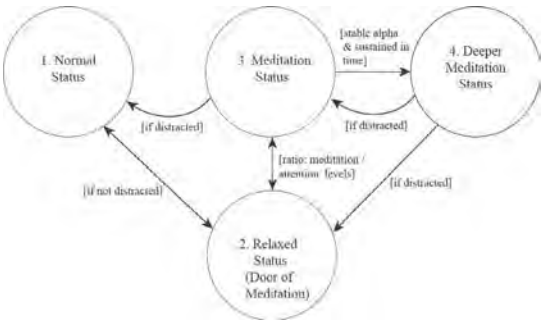

Figure 2: Model of Meditation State Diagram

Relaxed Status This status is the Door of Meditation. It can be interpreted as a shallow meditative status or a relaxed status without any distraction. The noise effect of the wavy circular lines will appear as the brainwave pattern eases closer to the meditation status and it slowly changes into the Mandala pattern (see Figure 1 (vii)). In this status, there is no distraction, but attention level is equal or higher than the meditation level. The outer circles in the mandala pattern would morph into a circle with noise. As the meditation level increased, noise in the outer circle would settle down into solid round lines (see Figure 1 (viii)).

The Model of Meditation

A model of meditation underlying the visualisation tool for *Narcissus Brainwave* is presented below. It emerged through a process of iterative technical prototyping and a series of two user studies. The state diagram in Figure 2 illustrates the key stages of the model of meditation. Each stage (or status) is defined in Table 1. The attention and meditation levels are designed as key parameters to deter-mine the timing of transitions, the size of the pattern and elements within it, and the stage of the model. The relative levels of alpha and theta brainwaves play a critical role too. See Table 1 for details of how these parameters are used to define, and transition between, the stages of the model.

Stage	Status	Interpretation	Attention and mediation level
1	Normal	State of intellectual activity, quite sensitive to external stimuli, and the opposite state of meditation.	Attention > meditation Theta brainwave > 32uV
	Normal - Attention	Occurring in normal status, it is caused by concentration.	Over 150000 ASIC EEG power units of theta brainwave.
	Normal-Distration	Occurring in meditation status, it is caused by internal or external stimuli.	Over 150000 ASIC EEG power units of theta brainwave.
2	Relaxed (Door of Medita-tion)	Attempting to meditate, relaxed, not particularly interested in anything. Intermediate state between normal and meditation status, low level of alpha and theta brainwave.	Attention >= meditation Theta brainwave < 32uV
3	Meditation	State of freedom from thoughts, alpha brainwave status, low level of theta brainwave.	Meditation > attention Theta brainwave < 32uV
4	Deeper meditation	A deeper level of meditation indicat-ed by stable alpha brainwave activity, for a sustained period of time.	Meditation > attention Ability to not get distracted

Table 1. Stages in the model of meditation

Developing the Model of Meditation

For the user studies, trained meditators and non-meditators were recruited to explore the nature of brainwave activity during stages of meditation, and to inform the model of meditation and corresponding rules for the visualisation tool.

Understanding Brainwave Data

In the first study, brainwave data was gathered from six meditators and six non-meditators. Participants were asked to perform two activities: i) Read a book, and ii) meditate for 10 minutes using their usual technique, or if a non-meditator, to perform the Zen technique of counting from 1 to 10 and back on each breath. Participants were asked to fill in a questionnaire so we could understand what was happening during their meditative experience for interpretation of the brainwave data.

Analysis of the brainwave patterns identified differences between the two groups (meditators vs. non-meditators), and was used as the basis to formulate a preliminary set of rules for the visualisation tool. The key findings are summarised here, with a view to informing the model and rules. It should be noted that our interpretation of the different types of EEG data may not correspond to those of scientific studies, as it is shaped by the limitations of the Neurosky Mindwave headset (see Discussion).

We can see from the graphs in Figure 3 that during the activity of reading a book, participants' brainwaves were seen to be more active than during the meditation activity. The most dominant brainwave recorded each second when not meditating was mostly the theta brainwave. The amplitude of theta (blue) brainwaves reduced when participants were meditating. During the meditation activity, red (low alpha) and green (high alpha) are the most dominant brainwaves, as expected from scientific studies.

When external distraction (especially noise) occurred, an increase of theta (blue) brainwaves was observed (the spikes in the graph). On examining the graph in Figure 3 (ii) we can see that the participant with no meditation experience was distracted several times, however this participant's brainwave was fairly constant in meditation status as indicated by the levels of high alpha (green) brainwaves. In Figure 3 (iv) the participant's (5 years experience) most dominant brainwave is high alpha (green) brainwave, which was relatively stable despite the occurrence of distractions. In Figure 3 (vi) the participant's (13 years experience) most dominant brainwave is low alpha brainwave (red). More distraction stimuli (loud sound) occurred for the 13 years experienced meditator, however that person never got fully distracted, and the alpha brainwave amplitudes were very high and constant. After the meditation session was completed, the participant of 13 years experience was asked about the distraction and answered that it had been felt as a vibration, but did not affect the participant because the Mantra practice created a buffering barrier in the mind deflecting the distraction. It can be observed

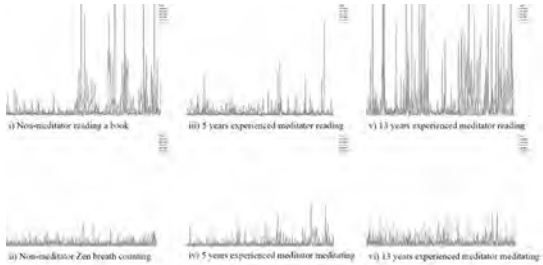

Figure 3: Graphed brainwave data of participants of varying meditation experience, either reading a book (i, iii, v) or practicing a meditation technique (ii, iv, vi)

therefore that the more experienced meditator's brainwaves were more stable than those less experienced.

These observations would indicate that – in the context of this study - the theta brainwave is connected to attention and distraction levels. When the attention level increased in normal status or distraction happened in meditation status, then the theta brainwave amplitude also increased over a threshold (150000 ASIC EEG power units, about 32.9 micro volts). Typical amplitude of the basic human theta brainwave is higher than 30 microvolts (Sałabun, 2014). Also the ratio between the peak level of alpha brainwave and the peak level of theta brainwave recorded each second, differs according to the level of experience. The more experienced meditator's ratio between alpha and theta waves was larger, inferring that meditation status could be calculated by the ratio of alpha to theta – this became an important parameter in our model.

This first user study informed the first version of the model of meditation. The rules of the model were focused on representing 'sustainability' of a meditative state of mind, and 'distraction'. Participants were sensitive to external stimuli such as noise if it occurred during meditation. This was applied to the 'distraction' effect and it was interpreted as a negative moment and not in the meditative state. For the purposes of creating a working model of meditation for the visualization tool, we mapped theta brainwaves to attention. In the non-meditation state, attention is interpreted as a positive factor in this research. However, attention is interpreted

as a negative factor and called 'distraction' in the meditation state.

In psychology and cognitive neuroscience, 'attention' is a polar opposite concept to 'distraction'. Both fields use the definition of attention, which was first defined by William James in the late 19th century (James 2007). Attention is defined as focusing on one thing whilst ignoring other things happening at the same time. In our model of meditation, we decided to work with levels of attention and distraction as represented by theta brainwaves. The choice of theta waves was related to how the Neurosky Mindwave measured brainwave activity via the single electrode attached to the forehead. It is possible that other headsets or higher-resolution devices may produce different readings, leading to a different mapping between types of brainwaves and categories of mental activity.

User Evaluation of Visualisation Tool

In the second study, 11 participants were asked to evaluate recorded sets of brainwave visualisation patterns, generated by the initial version of the visualisation tool using the data from the first study. The aim of this study was to find out how well the visualisations enabled the viewers to differentiate between trained meditators and non-meditators. The majority of participants (7 out of 11) were able to discern the differences in the patterns of data from meditators and non-meditators. They perceived scale, colour and the rate of change as the most important variables to differentiate visualised patterns representing the different stages in the meditation model.

Regarding scale, most participants found expansion of the shapes to indicate a deeper level of meditation. In the design, expansion represents a deeper meditation status and lower level of attention, which is considered as a positive status in terms of meditation. Contraction means opposite to expansion. As a variable, both expansion and contraction are the same criteria used to describe two opposite statuses.

In the mandala patterns, there are colour changes between red circles, and in certain frames several circles were blue. Participants interpreted the blue colour as distractions because of the breaking apart effect it caused in the manda-la pattern. The colour code has been changed to eliminate the blue (in RGB colour code to avoid this misinterpretation, blue value goes from 0 to 125 and never exceeds red or green values).

Some participants encountered difficulties in discerning between the stage of meditation and the stage of deeper meditation, because the difference was only indicated by the size of the whole pattern. This confusion led to changes in the model and visualisation rules to enable clearer differentiation between the two stages.

Adding the Door of Meditation The participants were also asked to contribute their brainwave recordings, obtained in the same way as the first study, in order to increase the sample size for data analysis. One important observation led to a major change in the model of meditation.

When participants opened their eyes after meditation, in the first version the mandala pattern would typically break into particles, symbolising a level of distraction. Surprisingly, several participants did not break the mandala patterns; even when they opened their eyes they appeared to remain in a state of meditation. Their status remained relaxed and they did not have any high values of attention or distraction. Even if there was no distraction, the outer mandala circles shrank down to minimum size. This was interpreted as the meditation level decreasing to less than the attention level (size is determined by the ratio between meditation level and attention level). As a result, one more variable was added in the code to measure how relaxed people are.

Through the observation of the brainwaves becoming calm in the state where there was no distraction right after the meditation, this was considered as a relaxed state, which is not actually in the meditation state itself. This state was described as the 'Door of meditation' and it was added to the model; to signify the door to enter a state of meditation. Previously participants could create the mandala patterns if they stayed calm and relaxed with low amplitude of brainwaves. After the Door of Meditation was added to the model, it was not as easy to create mandala patterns as before. This may not be an entirely accurate representation of the meditating mind, but it is a first approximation to a working model of meditation for visual design exploration.

Evaluation by Meditators of Their Own Data

In the third study, 10 participants were invited to meditate for 10 minutes whilst having their brainwave activity recorded with the visualisation tool. The aim of this study was to evaluate how well the visualisations reflected the personal inner experience of the meditation session, by the meditators themselves. After the

meditation session, the participants watched four minutes of the visualisations they created with their own brainwaves and then filled in a questionnaire related to describing the quality of their current body/mind state and sense-making of the visualisations. The final task was a video-cued recall in which they were asked to interpret and match the displayed imagery with their just experienced meditation session.

The participants were able to easily differentiate between the four stages of the meditation model, however they found it difficult to distinguish the meaning of the different stages. Most of the participants had no prior knowledge of the rules for the visualisation. Personal preference of the colours and visuals was the major factor when interpreting the meaning of the stages. P2 and P8 correctly interpreted stage 1 as a distracted state and felt that the red and green colours of the circles and squares in stages 2 – 4 represented a calm meditative state. In contrast, P4 and P5 described the blue flash in stage 1 as a calming presence, which represented in their opinion a meditative moment or state. This is contrary to the intent of the visual design for the blue symbol to represent distraction.

The shapes in stages 2 – 4 were also interpreted differently. P4, P5, and P7 thought that the squares represented thoughts and conflict, while achieving a state of meditation was represented with the circular shapes. For example, P7 depicted the squares as work, circles as life and the blue pulse as his children, while others such as P5 interpreted the squares as thoughts and the round objects as representing his meditative states.

Generally, participants found it difficult to align their personal meditative experience to the visualisations, with only P8 and P9 stating that the visualisations represented their inner meditative process very accurately, and only P4 felt that watching the recorded visualisation was somehow like meditating again. When watching the visualisations, 3 out of the 10 participants found their curiosity increased when they focused on the mandala patterns.

The expansion and contraction of the mandala patterns were obvious for almost all of the participants and they understood that the adjustment in size was a change in state. However, similar to the colour and shape opinions, participants had contradicting ideas about the meanings of the change in size. Some of the participants, such as P2, expressed that the smaller mandala patterns represented a need to concentrate, while P3, P4, and P6 thought the smaller pattern represented concentration and calmness.

Visualising the Meditating Mind: Challenges

Now we discuss the challenges revealed through our studies in creating aesthetic visual designs for representing the meditating mind. Of particular interest are the findings from the third user study, where we probed participants about their interpretations of the visualisations and whether the choice of pattern designs reflected their personal inner experience of meditation. As described in the previous section, there were conflicting interpretations of what the symbols, shapes and colours were supposed to represent. The major issue revealed through this third study is the tension between users' personal interpretations of the quality of their meditation and how it should be depicted through the visualisation, and what the brainwave sensor data is telling us about the meditating mind.

Although many participants in the second study could logically infer the meaning of the visualisation and link the visual parameters to concepts of meditation such as slowing of speed representing a tranquil mind, and expanding circles as representing going deeper into meditation, most participants in the third study found little connection between their own experience of meditation and the interpretation of the visualisation. Two aspects of the visual design stand out as contentious.

The first aspect is the use of the Buddhist mandala symbol, and the associated shapes and colours. Central to the mandala symbol is the combination of the circle and the square, representing unity and the essence of the Buddha, respectively. These shapes and the various colours found in Buddhist mandalas were incorporated in the visual design. For those participants not familiar with the cultural and spiritual meaning of these symbols, they found the geometry of the square jarring with their idea of how the qualities of meditation should be visually represented. The colours of bright red and green often appear in mandala illustrations, and thus were mapped to low and high alpha brainwave signals. However, some people disliked the use of these two bright colours and interpreted them according to Western convention as red meaning danger/heat. Thus, some participants found it confusing when red appeared in the stage of the visualisation representing a state of meditation.

This lack of consensus on what the patterns represent means the visualisation tool can be incorrectly

interpreted by participants. Therefore, it might be useful to note that either the participants should be aware of the mandala patterns' meanings or the participants should be able to customize the visualisations to their own preference.

The second aspect is the meaning of the blue flash as depicting a level of distraction. The observation that some participants interpreted the blue flash as a moment of meditation, instead of distraction, runs contrary to the assumptions we held in interpreting the sensor data. Interestingly, what this reveals about the personal experience of meditation, is that many meditators evaluate their own experience during the practice of meditation as having only fleeting moments of what they deem to be 'in a meditative state'. In contrast, from the first and second study, we could see relatively stable brainwave signals indicating the presence of alpha brainwaves, especially for experienced meditators. For most participants, a loud noise acted as a distraction, which registered as a spike in the theta brainwave signal, often accompanied by a decrease in alpha brainwaves. The relative interplay between calculated values of distraction, attention and meditation based on the sensor data were fundamental to the model of meditation we developed and the associated visualisation rules.

It should be noted that our model of meditation is contingent upon the reliability of the data provided by the Neurosky sensor. The error of the device is too high for clinical use (Roesler, Bader et al., 2014). Some important differences must be highlighted between the data from the single electrode of the Neurosky and scientific studies with full head coverage by multiple electrodes. Due to the positioning of the electrode on the forehead, the EEG data is limited to the frontal lobe of the brain – this will impact on the kind of data measured and how we can interpret the data. Scientific studies have shown that the alpha amplitude of the occipital region of the brain is bigger than that of the frontal lobe. However, when we recorded normal status and meditation status with the Neurosky, the biggest difference between the two was the theta amplitude. This led to the decision to interpret the level of theta brainwave amplitude as an indicator of distraction, in combination with the levels of alpha brainwaves.

Commercial flexible sensors like the Neurosky or another EEG headbands do not have as many sensors as clinical devices. We are aware of this potential issue, but do not see it as an obstacle to a first step in design exploration of appropriate aesthetic visualisation patterns to represent dynamically changing brain states in meditation. The knowledge gained through this design exploration process can be applied to future improvements, and adapted to the type of data provided by different brainwave sensors.

Conclusion and Future Work

Our paper explored the design of a visualisation tool by examining the aesthetics of brainwave data in the creative process. We presented the results and findings of the development of the visualisation tool that aesthetically represents brainwave data of meditators using a commercial EEG sensor. Despite positive results in the second user study regarding the ability of viewers to discern between meditators and non-meditators, a third user evaluation study revealed some issues regarding how well the visual design aligned with the inner experience of the meditators.

More investigation is required into the effect on brainwave data of longer (than 10 minutes) durations of meditation, which could lead to a revision of the meditation model. Future development of Narcissus Brainwave will include a fourth user evaluation to determine if changes in the visualisation can better assist participants to understand the states more clearly, and more authentically reflect the complexities of the inner experience of the meditating mind.

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