Brain Basis of Samadhi: The Neuroscience of Meditative Absorption

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Scientific and clinical interest in mindfulness has seen a dramatic increase in the past ten years, but there has as yet been surprisingly little deep engagement with the traditional Buddhist literature by contemporary clinical and scientific proponents of mindfulness. This literature review summarizes a classical Theravada Buddhist framework describing samadhi, a state of consciousness often translated as meditative absorption. Following the discussion of the stages of samadhi from the traditional phenomenological perspective is a review of the cognitive, neuroimaging, and neuropsychological literature that has begun to explore the brain bases of the subjective experience of samadhi during deep meditation. Due to the incipient nature of this literature, the review makes suggestions for interpretations and future directions of empirical research. Finally, the long-term effects of meditation practice are discussed.

Keywords: meditation, samadhi, brain basis, plasticity, consciousness, altered consciousness, jhana

This literature review seeks to analyze meditative absorption by juxtaposing two very different scholarly traditions, the cognitive neurosciences and the systematized matrix of Buddhist phenomenology known as the Abhidhamma. These two paradigms differ substantially in methodology. Whereas cognitive scientists and neuroscientists approach consciousness "objectively" and philosophically, from an ontological set of priorities, the Buddhist tradition approaches consciousness phenomenologically. That is, whereas the scientific tradition asks questions like, "what is consciousness?" the Buddhist tradition guides the practitioner toward structuring consciousness such that a person may experience subjective freedom from suffering and live a moral life. Despite these epistemological and pragmatic differences, there is great potential inherent in a dialogue between these two inquiries into the mind, which have arisen in radically different cultural contexts. The Abhidhamma is a body of scholarship that began to emerge in India in the 3rd century BCE, with modern scholarship centered in Myanmar and Sri Lanka (Bhikku Bodhi, 2000). It provides a coherent matrix of extremely precise and technical phenomenological descriptions of conscious experience during meditation, and prescriptions for inducing such experiences. Contemporary secular mindfulness practice and research often tend towards relatively simplistic approaches to meditation as stress-reduction strategies (e.g. Grossman, Niemann, Schmidt, & Walach, 2004). A more sophisticated set of constructs from the Buddhist literature could be valuable to scientific researchers motivated to engage in more nuanced inquiries into conscious experiences, intentional alterations to conscious experience, and the use of altered states of consciousness for the relief of suffering. Varela's (1996) call to arms for a "neurophenomenology" that more precisely correlates conscious experience with objective neurological activity initiated an interest among the sciences of the mind in collaborating with Western phenomenologists and Buddhist practitioners. Although concepts and practices from Buddhism have been infiltrating the sciences of the mind for several decades, the Abhidhamma remains largely unknown outside its traditional scholarly centers in Sri Lanka and southeast Asia, possibly because of its daunting technicality and the relatively recent availability of its primary texts in English.

Lutz, Dunne, and Davidson (2007) provide a very broad review of the state of neuroscientific research into Buddhist meditation. They lament that the term "meditation" tends to be used so imprecisely and references such a broad range of practices and

phenomena that research scientists may find it challenging to specify exactly what kind of activity they are studying. The current review responds to Lutz et al.'s complaint, and focuses more tightly on the neurological dynamics associated with a specific series of phenomena discussed in the Abhidhamma: the stages of meditative absorption. We will refer to meditative absorption by its Buddhist name in the Pali language: samadhi. A glossary of the Buddhist terminology used in this paper may be found in the Appendix. In the Abhiddhamic tradition, samadhi is attained through a series of stages, each stage representing a qualitatively different state of consciousness. These stages are called jhana. The scope of the current work will not permit a full discussion of the models of consciousness offered in the sciences of mind and Buddhist tradition, both of which lack a hegemonic theory, but it is hoped that this offering may provide a model for future lines of dialogue. By investigating neural correlates of the jhanas, we may understand the mechanisms by which such conscious experiences are generated and why meditative absorption takes on the subjective qualities it does, in the order it does, and to the effects that it does. In terms of potential for application outside the rather esoteric context of Abhidhammic scholarship, inducement of jhanas is a skill that must be developed, but it is not beyond the scope of motivated individuals with normal human neurology to attain (Bhikku Bodhi, 1999). Such cultivation should be of interest to cognitive and neuroscientists as well as clinicians.

The Context for Meditative Absorption

Human experience of the world is mediated by the neurological substrate, and it is via dynamic patterns of cortical activation and inhibition that we represent objects in the world, mental imagery, our own bodies in space, and connections with others (Dennett, 1991). Systematic alterations of that experience, in the service of the meaningful life, human character development, and transcendence over the fear of death, have been developed in a number of cultures (Ludwig, 1966). Intentional alterations of conscious experience have likely occurred for as long as human beings have experienced what Buddhists call dukkha. Dukkha is usually translated into English as "suffering," although the Pali word means something closer to "dissatisfaction" (Bhikkhu Bodhi, 1999). In the Buddhist tradition, the central analysis of suffering and unhappiness is laid out in the Four Noble Truths:

1. All conscious beings will experience dukkha.
2. Dukkha results from ignorance of the transient nature of all phenomena, and failure to recognize the lack of any essential, permanent self.
3. There is a way out of dukkha.
4. The way out of dukkha is laid out in the Eightfold Noble Path.

One of the elements of the Eightfold Noble Path is samadhi, or meditative absorption; this practice changes ordinary fluctuations of consciousness in such a manner that the practitioner experiences a deep, clear openness and focused stability. Acting from such a state of consciousness, a practitioner may develop the insight necessary to uncouple cyclical patterns that give rise to dukkha.

Samadhi

Samadhi has been most thoroughly and precisely described in the Abhidhammic literature. The Abhidhamma is a rigorous systematization of Buddhist doctrine, in which Buddhist phenomenology is "methodically organized, minutely defined, and meticulously tabulated and classified" (Bhikkhu Bodhi, 2000, p. 2). The technical set of constructs in the Abhidhammic discussion of samadhi is especially conducive to dialogue with cognitive science. It is just the sort of material that would be useful for connecting subjective experience with neurological correlates (Varela, 1996).

Samadhi is analyzed into stages of meditative absorption called the jhanas (Nyanaponika Thera, 1976). Each jhana is defined by the presence or absence of specific phenomenological qualities, called jhana factors. The jhana factors are enumerated with their standard English translations (Shankman, 2012), and with suggestions for corresponding cognitive scientific constructs, in Table 1. Transitions between jhanas are accomplished as a practitioner drops or adds one or more of these six factors.

Table 1
Jhana factors with standard English translations and cognitive science construct equivalents

Pali Term	Standard English Translation	Cognitive Science Construct
Vitakka	Movement of the mind onto the object	Orienting attention
Vicaara	Retention of the mind on the object	Maintaining a representation in focal attention
Piiti	Joy	Somatosensory pleasure
Sukha	Happiness	Positive affect
Upekkha	Equanimity	A state where neither approach nor avoidant motivations arise because no motivational representation is highly salient and attention is diffused
Ekaggataa	One-Pointedness	Activation of an attended representation to such a relatively high, sustained degree that the representation is all that is perceived in consciousness, with all other representations deactivated (at first by inhibition, later by failure to arise)

In most accounts, there are four jhanas. Of primary importance, these stages of meditative absorption are phenomenological descriptions. In the Abhidhammic literature, the jhanas are framed, purely and simply, as states of human conscious experience. The altered states of consciousness represented by the jhanas do not themselves represent Buddhist insight, or vipassana. Rather, they are a means of inducing conscious experience that is calm, present, vivid, void of strong, disturbing emotions, and most pliable, optimized for doing the work of cultivating insight. The cultivation of insight is a separate topic, of more characteristically Buddhist religious goals than is the cultivation of samadhi, and will not be treated in this review.

In the first jhana, all six factors are present. In successive jhanas, factors are dropped as the absorption deepens. So, in the first jhana, vitakka, vicaara, piiti, sukha, and ekaggataa are present. In the second jhana only piiti , sukha, and ekaggataa are present. In the third jhana, piiti drops out and only sukha and ekaggataa remain. In the fourth jhana, only ekaggataa remains and upekkha appears (Shankman, 2012).

According to the traditional literature and practice, the jhanas are induced as follows. A monk isolates himself to an area with minimal sensory stimulation, ideally in a hut in the forest. He sits cross-legged in the lotus posture, and folds his hands into his lap. Sitting up straight but relaxed, he focuses his attention on the sensation of in-breath and out-breath on the nostrils. This mindfulness of the breath is called anapanasati. The initiation of the jhanas is marked by upacaara, most commonly translated as "access consciousness." Upacaara has occurred when the sensation of breathing has become the sole content of conscious awareness (Bhikku Ñanamoli, 2010). Once this one- pointed concentration has been attained, the monk may initiate the first jhana.

Initiation of each jhana occurs by sustained shifts in attention (Shankman, 2012). The first shift in attention is from external vigilance to the breath, until upacaara is generated. The meditator initiates the first jhana by focusing on the feeling of pleasant warmth that arises during upacaara. Proponents of enactive views of attention suggest that part of what is happening when any representation is fixated in attention is that the motor system is preparing to act on that object (Kinsbourne, 2010). Thus, stringently controlling voluntary movement may aid in broadening and diffusing attentional focus. By ceasing both to orient attention toward any specific representation (i.e. by releasing vitakka), and by ceasing to hold any specific representation in attention (i.e. by releasing vicaara), the meditator shifts from the first to the second jhana. In the transition from the second to third jhana, somatosensory pleasure, or piiti drops away. Hagerty et al. (2013), discussed further below, suggest the dropping out of piiti results from a temporary dopamine depletion following

strong release during the second jhana. Finally, in the transition from the third to fourth jhana, sukha, or positive affect, also drops away, and all that remains is equanimity and one-pointed awareness.

What patterns in the neurological substrate accompany the jhanas? Systematic alteration of conscious experience entails, after all, systematic alteration of the brain basis of consciousness. Although a 2500-year-old living tradition of Buddhist scholarship has produced highly sophisticated descriptive schemata of conscious experiences, and meditative practices for inducing them, cognitive neuroscientists have only recently begun investigating meditative absorption. The literature is, however, promising.

Suggested neural mechanism for generation of upacaara

Characteristic of upacaara, or access consciousness as the first stage of samadhi, is the disappearance of the sense of self (Bhikku Nanamoli, 2010). Some models of the neurological basis for self-representation suggest that the medial prefrontal cortex (mPFC) supports the subjective sensation of a homuncular perceiver. The "homuncular perceiver" refers to a commonly held belief regarding a dualistic division between thoughts and the person perceiving the thoughts. The "perceiver" is often termed the "Cartesian homunculus," after Descarte's cogito (Crick and Koch, 2003). The mPFC has been associated with self- relevant trait judgments (Kelley, et al., 2002; Johnson et al., 2002), autobiographical memory recall (St. Jacques, 2012), and emotional introspection (Schmitz, Kawahara-Baccus, & Johnson, 2004). In other words, the mPFC supports self-mentalization. Baars, Ramsoy, & Laureys (2003) suggest a similar model where conscious perception occurs when self-related prefrontal regions interpret representations from more posterior sensory cortex.

However, Goldberg, Harel, and Malach (2006), in contrast to Baars et al.'s (2003) and Crick and Koch's (2003) predictions, found a reciprocal relationship between activation in the mPFC and posterior somatosensory areas. Goldberg et al. (2006) presented images to participants using functional magnetic resonance imagery (fMRI). In the introspection condition, they instructed participants to think about

how the image made them feel, and to click one button if it made them feel good and one if it made them feel bad. In the sensory categorization task, participants were to click one button if the image was an animal and one button if it was not an animal. The pictures were identical in both conditions. The sensory categorization task was further divided into two conditions, a fast condition and a slow condition, with the fast condition being the more challenging. During the introspection condition, participants showed preferential activation of the left mPFC, superior frontal gyrus, anterior cingulate, and paracingulate. In the introspective and slow sensory categorization tasks, they showed activation in the posterior cingulate, precuneus sulci, and inferior parietal cortex (IPC). This network largely overlaps the default mode network discovered by Raichle et al. (2001). When not engaging in goal-oriented activity, the default pattern for the people studied seemed to be to think about themselves, or to introspect. That an explicit introspective task would show preferential activation of this same network is therefore not surprising; likewise for an unchallenging sensorimotor task that leaves the mind free to wander. In the sensory categorization conditions, however, and to a greater degree in the challenging, fast condition, participants showed an inhibition of prefrontal areas and a selective activation of posterior regions associated with hierarchical visual processing, from the primary visual cortex to the lateral occipital complex (LOC), parietal, premotor, and motor areas.

There are two implications for Goldberg et al.'s (2006) study relevant to our discussion. First, conscious awareness of representations does not require a self-conscious homuncular observer, based in the mPFC, to "perceive" sensory representations in object areas of the LOC; the activation of occipitoparietal representations is sufficient for conscious awareness. No further perception by regions of the PFC are necessary. This contradicts Crick and Koch (2003) and Baars et al's (2003) suggestion that conscious perception arises from dialogue between prefrontal cortex, as the seat of the self, and sensory cortex. Self-consciousness is not necessary for conscious awareness. Second, this finding is in line with Kinsbourne's (1988) Integrated Field Theory, in which shifts in conscious awareness across the

visual field index shifts in the strength of relative activation between competing cortical subnetworks. Assuming Kinsbourne's (1988) framework, Goldberg et al's results would indicate a shift between relative activation from self-mentalizations in anterior regions toward task-oriented sensorimotor representations in posterior regions. Kinsbourne's (2006) work with hemineglect described a shift in relative strength of activation from the right to the left hemisphere and concordant neglect of the left visual field. Goldberg and colleagues' results seem to indicate a similar shift in relative strength from anterior to posterior networks during absorption in a challenging sensorimotor task, and the correlated shift from self-mentalization to consciousness of sensorimotor tasks.

Goldberg et al's (2006) findings grant some insight into why meditation practitioners report that self-mentalization seems to disappear during samadhi. Although introspection and meditation are colloquially treated as interchangeable concepts, the two activities are quite different. Anapanasati, or mindfulness of the breath, is a sensorimotor task. However, rather than emphasizing visual or auditory modalities, as in Goldberg et al's study, the target modality in anapanasati is the proprioceptive or haptic modalities. Indeed, the task of anapanasati bears more than a passing resemblance to Goldberg et al.'s sensory categorization task. In the sensory categorization task participants are presented with visual (or auditory) stimuli, and must categorize the stimuli. Alternately, in the introspective condition, participants must judge the feelings elicited by the image as pleasant or unpleasant. The sensory categorization task, then, demands attention to the sensory content and conceptual judgment. In anapanasati, the task is formally the same. The meditator must attend to the physical sensation of breath on the nostrils and upper lip, or the movements produced in the lower belly during breathing, such that this sensation occupies all her attention. She is explicitly instructed not to make a judgment about it in relation to herself, merely to let it be experienced (Bhikku Nanamoli, 2010). Goldberg et al. emphasize that the reciprocal patterns of activation between prefrontal cortex and posterior sensorimotor regions are not unimodal. Engaging tasks that utilized different sensory modalities produced the same inhibition in self-mentalizing

networks. We should therefore expect that engaging, attention-demanding proprioceptive/haptic tasks will induce the same inhibition of the default mode network in PFC. Although Czikszentmihalyi (1990) has indicated that people do report losing a sense of self-consciousness during engaging physical tasks such as dance and athletics, this particular prediction awaits demonstration via neuroimaging.

The degree to which Goldberg et al.'s (2006) participants reported being absorbed in the perceptual categorization task positively predicted the amount of inhibition in the default network. This selfless absorption in a task is a common subjective experience associated with what Czikszentmihalyi (1990) calls "flow." High, occluding activation of somatosensory representations associated with breathing, along with inhibition of self-mentalization in the default mode network may thus correspond to the generation of upacaara, or access consciousness. Once this pattern of cortical dynamics has been stabilized, the meditator's phenomenological experience is one of quiet, stable, and selfless presence, and she may begin to initiate the jhanas.

The jhanas

Hagerty et al.'s (2013) experiment was the first to look specifically at the jhanas using fMRI. Their single participant, a 55-year old male, trained in the Sri Lankan tradition of Theravada Buddhism, had practiced for an estimated 17 years, accumulating approximately 6,000 hours of meditation practice. The subject was instructed to click a button to signal transition into each jhana. Based on phenomenological reports of samadhi, Hagerty et al. made five predictions:

1. Awareness of external phenomena would dim.
2. Internal verbalization would fade.
3. Sense of personal boundary would be altered.
4. The subject would demonstrate intense focus on the object of meditation.
5. There would be an increase of joy.

Consistent with their predictions, they found decreased activation compared to rest state in the visual

and auditory cortex, specifically, Brodmann's areas 17-19 and 41-42. This supported their prediction of reduced processing of visual and auditory information. They further showed decreased activation in Broca's area (BA 44, 45) and Wernicke's area (BA 39, 40), which suggested the silencing of inner speech. Areas in the parietal cortex previously associated with the brain's representation of the body's orientation in three-dimensional space (Bucci, Conley, & Gallagher, 1999) showed decreased activation during jhanas. This deafferentation of the superior posterior parietal lobe indexed an alteration of the participant's sense of bodily boundaries, and accompanied a subjective sense of consciousness without physical boundary. This finding replicated Beauregard and Paquette (2006), who also showed a deafferentation of signal from the thalamic lateral posterior nucleus to this same area of superior posterior parietal lobe in Christian monastics reporting "mystical union with God" (p. 187).

Newberg and Iverson (2003) trace this posterior parietal deafferentation to an increased release of inhibitory gamma-aminobutyric acid (GABA) onto the lateral posterior and geniculate nuclei when the reticular nucleus becomes highly activated. They speculate that this thalamic excitation and concordant inhibition of afferent sensory signals to posterior parietal cortex is brought about by increased activation in right PFC during intense, voluntary concentration, as occurs in the stages of samadhi from upacaara through the second jhana. The degree of deafferentation seems to correspond to the degree to which participants maintain a focus on a meditational object (in the case of Beauregard and Paquette's (2006) monastics, an image of their target deity), or completely release any object of focused attention, as happens when Buddhist monks release vitakka and vicaara as they transition into the second jhana. In such cases as the transition to the second jhana, deafferentation is more complete. By circumventing the ordinary process in which the parietal lobes construct the experience of a three dimensional body, this deafferentation creates an unusual conscious experience of being alert and otherwise experiencing, but no longer bound within a discrete self.

A further effect of increased GABAergic activity in the pathways from thalamus to parietal and occipital cortex during meditation is that the signal to noise ratio of sensory information is improved, resulting in a clearer signal with fewer distracting representations (Elias, Gulch, & Wilson, 2000). Newberg and Iverson (2003) draw a further link between deafferentation of the posterior parietal cortex to stimulation of the right hippocampus; there is a modulatory relationship between hippocampal and cortical activity. Stimulation of the right hippocampus spreads to stimulation of the right amygdala during meditation (Lazar, et al., 2000), and stimulation of the right lateral amygdala stimulates the ventromedial hypothalamus, activating the parasympathetic nervous system (Davis, 1992). This parasympathetic activation could explain the relaxation and deep quiescence associated with samadhi, and specifically with the factor upekkhaa, or equanimity, which appears in the fourth jhana.

Hagerty et al. (2013) further found increased relative activation in the anterior cingulate cortex (ACC) during upacaara and the first jhana, congruent with the high degree of voluntary attentional focus in those stages. However, they found a decrease relative to baseline in ACC activation during the second through fourth jhanas, again congruent with the diffusion of attention during those states as the object of meditation (the breath) is released from focal attention. Finally, Hagerty et al. found increased activation during the first and second jhana of the nucleus accumbens (NA) and medial orbitofrontal cortex (mOFC). They cite these networks as the dopamine reward systems of the human brain, which are most frequently activated in response to reinforcing environmental stimuli such as food, sex, money, and other sources of pleasure. Hagerty et al.'s subject seemed, then, to be able to stimulate endogenous dopaminergic reward in the absence of external stimuli. The experiential correlate of this heightened activation of NA and mOFC is self-reported piiti, or intense somatosensory pleasure. As the meditator dropped this piiti during the transition from the second to the third jhana, Hagerty et al. also saw a return of NA and mOFC activation to normal baseline levels.

The intense pleasure of the first and second jhanas are not the ultimate point of the practice. Rather, as Hagerty et al's (2013) subject reported, after volitional orientation toward external objects had been released during upacaara, piiti and sukha

during the first and second jhanas serve to foster a firm sense of contentment that obviates any need to approach or avoid any stimuli whatsoever. This equanimity, or upekkha, signals transition to the fourth jhana. In the fourth jhana, only equanimity and single-point awareness remain. This is the target quality of consciousness, the culmination of samadhi. There is no directing of attention, no representation held in focal attention, no pleasure and no aversion, affective contentment has dropped away, and all that remains is an alert, clear, one-pointed, equanimous awareness. It is from this state that the meditator will start the work of vipassana, or insight.

Effects of meditative absorption

Traditionally, samadhi has been one arm of practice for Buddhist monastics engaging in a religious lifestyle. Subtle, calm, pleasant states of consciousness, mastery of attention, and regulation of involuntary emotional responses are cultivated because they conduce to the real work of the Buddhist tradition, which is the overcoming of suffering by gaining insight into the sources of suffering. Despite this religious background, or perhaps as a Zeitgeist-appropriate extension of it, the "spiritual technology" of Buddhist meditation practice has been adopted by many people from non-Buddhist cultures, as both Western monastics, psychological clinicians and scientists, as well as lay people discover the value of mindfulness.

An explosion of cognitive neuroscientific research in the last ten years has examined the neurological, affective, and cognitive effects of the practice of anapanasati, or mindfulness of the breath (e.g. Bishop et al., 2004). The qualities cultivated in samadhi condition impact experience even after a practitioner is no longer in the altered state. Major efforts have been invested in adapting traditional Buddhist meditation practices to secular purposes (e.g. Baer, 2006). In previous sections, we have discussed immediate changes in neurological dynamics during the attainment of samadhi, through the stages of the jhanas. In this final section, we will discuss some of the longer-term changes in the neurological substrate and cognitive functions associated with samadhi practice. This section should serve as justification for a scientific and clinical interest in Buddhist frameworks.

Bishop et al. (2004) operationalize mindfulness as self-regulation of attention and orientation to experience. Researchers have replicated the beneficial effects of apanasati practice on cognitive function using a variety of measures. Meditators with six weeks of mindfulness practice showed improved cognitive flexibility, indexed by better performance on the Stroop task and d2-concentration and endurance test, which measures processing speed, rule compliance, and quality of performance (Moore & Malinowski, 2008). Practice for two weeks at 20 minutes per day improved participants' Graduate Record Examination (GRE) reading comprehension scores as mediated by increased working memory capacity. Participants reported this effect to be due to decrease in distracting thoughts (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). For participants in a three month meditation retreat with five hours per day of practice, MacLean et al. (2010) discovered that meditators, compared with a wait-list control group, demonstrated increased visual sensitivity, improved vigilance, increased precision of visual working memory, and improved ability to sustain attention. Positive cognitive effects may result even from relatively short interventions. Zeidan, Johnson, Diamond, David, and Goolkasian (2010) found improved performance on word association tests, symbol digit modalities tests of visual tracking and working memory, forward/backward digit span, and n-back tests, as well as a reduction in fatigue and anxiety in a meditation training group, compared to controls, after training for four days at twenty minutes per day.

Such changes in cognitive performance suggest long-term structural or functional changes in the associated neural networks, and indeed multiple groups have documented such plasticity. Lazar and colleagues (2005) assessed cortical thickness using magnetic resonance imaging (MRI) in a group of meditators in the vipassana tradition, averaging a daily practice of 40 minutes over nine years. They found increased thickness, relative to non-meditator controls, in the right middle and superior frontal sulci, right anterior insula, and occipito-temporal visual cortex, areas previously associated with attention, interoception, and sensory processing. Differences in cortical thickness were especially pronounced in the

older participants, suggesting that meditation practice can offset age-related cortical thinning. Luders, Toga, Lepore, and Gaser's (2009) participants came from several Buddhist traditions, including Japanese zazen, Tibetan samatha, and Thai, Burmese, or Sri Lankan vipassana, but all of these traditions teach and practice samadhi itself in more or less the same manner. Their participants practiced from 10 to 90 minutes daily, for 5 to 46 years. Luders, et al. (2009) found larger gray matter volume in right orbito-frontal cortex, right thalamus, and left inferior temporal gyrus, as well as much larger volumes in right hippocampus in meditators relative to controls; they link these areas to practice in emotional regulation and response control. This is to be expected given Lazar et al.'s (2000) link between the right hippocampus and parasympathetic activation mediated by the ventromedial hypothalamus; such a structural change could index a fundamental, trait-level shift in capacity for affective calm.

Conclusion

This review has attempted to correlate phenomenological descriptions of samadhi and the jhanas with what is known of the neurological correlates of such altered conscious experiences. It discussed samadhi from the perspective of Buddhist Abhidhamma scholarship, as well as recent work in cognitive psychology, cognitive neuroscience, and neuroimaging that sheds light on the neural mechanisms supporting meditative absorption. Finally, justification for research interest in such phenomena was provided by briefly sampling some of the reported cognitive, affective, and neurological effects of the practice of samadhi. This field is ripe for continued research, as the Abhidhamma provides a dense matrix of extremely precise and technical phenomenological descriptions that may provide ideal reference points for future neuroscientific inquiries into the altered states of consciousness and their applications to promoting human excellence and relief from suffering.

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Appendix

Glossary of Pali terms

Abhidhamma – a systematized body of literature organizing and tabulating phenomenological concepts from the Buddhist sutras. The *Abhidhamma* is composed of seven books, not all of which have been translated into English. Sri Lanka and Myanmar have traditionally been the centers of Abhidhammic scholarship.

Apanasati – mindfulness of the breath

Dukkha – dissatisfaction, or suffering

Ekaggataa – one-pointed attention

Jhana – a stage of meditative absorption. There are either four or nine *jhanas*, depending on the source. Each *jhana* is characterized by the presence or absence of each of the six *jhana* factors.

Pali – the language of the Buddhist cannon. *Pali* was a lingua franca in north India in the third century BCE, but is now a dead language and used only to access the Buddhist texts.

Piiti – joy, or pleasure

Samadhi – meditative absorption

Sati - mindfulness

Sukha - happiness

Theravada – form of Buddhism dominant in southeast Asia and Sri Lanka. Widely regarded as the oldest and most authentic school of Buddhism.

Upacaara – "access consciousness," where the sensation of breathing is the only object of consciousness

Upekkha - equanimity

Vicaara – retention of the mind on the object

Vitakka – movement of the mind onto the object