Performing Sleep/Wake Cycles: An Arts-Science Dialogue through Embodied Technologies

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performance, cross-disciplinary collaboration, wearable technology, interactivity, sleep science

Abstract

This paper describes an arts-science collaborative project titled Standing Waves, which creatively entwines data drawn from the rhythms of the body in sleep/wake cycles with sensor-based technology for synaesthetic performance. The project partners situate their practice and research in the fields of choreography/dance, sleep science and media art and design. Our work explores how the non-literalness of scientific phenomena can be embodied in interactive performance and made meaningful for audiences. The aim of this collaboration is to create a unique performance ecology, by bringing together elements of the collaborators' respective disciplines and expertise and experimenting within the areas of intersection.

The Standing Waves performance system involves wearable electronic sensor technology to allow a dancer to interact with a malleable sound environment. Sensing the body, its gestures, and its environment through the measurement of light and acceleration, the 'sensor suit' allows the dancer to intuitively control sound. In turn, the sonic feedback influences the emerging choreographic score, inducing constraints and generative cyclic patterns for movement. This feedback loop between movement and sonic state creates waves of sensation heightening the experience of the space as a perceptible field of embodied technology. The performance exists at the threshold between the figurative and the factual as it takes data and information from the lab practice of a sleep scientist and reinterprets this within the condition of a performance environment, effectively making visible the dynamic processes of subtle physiological phenomena.

Intersecting pathways

Standing Waves was initiated in early 2010 when the project partners met at a workshop titled Waking Incubator. Held at the Sleep/Wake Research Centre in Wellington, New Zealand, this workshop brought artists from various backgrounds together with sleep science researchers. Stimulating a trans-disciplinary dialogue was one of the intentions the organisers Sam Trubridge and Philippa Gander held for this one-week event. Not only did the participants enjoy a rewarding exchange through dialogue, but practical experimentation was also a welcome part of the process. A large industrial space adjacent to the Sleep/Wake Research Centre was made available for use, as were parts of the Centre itself, such as the sleep laboratories.

Participating in the Waking Incubator was a gratifying experience – the open format encouraged a critical investigation of the relationship between the disciplines, as well as playful interaction. Early in the process, clichés were dismantled and misconceptions uncovered. This led to identifying differences amongst the varied practitioners, but eventually ushered forth the forging of liaisons and the constitution of collaborative teams. This culminated in a confidence in trans-disciplinary

communication, not only between the arts and sciences, but also between the various disciplines within the larger fields.

Intersecting rhythms

Several collaborative projects were seeded during the workshop, Standing Waves being one of them. The first iteration of the project was triggered by a thread of discussions evolving around cycles within sleep, and the daily sleep/wake cycle driven by the circadian clock. The circadian clock is an ancient adaptation to life on our 24-hour rotating planet (even cyanobacteria have something equivalent, which means that circadian clocks have been around for several billion years).

A feature of circadian clocks is that they are light sensitive: the human circadian clock monitors light intensity through a special input pathway from the eyes that is not involved in vision. Being light sensitive enables the circadian clock to 'lock on' to the 24-hour day/night cycle, which is a key feature of its usefulness for most species, making them diurnal or nocturnal as needed to enhance their survival. However, it has become a disadvantage in the 24/7 society, because it causes the human circadian body clock to resist adaptation to any pattern other than sleep at night.

The 24-hour rotation of the planet is only one of many that influences life on earth. The 28-day cycle of the moon around the earth, and the 365.25-day cycle of the earth around the sun, have resulted in many species having endogenous rhythms that lock onto monthly and season cycles in the environment. Organisms that live in the intertidal zone also have complex mechanisms for matching their activity and breeding to the 12.4 hour tidal cycle, and the monthly patterns in spring (highest) and neap (lowest) tides that occur at specific times of alignment of earth, sun and moon.

When longer and shorter cycles overlap, new rhythms arise through their interaction, such as that of the spring tides. Speaking about these fascinating phenomena and the essential influence of planetary movements and light on our existence and well-being, brought about the inspiration for Standing Waves. The observation of a third cycle emerging from the interplay of two evoked the association of the auditory beat, and through the discussion of circular movement came the idea of influencing a beat through movements of the body.

Interfering frequencies

The auditory beat results from the overlapping of acoustic waves. When two sine waves (pure tones) of different, but neighbouring frequency are played together, the interference of two seemingly unchanging tones will create an audible beat, perceived as a periodic pulsing of the sound. For example, playing a sine tone of 200 Hertz together with a tone of 205 Hertz will result in a beat frequency of 5 Hertz. These beats are both an acoustic and psycho-acoustic phenomenon. When two speakers in a room play sine tones of similar frequencies, the sound waves interfere in space and monaural beats arise. When each ear is separately exposed to a sine wave through headphones, however, the brain constructs the equivalent perceptive phenomenon – the binaural beat.

This 'auditory illusion' (Pratt et al., 2009) is clearly perceptible as a pulsating wave, but is in itself subsonic. Few humans can hear frequencies below 20 Hertz, but if the volume is loud enough (as in a dance club) the oscillations may be felt. One of the aspects that makes auditory beats so interesting to the musician, is that low frequencies are made experiential in an audible way, and again, if loud enough, also in a physical sense. Exposure to auditory beats can help a listener to attune to specific brain wave states. For example, Foster's work suggests 'the possibility that binaural beats can be used to evoke specific cortical potentials through a frequency-following response' (1990).

In sleep science, rhythms in the brain are monitored by applying electrodes to the face and scalp to monitor its electrical activity – known as Electroencephalography or EEG. During alert wakefulness with eyes open, the EEG is a low amplitude mixture of fast frequencies. In relaxed wakefulness with eyes closed, a rhythm of 8-13 Hz (the 'alpha' rhythm) becomes dominant. Across a normal night of sleep, the brain alternates between two very different states – Rapid Eye Movement (REM) sleep and non-REM sleep. Slipping first into light non-REM sleep, the eyes begin to roll slowly and uncontrollably, and the predominant frequency in the EEG slows to 4-7 Hz (the 'theta' rhythm). As non-REM sleep progresses, the voltage (amplitude) of the EEG increases as huge numbers of neurons across the cortex begin to fire in synchrony, producing a dominant frequency slower than 4 Hz (the 'delta' rhythm). These large, slow undulations in the EEG indicate that the brain has entered deep non-REM sleep, also known as slow-wave sleep. It is difficult to arouse a sleeper from this state, and for few minutes they may experience the disorientation and grogginess of sleep inertia, as the brain struggles back into its waking configuration.

If the sleeper is not woken, he would typically transition out of slow-wave sleep, back up through the lighter stages of non-REM sleep, and into REM. In this paradoxical state, the eyes dart around from time to time under closed lids, accompanied by surges in blood pressure and faster breathing and heart rate. The EEG is a low amplitude mixture of fast frequencies that resembles wakefulness, but in fact the brain is actively dreaming. At the same time, voluntary movement is blocked (presumably so that dreams are not acted out). REM sleep thus presents the paradox of an active brain in a paralyzed body.

Across the night, non-REM and REM sleep continue to alternate in cycles that last roughly 90 minutes. The bouts of slow-wave sleep last longer in the first few cycles of the night, while the bouts of REM sleep get longer towards morning.

While binaural beats can be used for brainwave entrainment, their usefulness for health applications remains debatable and studies give conflicting results. For example, in a study with twelve participants, C. Carter found that entraining brain activity with a 7-minute exposure to binaural beats had no effect on the participant's blood pressure or pulse (2008). Similarly, a pilot study using binaural beats to treat children with Attention-Deficit/Hyperactivity Disorder could not show a significant reduction of inattention (Kennel et al., 2010). On the other hand, a study conducted with 29 participants in 1997 demonstrated that binaural beats can affect both psychomotor performance and mood, and concluded that 'the theta/delta binaural beats produced a subjective impairment in the ability to think clearly' (Lane et al. 1997). Another group of researchers found that 'listening to binaural beat tapes in the delta/theta electroencephalogram range may be beneficial in reducing mild anxiety' (Le Scouarnec et al., 2001). A study into treatment of pre-operative anxiety using binaural beats suggests that 'binaural beat audio has the potential to decrease acute pre-operative anxiety significantly'. In this study, the 108 participants listened to binaural beats for a period of 30 minutes or longer (Padmanabhan et al., 2005).

To our knowledge, few of the studies recorded the time of day of the experiments, and none considered prior sleep history of the participants. We suspect that the states of the brain during different parts of the circadian cycle may well make it more or less susceptible to binaural beats. The extent of the influence an auditory beat can have on the brain depends on many factors, however, the sensation of listening to a slowly undulating, physically moving rhythm is certainly a powerful sensation.

The sound design of Standing Waves examines the intersecting cycles of different wave frequencies, and therefore the auditory beat plays a big role. Two sine waves create the basic sonic material for the performance. The frequencies are modulated and filtered in real-time, forming not only varied

interferences, but also rich and complex acoustic expressions. It was an intuitive choice to create a mainly low-frequency interactive sound environment for Standing Waves. Low frequency tones at sufficient amplitudes manifest themselves not only on the auditory level, but in physically experiential form. The choice of bass sounds over high frequency tones is also grounded in the fact that auditory beats can only be heard between frequency tones up to approximately 1.5 kHz. It is not surprising that a study, in which brain activity in response to binaural beats was measured, showed that stronger oscillations were detectable when the base frequencies were lower (Pratt et al., 2009).

Interacting with light

We proceeded to experiment with creating an extended sensorial tool for the body, which would allow for a focused interaction with an environment of sound and light waves. The layered symbolism of using movement to modify light exposure and thereby to generate sound has beautiful resonances with key concepts in chronobiology. The light sensitivity of the circadian body clock enables it to be entrained by the day/night cycle of our rotating planet. In human beings, the circadian clock is located deep in the brain, but it has a dedicated light input pathway connecting it to special cells in the retina of each eye. This pathway is separate from vision. Beyond our conscious perception of light, the circadian body clock continuously monitors light intensity and directs our bodies through the cycles of sleeping and waking that are the dominant rhythm of our lives.

Through investigating the movement of the body with improvised and stylised gestures, we explored mappings of sound responses to experiential choreographic states. The placement of the sensors, as well as their method of measurement, affected the outcome of these experiments. Placing light sensors on the wrists of the dancer allowed for a full range of movement in all dimensions and a good range of control in interaction with the auditory and visual environment. Flex sensors (bend sensors) were also found to be suitable tools for measuring certain movements of the limbs as the proprioception of joints allowed the dancer to choreograph her movements towards the shaping of sounds that held interest and attention. Additionally, one accelerometer was added to the torso, gauging the speed of acceleration, and indirectly, the angle of the body in relationship to the ground.

On the final day of the Waking incubator we performed to a public audience with this first experimental setup of Standing Waves. The performance took place at The Print Factory, Massey University Wellington, which is a beautifully raw industrial hall with reverberating sound properties. After this initial successful trial of the sensor and sound system, we decided to progress the project further through a second development phase, which took place at the University of Auckland in June 2010. We translated the configuration into a garment design, which focused on exposing the cabling for the sensors whilst allowing the sensors themselves to sit comfortably and securely on the underside of the body and internal to the garment. This design revealed the ‘wired nature’ of the dancer’s interactions, ensuring that audiences were aware that they were in realtime and not pre-recorded in any way. The fine cabling that was stitched into a simple pantsuit had the effect of a second skin that could powerfully direct attention to the role of gesture in shaping sound. At the end of the workshop we performed Standing Waves in the theatre space of the Kenneth Myers Centre to an invited audience, followed by a discussion of the work.

Intertwined choreography

The performance of Standing Waves developed through an emergent choreographic score based on four states – deep sleep, REM sleep, wakefulness, and a fourth state focused on the earth’s rotation on its axis. These states included biological and planetary rhythms towards the creation of an ecology of performance contained within a black box environment. The performer, wearing a sensor suit with exposed wearable technology, manipulates the sound environment through gestures that probe the

space around the body whilst paying attention to its reverberations inside the body. Listening to the somatic language of performance enables the performer to attune the movement of sound to her physical state altered moment by moment.

For the research, the temporal dimension of the performance compressed the real-time of the body's experience of the diurnal cycle to within a frame of approximately 30 minutes. Whereas a sleep scientist works at the level of the actual time of the body and its rhythms, the performing artist appropriates information from the scientist and maps this data through a scoring process. Of interest here in the process has been not only the translation across disciplines of understandings about the nature of human bodies, but a trans-disciplinary practice enabled by the technology. What Donna Haraway calls 'natureculture', a refusal to separate nature from culture (1991, p. 109) by investigating the stories in which we live as organic beings. Scientific work and knowledge meets media design and choreography through a series of conversations and most significantly, a narrativising of scientific research into a series of stories about the body that provide a lexicon of terms for the embodying of states. If, as Haraway states, 'Understanding the world is about living inside stories' (Haraway with Goodeve, 2000, p. 107), these stories suture the factuality of the scientists data to personal movement signature of the artists encounter with the spatial and temporal dimensions of her performance.

Live performance is a place where fiction and reality come together and co-exist. There is a constant interplay between what is real and not real. In Standing Waves real-time one-to-one mapping of audio frequencies to bodily movement through wearable sensor technology generates meanings, frames and opens up potential spaces. The performer and the computer engage in a form of meta-improvisation within the defined parameters of interaction. The scenographic and the choreographic are co-determinants of the event and intertwined.

Dramaturgy

The dramaturgy is driven by concepts around the physiological cycles that underlie sleeping and waking. Four states guide the choreography, light and sound design of the Standing Waves performance. Each of these four phases has a unique character with implications for the body and mind.

Rotation

The phase that stands as introduction to the Standing Waves performance is led by the concept of rotation, inspired by the rotation of the earth, the origin of the circadian rhythm and all that derives from this cycle. The performer spins around her base in circles with outstretched arms, first slowly and then more and more vigorously. The stage is lit with white sidelights. Every time the sensors on the wrists of the performer are exposed to light, the frequency of the sound is raised according to the amount of light. With every revolution around her own axis, the sensors on the performer's wrist are activated alternately, creating a rhythmic sonic landscape, reverberating in synchrony with the body's spin, extending its motion into the space occupied by the audience. At the height of the spin, when the motion has reached its most mesmerizing effect, the performer halts, and the sound calms. The light slowly shifts into the next state.

Deep Slow-Wave Sleep

The choreography of the performance in the Deep Sleep phase focuses on smooth, introverted movements. The stage is lit with deep blue light to which some dim white side lighting is added, enveloping the space in a dark and intimate atmosphere, with streaks of white light piercing the blue, as if in a scene from the deep sea. The eyes of the audience adjust, and the performer's body is visible at the threshold of perception. Through her slow and guarded movements the performer carefully finds positions of balance, evoking powerful monaural beats when both sound frequencies come close to each other. In Deep Sleep, the interactive sound environment is made up of pure, low-frequency

tones, unmodified by effects or filters. The auditory beats are the strongest in this phase, physically experiential in space, permeating the bodies of both performer and audience.

REM

In this phase of the Standing Waves performance, the performer wears a blindfold, helping her to focus on activity with a dynamic that is focused inwards, just as the REM sleeper focuses on the inner world of dreaming. The stage is dark with the exception of a stripe of yellow light reaching diagonally from one side to the other. This band of light might remind one of light falling into a bedroom through Venetian blinds. As the performer moves in and out of this strip of light, the sound changes are vigorous. Different to the smooth and deep character of the previous state, this state is driven by erratic and energetic movements, coupled with volatile sound responses. The sounds range from low to high frequencies, with rhythmic to grainy textures that recall the mixed frequency low amplitude EEG of REM sleep.

Wakefulness

Finally, at the end of the performance, the state of Wakefulness is reached. The stage is illuminated in a warm, orange-red light, creating a large circular shape on the floor. Snapping out of the erratic nature of the REM state, the performer consciously re-engages with the outside world. Her movements are now smoother and controlled, balancing each movement with the sonic feedback. The sound environment is dynamic and responsive, similar to that of the REM state, but without the more volatile aspects.

Reflections on the Collaborative Process

As mentioned previously, this project had its origins in an arts-science Incubator developed and led by Philippa Gander and performance designer Sam Trubridge. The Incubator was an experiment, bringing together six artists and five scientists who had not previously worked together, in an environment where they were challenged to move beyond their usual professional comfort zones. The notion of 'incubating' collaborations contrasts with their more usual 'natural' development on the basis of mutual interest and compatibility. The incubator metaphor also captured the notions of confinement and technological support, which came through the provision in the same building of a sleep research laboratory and an experimental theatre space, each with technical support staff available to help the participants realise their collaborative ideas. The Incubator lasted 7 days and was designed to include two stages:

1) Dialogues – in which participants explored through discussion the issues associated with working across their disciplinary boundaries and experimented with collaborative ideas.

2) Iterations – in which participants worked together to refine some of their collaborative ideas for presentation at a public Open Laboratory on the final day of the Incubator.

To facilitate reaching out across disciplinary and cultural boundaries, participants spent the first night of the Incubator on the Te Kuratini Marae, where they followed traditional Maori protocol including personal introductions (mihi mihi) and sleeping communally in the Wharenui. The following day was scheduled for introducing the Incubator and for participants to present their professional interests and ideas on the theme of 'Waking'. In the event, these discussions extended to occupy two full days. A recurrent theme that arose early was scepticism about the explicit intention of the Incubator to focus on process rather than outputs, which have become the dominant driver for both artists and scientists, particularly in academia. The unstructured exploratory nature of the Dialogues stage enabled participants to relinquish these concerns and enter into trans-disciplinary dialogues.

The transition to the Iterations stage of the Incubator was signalled during the group discussion session at the close of the fifth day. Although participants were aware that this would happen, both from material circulated before the Incubator and discussions in the introductory phase, the transition prompted tension and vigorous discussion that only abated slowly across the following two days. The main issue of concern to both artists and scientists was their inability to produce works for the Open Laboratory that would meet their own high professional standards. The time frame was clearly a factor, but this also signalled a retreat by participants towards their respective professional cultures and their associated expectations of critical review. Among both artists and scientists, some felt a lack of respect for the dedication, knowledge, and skill required to achieve professional recognition in their particular discipline. This could be paraphrased as 'artists pretending to be scientists' and 'scientists pretending to be artists'.

As described above, the Standing Waves collaboration arose early in the Incubator around a shared fascination with rhythms (planetary, physiological, and in movement, light, and sound). In addition, the scientific domains (sleep and chronobiology) and the artistic domains (acoustics and light) had a shared theoretical language (oscillator theory). These factors greatly facilitated the trans-disciplinary discussions and the collaboration moved through the entire Incubator process (and beyond) with minimal friction or professional discomfort. Another factor identified as contributing to the success of this collaboration, and of the Incubator in general, is that sleep science, chronobiology, and performance arts are all multidisciplinary domains, so most of the participants were already accustomed to working with professionals from other disciplines, albeit not usually as disparate as those brought together here.

Summary

Standing Waves takes the concept of wave cycles and combines dance, wearable technology, sound and sleep science, through interactive performance to make a meaningful encounter for audiences.

The dancer's body is given an extended sensorial tool to interact with an environment of sound and light waves, which stand in relationship to brain waves and the bodily sleep/wake cycle.

The biggest cycle in the conceptual context is the planetary rotation of the earth, from which the human sleep/wake cycle stems, and light is the smallest wave cycle, triggering the sensors on the dancer's suit. Unsettling in its malleability and rhythmic complexity, Standing Waves is an experiment that yielded valuable information for furthering our research in this area of intersection. Beyond the metaphorical resonance of this work with the actual sleep/wake cycles of the body, we are interested in extending this visceral impact of the performance on audiences. Can the physical impact of the sound on the observer induce states of euphoria, bliss, agitation or calm?

The dancer, working with an improvised score, becomes attuned to the audience state and is able to steer and guide the experience, heightening, changing or shifting the nature of the performance through interaction with the rhythms and oscillations of the auditory beats. From calm and soothing rhythms that phase-shift into more agitated, oscillating vibrations, the audience is taken through the dramaturgical states and drawn into this work through its multi-sensory character: sound is as important as sight, and the fluidity of the interplay between physical gesture, light and acoustic feedback in space develops into an immersive, visceral experience. Whilst we have so far tested the performance on small groups of informal audience for an approximately 30 minute period, future research will investigate these qualitative shifts in audience response over a longer period and through a season of performances.

As science delves further and further into the complex mysteries of our physical bodies, there is increasing impetus to use multiple modes to understand and communicate its discoveries. Standing Waves is in many ways an attempt to give scientific discovery a new avenue for illumination through creative expression. Enacting science through artistic interpretation is not only a way of bridging the world of specialist and non-specialist, but also provides another mode of experience that can address our multimodal consciousness and social exchange.

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Carol Brown's practice takes place at the intersections between movement, architecture and performance and includes solos, group works for theatre, performance installations and site responsive works. Formerly Artist in Residence at the Place Theatre London she is currently a Senior Lecturer in Dance Studies at NICAI, University of Auckland. She fosters work that is experimentally collaborative and evolves through dialogue with other art forms and media in particular architecture, music and media design. She has received a number of awards in recognition of her work including a Jerwood Award, an AHRB Research Fellowship in the Creative and Performing Arts, an Arts Plus Award for GLOW and a NESTA Dream Time. In 2003 she was awarded the Ludwig Forum International Prize for Innovation.

Philippa Gander (Massey University, Wellington) is Research Professor and Director of the Sleep/Wake Research Centre at Massey University Wellington. She received her PhD from the University of Auckland in 1980, in chronobiology. Following a Senior Fulbright Fellowship at Harvard Medical School (1980-1982), she joined the Fatigue Countermeasures Program at NASA, working on field studies of fatigue in different aviation operations and on mathematical modelling of the human sleep/wake cycle. In 1996, Philippa was awarded a Repatriation Fellowship by the Health Research Council and returned to New Zealand to establish the Sleep/Wake Research Centre. The Centre has four main research themes: epidemiology of sleep disorders in Aoteroa/New Zealand and the implications for health services; sleep across the lifespan and its relationship to health and quality of life; basic sleep and circadian physiology, with experiments conducted in the Centre's 3-bed time isolation unit; and practical application of sleep science and chronobiology to fatigue risk management in 24/7 industries. Philippa has received a number of international awards for her applied research and was elected to the Fellowship of the Royal Society of New Zealand in 2009.

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