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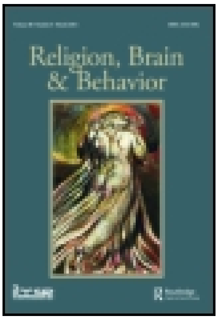

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Bridging the communication and cultural gap between the cognitive sciences and the contemplative traditions

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TARGET ARTICLE

Meditation-induced bliss viewed as release from conditioned neural (thought) patterns that block reward signals in the brain pleasure center

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The nucleus accumbens orchestrates processes related to reward and pleasure, including the addictive consequences of repeated reward (e.g., drug addiction and compulsive gambling) and the accompanying feelings of craving and anhedonia. The neurotransmitters dopamine and endogenous opiates play interactive roles in these processes. They are released by natural rewards (i.e., food, water, sex, money, play, etc.) and are released or mimicked by drugs of abuse. Repeated drug use induces conditioned down-regulation of these neurotransmitters, thus causing painful suppression of everyday pleasure. As with many spiritual traditions, Buddhism provides strong advice against the pursuit of worldly pleasures to attain the "good life." In contrast, many forms of meditation give rise to an immense and abiding joy. Most of these practices involve "stilling the mind," whereby all content-laden thought (e.g., fantasies, daydreams, plans) ceases, and the mind enters a state of openness, formlessness, clarity, and bliss. This can be explained by the Buddhist suggestion that almost all of our everyday thoughts are a form of addiction. It follows that if we turn off this internal "gossip of ego," we will find relief from the biochemical dopamine/opiate down-regulation, which is, perhaps, the perpetual concomitant of our daily rumination.

Keywords: bliss; Buddhism; default mode network; dopamine; meditation; nucleus accumbens; mind wandering; prediction error

Meditation-induced bliss results (in part) from clearing the mind of discursive thoughts

> With the stilling of thought and examination, he enters and abides in the second jhana [which is characterized by] rapture and pleasure born of concentration, and accompanied by inner composure and singleness of mind, without thought and examination. (The Pali Sutras, as quoted in Shankman, 2008, p. 43)

The above quote describes a state of extreme positive affect, which can be reached by adept practitioners of Buddhist meditation upon entering a state of deep, meditative concentration known as Samadhi (Shankman, 2008). This state initially involves clearing the mind of its usual routine thoughts, which are often repetitive and discursive. Calming the mind in this way often involves fixed concentration on an object, such as the meditator's own breath, or perhaps a basic element or color. As everyday thoughts subside, a state of philosophical examination follows, perhaps over the nature of thought itself. Eventually, this examination stills and gives way to the feeling of bliss, as described in the quote above. This blissful state not only fills the mind but reportedly extends throughout the body as well. Thus, according to the

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sutras: "He makes the rapture and pleasure born of seclusion drench, fill, and pervade this body, so that there is no part of his whole body unpervaded by the rapture and pleasure born of seclusion" (Shankman, 2008, p. 37).

According to traditional descriptions of meditation, this state can deepen even further and last for many hours, thus offering a continuous state of positive affect that, interestingly, lasts longer than mundane pleasurable states such as those induced by food, orgasm, or drugs. It should be noted that this blissful state is eventually replaced by an even deeper absorptive state—the fourth jhana—that is beyond pleasure and pain, whereby "He sits pervading this body with a pure, bright mind . . ." (Shankman, 2008, p. 48).

As outlined elsewhere (Wallace, 2009), many religious and philosophical traditions throughout the world have discovered similar states of calm, meditative concentration that can give rise to states of heightened positive affect.

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Bliss induced through meditation may share common neural/biochemical processes with everyday pleasures such as sex, drugs, and food

The nucleus accumbens is thought to be centrally involved in the generation of pleasure, regardless of the source of that pleasure

As will be elaborated throughout this paper, the brain region known as the nucleus accumbens (Figures 1 and 2), along with certain anatomically connected regions, is thought by many neuroscientists to constitute one of the main "pleasure centers" in the brain. It seems that the accumbens is centrally involved in orchestrating both subjective and behavioral aspects of pleasure and reward, regardless of the nature of the inducing stimulus (e.g., food, water, sex, drugs, monetary reward, social reward, etc.). This suggests that joyful states induced through contemplative practices may also be dependent on these accumbens-related processes.

Certain meditative practices share subjective and physiological components with those involved in sexual arousal and orgasm, suggesting a common neural substrate in the nucleus accumbens

Similar to the concentration of Samadhi, there are numerous Buddhist and Yogic practices that involve calming the mind through meditation (i.e., clearing the mind of its usual repetitive thought patterns), from which practitioners report an attendant bliss that pervades both mind and body.

Interestingly, certain of these blissful experiences involve a clear and acknowledged overlap with bodily regions and sensations that are related to sexual pleasure. For example, the Tantric Buddhist practice of Tummo—or "Inner Fire"—involves the visualization of certain Yogic channels and chakras, as described by Lama Thubten Yeshe (1998). In particular, the practice focuses strongly on the naval chakra, located four finger-widths below the navel. The Tummo visualization involves pulling energy down into this region while inhaling, while imagining that doing so generates intense heat at the chakra. Upon exhaling, the heated energy is said to shoot up through the central channel and gradually grows stronger (over repeated exhalations) until it reaches the crown chakra,

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located in the head. As the practice ensues, substantial temperature increases are actually generated within the body (see Benson et al., 1982), which provide the practitioner with the remarkable ability to stay warm even in extremely frigid conditions (David-Neel, 1932).

More relevant for the present context, however, is that the practice is said to result in the eventual "awakening of kundalini," whereby bliss rises into the body's central channel and through the higher chakras, which are said to contribute to developing the experience of bliss. Upon reaching the crown chakra, intense bliss is said to be fully energized and to flow back down through the central channel and throughout the body.

According to traditional descriptions, "ordinary people" who are not Tantric practitioners can nevertheless experience the melting of Kundalini during normal sexual orgasm. In fact, responses similar to orgasm can also result from the Tummo practice described above. However, practitioners are warned against allowing this "uncontrolled Kundalini" to arise, since it results in an ultimate loss of Kundalini energy. Moreover, it ultimately continues the painful cycle of desire and release (i.e., Samsara). Thus, male practitioners are advised that losing a few drops of semen during Tummo practice is not a problem, but arising to full orgasm should be avoided (Yeshe, 1998, pp. 147–150).

As is well known within biological science, ordinary sexual pleasure involves not only the genital and reproductive organs, but also brain regions related to subjective pleasure. As already noted, the nucleus accumbens has been the focus of interest as a possible locus for this pleasure. As described above, the Tummo bliss (viz., the awakening of Kundalini) also centers on more than one bodily region. Two of these seem to correspond to anatomical areas identified by western biological science: (1) the naval chakra located in or near the reproductive organs; and (2) the crown chakra located in the head.

Across different Buddhist teachers and practices, there is variability concerning the precise location of the crown chakra. However, some descriptions seem to place the crown chakra in a location that coincides with the nucleus accumbens (see Figure 1). Consider the following discussion of this point from Lama Yeshe's teaching on the Tummo practice:

> There are doubts about the location of the crown chakra, which is also called the bliss chakra. Literally, "crown" refers to the top of the head; therefore, the crown chakra is sometimes said to be between the skin and the skull at the top of the head. In my opinion, however, the chakra is in the brain, where there is much active energy. This is where the bliss center is located. Some texts call this the head chakra, but we could also call it the brain chakra. In any case, visualize this chakra somewhere between your eyebrows and your crown, at a point more toward the back of the head . . . (Yeshe, 1998, p. 107)

This seems to open the extremely speculative possibility that the ancient Vedic and Buddhist traditions may have developed meditative methods to tap into the pleasure and biochemical possibilities provided by the accumbens. It is also possible that the ancient practitioners were somehow able to detect the location of this activity. Indeed, Lama Yeshe (1998, p. 107) asserts that practitioners can gradually discover the exact locations of each chakra for themselves, as a result of their practice.

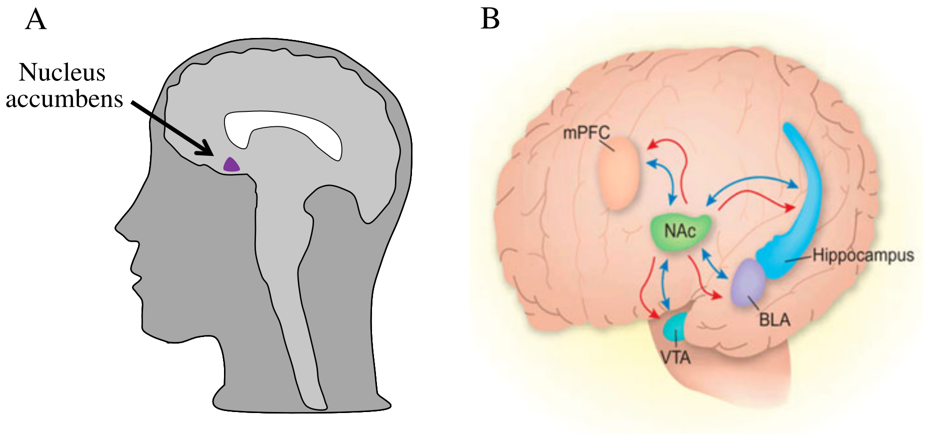

Figure 1. Illustrations of the location of the nucleus accumbens.
Note: The nucleus accumbens is thought to be a major center for the generation of positive hedonic (pleasure) states. (A) Here is shown a mid-sagital view. (B) Here is an additional view, which also indicates some of the accumbens' connections with other brain regions. As described in the text, the location of the accumbens seems to correspond well with at least some descriptions of the location of the crown (bliss) chakra within the Tantric tradition. BLA = basolateral amygdala; mPFC = medial prefrontal cortex; NAc = nucleus accumbens; VTA = ventral tegmental area (the location of dopaminergic cells).
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Drug-induced euphoria is sometimes described as being similar to orgasm, and is thought to depend (in part) on biochemical activity in the accumbens

> I was scared to main, but I gave in, Pudgy hit it in for me. I did half a fiver and, shit, what a rush . . . just one long heat wave all through my body, any ache I had flushed out. You can never top that first rush, it's like ten orgasms . . . (Carroll, 1987, p. 30)

This quote provides a description of a heroin-induced high. As with Tummo practice, Carroll describes a subjective state of bliss, which apparently has marked similarities to that of sexual orgasm, even though it was not induced through any overt or otherwise obvious sexual activity.

Most drugs of abuse are thought to work, in part, by activating dopamine and/or opiate systems within the region of the nucleus accumbens, and possibly also related structures. In some cases, the drug may act by directly causing increased levels of dopamine and/or opiates within the nucleus accumbens itself. In other cases, a drug may act indirectly at a more remote site. For example, opiate drugs have been shown to cause dopamine release within the accumbens indirectly, by inhibiting GABAergic interneurons in the midbrain. In turn, these interneurons exert an inhibitory influence on dopamine neurons in the ventral tegmental area, which project to the accumbens (Johnson & North, 1992).

This dopamine/opiate activation is thought to initiate a series of biochemical events in the accumbens region, which orchestrates both reward learning (in this case, reward for drug seeking and drug using) and a subjective "high." These accumbens transmitter systems are also activated during sexual foreplay and

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especially at the moment of orgasm, which perhaps explains the similarity between sexual pleasure and certain drug-induced experiences.

Critical differences between meditative and "worldly" pleasures: meditation does not seem to initiate conditioned down-regulation of either the positive affective states or the correlated biochemical brain activities as a result of repeated exposure

The experiences quoted above suggest that religious states of transcendent bliss may be similar to the subjective experiences of pleasure induced by wordly pleasures such as food, sex, and drugs. They further suggest that religiously evoked states of bliss may somehow be related to biochemical changes similar to those induced by these worldly pursuits (Linden, 2011, p. 159). Indeed, the one study (to my knowledge) to examine brain dopamine levels during meditation (Kjaer et al., 2002) has demonstrated that advanced practitioners experience a large increase in dopamine levels (65%) in the nucleus accumbens during meditative states.

However, there are major differences between contemplatively induced bliss and that derived from worldly pursuits. First, repeated experience with the same external reward (e.g., food, drugs, money, etc.) within a given context typically leads to a reduction in the level of pleasure induced over the course of repeated exposures (e.g., see Hyman, Malenka, & Nestler, 2006). In other words, exposure leads to tolerance for the euphoric effect.

Interestingly, many drug-related forms of tolerance are associative (i.e., learned) in nature, such that they appear dependent on contextual cues present during exposure (see Hyman et al., 2006; Siegel, Baptista, Kim, McDonald, & Weise-Kelly, 2000). For example, when repeated morphine injections are paired with a predictive audiovisual cue, subsequent presentations of the cue cause greater morphine tolerance in conditioned individuals than in those who received the same number of morphine injections in the absence of the cue (Siegel et al., 2000).

Investigations of the biochemical effects caused by chronic drug use have revealed numerous compensatory changes in affective brain systems, including the nucleus accumbens and the extended amygdala. It is likely that these effects combine to cause the exposure-induced loss of the hedonic response. Of particular relevance here is that the down-regulation of hedonic effects, which results from repeated exposure, corresponds to the conditioned suppression of dopamine caused by worldly rewards (Schultz, 1998).

In contrast, the ability to induce blissful states via meditative techniques (as opposed to worldly vices) appears to increase over repeated efforts. Thus, long-term and devoted practitioners tend to improve in this ability over time. Also, the fact that Kjaer et al. (2002) find high dopamine levels in long-time practitioners suggests that dopamine release remains intact (or increases) with repeated exposure to the meditative practice.

A proposed mechanism for how clearing the mind leads to subjective bliss

In what follows, I will propose a theory for how these spiritually induced states of positive affect generate dopamine/opiate activity in the accumbens, and yet are not accompanied by the typical dysphoric consequences of repeated exposure to more worldly pleasures. Centrally, this will include an explanation for why these blissful states are induced by clearing the mind of its usual thought patterns. Specifically,

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I suggest that enduring meditative bliss may result, at least in part, from the release of conditioned dopamine suppression, which often accompanies daily life. In particular, I will propose that the human tendency toward repetitive, compulsive thought patterns (i.e., daydreams, fantasies, and obsessions) may constitute an internal form of reward. They are addictive "behaviors" that may be shaped by the same mechanisms that shape behaviorally exhibited addictions. As such, they may come to down-regulate dopamine release into the nucleus accumbens and thus maintain an ongoing state of relative dysphoria.

The proposed mechanism will take the form of a neural network model that incorporates the idea of reward prediction error, as exemplified by traditional learning theory (see Rescorla & Wagner, 1972) and subsequent models of reinforcement learning (e.g., Hazy, Frank, & O'Reilly, 2010). This earlier work, conducted in the context of animal conditioning, provided compelling evidence that conditioned cues not only come to predict a given reward, but also to block the reinforcement signal otherwise provided by that reward. For example, when a tone becomes a robust predictor of food reward (as evidenced by the animal's conditioned salivation), it will subsequently block the animal's ability to learn another stimulus-response association (Kamin, 1968).

In the original Rescorla-Wagner (1972) theory, the reinforcement signal was a strictly theoretical entity proposed to "stamp in" the associative connection between the conditioned stimulus (e.g., tone) and the unconditioned stimulus (e.g., food). However, a remarkable biological parallel has recently been discovered in the activity patterns of midbrain dopamine cells over the course of conditioning (see Schultz, 1998). Specifically, these cells fire strongly and preferentially in response to hedonically positive stimuli, such as food or juice (Mirenowicz & Schultz, 1996). Thus, during initial conditioning trials with food reward, these cells fire robustly in response to the food delivery. However, this response gradually diminishes over the conditioning trials: once the food comes to be well predicted by the conditioned stimulus, there is no longer a response to the food by dopamine cells. These findings have led to the idea that dopamine may, in fact, constitute the theoretical reinforcement signal postulated by several theorists (Rescorla & Wagner, 1972; Sutton & Barto, 1998).

If it is true that these reward-related dopamine signals are also causally related to the subjective pleasure provided by worldly rewards, then the findings from Mirenowicz and Schultz (1996; Schultz, 1998) may provide at least part of the explanation for why worldly attainments inevitably lose their subjective pleasure.

Further, if it is true that our compulsive, everyday thought patterns are also a form of repetitive, predictable, and rewarded behavior, they may also lose their ability to provide the rewards that initially supported their development. In fact, to the extent that they are a constant concomitant to our mental life, they may constitute a continuous suppression of dopamine-related activity in the accumbens.

Anatomical overview of the nucleus accumbens and its connections

Information from cortical regions is filtered through the accumbens and ultimately back onto prefrontal motor regions of the cortex

The nucleus accumbens (along with a portion of the olfactory tubercle) is thought to comprise the ventral portion of a larger structure known as the striatum (Heimer et al., 1982). As indicated in Figure 2, the striatum as a whole receives inputs from

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nearly all cortical regions (Graybiel, 2008; Parent & Hazrati, 1995; Voorn et al., 2004). In turn, it sends indirect projections back to motor areas in the frontal and pre-frontal cortical regions, via a series of synaptic relays through the pallidum, subthalamic nucleus (not shown in Figure 2), and thalamus (Alexander & Crutcher,

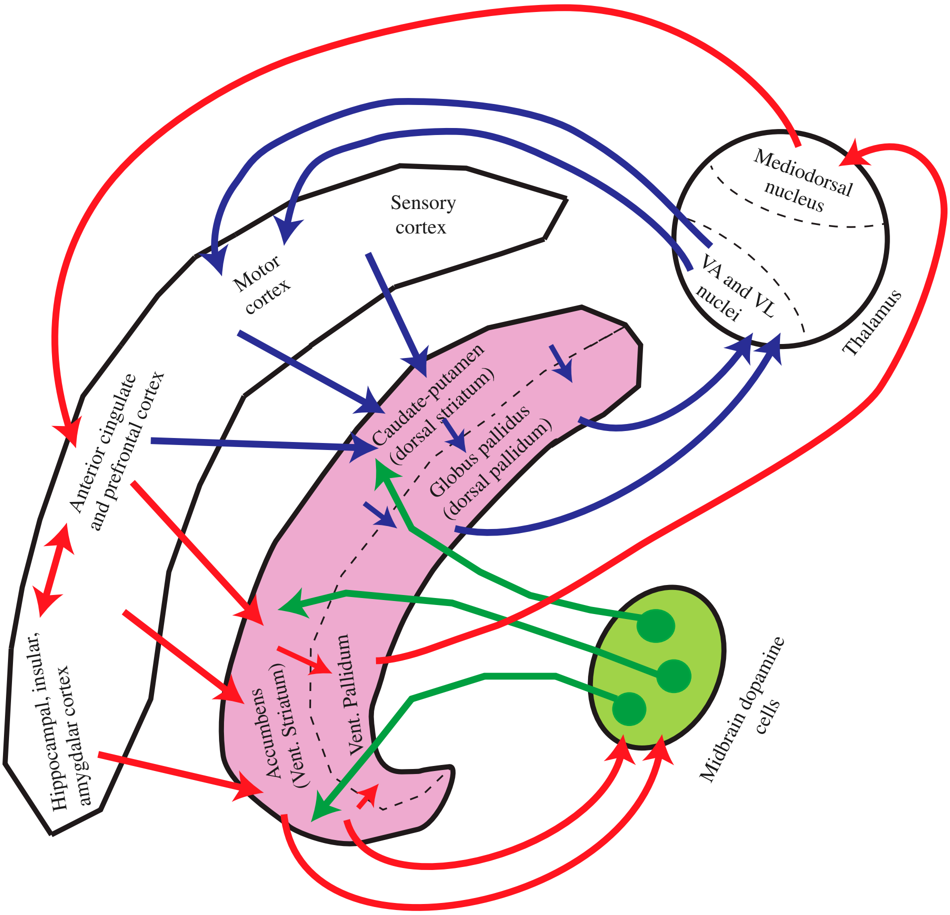

Figure 2. A highly schematized and simplified diagram of portions of the striato-pallidal circuitry.

Note: The striatum and pallidum are shown in purple, while the midbrain ventral tegmental area is shown in light green. The topographically organized projections that form cortico–striatal–pallidal–thalamo–cortical loops are shown separated into a dorsal (blue arrows) and a ventral (red arrows) division. The dorsal loop includes information from sensorimotor and associative cortices that projects onto the caudate-putamen nucleus (dorsal striatum), then onto portions of the globus pallidus (dorsal pallidum), and then through the ventral anterior (VA) and ventral lateral (VL) thalamic nuclei and back onto the motor cortex. The ventral, or limbic, loop includes information from medial prefrontal, hippocampal, insular, anterior cingulate, and amygdalar regions, which projects onto the ventral striatum (nucleus accumbens), then onto the ventral pallidum, and then via the dorsomedial thalamic nucleus onto several prefrontal (executive motor cortex/working memory) and anterior cingulate cortical regions.

Source: Based on Heimer, Switzer, and Van Hoesen (1982); Graybiel (2008), and Voorn, Vanderschuren, Groenewegen, Robbins, and Pennartz (2004).

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1990; Gerfen, 1992; Parent, 1990; Parent & Hazrati, 1995). In this way, cortical information is filtered through a cortico–striatal–pallidal–thalamo–cortical loop in order to ultimately influence behavior via the frontal cortices.

The entire striatum (dorsal and ventral), along with its associated regions, is thought to be involved in reward learning and hedonic tone. However, the nucleus accumbens in particular has received the most attention in relation to the obviously pleasure-related instrumental responses, addictions, compulsions, and obsessions.

The nucleus accumbens receives input from cortical regions implicated in the production of "offline" mental events such as daydreams and fantasies

The nucleus accumbens, in particular, receives input from limbic cortical regions thought to be involved in emotional processing and certain mnemonic functions. These include three regions: (1) the hippocampal area; (2) medial and orbitofrontal portions of the prefrontal cortex and the anterior cingulate; and (3) the basolateral amygdala (see Pennartz, Groenewegen, & Lopes da Silva, 1994; Voorn et al., 2004).

Of particular importance here is that both the medial prefrontal and the hippocampal regions are critical nodes in the so-called "default mode network" (DMN) (see Buckner, Andrews-Hanna, & Schacter, 2008). This network refers to a set of interconnected associative cortical regions, including the ventral and dorsal medial prefrontal cortex, the posterior cingulate/retrosplenial cortex, the inferior parietal lobule, lateral temporal cortex, and the hippocampal formation (Buckner et al., 2008).

The DMN was initially identified accidentally in the midst of technical concerns related to how best to choose a control condition when conducting brain-imaging studies. Many early imaging studies included a control condition that simply involved "rest" (i.e., undirected mental activity). This rest state was intended to provide a backdrop of relatively low overall brain activity against which to assess activity induced during particular sensory and cognitive tasks. However, careful examination revealed that these rest times consistently involved elevated activity in a correlated set of three regions (listed above), which then became selectively deactivated during experimental task performance (Buckner et al., 2008).

Since this network was initially identified as being involved in rest states that did not include the experimental task itself, it was named DMN, meaning it is the state that the brain enters "by default" when no explicit externally driven cognition is required. However, subsequent work on this system has shown that it is actively involved in self-referential mental activities (that arise spontaneously during "rest" periods), which are commonly involved in daydreaming, fantasizing, and planning (e.g., Mason et al., 2007; Vanhaudenhuyse et al., 2010).

In particular, the hippocampal and parahippocampal portions of the default network are thought to help orchestrate the mental "time travel" abilities (Schacter & Addis, 2009; Tulving, 1985) involved in episodic memory and the construction of possible future scenarios. Thus, the accumbens appears to receive ongoing neural activity patterns that constitute the neural code for daydreams, fantasies, and planning.

Midbrain dopaminergic cells also converge onto the accumbens cells

Along with the cortical inputs described above, dopaminergic cells from the ventral tegmental area, medial substantia nigra, and pars compacta converge onto the

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projection cells of the accumbens (see Joel & Weiner, 2000). These dopaminergic cells are critical for the central hypothesis being presented here for the following reasons. First, dopamine release from these cells is thought to be related to subjective hedonic states. Second, activity in these cells is also strongly implicated as being critical for reward learning observed at the behavioral level. Finally, the dopamine activity itself is down-regulated over the course of repeated conditioning trials (as mentioned above).

The nucleus accumbens contains endogenous opiates

One striking aspect of the striatum is the fact that it contains a rich variety of neuropeptides and other neurochemical transmitters and receptors, many of which are involved in emotional responses related to euphoria, mating, social bonding, and trust (Herkenham, 1992; Lim & Young, 2006; Mailleux & Vanderhaegen, 1992; Parent & Hazrati, 1995; Pennartz et al., 1994). Of particular relevance here (see Figure 3) is that many of the accumbens neurons themselves manufacture and release endogenous opiates as one of their neurotransmitters (Gerfen, 1992; Voorn, Gerfen, & Groenewegen, 1989).

The nucleus accumbens and positive affect

Dopamine and positive affect

Several lines of evidence suggest that dopamine release in the accumbens is causally related to euphoria and positive mood. First, all drugs of abuse lead to the release of dopamine in striatal regions (Hyman et al., 2006; Koob & Volkow, 2010), and these drugs are of course typically associated with euphoric or mood-elevating effects (e.g., Hyman & Nestler, 1996). Thus, the various drugs of abuse (viz., cocaine, heroin, alcohol, nicotine, etc.) are quite heterogeneous in terms of molecular structure and their initial chemical target(s) within the brain; yet they all—either directly or indirectly—cause dopamine release into the accumbens. This suggests the possibility that such dopamine release may be the common factor in the ability of these various drugs to induce positive hedonic effects.

In addition, natural rewards also cause dopamine release into the accumbens. For example, research suggests that dopamine neurons fire preferentially to appetitive stimuli, such as food and juice, as well as to conditioned predictors of these natural rewards (Mirenowicz & Schultz, 1996; Schultz, 1998). Similarly, *in vivo* microdialysis and electrochemistry have confirmed that dopamine levels are elevated during presentations of food and/or conditioned predictors of food delivery (see Berridge & Robinson, 1998).

Another natural reward that induces dopamine release in the accumbens is stimuli and behavior related to sexual activity. For example, Fiorino, Coury, and Phillips (1997) discovered the following. When male rats were allowed to view a receptive female rat from behind a screen, they experienced an increase in accumbens dopamine levels. Following this introductory period, the male rat was allowed access to the female and copulation ensued, which caused a further dramatic increase in dopamine levels. In the following period of sexual satiety, dopamine levels returned to baseline; but in a subsequent manipulation, a new receptive female was presented behind the screen, and this resulted in a slight increase in dopamine levels, so that

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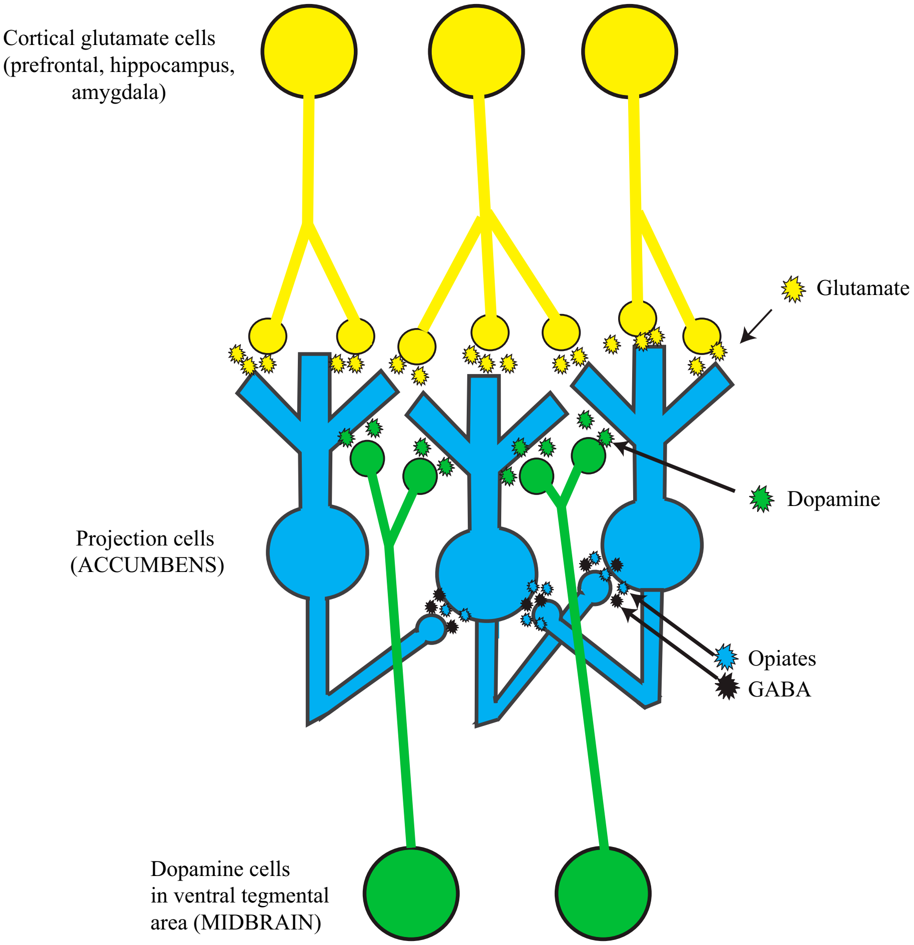

Figure 3. A schematic view of the medium spiny projection neurons that constitute the main cell type within the accumbens.
Note: Also shown are glutamatergic inputs from cortical regions such as the prefrontal and hippocampal areas, as well as inputs from midbrain dopaminergic neurons. The medium spiny cells use the inhibitory transmitter GABA for synaptic communication, and many also release a co-transmitter. This figure depicts a set of medium spiny cells that co-release GABA and endogenous opiates.

they were again above baseline. Upon removal of the screen, copulation ensued with the new female, which caused a concomitant and renewed spike in dopamine levels.

Although technically challenging, studies of this kind have also been conducted using human subjects. For example, Holstege et al. (2003) conducted an experiment in which regional brain activity levels were examined as human males received genital stimulation to the point of ejaculation from their sexual partner. The single most intense area of elevated brain activity during the moment of ejaculation was the mesodiencephalic transition zone, which includes the ventral tegmental area. This is the area containing the dopaminergic neurons that project to the accumbens. Thus, research on both humans and animals suggests that there is intense dopamine release in the accumbens during sexual climax.

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Finally, it has been suggested that a chronic down-regulation of dopaminergic levels in the nucleus accumbens may play a role in the anhedonia associated with depression (see Nestler & Carlezon, 2006).

Endogenous opiates and positive affect

The above quote from Carroll (1987) attests to the euphoric effects of opiate-like drugs. As is well known, the brain produces its own opiate-like substances, as well as receptors with which these endogenous opiates interact. It is these same receptors that also interact with exogenous opiate drugs, such as morphine and heroin, to produce their various physiological and subjective effects. One type of cell that utilizes these endogenous opiates is the projection cells. These cells group together in the striatum, including those in the accumbens (Gerfen, 1992; Voorn et al., 1989).

As suggested in Figure 3, the opiate and dopaminergic systems are closely intermixed within the circuitry of the accumbens. For example, dopaminergic inputs play a powerful role in influencing the firing rate of the accumbens neurons (Sesack & Grace, 2010). This in turn suggests that dopamine plays a role in controlling the release of endogenous opiates into the accumbens via the intrinsic feedback projections from accumbens neurons. It is worth noting that this suggestion has been supported empirically (e.g., Llorens-Cortes, Zini, Gros, & Schwartz, 1991).

Thus, three inferences can be made: dopamine and endogenous opiates are both located in the accumbens, they have both been implicated in the production of positive hedonic states, and they are released interactively. This situation has led to a great deal of controversy as to which of the two neurotransmitters may be most directly responsible for the euphoric reactions caused by exogenous substances, such as opiates (e.g., heroin and morphine) and dopaminergic agonists (e.g., amphetamine and cocaine) (Berridge, 2007; Berridge & Robinson, 1998; Wise 2004, 2008).

It is beyond the scope of the current paper to address this issue. However, for the present purposes, it is sufficient to suggest that euphoric effects are likely due to some unknown details of neurochemical events. Under normal circumstances, these are likely caused by interactions involving dopamine and endogenous opiates, as well as additional mechanisms. Of course, the precise neural correlates—perhaps causes—of subjectively experienced emotions are unknown. This mystery is partially due to the larger mystery of consciousness; namely that science lacks fundamental principles to relate inner conscious experience to neural activity. Indeed, this issue corresponds to the “hard problem” of consciousness: relating consciousness to the brain (Chalmers, 1996).

However, the data reviewed in this section suggest that cellular processes within the accumbens somehow allow for neurochemical activity, which, at the subjective level, corresponds to various aspects of euphoria, pleasure, satisfaction, satiety, and so forth.

In addition to orchestrating subjective hedonic responses to stimuli, the nucleus accumbens also seems to orchestrate reward learning in relation to these positive stimuli

It is often assumed that events that give rise to positive subjective experiences also serve as reinforcers for behaviors that lead to their occurrence. For example, when we use food to help train a dog, there is often the assumption that the dog subjectively enjoys the food and also will have an increased likelihood of engaging in any behavior that is quickly followed by food. On the theoretical level, the food serves as a "stamp" (Thorndike, 1911), which strengthens the connection between the stimulus context (i.e., the training environment and the trainer's commands) and the dog's behavior.

The anatomy of the striatum (Figures 2 and 3) suggests that its structure is well suited to serve as the region in which environmental stimulus representations converge onto cells that guide behavior. Thus, stimulus-related activity in the prefrontal, hippocampal, and amygdalar regions converges onto the striatal neurons, which ultimately project signals back onto motor response regions in the cortex.

Evidence that dopamine release in the striatum serves as a reinforcer

There is a great deal of evidence indicating that the striatum—in general—and the nucleus accumbens—in particular—are critical for orchestrating reward learning, whether it is for natural rewards or drugs of addiction. Much of this work further suggests that dopamine release into the accumbens is a critical step in the reinforcement process. These ideas have been reviewed extensively (see Berridge & Robinson, 1998; Graybiel, 2008; Hyman et al., 2006; Koob & LeMoal 2008; Koob & Volkow, 2010; Packard & McGaugh, 1996; Schultz, 1998; Wise, 2004, 2008).

As already mentioned, all drugs of abuse and natural rewards cause an increase in accumbens dopamine levels, at least during initial presentations. In addition, conditioned and social rewards, such as money, social approval, or scoring points in a game, also cause the release of dopamine into the accumbens (see Linden, 2011). All these events can serve as reinforcers, since individuals will learn how to obtain these rewards.

Evidence that dopamine within the accumbens specifically can serve as a reinforcer is provided by the fact that animals will learn to work (e.g., press a lever) in order to obtain micro-injections of dopamine agonists into the accumbens itself. This supports the idea that dopamine in the accumbens may serve as Thorndike's biochemical "stamp," which strengthens the connection between stimulus and response representations.

Theoretical models for reinforcement learning in the striatum often involve dopamine-dependent strengthening of stimulus–response connections

Figure 4 provides a schematic representation of the postulated sequence of events for the neural circuitry of accumbens-based reward learning. The ideas represented here are compatible with a number of previously developed learning models, and are most closely based on the work of Hazy et al. (2010) and O'Reilly and Frank (2006).

Initially, during the process of development there are connections made from limbic cortical regions onto the accumbens cells; but the exact strengths of these numerous cortico-accumbens connections are initially random (Figure 4A). Note that any accumbens cell that happens to fire will play a role in determining the ongoing stream of behavior via projections to the motor cortex, as discussed above.

Since the connections are random in strength during development, there are initially no strong (i.e., compulsive) tendencies for certain accumbens cells to fire in the presence of particular contexts or stimuli. For example, during childhood there is no particular tendency for the sight of a whiskey bottle to prompt approach and consumption, or for the slot machine to evoke the afforded gambling activity.

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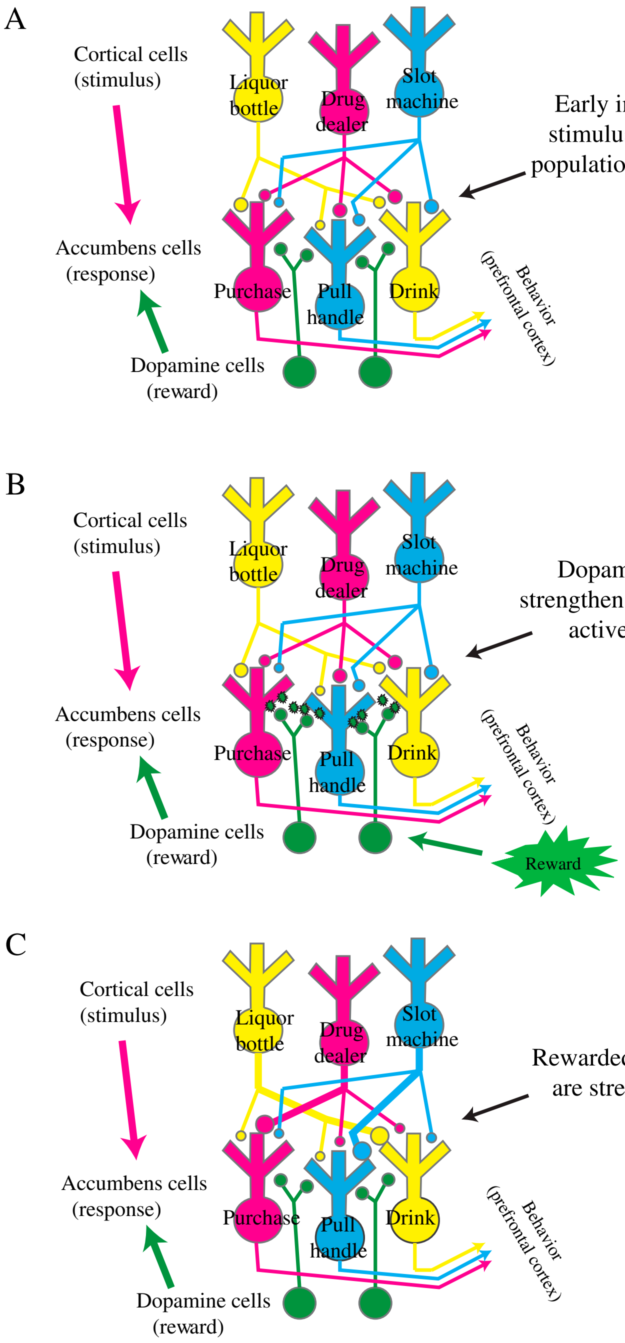

Figure 4. Schematic depiction of the postulated events involved in the development of the pattern of synaptic weights between the cortical and accumbens cells.
Note: The reward (dopamine)-induced strengthening of recently active synapses causes the emergence of stimulus–response habits at the behavioral level, as described in the text.

However, at some point in life the individual may be prompted to take a drink from the bottle, purchase drugs from the dealer, or play the slot machine. If it happens that this stimulus–response event is quickly followed by a surge of dopamine release (Figure 4B) into the nucleus accumbens (which is likely given the tendency for such stimuli to cause dopaminergic activity), then the stimuli will strengthen any recently active cortico-accumbens connections. Each of these training experiences causes long-lasting strengthening of the involved synapses (Figure 4C).

It is hypothesized that throughout the course of one's lifetime, many different stimulus–response configurations are shaped in this way, such that the individual comes to have a wide repertoire of conditioned response tendencies. These tendencies are orchestrated by the many cortico-accumbens loops that are formed in relation to the various contexts and stimuli afforded by their environment.

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Predicted rewards lose the ability to cause dopamine release and subjective hedonic effects

The learning mechanisms depicted in Figure 4 suggest that we should be able to generate endless happiness through instrumental learning of successful responses for each behavioral context

Figure 4 represents how the nucleus accumbens may work to orchestrate the development of maladaptive behavioral compulsions, such as drug, alcohol, and gambling addictions. Of course, it is assumed that these instrumental-learning mechanisms evolved within the animal kingdom long before the appearance of human vices. In this context, it is also assumed that these mechanisms are of tremendous value in relation to the survival of the individual. So, these learning processes would, presumably, provide a rich repertoire of behavioral knowledge related to which affordances are appropriate—such as foods, drinking sources, sources of warmth, social comfort, bonding, and so on—and which are likely to be successful in the different times and places experienced by the animal.

The fact that these reinforcing (i.e., dopaminergic) events within the accumbens also seem to be associated with subjective pleasure would seem to bode well for the subjective happiness of the individual. This arrangement suggests that, given a series of fortunate learning opportunities, the individual could develop a large set of context-specific behaviors that would lead to beneficial effects at the biological level, and would also cause contentment and joy at the subjective level. In fact, the mechanisms (see Figure 4) suggest that as we go along in life, we are likely to become increasingly skilled at obtaining the "good things" in life, and will also become increasingly "happy" in a parallel fashion. Given that even abstract rewards, such as money, social approval, winning points in a game, and so forth, can activate the dopamine system, it seems that there would be no limit to the happiness we could have, provided that we develop the ability to earn large amounts of money, fame, power, and so on.

However, it is almost a truism that our hedonic well-being does not necessarily parallel our objective financial or social status (within certain limits). Thus, given a certain basic level of safety and nourishment, happiness does not necessarily increase with additional success. Many have documented the "hedonic treadmill" effect in which worldly success only enhances the longing to gain even more worldly goods (see Compton & Hoffman, 2013).

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Of course, this inability to find abiding happiness through the pursuit of worldly attainments is not only a recognized phenomenon within the psychological literature, but also the standard advice offered by many religious, spiritual, and humanist traditions. In short, the fact that money cannot buy happiness seems to be discovered again and again by different cultures, and by many individuals over the course of their lifetime.

The ancient Buddhist and Yogic traditions are among those that warn against the dangers of attempting to find happiness through worldly attainments. They, too, warn of the endless craving and dissatisfaction that ultimately result from this approach. Instead, they recommend a path of renunciation in which all pursuit of worldly pleasures is abandoned.

There are learning mechanisms within the accumbens that provide a conditioned down-regulation of dopamine release for predicted rewards

This aspect of the human condition suggests that the biochemical events induced by worldly gains and orchestrated by inner pleasure must somehow be suppressed or down-regulated in response to repeated reward acquisition.

Indeed, the study of brain mechanisms related to drug addiction has revealed a variety of compensatory mechanisms that are induced by repeated drug exposure. These changes purportedly explain the spectrum of behavioral and subjective changes involved with the development of addiction and craving, including the fact that chronic drug abusers may no longer experience the “high” that the drug originally provided.

One set of results in this area has to do with studies examining the reward-related activity of dopaminergic neurons over the course of various Pavlovian and instrumental conditioning paradigms involving a food reward (see Schultz, 1998). As already discussed, this work has revealed that the ventral tegmental and substantia nigra dopaminergic neurons exhibit a reward-prediction error similar to that postulated by Rescorla and Wagner (1972) and based on earlier work in animal conditioning.

It should be noted that the error-prediction view of dopaminergic function provided by the work of Schultz (1998) is not the only function that has been postulated for the dopaminergic system. For example, Panksepp (1998) has suggested that dopamine is part of a more general “seeking” system that is involved with reward anticipation and motivates animals to forage and thereby find rewards. A similar view is that the dopamine system provides incentive salience and motivation (Berridge, 2007; Berridge & Robinson, 1998). Although a review of these issues is beyond the scope of the present paper, it seems possible that the postulated reward-prediction error and hypotheses concerning seeking and incentive motivations are not mutually incompatible. Rather, they may be complimentary and related functions all of which are supported by the dopamine system.

A study along these lines is reported by Schultz, Dayan, & Montague, (1997) and depicted schematically in Figure 5. Here, animals are presented with conditioning trials in which an initially neutral stimulus (viz., a light) is paired with delivery of an appetitive stimulus (viz., juice). During initial learning trials on this task, delivery of the juice reward caused an expected short-latency burst of dopamine cell activity (Figure 5, left panel).

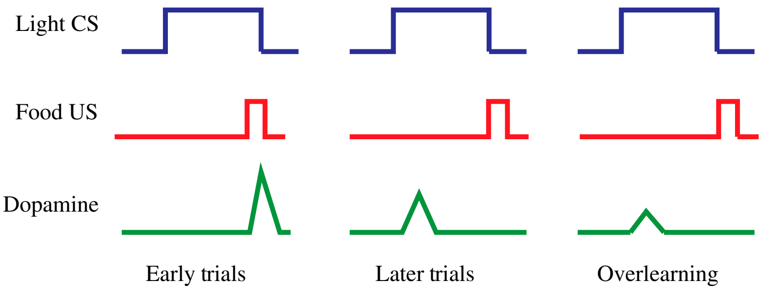

Figure 5. Representation of midbrain dopamine cell firing patterns over the course of conditioning trials.
Note: Each of the left, middle and right panels depicts a representative training trial, in which the light conditioning stimulus (CS) is presented briefly, and is followed by presentation of a food reward (unconditioned stimulus: US), contingent on an instrumental response. As shown in the left panel, during early trials, the food US causes a burst of activity in the dopaminergic cells. This is because the food is not yet predictable for the subject. The middle panel depicts trials later in conditioning, when the animal has learned that the light CS predicts the arrival of the food. Since the food presentation is now predictable for the subject, there is no longer a dopamine response at the time of food delivery. Note, however, that the light has come to elicit a dopamine cell burst. Finally, following many additional training trials (right panel) the dopamine response to the light also fades away, so that there is no dopamine cell bursting at any point during the trial, even though the animal continues to touch the lever in order to obtain the juice.
Source: Based on data reviewed in Schultz et al. (1997, 1998).

However, as the training continued and the reward delivery became predictable to the animal, the dopamine release at the time of reward gradually diminished (Figure 5, middle panel). This dopamine suppression was based on an associative learning process, as evidenced by the fact that unpredicted food delivery still resulted in vigorous dopamine cell bursting (data not shown). As also indicated in Figure 5 (middle panel), a brief dopamine burst to the conditioned (light) stimulus developed as learning progressed. Thus, dopaminergic release into the accumbens moved from the time of reward to the time of the conditioned stimulus presentation.

Finally, with even more learning trials (Figure 5, right panel), even the dopamine response to the light began to diminish. In the end, the animal still performed the instrumental response to receive juice each time the light was presented, but this now took place in the absence of any appreciable dopamine release.

There are numerous neural network models that have been developed to account for the observed down-regulation of dopamine to the unconditioned stimulus, and also the development of the dopaminergic response to the conditioned stimulus. One of these proposed mechanisms (Hazy et al., 2010) is partially depicted in Figure 6. Here, a subset of the accumbens cells, consisting of so-called patch-like cells, is postulated to be responsible for the conditioned suppression of dopamine neuron responses that develops under the influence of the unconditioned stimulus. These patch cells are thought to undergo the development of conditioned enhancement of their response to the light conditioned stimulus (CS), just as do the other (matrix) accumbens cells (see Figure 6). However, in the case of patch cells, rather than providing an influence on behavioral output (as matrix cells do), the patch cells project back onto the midbrain dopamine cells. Since the accumbens cells use an inhibitory transmitter, this patch cell conditioning constitutes a conditioned

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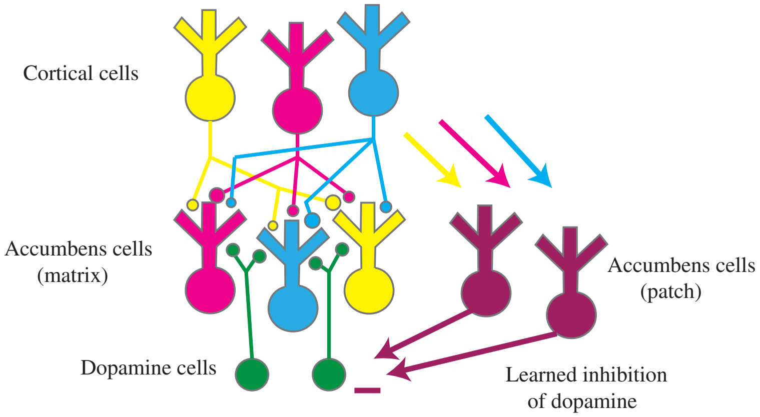

Figure 6. Schematic depiction of the accumbens circuitry involved in reward learning, as in Figure 4.

Note: Also included here are patch-like neurons that send an inhibitory projection down to the midbrain dopamine cells. These neurons are postulated to develop a conditioned response to rewarded stimuli (just as do the matrix neurons). However, rather than helping orchestrate conditioned behavioral responses, these neurons provide conditioned down-regulation of dopamine release (see text).

suppression of the dopamine signal (i.e., learning). This component of the dopamine-induced plasticity thus serves to turn off the dopamine-learning signal.

To the extent that phasic dopamine release is causally related to biochemical states that provide subjective pleasure, it appears that predicted rewards become less capable of evoking pleasure over repeated trials. Thus, in the advanced stages of developing a conditioned reward behavior, the individual is left with a strong behavioral compulsion (due to the earlier dopamine-induced synaptic plasticity in the matrix cells), but little or no attendant pleasure. This proposed mechanism is thus in accordance with the spiritual advice that lasting happiness cannot be obtained through the acquisition of worldly goods.

Habitual thoughts may also be a form of rewarded (compulsive) behavior orchestrated by the nucleus accumbens and causing a reduction in ongoing dopamine levels

Humans tend to spend a great deal of time engaged in discursive, "offline" thought, and this mind-wandering may be associated with negative affect

Recent data suggest that we humans spend a great deal of time engaged in what is known as "stimulus-independent thought" or "mind-wandering" (Killingsworth & Gilbert, 2010; Klinger, 2009). This type of mental activity includes phenomena such as daydreaming, fantasizing, and obsessing. A recent study by Killingsworth and Gilbert (2010) used a technique in which subjects received automated phone calls randomly interspersed throughout their waking hours. Results from a sample of 2,250 adults (58.8% male, 73.9% residing in the USA, mean age of 34) reported that individuals were engaged in mind-wandering during 46.9% of the samples. This corresponds well with Klinger's (2009) estimate that approximately 50% of all human thought can be classified as daydreaming.

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This type of mental activity often involves self-referential thoughts, perhaps related to possible future plans or future successes. It may also involve rumination or reliving past events. It may consist of rather mundane thoughts, such as rehearsing our to-do list, or planning our next project. Alternatively, it may involve dreams of victory or glory.

Interestingly, the Killingsworth and Gilbert (2010) study also reported that our affective state is negatively impacted by mind-wandering activity. During each of the calls mentioned above, subjects were not only asked to report their mental activity, but also to state what physical activity they were engaged in (e.g., working, reading, listening to music) and their current affective state (scaled from 0 to 100). As might be predicted, these authors found that our momentary physical context influences our mood: our hedonic tone is relatively low when we are at work, but relatively high when we are engaged in conversation. However, the biggest single influence on hedonic tone was the occurrence of daydreaming. There was a prominent reduction in happiness scores during mind-wandering, and this variable accounted for more of the between-subject variance in happiness scores (17.7%) than the actual activity in which subjects were engaged (which accounted for only 3.2% of the between-subject variance).

The Buddhist tradition also notes our tendency toward mind-wandering. For example, the well-known Buddhist teacher Pema Chodron (2010) refers to our "substitute life," which we live just in our own head. The Buddhist tradition has also observed that these thoughts, regardless of whether they seem to be pleasant (e.g., dreams of glory) or unpleasant (e.g., fears of defeat) lead only to unhappiness.

It is very difficult to calm these discursive thought patterns

Beginning meditators often report that it is extremely difficult to clear the mind of these discursive thoughts, even briefly. The fact that it is so difficult to halt the ongoing stream of discursive thoughts suggests that they may be a form of addictive behavior, not unlike the externally observable addictions involved with compulsive hand-washing, gambling, sexual activity, eating, drug use, and so forth. Indeed, Bigelsen and Schupak (2011) have identified a set of individuals who suffer from compulsive fantasizing, which interferes with other productive life activities.

This analysis fits well with the Buddhist tradition, which tends to regard all repetitive tendencies as addictions, regardless of whether they are outwardly observable or involve commonly described substances of abuse.

Indeed, if this mind-wandering activity is a form of addictive behavior, it may be shaped by the reward mechanisms that are dependent on the nucleus accumbens and related structures. In fact, this mechanism has been suggested as a possible explanation for the repetitive thought patterns involved in obsessive–compulsive disorder (Lambert & Kinsley, 2011).

Obsessive daydreaming can be incorporated into learning models as a form of addictive, rewarded behavior

This idea is outlined in Figure 7. Here, elements of possible fantasies are depicted as being represented by cortical activity in the prefrontal and hippocampal regions that project to the accumbens. As mentioned above, both regions are part of the default

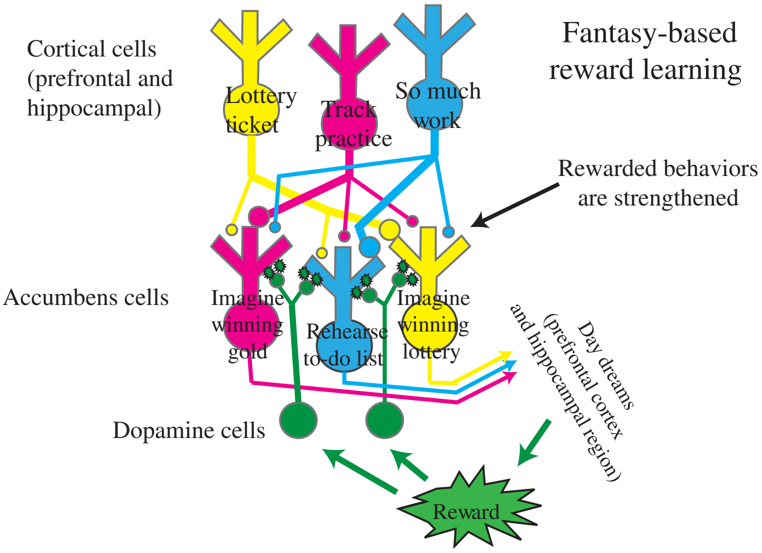

Figure 7. Here the reward-learning model developed in Figure 4 is applied to the learning of habitual thought patterns such as fantasies, daydreams and obsessions.

network and have been implicated as critical for the types of mental activity that constitute mind-wandering.

These cortical activity patterns may, at least in many cases, be prompted by external stimuli. For example, an office worker may glance at a recently purchased lottery ticket while thumbing through his wallet; or a high-school student might be reminded of track practice taking place later in the day. Also depicted in the cortical layer (see Figure 7) is the stimulus representation provided by an overload of expectations at work.

Such external cues can be expected to perhaps initiate ongoing prefrontal (i.e., working memory) and hippocampal representations related to the stimuli and associated events. As is well known, the hippocampus is thought to be responsible for episodic/declarative memory. Thus, an input of lottery-related cues could be expected to result in hippocampally driven representations of facts and episodes related to the lottery. Presumably, these would consist of stored representations within the hippocampal circuitry itself. As a result, this would engage the broad range of associative, language, and sensory cortical regions with which the hippocampal formation is interconnected (McClelland, McNaughton, & O'Reilly, 1995). So, the individual may be prompted to recall stories about others who have won the lottery, and related facts about the life-changing results of such winnings.

In addition, the hippocampus is also thought to be involved in the construction and elaboration of possible future scenarios. In the circumstance depicted here, it is suggested that the sight of the lottery ticket may induce a hippocampal-based daydream about the possibility of winning the lottery. As this daydream or fantasy unfolds it will: (1) be projected onto the nucleus accumbens via projections from the hippocampal and prefrontal regions; and (2) induce periodic activity in the dopamine cells, as when the daydreamer imagines receiving the lottery check, quitting work, buying a yacht, and so on.

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Thus, the cortico-accumbens loops will be engaged in a series of lottery-related neural representations, which will periodically be punctuated by dopamine release onto the accumbens cells. Presumably, the periodic dopamine release initiates subjective experiences of pleasure and joy. Also, in accordance with the learning mechanisms depicted in Figure 7, this lottery-related activity, along with the accompanying dopamine release, can be expected to increase the strength of the involved cortico-accumbens synapses. This means that these particular neural activity loops are increased in their frequency of occurrence —that is, they come to be mental compulsions.

These conditioned discursive thoughts (daydreams) would also be expected to lose their initially pleasant aspects

Just as the dopamine release in response to external rewards is gradually down-regulated over the course of conditioning (Figures 5 and 6), it is expected that conditioned daydreams would also induce dopamine suppression (Figure 8). *In fact, the central claim of this paper is that our constant engagement in compulsive, repetitive thought patterns tends to cause an ongoing, powerfully conditioned decrease in dopamine release, so that dopamine is chronically below what would be expected in the absence of these ongoing mental patterns.* Thus, we are left with obsessive tendencies to daydream about winning the lottery or getting through our workload, but the sense of relaxation or happiness to all aspects of these daydreams erodes: these thoughts become empty obsessions.

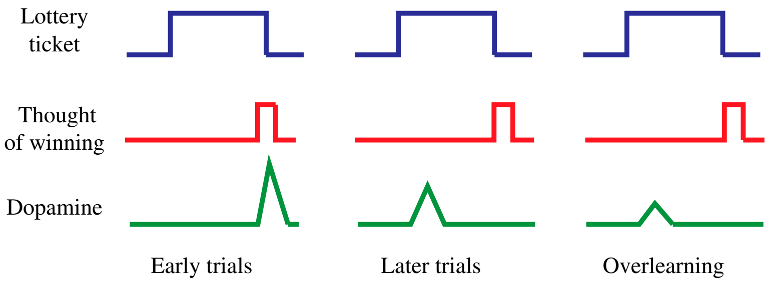

Figure 8. Here the theoretical time course of dopamine release as a particular fantasy (about winning the lottery) is repeatedly rehearsed.
Note: Initially, the fantasy evokes periodic dopamine bursts at points in the narrative of the fantasy involving desirable events, such as early retirement, or the ability to purchase expensive luxuries. As these "high points" become predictable due to repetition of the fantasy, the dopamine activity decreases, just as was the case for the repeated conditioning trials conducted by Schultz et al. (1997, 1998).

Buddhist meditation practice as a release from chronic down-regulation of dopamine activity

Our ongoing stream of behavior and consciousness is controlled by constantly shifting and competing activity patterns in large sets of strongly interconnected neurons known as attractor networks

Throughout this paper I have made reference to the idea that various sets of strongly interconnected cells located within the cortico-accumbens neural loops sometimes fire together, and when they do so, they orchestrate the mental and behavioral events that they "represent." However, this idea is just one aspect of the global understanding of attractor networks or the role of Hebbian cell assemblies (i.e., connected sets of neurons) in brain circuitry. Indeed, neural plasticity (usually not dependent on dopamine) is observed throughout the nervous system.

Activity in these sets of conditioned cell assemblies is thought to arise, fall, and hand off to other cell assemblies throughout our conscious life. In so doing, they not only orchestrate our ongoing and shifting thought patterns, but also our behaviors (Spivey & Dale, 2004).

Meditative concentration apparently breaks up the attractor-based "ruts" in neural activity patterns

Elsewhere, I have argued that Buddhist meditation practices serve to break up the ongoing activity in these cortical attractor networks (Sharp, 2011). I have suggested that the brain in fact enters a state in which nearly all attractor-based activity is stilled, from which there is unstructured and random activity throughout most, if not all, of the cortex (Figure 9B). Since these random patterns would be entirely novel, they would be nameless (i.e., not attached to any conditioned assemblies in language-coding networks) and imageless (i.e., not corresponding to any worn-in visual system assemblies).

The argument (presented in Sharp, 2011) that meditative absorption (viz., Samadhi) involves novel (i.e., non-attractor-based) cortical activity patterns is complex, and involves a number of interlocking observations.

First, an essential background assumption is provided by the work of Singer and Gray (1995; Singer, 1998). Work from Singer's laboratory has suggested that any one element (e.g., a percept) within conscious experience somehow emerges (or is correlated with) activity in a closely synchronized set of concurrently active neurons.

The exact nature of any conscious event is, presumably, determined by the neurons involved (viz., olfactory neurons cause olfactory aspects of an experience, auditory system neurons cause auditory components, etc.). Thus, it is postulated that stimulus processing and other cognitive and emotive processes result from the momentary arising of synchronous activity, which involves the neural members of previously established attractor networks (Crick & Koch, 1990; Engel, Fries, König, Brecht, & Singer, 1999; Singer, 1998; Singer & Gray, 1995).

Second, electroencephalogram (EEG) recordings from adept practitioners of Buddhist meditation reveal extreme levels of cortical synchronization during meditative absorption (e.g., Austin, 2006; Cahn & Polich, 2006; Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). This is so extreme that Gyorgy Buzsáki (2006), a leading EEG researcher, has suggested that the EEG activity present during meditation is strikingly similar to the activity observed during seizure activity. I have suggested elsewhere (see Sharp, 2011) that the ability of individual attractors to emerge under these conditions may be "swamped" by high levels of cholinergic activity, which is possibly induced during these states. These high levels of acetylcholine would be expected to reduce temporarily the strength of feedback synapses that are responsible for connecting neurons within local attractors (Giocomo & Hasselmo, 2007; Hasselmo & McGaughy, 2004). At the same time, the high acetylcholine levels would temporarily increase the strength of synapses that

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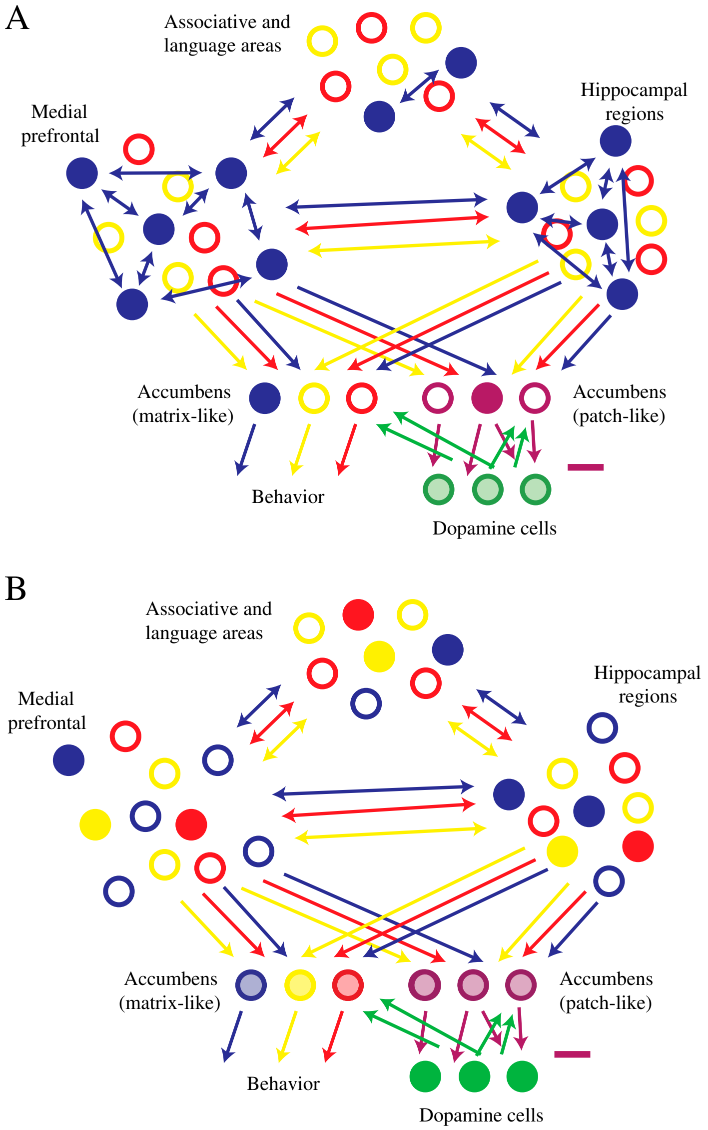

Figure 9. Sets of neurons located throughout cortical and striatal regions, which have, through the process of repetitive, conjunctive activity, become strongly interconnected so that they form attractor networks.

Note: Three such networks are depicted here, each using a different color. (A) In this case, the attractor network depicted in blue is currently active. Note that this attractor activity provides strong inputs to accumbens cells that control response selection, as well as to those that inhibit the midbrain dopamine cells. (B) Here, attractor-based activity has been broken up, so that even though there is still random neural activity (from randomly selected cells in all three attractor networks), no one attractor is dominant. It is suggested that this state may be induced through meditation, and may correspond to the meditative state in which there are no identifiable thoughts, even though there remains the "clear light of consciousness." Note that this random activity does not provide any strong input to any particular accumbens cells, since, under these conditions, any one such cell receives input from a random set of both strong and relatively weak synapses.

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convey stimuli from more distant afferent brain regions (Giocomo & Hasselmo, 2007; Hasselmo & McGaughy, 2004).

Thus, I suggest that this combination of extreme levels of membrane oscillatory synchronization, along with the postulated high levels of acetylcholine, may have created the following conditions: those in which the usually isolated packets of synchrony, which are necessary for the emergence of individual attractor networks, including their corresponding conscious events (e.g., thoughts, perceptions, and memories), have disappeared.

Indeed, perhaps the most obvious evidence for this very speculative idea comes from introspective reports about these very practices. As described above, these practices can achieve a state of consciousness in which the mind is calmed and ordinary thoughts no longer occur. If ordinary thoughts are dependent on attractor network activity in highly synchronous cells, then disruption of these networks would be expected to lead to "contentless" awareness. The following quote describes this state, which arises during deep meditation:

> The ordinary mind of an ordinary sentient being, as it were, disappears. Consequently, discursive thoughts become dormant, and roving thoughts vanish into the space of awareness . . . Adhering to the experiences of vacuity and luminosity, while looking inwards, the appearance of oneself, others, and objects vanish. This is the substrate consciousness . . . one has come to the essential nature of the mind. (Dudjom Lingpa, as quoted in Wallace, 2007, p. 18)

It can be noted that these attractor-free activity states might be expected to have some lasting effects—that is, beyond the individual meditation session (Sharp, 2011). Specifically, they might be expected to provide an opportunity for counter-conditioning the synaptic patterns that are in fact responsible for the continued existence of the attractors themselves. Thus, following a deep absorptive state, one might be left with a general loosening of the existent attractor networks. According to the hypothesis presented here, this might be expected to leave the practitioner with an ongoing sense of relative positive affect and freedom of thought, even after having returned to everyday conceptual capabilities.

The absence of habitual attractor activity would release dopamine cells from the suppression normally caused by our addictive thought patterns

The representations of reward conditioning shown in Figures 4 and 7 are extremely simplified neural circuits in which each neural conditioning stimulus was represented by activity in just one cortical neuron. Of course, any reward context will involve activity in attractor networks consisting of many thousands or millions of concurrently active cells. Presumably it is activity in large subsets of these attractor cells that serves as the neural conditioning stimuli for the accumbens cells shown in these figures. Thus, following conditioning, the patch-like cells responsible for conditioned dopamine cell inhibition would be dependent—for their activation—on concurrent activity in large subsets of attractor network cells, with which they have formed strong connections.

Thus, when the attractor networks are broken up such that cells within any one network no longer fire synchronously, there would no longer be any strong activation of any particular accumbens cells. This random cortical activity might thus serve to

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disinhibit the dopamine cells and, according to evidence reviewed above, give rise to a state of positive affect.

Evidence that is compatible with this general account comes from a recent functional magnetic resonance imaging (fMRI) investigation of brain activity in long-time meditation practitioners (Brewer et al., 2011). These accomplished meditators showed lower activity levels in two critical DMN components (viz., medial prefrontal and posterior cingulate cortices) during three different types of traditional meditation, as compared to matched controls. These findings suggest that there was reduced attractor network activity in DMN regions, which is critical for the model being presented here.

The hypothesis presented here is compatible with the fact that accumbens cells also respond to novelty

In general, this theoretical suggestion is highly compatible with the finding that novelty is a strong activator of dopamine cell activity (see Schultz, 1998) and accumbens dopamine levels (LeGault & Wise, 2001; Rebec, Christensen, Guerra, & Bardo, 1997; Saigusa, Tuinstra, Koshikawa, & Cools, 1999). In other words, presentation of any salient novel stimulus will induce dopamine release into the accumbens during initial presentations. This dopamine activity diminishes over repeated presentations unless the stimulus is an unpredicted reward (e.g., food, water, sex) or paired with reward stimuli, as evidenced in the conditioning paradigm (see Figure 5).

Thus, meditative states, such as Samadhi or Shamatha, can be regarded as states involving extreme levels of novelty in the cortical firing patterns, since, apparently, none of the familiar attractor patterns are activated. According to the reward prediction error hypothesis, these novel activity states could not provide any conditioned input patterns to suppress dopamine release.

Why do the objects of meditation themselves not become conditioned stimuli for the cortico-accumbens circuits?

One question raised by this analysis has to do with the fact that the meditative practices discussed herein often employ concentration on an object of meditation, such as the breath or a mantra, as a means to achieve the gradual disruption of discursive thought patterns. Yet, this raises the question: why do the neural representations of these objects not become a part of the cortico-accumbens loops that drive compulsive thoughts and behaviors? That is, one could theorize that the meditator might become compulsively attached to repeating the mantra or obsessing on the breath.

I propose two reasons for why this does not happen. First, in many cases, the meditation objects are chosen to be fairly neutral (as is one's own breathing), such that they may not cause dopamine release (as opposed to thoughts of winning the lottery). Thus, any breath-related neural activity that reaches the accumbens would not directly coincide with dopamine release, since such release would not happen until the meditative objects begin to give way to the absence of thought. In other words, the conscious representation of the meditative object itself must be broken up at least somewhat in order for the random activity (i.e., the attractor-less state) to be generated.

Second, it is possible that the attractor states that represent these neutral objects of meditation (e.g., breath, mantra, etc.) do not include activity in the regions projecting to the accumbens (see Figure 2). For example, both the medial prefrontal

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cortex and the hippocampal regions are thought to be involved in self-referential, autobiographical information processing, and thus may not be strongly involved in representations of the objects of meditative concentration.

Neural network analysis and the risk of materialistic reductionism

This paper has defended the idea that enduring bliss may be attained through meditative processes that break up habitual cortical firing patterns, and thereby disinhibit neurochemical processes in brain reward structures.

These theoretical suggestions about brain mechanisms are meant to parallel Buddhist teachings, which claim that the potential for lasting happiness exists abundantly within each of us—and is always available—once we become fully open to the present and give up our grasping for external attainments.

However, the neural network analysis provided here runs the risk of seeming to constitute a rather crude materialistic reductionism in relation to the states of consciousness and spiritual insights offered by Buddhism and other meditative traditions.

One sense in which the idea of reductionism might apply here would be that the analysis of meditative positive affect in terms of activity in brain pleasure centers could suggest that the goal of Buddhist practice is simply to attain the "natural high"offered by some meditative states. On the contrary, Buddhist teachers of course warn against such an attitude. Instead, they emphasize that a truly useful, personal transformation must involve the disruption of ego and grasping at momentary gratification, even if that gratification comes from simple emotional states induced through meditation (Trungpa, 1973). Thus, although traditional Buddhist teachings acknowledge the potential for blissful states during meditation, they also emphasize that bliss should not be viewed as the central goal.

A second sense in which materialistic reductionism could be mistakenly inferred here is the metaphysical suggestion that phenomenal states (i.e., conscious experience) do not in fact exist as genuine entities (for descriptions of this position, see Chalmers 1995, 1996). According to this materialist view, only physical elements truly exist. It is assumed that once we have described neural mechanisms which, in some sense, could be said to provide an explanation for vicissitudes in consciousness, then we will no longer need (or want) to acknowledge the existence of any experiential plane.

This form of materialistic reductionism is not intended here. Rather, the philosophical underpinning for this work is provided by the naturalistic dualism proposed by several contemporary philosophers (e.g., Chalmers 1995, 1996; Nagel, 1974). According to naturalistic dualism, conscious events (i.e., phenomenal states) are "what it is like to be" the particular brain state of the experiencer.

The scientific rationale for developing the current network model is the immense body of neuro-scientific evidence that shows that neural activity and conscious experience are subtly and intractably entangled throughout the course of an individual's life. Accordingly, the introspective changes observed over the course of a practitioner's meditative Buddhist practice must be accompanied by corresponding (arguably explanatory) changes in brain function.

This entanglement of mind and body is also emphasized within the ancient Vedic and Buddhist traditions, where both the body and the mind are considered sacred. For example, the "kundalini" that arises during Tummo and other Yogic practices is viewed as involving both body and mind. These ancient traditions teach us that it is our sacred commitment to investigate, explore, and develop these positive energies within others and ourselves. Perhaps the current efforts of many laboratories to investigate the neural aspects of these energies can be viewed as a modest extension of this ancient tradition.

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COMMENTARIES

Meditation and the DMN: an intentional approach to attention

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Sharp's model posits an important relationship between the brain's "default mode network" (DMN) and meditation. However, three central tenets of this model are problematic from both evolutionary and neurophysiological perspectives: (1) DMN dysfunction; (2) unstructured and random meditative brain activity; and (3) a dopaminergic default state of subjective happiness and bliss. Recent neuroimaging research allows assessment of each of these assumptions and suggests an alternative DMN/meditation model.

DMN dysfunction

The conscious resting state of the human brain is characterized by activity in a DMN associated with daydreaming, and other discursive thought. Midline cortical and lateral structures are linked in a "set of interacting hubs and subsystems . . . [that] . . . play an important role in 'internal mentation'" (Andrews-Hanna, 2012, p. 251). Stimuli related to emotional attention, self-referential processing, and decision-making differentially engage various subsystems of the DMN, while stimuli related to self-awareness and introspective attention engage others (Eldaief, Deckersbach, Carlson, Beucke, & Dougherty, 2012). Although several mental disorders, including perseveration, obsessive-compulsive disorder, and depression, have been linked to abnormal DMN function, normal functioning of this network is generally viewed as an evolutionarily adaptive state "in which the environment is continually being surveyed and events are assessed in relation to their impact on self to maximize the potential for survival" (Ives-Deliperi, Solms, & Meintjes, 2011, pp. 239–240). Rather than "a form of addiction" (Sharp) resulting in habituation and dopamine down-regulation, as posited by Sharp, DMN-generated discursive thought is more likely to represent an evolved adaptation for reflective evaluation and planning that benefits future behaviors, thereby enhancing fitness.

Meditative brain function

According to Sharp's model, novel cortical activity induced by meditation alleviates DMN dopaminergic down-regulation by "breaking-up the DMN attractor-based 'ruts' in neural activity patterns". This results in "a state in which nearly all attractor-based activity is stilled, from which there is unstructured and random activity throughout most, if not all, of the cortex". Although neuroimaging research supports Sharp's contention that meditation alters DMN function, it does not provide evidence of random, unstructured cortical activity.

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Meditation and mindfulness training down-regulate dorsomedial prefrontal cortex (DMPFC) and various associated networks related to "self-referential thought and attribution of subjective significance to emotions . . . [resulting in] . . . an overall 'quietening' effect on brain regions associated with subjective and cognitive appraisal of emotions" (Ives-Deliperi et al., 2011, p. 239). Concomitant with this down-regulation, up-regulation of other circuits occurs. This includes greater connectivity between the dorsal posterior cingulate cortex (DPCC) and the precuneus (Prakash, De Leon, Klatt, Malarkey, & Patterson, 2013), as well as changes in insular signal amplitude and connectivity (Farb, Segal, & Anderson, 2013). While the precuneus has been implicated in self-awareness (Kjaer, Nowak, & Lou, 2002), the bilateral insular cortex comprises the neural locus for interoceptive attention to visceral body sensations and is a critical component of the corticostriatal network that underlies "the ability to learn stimuli-rewards and stimuli-punishment contingencies" (Metereau & Dreher, 2013, p. 477).

Specifically, the insular cortex receives homeostatic sensory input via the thalamus and sends output to brain regions associated with emotions and reward processing. The anterior insula functions in error awareness (Klein, Ullsperger, & Danielmeier, 2013). "Increased cortical dopamine levels increases BOLD activity in anterior insula and attenuates impulsive choice" (Kayser, Allen, Navarro-Cebrian, Mitchell, & Fields, 2012). The insular cortex is well positioned to initiate alterations in emotional and self-referential processing, decrease error prediction (thereby increasing certainty), and up-regulate impulse control.

Neuroimaging studies identify the insula as a "key structure involved in aspects of meditation" (Luders et al., 2012). Experienced meditators not only show increased right anterior insula gray matter (Lazar et al., 2005), but also greater gyrification of right anterior dorsal insula correspondent with increased meditative experience (Luders et al., 2012). While early studies reported signal decreases in insula during meditation (Ives-Deliperi et al., 2011), more recent research shows increased activity in the insular cortex (Farb et al., 2013) and the inferior parietal lobe (Taylor et al., 2013) in experienced meditators. Ongoing mindfulness training alters insular functional connectivity, as well, with increased negative connectivity to the DMPFC and increased positive connectivity "between primary interoceptive cortex in the posterior insula and adjacent short gyri of the middle insula" (Farb et al., 2013, p. 23).

Meditation (Ives-Deliperi et al., 2011), mindfulness training (Farb et al., 2013; Taylor et al., 2013), and dispositional mindfulness (Brown, Goodman, & Inzlicht, 2013; Paul, Stanton, Greeson, Smoski, & Wang, 2013; Prakash et al., 2013) all alter DMN function; long-term meditative practice results in DMN network connectivity alterations, as well. The cortical activity associated with these changes is neither unstructured nor random, but instead reflects intentional engagement of interoceptive attentional networks, with concomitant disengagement of networks related to emotional, self-referential processing.

DMN, meditation, and dopamine

The positive affect and bliss reported by meditators are considered by Sharp to result from "release" of dopamine braking that occurs when the "addictive" discursive thought patterns of the DMN are disrupted and dopamine levels return to a higher baseline "default" state. Yet, no evidence of either addiction or higher dopamine baselines is presented. Moreover, such a default state is unlikely to be the case from

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evolutionary and reinforcement-learning perspectives. Since dopamine functions to motivate approach behaviors and reinforce associational learning, high levels of dopamine could be expected to increase risky behaviors and decrease the incentive salience of stimuli. The developmental plasticity of dopamine also argues against a uniformly high default state.

A more parsimonious explanation for meditatively induced feelings of peace, certainty, and bliss is right anterior insula activation with concomitant down-regulation of emotional and self-referential networks. In the absence of negative emotional input, insular responses and error monitoring would produce positive feedback, resulting in both "raised hemodynamic activity in the ventral striatum [nucleus accumbens]" (Ullsperger & von Cramon, 2003, p. 4308) and a subjective sense of pleasure and certainty (Picard, in press). Neuroimaging research on ecstatic epileptic seizures provides strong support for this hypothesis. These studies show hyperactivity of the right anterior insula during feelings of a "sensed presence," certainty, heightened self-awareness, and ecstatic bliss (Landtblom, Lindehammar, Karlsson, & Craig, 2011; Picard, in press; Picard and Craig, 2009), all of which have been reported by experienced meditators, as well.

Conclusion

Sharp's model correctly posits impacts of meditation on the DMN, with deactivation of various components. There is no evidence, however, of obliteration of existing DMN "attractor-based" networks, random cortical firing patterns during meditation, or a general high dopaminergic default state. Rather, mindfulness traits, meditation, and mindfulness training all appear to involve an attentional shift in neural networks that preference interoceptive over exteroceptive processing (Farb et al., 2013; Paul et al., 2013). This shift activates neural structures and pathways in a decidedly structured and non-random pattern that is specifically focused on insular networks, particularly the right anterior insula. Activation of these networks down-regulates emotional, self-referential processing with a concomitant up-regulation of dopamine in insular and striatal regions. The outcome is greater impulse control, decreased error prediction, and subjective feelings of meditative clarity, self-awareness, certainty, and bliss.

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Bliss and authenticity: a commentary on target article by Pat Sharp

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Sharp proposes an innovative, albeit speculative, theory that accounts for an often-reported experience of bliss or ecstatic pleasure that accompanies practices of meditation. She proposes that meditative practices disrupt the learning-dependent, down-regulation of dopaminergic neurons in the nucleus accumbens, which are associated with various addictions and repetitive mental states such as certain types of mind-wandering or ruminating. The result of such dis-inhibition is an increased level of pleasure and bliss that are experienced as one's ongoing baseline state.

Sharp primarily references the Buddhist teachings found in the Tibetan Tantric Vajrayana tradition that use the generation of bliss as a method for enhancing realization of emptiness (see Lama, 1985). Her starting claim is that the nucleus accumbens (NAcc) might be the site primarily affected by these meditation practices, since they specifically simulate stages of sexual arousal, known to involve NAcc. Her

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less obvious and more intriguing idea is that, unlike behaviors and substances usually associated with pursuing pleasure, these meditation practices do not lead to habituation and down-regulation of dopaminergic neurons in NAcc, despite the constant repetition of meditation practice. Sharp draws this conclusion, in part, from a study by Kjaer et al. (2002) that found high dopamine levels in long-time meditation practitioners. Furthermore, Sharp hypothesizes, in line with the teachings of these traditions, that our ordinary state of mind is engaged in repetitive compulsive thought patterns that constitute mind-wandering, and that such repetitive patterns decrease levels of dopamine, and are meditated by various neuronal attractor network states. On this theory, the mechanism responsible for the relaxation or even abolishment of such attractor networks and the dis-inhibition of dopaminergic cells in the NAcc during deep meditation (when consciousness is isolated from phenomenal content and reduced to a basic non-conceptual awareness) is an increase in acetylcholine. This neurotransmitter causes de-synchronizations in local neuronal populations and increases in long-range gamma synchrony.

This view tallies well with the behaviorist notion that human psychology is primarily driven by conditioning. It also tallies well with a view of enlightenment found in certain schools of Buddhism. This view sees enlightenment as a gradual purification or removal of unwanted conditioning from the “substrate” (*Sansk*. Alaya vijnana). that is, a level of consciousness that some Buddhists believe is responsible for storing memories (e.g., Thrangu, 2002).

However, these contemplative traditions also contain a different, perhaps more refined view, according to which enlightenment is not a matter of purifying the conditioned patterns of thought, endless as they are. Rather, spiritual maturation is a matter of realizing a deeper, more fundamental level of our consciousness—namely, the nature of mind itself, which is present, although usually unrecognized, as basic background awareness in all conscious experiences (Rabjam, 2007). According to these philosophies, the goal of the meditation is to bring such awareness into ‘full view’, allowing it to encounter and realize itself. This can be done by either reducing the phenomenal content, as in the example of Tantric meditation, or by identifying this very subtle awareness within the stream of one’s usual daily experiencing (Lama xiv, 2004). The result of such nondual realization is not only a relaxation of some of the habitually conditioned states of mind and body, but also a re-contextualization in which conscious experiences ‘self-liberate’ because they are recognized to be phenomenally non-different from nondual awareness (Norbu & Lipman, 1987). This view may be significant for contemporary research on consciousness in several ways. For one thing, not all mind-wandering is constituted by repetitive neurosis-driven thought patterns. Mind-wandering can also be a form of creative thinking that in itself can be highly pleasurable, and is directly related to one’s creative capacity, as recent studies show (e.g., Baird et al., 2012; Takeuchi et al., 2011). Thus, an overgeneralization of all mind-wandering and its underlying default-mode network activity as being undesirable could result in dissociating ourselves from important aspects of our experience that make us fully human. The key here is to acknowledge the broad aims of meditation. The purpose of meditative practices is not only to construct a post-meditation state of quiescence (one in which attractor networks are abolished), but also to realize the “all-pervading” space of basic nondual

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awareness that contextualizes both self-related and other-related, as well as intrinsic and extrinsic experiences.

In terms of the possible neural mechanisms of such large-scale integration, recent research (Josipovic et al., 2012) shows that nondual awareness meditation results in an increase of functional connectivity, and by inference in the underlying synchronization, between large-scale globally distributed neural networks – the intrinsic default mode network and the extrinsic task-positive network. As hypothesized elsewhere (Josipovic, in press), a network for nondual awareness may provide an organizing center, re-contextualizing the activity of other networks and attractors involved in representing experience during a "nondual state." A somewhat similar contextualizing and organizing function has been proposed for the paralimbic areas that overlap with the intrinsic default mode network and mediate the sense of self (Baars, Franklin, & Ramsoy, 2013; Lou et al., 2011). However, this awareness network is different in that it involves the central precuneus, and also its projections to the lateral prefrontal and inferior parietal areas (Margulies et al., 2009). It is possible that during nondual states, this network contributes to binding other networks into an enlarged global workspace. A key feature of such a network would be that it could represent its own state, in addition to integrating informational content. This would enable the network to mediate awareness independently of phenomenal content.

Thus, from a nondual point of view, the purpose of meditation practice is not a state of perfection in which all bothersome experiences and their corresponding attractor networks have ceased, but rather a freedom of being in which we can allow all of our experiences to be authentic ("as they are"). This would result from our experiences being recontextualized and integrated within the larger "all-encompassing" space of nondual awareness, such that they would "reflect," in addition to their specific phenomenal properties, the more or less invariant—some would say innate—properties of the nature of mind: spacious openness, luminous clarity, and compassionate bliss.

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Adaptive functions and default nature of undirected thought, bliss or not: correcting some misconceptions

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With great thanks to Patricia Sharp for her excellent synthesis of a wide-ranging field, I nevertheless seek here to correct depictions of "daydreams, fantasies" and "discursive thoughts," presumably subsuming mind-wandering—that is, *undirected thinking,* consciously unintentional—as wasted mental activity that lowers mood.

First, there are observational reasons to suppose that undirected thinking constitutes a natural baseline for mental activity (Klinger, 1971). For instance, brain-imaging results reported by Mason et al. (2007) demonstrate a close association between mind-wandering states and the brain's "default network." This network is typically active when participants are unengaged in goal-directed mental activity (Gusnard, Akbudak, Shulman, & Raichle, 2001). Behavioral studies also suggest that undirected mental activity, such as mind-wandering, occurs during a third or even up to a half of all waking states on average (Killingsworth & Gilbert, 2010; Klinger & Cox, 1987–88). It is highly unlikely that such a large portion of brain activity would have survived in the course of evolution without some kind of adaptive function (e.g., Baars, 2010).

It is now reasonably well established that the content of undirected thinking and dreams is predominantly associated, directly or indirectly, with the particular individual's pursuit of goals (Baird, Smallwood, & Schooler, 2011; Hoelscher, Klinger, & Barta, 1981; Klinger, 1978, 1990, 2009; Klinger & Cox, 2011; Nikles, Brecht, Klinger, & Bursell, 1998; Smallwood, Brown, Baird, & Schooler, 2012; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011), which is readily activated in the presence of goal-related cues. It would be surprising if such cues filled the mind with goal-related content that was not helpful in the individual's pursuit of his or her goals.

There is, in fact, ample anecdotal evidence of creative problem-solving instances, in both the arts and the sciences, occurring during moments of undirected thought (Klinger, 1990; Singer, 2009). Moreover, there is experience-sampling evidence of spontaneous planning (Baird et al., 2011; Stawarczyk et al., 2011) and experimental evidence that undirected thought incubates problems and increases subsequent creative solutions (Baird et al., 2012). Such spontaneous, undirected planning, which may involve executive brain components (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009), and sometimes shifts thought content into operant or directed planning, is likely to benefit individual success in the pursuit of one's particular goals. Mental activity of this sort is a way of keeping individuals aware of their larger

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agendas even while occupied with a single task. Thought-sampling evidence indicates that the median duration of thought segments (that is, continuous focus on a single topic) is only about five seconds, with a mean of about 14 seconds (Klinger, 1978, 1990); i.e., the undirected stream of thought typically visits a variety of the individual's goal domains. This continuous mental review serves as a *reminder mechanism* regarding an individual's agenda of goals, both short-term and longer-term. Thus, undirected thinking is a way for the brain to process goal-related material during times when ongoing tasks do not fully absorb the brain's resources.

Indeed, meditation disciplines strive to suppress this kind of undirected thought, and focused perception is one way of doing so. The classical forms of meditation involve prolonged instances of continuous perception, such as focusing upon a mandala, or repetitive focused activity, as in a mantra or dance exercise, and instances such as these strive to maintain a thought-suppressing perceptual set, even as the perceptual contents fade. Achieving this perceptual set may be the central ingredient of meditative disciplines.

Sharp's statement about Killingsworth and Gilbert's (2010) findings, that "There was a prominent reduction in happiness scores during mind-wandering," reflects a reasonable interpretation of what Killingsworth and Gilbert implied, but not what their data actually revealed. Their participants rated 42.5% of their mind-wandering episodes as about something "pleasant," with their moods during such episodes averaging only slightly above their overall mood, and thus roughly equaling their mood when their minds were not wandering. They rated 31% of the remaining mind-wandering episodes as being about something "neutral," with their average mood being slightly below the overall average but above the midpoint of the mood scale. Participants rated their mood as sharply below the overall average and below the scale midpoint during only 26.5% of mind-wandering samples, which they characterized as being about something "unpleasant." Thus, only particular thought content, not mind-wandering *as such*, was associated with lowered mood (see also Stawarczyk, Majerus, Van der Linden, & D'Argembeau, 2012). Killingsworth and Gilbert (2010) also performed time-lag analyses, finding that mood was lower in samples obtained after a mind-wandering episode than after a non-mind-wandering episode, but these episodes were on average hours apart, sometimes separated by a night, which suggests that something other than mind-wandering accounted for their results. These results are inconsistent with another investigation that found no effect of mind-wandering on mood 15 minutes after the mind-wandering episode (Poerio, 2012). Furthermore, Killingsworth and Gilbert (2010) found little effect of low-mood episodes on subsequent mind-wandering, which is inconsistent with other evidence indicating that inducing negative moods increases mind-wandering (Smallwood, Fitzgerald, Miles, & Phillips, 2009) during approximately the following half hour, measured both objectively and by subjective self-report.

Sharp suggests that undirected thinking may be "addictive," but there are reasons to doubt that this is the case in most instances. Certainly, some individuals spend more time in imaginative daydreams than others, and a subset of these individuals regret the time that they waste during mind-wandering episodes (e.g., Bigelsen & Schupak, 2011); but many of these individuals are nonetheless accomplished professionals with successful family lives (e.g., Singer, 1975, 2009; Wilson & Barber, 1983). As indicated above, undirected thinking appears to be a universal human activity governed by the individual's goal commitments and emotional reactions to those goals. The tone of their thought content governs their degree of "enjoyability."

However, the people who would perhaps have the greatest reason to escape into fantasy, those who are depressed, tend to have on average rather unhappy and boring daydreams (Giambra & Traynor, 1978) and negatively toned ruminations (e.g., Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). These states are unlikely to be addictive. The literature on "fantasy proneness," triggered by Wilson and Barber's work, for a time suggested a tie of fantasy-proneness to psychopathology. Yet, analysis of the items in the most commonly used measure of fantasy-proneness, namely the Inventory of Childhood Memories and Imaginings (which is flawed for assessing daydreaming), yields two strongest factors. Of these, one is heavily associated with dissociative symptoms and correlated with a variety of psychopathologies, and the second is associated with enjoyment of imaginative products, including ordinary daydreaming, and is uncorrelated with nearly all psychopathologies (Klinger, Henning, & Janssen, 2009).

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A creative and insightful cognitive neuroscience approach for understanding the effects of contemplative training on pleasure and the "gossip of the ego"

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In "Meditation-induced bliss viewed as release from conditioned neural (thought) patterns that block reward signals in the brain pleasure center," Sharp provides an innovative framework for understanding the neurochemistry of pleasure, addiction, and sustained states of positive mood that can be realized through contemplative training. Sharp presents a clear and comprehensive overview of how traditional sources of pleasure, such as sex and various recreational drugs, are reinforced neurochemically to the point of addiction, resulting in pleasure saturation and down-regulation of dopaminergic circuits with repeated exposure. A critical focus is demonstrating how thoughts—the ever-present, mostly self-referential background chatter of the mind—are another dopamine-enhanced pleasure-inducing activity that turns into an addiction. The pleasure of this "gossip of the ego" is down-regulated over time, resulting in meaningless repetition of self-referential fantasizing and daydreaming in a vain attempt to regain the initial pleasure, followed by boredom and depression.

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Sharp presents the intriguing hypothesis that contemplative training, via its effects on reward pathways in the brain, offers a sustainable and blissful alternative to our habitual patterns of endless thinking and pleasure seeking. This hypothesis is informed by a large body of literature on the nature of addiction and treatment of substance dependence, including how craving, stress, and negative psychological states, such as anxiety and depression, fuel the cycle of suffering (see Brewer, Elwafi, & Davis, 2012). A key point is how meditation creates pleasurable states similar to those generated by traditional reinforcing stimuli using similar neurotransmitters and routes. Yet the pleasures associated with meditation do not diminish with repeated exposure. Indeed, long-term practitioners report enhanced positive experiences of everyday stimuli, a claim that can be tested using techniques in psychophysics, visual neuroscience, and affective neuroscience.

Sharp's paper is an important addition to modern scholarship on Buddhism, as few Buddhist teachers in the West mention a "thought-free" approach, since most regard elimination of thought as undesirable or impossible. There are many other meditative traditions that do focus on the elimination of the "gossip of the ego" to reduce suffering. For example, the iconic Zen Buddhist teacher Dogen stated: "Be without thoughts—this is the secret of meditation" (Dogen Fuken Zazengi, 1227). Similar comments are made in a variety of eastern sources, such as the following: Tao Te Ching: "Empty your mind of all thoughts. Let your heart be at peace" (Mitchell, 1992, p. 101); Advaita Vedanta: "The thought-free state is one's primal state and full of bliss" (Ramana Maharshi, 2000, p. 224) and "To be free from thoughts is itself meditation" (Nisargadatta Maharaj, 1973, p. 224); the Bhagavad Gita: "With the intellect held steadfast and the mind sunk in the Self, allowing no thought to arise" (Ramana Maharshi, 1995, p. 11); and, finally, Dzogchen: "All thought activity is naturally liberated . . ." (Ray, 2001, p. 314).

The contemplative approaches described by Sharp are those most commonly studied in psychological and neuroscientific research. For instance, they advocate the use of concentration upon an object (e.g., the breath) or receptive awareness of sensations (Lutz, Slagter, Dunne, & Davidson, 2008). The "ego deconstructive" approaches used in Zen and Advaita Vedanta specifically focus on deconstructing the self through inquiry, ultimately leading to a state of effortless awareness characterized by no (or few) self-referential thoughts. Anecdotally, practitioners report that analytical thoughts used for planning and problem-solving are functionally enhanced. The neurochemical framework presented by Sharp should apply to the inquiry-based approaches, as well as concentrative and receptive meditation approaches.

However, considering the abundance of neurophysiology (electroencephalography (EEG)) and neuroimaging (functional magnetic resonance imaging (fMRI)) studies of meditation (e.g., Jha, 2012; Tang & Posner, 2013), it is remarkable that more research has not been done on the neurochemistry or neurobiology of contemplative training. Sharp draws attention to the single published study showing meditation-related increases in dopamine in the nucleus accumbens (Kjaer et al., 2002). One study of a 12-week yoga intervention found increases in thalamic levels of GABA (a major inhibitory neurotransmitter) that were correlated with decreases in anxiety and improvements in mood (Streeter et al., 2010). Other studies have examined meditation training-related changes in stress hormones such as cortisol (e.g. Jacobs et al., 2013).

Controlled studies of changes in neurochemistry during meditation (acute, state effects) and following periods of meditation training (longitudinal, trait effects) would be important, and are now possible. For example, neuroimaging techniques, such as positron emission tomography (PET), can be used to study changes in dopamine, endogenous opioids, and serotonin. Additionally, advances in high-field-strength magnetic resonance spectroscopy (7T MRS) offer new opportunities to study in vivo changes in glutamate and GABA. It will also be important to examine concomitant changes in neuro-hormones such as oxytocin.

A potentially fruitful approach would be to combine meditation with pharmacologic manipulations to test the role of specific neurotransmitter systems in contemplative training. Cross-study findings suggest some overlap in brain regions that are deactivated (and functionally uncoupled) during meditation (e.g., Brewer et al., 2012) and after administration of the selective serotonin agonist psilocybin (Carhart-Harris et al., 2012). These regions in medial prefrontal and posterior cingulate cortex are key nodes in the default mode network, and are alleged to maintain a representation of self versus other, and self in time (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010). Psilocybin has been shown to occasion experiences of selflessness and unity associated with acute and long-term increases in positive mood, well-being, and openness (Griffiths et al., 2011; Griffiths, Richards, Johnson, McCann, & Jesse, 2008; Griffiths, R.R., Richards, W.A., McCann, U.D., & Jesse, 2006; MacLean, Johnson, & Griffiths, 2011). Administering psilocybin to meditators is one way to investigate the role of serotonin in contemplative training, and experiences of selflessness and bliss.

A developmental perspective is also useful when investigating the human mind, whether through neuroscience or contemplative training. Most research studies of meditation have focused on adults, but it may be possible to use findings from neuroscientific studies of reward, learning and motivation (see Ernst, Daniele, & Frantz, 2011) to pinpoint critical stages in development when meditation may be most effective.

Prominent Buddhist scholars have proposed that the purpose or goal of contemplative practice is to cultivate enduring happiness through selflessness and compassion (Dambrun & Ricard, 2011; Ricard, 2011). Sharp's paper is likely to draw criticism from some Buddhist teachers out of concern that naïve practitioners may incorrectly assume that bliss is the primary goal of meditation, and thus become attached to the meditative object. Future research can clarify how phenomenological states such as bliss contribute to the practical and ethical issues of alleviating one's own suffering and the suffering of others.

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Seizure-induced bliss: a commentary on "meditation-induced bliss viewed as release from conditioned neural (thought) patterns that block reward signals in the brain pleasure center"

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In her thought-provoking paper, Sharp argues that blissful joy is suppressed by discursive thoughts and, conversely, enabled by states of absent thought that she characterizes as openness, formlessness, and clarity, such as that produced during

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meditation when "content-laden thought (e.g., fantasies, daydreams, plans) ceases." The proposed neuroanatomical basis for this phenomenon is the nucleus accumbens, identified as one of the brain's centers for producing bliss, which is hypothesized to be inhibited by everyday thoughts. Neurochemically, dopamine and opiates, neurotransmitters that activate the nucleus accumbens and which in turn are used by this structure to engage a neural network to achieve a blissful state, are theorized to become down-regulated by everyday thoughts, analogous to the consequences of exposure to exogenous opiates or dopaminergic drugs.

This commentary focuses on so-called ecstatic and orgasmic seizures in persons with epilepsy, and how these experiments of nature may provide empirical support for Sharp's central argument. Beyond the scope of these comments are the related topics of the association of meditation with seizures or seizure-like activity (Lansky & St. Louis, 2006), briefly mentioned by Sharp, and the religious aspects of ecstatic seizures.

Epileptic seizures are sudden changes in behavior, which may or may not be apparent to others, that result when interconnected neuronal networks in the brain suddenly become hypersynchronized in their functioning. The resulting behavioral manifestations are determined by the specific neuronal networks that are involved during the seizure. Consciousness may or may not be altered, in which case the patient may or may not be aware of motor, sensory, autonomic, or subjective experiences, including affective states such as blissful joy.

According to Hughes (2005), the ecstatic seizure was made famous by the Russian writer Fyodor Dostoevsky (1821–81) as described by his character Prince Myshkin in *The Idiot*:

> The sensation of life, the consciousness of self, were multiplied almost tenfold at these moments, which lasted no longer than a lightning-flash... all his anxieties were laid at rest at once... they were all resolved into a lofty calm, full of serene, harmonious joy and hope, full of reason and ultimate comprehension. (Yarmolinsky, 1965, p. 158)

Dostoevsky himself had epilepsy, and the description of his own seizures is similar:

> I experience such happiness as is impossible under ordinary conditions, and of which other people can have no notion. I feel complete harmony in myself and in the world and this feeling is so strong and sweet that for several seconds of such bliss one would give ten years of one's life, indeed, perhaps one's whole life. (Yarmolinsky, 1965, p. 158)

Interestingly, Dostoevsky was also a compulsive gambler (Hughes, 2005).

Published case reports further document the nature of ecstatic seizures and the similarity to the state of bliss described by Sharp. For instance, Cirignotta, Todesco, and Lugaresi (1980) reported a 30-year-old man with episodes of "psychomotor arrest, slight lapse of consciousness, and above all, an ineffable sensation of 'joy'." The joy he felt was "so intense that he cannot find its match in reality... His mind, his whole being is pervaded by a sense of total bliss." (p. 706). Naito and Matsui also reported a 62-year-old woman with epilepsy from a head injury who explained her seizure as follows:

> Triple haloes appeared around the sun. Suddenly the sunlight became intense. I experienced a revelation of God and all creation glittering under the sun. The sun

> became bigger and engulfed me. My mind, my whole being was pervaded by a feeling of delight. (Naito and Matsui 1988, p. 123)

In their series of five patients with ecstatic seizures, Picard and Craig (2009) defined ecstasy as a "state of heightened consciousness in which an individual has a transcendent capacity for exceptional mental clarity and an intensely positive emotional experience," (p. 539) again similar to the phenomenon described by Sharp. They observed that during ecstatic seizures, patients had a strongly altered subjective perception of time, space, and the self. Neurophysiological and neuroradiological investigations suggested that these seizures and the resulting affective state were produced by hyper-activation of the anterior insula, which is consistent with the putative role of the anterior insular cortex in time perception (Craig, 2009) and the subjective feeling of states that underlie self-awareness and self-consciousness (Craig, 2009; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004). While the insula has reciprocal connections with a number of brain regions, particularly germane to Sharp's thesis are the insular connections with the basal ganglia, which are said to support "hedonic evaluation and motivational approach to positively valenced stimuli" (Vijayaraghavan et al., 2012, p. 1). The nucleus accumbens and insula are reciprocally interconnected; the insula influences activity of the nucleus accumbens (Cho et al., 2012) and stimulation of the nucleus accumbens activates the insula (Knight et al., 2013).

Orgasmic seizures were first described in 1983 by Remillard et al. (1983). Janszky et al. (2004) reported seven patients who experienced orgasmic sensations at the start of their seizures. The authors speculated that the seizures arose from the same brain regions responsible for physiological orgasms during coitus or masturbation. A candidate region for producing orgasmic seizures is the right amygdala, which was the site of seizure onset of another patient with orgasmic seizures whose symptoms were reproduced with electrical stimulation of the same area (Bancaud et al., 1970), and which has been shown to be activated during non-ictal orgasm (Heath, 1972). Of relevance to Sharp's hypothesis, excitatory transmission from the amygdala to the nucleus accumbens, which could occur during seizures arising from this structure, facilitates reward-related behavior (Stuber et al., 2011).

Indeed, a fuller understanding of seizure-induced bliss would likely yield additional insights into Sharp's hypothesized antagonistic relationship between everyday thoughts and "immense and abiding joy," including the relevant neuroanatomy, neurophsysiology, and neurochemistry, and advance the ongoing efforts in neurophilosophy to elucidate the borderlands between mind and brain.

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Modeling meditation bliss: addiction and the "default mode" of self-referential processing (Comment on Sharp, "Meditation Bliss…")

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When western cognitive science engages and tries to explain cognitive stages or states or processes claimed by religious traditions, two critical questions must be asked. First, is the scientific construal of the targeted stage, state, or process adequate to the meaning of the religious claims? Second, even if the answer to the first question is "No," does the proposed theory of the targeted stage, state, or process have scientific merit? That is, does it identify a stage, state, or process that is of interest apart from religious contexts, and does it propose an evidentially compelling theory of the said target?

Not all scientific approaches to religiously based practices or claims have the rigorous engagement of religious traditions, concepts, or contexts as a goal. A significant number of scientific investigations into mindfulness, for example, have no interest in or connection to the conceptual roots of Buddhism (Payne, 2011; Rapgay & Bystrisky, 2009). Widely used self-report instruments of "mindfulness" as a psychological construct, such as the Mindful Attention Awareness Scale (MAAS), are broadly taken to accurately measure trait mindfulness construed as attentive awareness (Brown & Ryan, 2003; Brown, Weinstein, & Creswell, 2012; Way, Creswell,

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Eisenberger, & Lieberman, 2010). However, it is known that the construal of mindfulness as "attentive awareness" in the MAAS construct (Brown & Ryan, 2003) neither captures Buddhist meanings of mindfulness (Payne, 2011), nor does it amount to much more than a positive measurement of dispositional *in*attentiveness, the reverse of which does not directly correspond to the desired measurement of mindful attention (Van Dam, Earleywine, & Borders, 2010). So the MAAS neither concerns itself with Buddhist mindfulness, nor does it appear to have good construct validity as a measure or component theory of what cognitive science defines as attentive awareness.

The target article proposes a theory that meditation results in bliss by reducing the chronic down-regulation of dopaminergic input into the nucleus accumbens (NAcc), and it identifies the causes of this down-regulation as compulsive, offline thought that is discursive in nature and is equated to mind-wandering. According to the theory, compulsive, repetitive thought is akin to addiction and the meditation-induced bliss is akin to pleasure elicited by food, drugs, and sex. Thus, the effects of compulsive, repetitive thought—also expressed as meta-stable attractors—can be analyzed via mechanisms of substance addiction. Moreover, the process of meditation-induced bliss can be analyzed via mechanisms of cocaine- and other stimulant-induced pleasure—though it should be noted that lesions of the dopamine system in NAcc do not interfere with addiction-related behaviors in response to heroin (see Koob & Volkow, 2009). It is not entirely clear if the theory targets only reward-based fantasization, or if it includes rumination that is rewarding only according to a subjective utility theory, and thus might include negative outcomes or memories as content. Likewise, it is unclear whether it includes all compulsive, repetitive thought. The emphasis in the paper is on daydreaming or positive fantasy, such as fantasies about winning the lottery. The theory has these repeated reward-expectancy self-narratives (RESNs, "resins") habitually predicting rewards, and thus driving down dopaminergic input into the NAcc.

Several elements of the theory deserve brief mention without expanded treatment, due to space limitations. First, the identification of hedonic bliss with concepts of bliss and rapture in Buddhism's Pali canon is not well supported, especially given the complex constructs of *samādhi* and *jhāna*. Second, the Pali canon clearly has bliss co-occurring with stable mental states, such as discernment and concentration, both of which could be expressed as stable attractor networks. The first and second *jhānas* associate with the distinct states of *pīti* (joy, rapture) and *sukha* (happiness, pleasure, bliss), where *sukha* is less intense than *pīti* (Griffiths, 1983). Both rapture and bliss co-occur with "the basic cognitive/verbal functions of the mind" (i.e., the conception and discernment of *vitakka* and *vicāra*) in the first *jhāna*, while the second *jhāna* has rapture and bliss together with concentrative mind (*ekāgratā*), leaving classification behind (Griffiths, 1983, pp. 59–60). Third, the proposed theory does not address the cognitive processes of contemplative practice or the cognitive processes entrained in the contemplative character, all of which would be expressed as some form of stable or meta-stable attractor network. Indeed, one study cited by the discussion paper shows stable functional connectivity networks in contemplative adepts, both during and after specific meditative practices, consistent with state- and trait-associated network stability and habitual cognition (Brewer et al., 2011). Such transformation of habit/us is an expected outcome of any practice that aims to affect value-based choice, especially in the context of virtuous character (Peterson, Van Slyke, Spezio, Reimer, & Brown, 2010;

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Porter, 2005; Reimer, Spezio et al., 2011; Reimer, Young et al., 2012; Romanus Cessario, 2009).

The proposed theory relies primarily on two lines of evidence from the scientific literature, both of which should be examined in detail. The first uses a model of dopaminergic-dependent learning and relates it to addiction to argue that stable, habitual cognition depresses dopaminergic signaling to, and within, the NAcc. The second uses neuroimaging analyses of the "default mode network" (DMN) in contemplative adepts to argue that stable, habitual cognition is reduced or eliminated in the contemplative character.

The basis for the theory's claim that addiction leads to decreased dopaminergic signaling is the primary value learned value (PVLV) connectionist model proposed to explain dopamine responses in reinforcement learning (Hazy, Frank, & O'Reilly, 2010). In reinforcement learning, dopamine release associated with a primary value (PV), or unconditioned stimulus (US), becomes associated with the learned value (LV), or conditioned stimulus (CS) (as shown in Figure 5 of the discussion paper). Yet the PVLV model is a theory of dopaminergic responses during learning and not a theory of dopamine activity in addiction. Indeed, established models of addiction, including those referenced by the discussion paper (Koob & Volkow, 2009; Volkow et al., 2007), do not implicate reinforcement-learning mechanisms in explaining dopamine activity differences due to addiction. Rather, prevailing models by Koob, Volkow, and others (e.g. Koob & Le Moal, 2008; Koob & Volkow, 2009) implicate increased dopamine activation in the NAcc during the transition to addiction, developing into dopamine-increased signaling in the dorsal striatum (i.e., caudate, putamen) in "habitual, compulsive" addiction (Koob & Volkow, 2009, p. 229). Additionally, these models specify a key role for dysfunction in connectivity of the prefrontal cortex, resulting in dysfunctional associations between context and reward processing in the striatum. None of the explanatory models of addiction rely on reinforcement-learning models to the same degree that the discussion paper does when it links meditation-induced bliss to the elimination of habitual, compulsive, addictive thought. The model of meditation-induced bliss presented in the discussion paper would benefit from additional engagement of the details of these prevailing, evidence-based addiction models.

A second area for additional consideration by the proposed theory is the use of literature surrounding the so-called DMN. There is now clear evidence that what was once thought to be a unitary system called the DMN is really best understood as a heterogeneous set of functionally connected systems that are active during times when no defined goal-oriented task is being done (Salomon, Levy, & Malach, 2013). The discussion paper emphasizes the originally identified DMN, that connectivity between the medial prefrontal cortex (mPFC) and the perigenual anterior cingulate cortex (pACC). While it is true that experienced practitioners of meditation show significant differences in this network compared to inexperienced controls, these differences were only significant when participants followed specific instructions to meditate (Brewer et al., 2011). It is likely that the meditation-naïve controls had no knowledge of how to follow the instructions, and so they gave up after a time, and thus it would be expected that they reverted to "default" modes of "self-referential processing." Further, in many experiments investigating DMN systems, goal-related tasks reduce DMN-related activation (Salomon et al., 2013), with no systematic increase of bliss.

Quite independent of the question of whether the model of meditation-induced bliss adequately captures Buddhist phenomenology and theories of mind, the scientific elements of the model are suboptimal. They do not adequately draw on the best current science of either addiction or of habitual, self-referential processing, to say nothing of the relation between them.

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RESPONSE

Bridging the communication and cultural gap between the cognitive sciences and the contemplative traditions

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Introduction

I want to thank the commentators for their thoughtful and thought-provoking responses to this target article. Each has provided a perspective that has helped me expand my knowledge and further refine my theoretical efforts.

A few general themes emerged across the set of commentaries, so I will focus most of my responses on these, and I apologize for having omitted consideration of some of the issues raised by single individuals.

Clarification of my hypotheses regarding meditation and brain processes

Much of the ensuing discussion will involve examination of my theoretical proposals for how meditation may affect the brain. In particular, I presented two separate hypotheses, and each involves a very specific aspect of Buddhist practice/experience, as well as very specific postulated brain mechanisms.

Hypothesis for contentless consciousness as proposed in Sharp (2011)

In an earlier paper (Sharp, 2011), I provided a possible neural explanation for states of deep concentration in which, eventually, all recognizable thoughts and perceptions vanish. Within the Buddhist tradition, this state may be referred to as Samadhi or as a series of stages known as the Jhanas. In these deep states one is said to reach pure consciousness or substrate consciousness, in which all everyday perceptual categorization and thought vanishes. In exchange for these more usual contents, there is a sense of pure luminosity (Shankman, 2008).

In this earlier paper (Sharp, 2011), I pointed out that our day-to-day perceptual, cognitive and mnemonic abilities are thought to depend on Hebbian synaptic plasticity mechanisms, which create sets of strongly interconnected neurons that then support pattern classification (perception), classical and instrumental conditioning, episodic and semantic memory, and so on.

To explain how certain meditation practices may produce a mental state devoid of all recognizable content, I suggested that certain biochemical processes possibly evoked during these practices may disadvantage activity in these previously conditioned attractor networks. In the limit, with no attractor activity anywhere in the brain, there would be something closer to random, novel activity patterns. I argued that this might correspond to the contentless, luminous states described in the Buddhist literature.

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Hypothesis for blissful meditative experiences

In the target article under discussion here, I sought to provide a theoretical possibility for how to explain the affective state of bliss, which is said to arise frequently during concentrative practices such as Samadhi. For this, I focused on the conditioned attractor states in only those brain regions that project directly to the nucleus accumbens, and I further focused on only those attractors involving periodic release of dopamine into the accumbens, and which, arguably, have thus become repetitive covert behaviors that can be likened to addictions. I then point out that, as for any addiction, it might be expected that repetition of these neural activity patterns might be accompanied by conditioned down-regulation of dopamine release, and the concomitant dysphoria and craving. Thus, a meditative state that breaks up these particular attractor states might be expected to result in relative euphoria.

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Responses to reviewer comments

The collision between ancient meditative traditions and contemporary neuroscience can sometimes be misleading and dangerous

Both Josipovic and Weber have correctly pointed out that the focus of the target article may leave some readers with the impression that the overall goal of the Buddhist path consists of simply learning to "joyride" on these blissful meditation-induced states. I thank these commentators for making it clear that these meditative traditions, in fact, warn against this form of "clinging," and that these traditions encompass a much broader set of psychological, philosophical, and ethical considerations.

Spezio provides a more detailed critique of ways in which my theoretical proposals fall short of capturing genuine and important aspects of traditional eastern spiritual paths in general, as well as the bliss-inducing Jhana practice in particular. He first points out that many scientific studies of religious phenomena fail to make any reasonable connection with the genuine spiritual, philosophical or ethical messages of the religious tradition itself. He repeats the warning issued elsewhere (e.g., McNamara, Sosis, & Wildman, 2011) that this type of intellectual sloppiness causes serious difficulties both ethically (it constitutes a disregard for and a misrepresentation of the spiritual tradition) and in terms of the science itself.

Personally, as a devoted practicing Buddhist, I am very concerned about these issues as well, and thus I am chagrinned to be taken to task, myself, for this very failing. Consequently, I will do my best to defend my efforts with regard to this issue.

First, I might comment that in my experience during my few initial forays into what is, for me, a new field (psychology of religion), I have found it extremely difficult to publish anything related to Buddhism in any scientifically oriented academic journal without first: (1) scrubbing the text clean of any vocabulary words used within the religion itself (e.g., "bliss" should be changed to "positive affect"); (2) feigning indifference with regard to either the value system or value to humans inherent in the tradition (unless accompanied by "scientific evidence" of this value); and (3) pretending to be agnostic (at best) as to whether any of the spiritual, philosophical, or psychological teachings within the tradition have any validity. Thus, the two cultures (contemplative spiritual traditions versus contemporary biological and social sciences) have different goals, different linguistic traditions, and different

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empirical techniques. This must explain at least part of the seeming disconnect between the two in academic contexts, especially when this disconnect is generated even by those who have one foot in each camp.

I find these restrictions within academic scientific venues quite troubling, and this issue relates to the question, discussed elsewhere (Wildman & McNamara, 2008), as to what the point (purpose or value) may be for any neural investigation of any religious activity. I have made an effort to provide my own view on this question in the closing paragraphs of the target article, and so I will not repeat myself here.

In relation to this issue, Spezio raises three specific criticisms of my approach. The first of these is to question my assertion of the identity between "hedonic bliss" versus bliss induced during meditative absorption. If I understand it correctly, his criticism here has to do with the fact that Samadhi and Jhana are complex constructs, as described in the traditional teachings, and are thus unlikely to be identical with euphoria that results from, for example, a hit of cocaine. In response I will say, first, that my theoretical effort is aimed at explaining just the isolated phenomenal presence of bliss itself. Indeed, I appreciate that the context in which this is embedded during Jhana is very different from that of the worldly pleasures, and, in fact, this is really my main point. With regard to the empirical question of whether the bliss itself during Jhana versus that during consumption of worldly goods is similar, either experientially or neurologically, I have given my best effort at addressing this issue in the opening sections of the target article, and I will not repeat myself here.

However, it is worth noting that since the acceptance of this target article there has appeared the first ever brain-imaging study of an adept meditator during the specific practice of Jhana (Hagerty et al., 2013). These investigators examined several regions of interest as the single subject underwent the full sequence of the eight stages of Jhana meditation. The main research question was, in fact, whether the bliss induced during certain stages of this practice was accompanied by activation of the dopamine/opiate brain reward center (nucleus accumbens), which is also activated by worldly rewards, and which was the focus of my target article. The results confirmed a highly significant increase in BOLD (blood oxygen level-dependent) signal in accumbens, compared to rest, during those stages of Jhana which were accompanied by introspectively reported "ecstatic joy,", along with a concomitant, striking decrease in activity in sensory, language, and personal orientation regions. Thus, this recent study provides additional evidence for the possible identity of neural processes involved in hedonic and meditative bliss.

The second specific issue raised by Spezio is that, in the Pali canon (thought by many to be a transcription of the teachings of the Buddha himself, as recalled and recounted by his closest followers), bliss during Samadhi is said to arise initially in conjunction with discernment and concentration (vitakka-vicara), which are still present in early stages of a meditation practice session. Since these thought processes would presumably require co-activation in the subsets of neurons responsible for this content, their coexistence with the arising of bliss would appear to contradict my hypothesis that bliss results from the disruption of all attractor network activity.

In relation to this criticism, the sustainability of my hypothesized neural mechanism for bliss depends on the answer to two questions. First, do these thoughts (neural patterns) constitute well-worn patterns that cause periodic, predictable dopamine release and that have been rehearsed often enough to have become genuine attractors, as defined by having above average synaptic strength in the connections between the involved neurons? The answer to this is critical, because the down-regulation of dopamine I propose would take place only in relation to well-worn (over-conditioned) neural/thought patterns. According to the description of the early Jhanas provided by Shankman (2008), it seems that, to the contrary, these speculative philosophical thoughts would likely be novel "attainments," such as philosophical insights provided by the altered state of progressing mental quiescence. As described by Shankman, the collection of thoughts that may take place during this time seems to be somewhat of a grab-bag. However, Shankman is careful to point out that:

> Vitakka-vicara should never be understood as thinking or musing in the ordinary sense. The salient unifying feature unique to vitakka-vicara as Jhana factors is the function of applying and sustaining the mind to its object, rather than just recognition that thinking is present in the first jhana. (Shankman, 2008, p. 40)

If this is true, then the arising of bliss in the presence of such thoughts is compatible with my hypothesis.

The second relevant question is whether any components of the neural circuits involved in these thought processes are located in regions that project directly to the nucleus accumbens. That is, even if the thoughts do, in fact, consist of repetitive activity in well-developed attractors, this would be irrelevant to my hypothesis if those attractors do not involve neural groups that project directly onto the accumbens. The answers to the above two questions are critical to the support or abandonment of the central hypothesis in my target article.

Spezio's third criticism regarding infidelity to the authentic religious tradition has to do with the fact that my hypothesis does not address the cognitive processes involved in the development and expression of the "contemplative character." He points out that these would all be expressed using attractor networks. I agree that my work does not address these issues, and I will discuss this further below.

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The path toward enlightenment involves cognitive, attractor-based restructuring of mind, in addition to the 'luminous', no-thought (no-attractor activation) states which are central to my target article

Several of the commentators (Alcorta, Josipovic, and Spezio) have noted that the Buddhist spiritual path does not involve simply getting rid of thoughts, but rather involves a serious cognitive restructuring of thought, perception, and emotional reactivity. This restructuring is based on insights developed from the teachings on philosophy and psychology, as well as insights that arise during meditation itself. I completely agree with this. I acknowledge that this restructuring involves reorganization (rather than complete destruction) of the brain's attractor networks, at least as they exist during normal daily activities. Thus, I appreciate the reminder that advanced meditators still have organized thoughts, perceptions, and actions when off the meditation cushion, and that these are, of course, based, at least in part, on attractor networks.

Shamatha-Vipashyana meditation

I would like to frame my comments on this issue around the very basic, beginner's Tibetan Buddhist meditation practice known as Shamatha-Vipashyana (for an introduction to this practice, see Pema Chodron, 1994). Although

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Shamatha-Vipashyana is widely used for beginners, it is also said that this basic practice is all that is needed to go all the way to enlightenment. Also, in my own understanding, many Buddhist and Yogic practices involve, at their core, various combinations of these same two processes (Shamatha and Vipashyana).

Shamatha (calming)

The instructions for Shamatha-Vipashyana begin with the direction to first take a proper sitting pose, and then simply notice (for example) one's own breath as it goes in and out. The idea is to calm the mind by attending to a neutral object, so that the usual frenetic pattern of thoughts and emotions will settle down. This calming due to focus on a neutral object constitutes the Shamatha aspect of the practice. Ultimately, when the practitioner develops skill at keeping the mind steady on the object, this Shamatha transforms into deeper absorptive states that, in my understanding, would then likely be referred to as Samadhi, in which all identifiable mental objects, including the object of focus itself, disappear. *It is this Shamatha (or Samadhi) aspect of meditation that is relevant to my two hypotheses as stated above.*

This process of Shamatha/Samadhi is often likened to the calming of the ocean. When the waves (thoughts) are high, as during everyday discursive thinking, the water is churned up and frothy, creating constantly changing, unpredictable patterns. In this state it is impossible to see the true clear nature of the water. However, on a calm day (as during Shamatha/Samadhi), the clear, luminous, formless nature of water itself can be observed. In my earlier publication (Sharp, 2011) I replaced the metaphor of waves in the ocean with the metaphor of attractor network activity in the brain.

The commentators (Alcorta and Josipovic) have noted that brain-imaging studies do not provide support for the idea that there is random brain activity during meditation. Rather, there are specific increases of activity in some areas, while there are systematic decreases in others, depending on the type of meditation. Also, studies that look specifically at functional connectivity reveal that there may be systematic changes in, but not disappearance of, patterns of connectivity, and that these are dependent on the type of meditation employed (Josipovic, Dinstein, Weber, & Heeger, 2011).

These comments raise a few important technical issues. First, as discussed below, many of the relevant studies are conducted during Vipashyana-type meditation, rather than Shamatha. Both of my hypotheses, as stated above, are relevant primarily for successful Shamatha/Samadhi versions of meditation.

In addition, even when a Shamatha type of technique (focus on a neutral object) is used for a study, it is not clear that my hypotheses would dictate that there be no sign of any organized activity in a brain scan. First, it is unlikely that many studies have used subjects who actually reach full Samadhi (complete absence of thought and perception) during the brain-imaging session. Instead, it seems likely that subjects obtain only partial calming of thoughts, and that, at a minimum, conscious activity related to the object of focus (breath, mantra, etc.) used to reach the no-thought state is still present. If so, this would predict increased brain activity in regions that process the object, and this would be accompanied by decreases in areas responsible for content that has, indeed, begun to drop out. Thus, if discursive thoughts related to self and future plans have begun to be replaced by concentration on, for example, the breath, then this would predict, as mentioned by Alcorta,

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increases in activity in interoceptive areas, such as the insula, with concomitant decreases in the default mode network.

In addition, even if full Samadhi is reached, as it was, apparently, by the subject used in a recent study mentioned above (Hagerty et al., 2013), there would still, presumably, be some brain regions with higher activity levels than others, many of which would be different from those during the selected baseline condition. Perhaps the overall pattern would depend on static biological variables related to relative vascularization and vegetative state maintenance. In fact, the Hagerty et al. study revealed a very patchy set of cortical activation and deactivation clusters relative to the rest condition, and the authors state that this is suggestive of "an overall pattern of diffuse activation during jhana." It is not clear whether this particular pattern of patches would be reproducible, since these data were from a single session with a single subject.

A final technical comment has to do with the level of resolution provided by brain-imaging studies. Even the very impressive levels provided by recent developments in functional magnetic resonance imaging (fMRI) technology do not provide the level of resolution necessary to examine activity in the exact collections of neurons that constitute individual attractor networks. For example, a set of pictures of Barak Obama might be expected to activate various regions of the visual-processing system (e.g., the fusiform face area), as well as various language and, possibly, emotional centers. Pictures of Hillary Clinton would likely activate a similar set of general regions, but would, nonetheless, likely involve a non-overlapping set of particular neurons in at least some of these areas. Thus, any two pictures of Clinton might involve certain attractor networks that would be similar or identical to each other, yet very different from those in the same brain region activated by pictures of Obama. An fMRI image could not necessarily resolve this difference. Thus, the relative activity level of a given region, based on brain-imaging data, does not allow for a determination of whether there is organized attractor activity.

Vipashyana (insight or mindfulness)

Students of meditation inevitably discover that it is extremely difficult to follow the instructions (summarized above) for Shamatha meditation. That is, it turns out that it is nearly impossible to clear the mind and simply rest the consciousness on a single neutral object, especially during the early stages of training. Rather, thoughts and reactive emotions inevitably arise. The Vipashyana component of the Tibetan Shamatha-Vipashyana practice has to do with how to handle and learn from the arising of these thoughts. The student is instructed simply to label these intrusions as "thinking" and return to the neutral object. There is also some brief and distanced examination of these thoughts, and a great deal can be learned in this process. One major insight that can arise is that all thoughts and emotions are inconsequential conscious events like clouds in the sky or waves in the ocean.

As noted by Weber in his commentary, it is this second, Vipashyana (mindfulness) aspect of Buddhist meditative practice that is most frequently utilized (often in a modified form) in clinical and other secular settings in the West. Indeed, many of the studies cited in the commentaries involve this mindfulness aspect of the practice, and so are not relevant to either of my above-mentioned hypotheses. Mindfulness itself does not involve the absence of attractors and does not, to my knowledge, induce states of bliss.

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I would postulate that it is within this Vipashyana aspect of the practice that much of the *organized cognitive restructuring* referred to by the commentators may take place. Indeed, Josipovic et al. (2011) have reported a restructuring of the usual anti-correlation between brain regions involved in external, task-oriented processing versus those involved in internal, self-related processing. This restructuring took place specifically during a type of *mindfulness* meditation that Josipovic et al. refer to as non-dual awareness (NDA). For this, the instructions were: "Rest in reflexive NDA, equally aware of inside and outside of your body, allowing experiences to arise and subside of their own accord." The meditators in this condition were additionally instructed to avoid allowing the focus to become exclusively on either internal or external phenomena, and *to avoid trying to keep one's mind empty* of thoughts and feelings (see "Instructions to participants" in the methods section of Josipovic et al., 2011). Thus, the functional connectivity between the usually anti-correlated external versus internal based networks was induced during mindfulness meditation in which the subjects were instructed to think of both internal and external events during the same session.

The characterization of undirected thinking (mind-wandering or daydreaming) as either dysfunctional and/or dysphoric is misleading

Several of the commentators (Josipovic, Klinger, and Spezio) have noted that I mischaracterized mind-wandering by overstating the idea that this undirected thinking is typically dysfunctional and dysphoric. I agree: I should have been more careful and truer to the data in my overall presentation of mind-wandering. In the discussion below I acknowledge this misrepresentation of the data but will also defend the Buddhist view that these tendencies play a negative role overall.

The most detailed presentation of this issue was provided by Klinger, and in the following list I will provide a summary of each of his main points, along with my own response.

(1) The mind-wandering typical during the brain's default state is present during 30–50% of our waking hours and so must be adaptive.

This argument is an example of adaptationism. According to this idea, every trait exhibited by members of a species can be viewed as a separable unit that has been fostered through a relatively independent process of natural selection. Of course, this adaptationist view has been widely criticized, at least since the seminal "spandrels" paper by Gould and Lewontin (1979). This points out that a given trait may exist not due to a natural selection process, but rather as a consequence of historical events, along with an overall set of traits that have, in fact, been acted on through natural selection processes.

Thus, in the case of mind-wandering, we might first consider that humans possess a combination of (a) remarkable abilities for mental time travel, (b) highly developed language-based storytelling abilities, and (c) a dopamine reward system (that can be activated by the covert neural activity involved in (a) and (b); see Sulzer et al., 2013). It could be that our tendency to frequent mind-wandering may simply be a consequence of this combination of traits (each of which is presumably adaptive), and may not have been acted on independently through natural selection. As such, mind-wandering may, nonetheless, have at least some beneficial consequences (as referenced by the commentators), but it cannot be assumed to be adaptive overall, or to be *optimally* adaptive.

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(2) Mind-wandering is connected with the pursuit of personal goals and is helpful in this pursuit. It serves as a continual reminder mechanism for the complete agenda of short-term and long-term goals.

One point I had hoped to emphasize in the target paper is the remarkable correspondence between recent insights from cognitive neuroscience and those of Buddhist psychology in relation to the human tendency constantly to mentally drift from the present moment into a stream of transient, discursive thoughts related to an ongoing narrative about self and self-related goals. Both traditions agree that this is a central feature of human existence.

However, it seems that the two traditions are quite opposite in how they *value* these tendencies. Indeed, the Buddhist teachings agree that much of our offline mental activity is in the service of our external, online task-oriented behavior. However, in the Buddhist system such preoccupation with these goals is viewed as addictive and undesirable. They readily acknowledge that both daydreams and external achievement of goals provide momentary gratifications, and can allow for successful acquisition of necessary food, shelter, safety, and so on. They caution, however, that the constant obsession with self-image and self-service may also cause aggression, paranoia, fear, and a host of additional negative emotions that lead to *relative* unhappiness for the individual and for the larger community.

Buddhist teachings promise that renunciation of striving for worldly goals leads to freedom of thought and action, compassion and kindness toward others, and unshakable happiness for the individual. They also promise that, as mentioned by Weber in his commentary, there will actually be a superior ability to think through problems and solutions on the spot, when necessary, so that goods essential for well-being can be obtained.

In relation to point (1) above on the adaptive value of mind-wandering, it could be noted that practices of meditation and renunciation are observed in many different cultures. Thus, we could also raise the question as to whether these meditative practices are adaptive, and whether these, too, have been acted on through processes of natural selection. This may be an interesting empirical question.

However, it is important to remember that from the Buddhist perspective, survival is not necessarily a central goal. In fact, Buddhist teachers encourage students to give up on their own survival. Thus, the ancient Buddhists were lacking a Darwinian line of thought, which might have surreptitiously served as a value system, rather than just an explanatory framework. Accordingly, it is possible that meditative and renunciative practices may constitute a spandrel that is not, in fact adaptive.

(3) There is not good support for the idea that mind-wandering induces negative affect.

I appreciate the more careful look at the data on this subject prompted by Klinger's comments. One useful clarification of my own thinking here is that, from the Buddhist point of view, there is no prediction that mind-wandering would be more dysphoric than many of the comparison (on-task) activities used in the relevant studies. Many on-task behaviors would also likely involve self-presentation and promotion and so be equally problematic from the Buddhist view. Again, the Buddhist teachings readily acknowledge the gratifications available based on our typical goal-driven activities and thoughts. They also assert, however, that far greater happiness is available when these are relinquished. This suggests that future studies should employ (successful) concentrative meditation as a comparison condition for mind-wandering.

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(4) Mind-wandering is not addictive. Individuals who engage in extensive daydreaming may well be, nonetheless, successful and mentally healthy.

According to Koob and Volkow, drug addiction is characterized by: (1) compulsion to seek and take the drug; (2) loss of control in limiting intake; and (3) emergence of a negative emotional state reflecting a motivational withdrawal syndrome.

Mind-wandering is somewhat difficult to assess in relation to points (1) and (2), since it is a covert behavior and is readily available based on resources inherent within the individual. However, distraction from performance of directed tasks that require devoted attention could provide one measure. Klinger's point that many avid fantasizers are also successful both professionally and in family life does indicate that, if there are addictive aspects to this behavior, they are at least not overwhelming in most cases.

However, recall that beginners at Shamatha meditation typically find it impossible to focus the mind even briefly on a single neutral object. This suggests that it is, indeed, difficult to withhold mind-wandering, at least in the absence of an alternative equally engaging task. Also, Buddhist teachings claim that reasoning and problem-solving abilities are superior for highly attained practitioners for whom mind-wandering in daily life has subsided. If this Buddhist claim is true, it suggests that daydreams may intrude even when an individual appears to be on task. Thus, closer empirical examination is necessary to assess whether addiction-like mechanisms may be active in relation to mind-wandering.

With regard to Koob and Volkow's third point (negative affect during withdrawal), the Buddhist teachings do not, to my knowledge, document any withdrawal syndrome, as observed during prolonged withdrawal from drugs of abuse. This could be due to the fact that sustained withdrawal from mind-wandering develops only very gradually over a long time for the typical practitioner, and so the expected withdrawal symptoms may not be observable. Alternatively, this could indicate important differences between mind-wandering versus addictive processes.

Klinger also mentions that it is hard to explain rumination on negative thoughts as being addictive. Of course, one possibility is to suggest that instances of negative reinforcement are embedded in these thought processes, so that they are reinforced even though they continue to be an overall negative experience. Consideration of this possibility involves complexities beyond the scope of this discussion.

The involvement of the insula in meditative practice

Two of the commentators (Alcorta and Schachter) have noted that the anterior insula may play a critical role both during and as a long-term result of meditation. Activation of this area has been observed during meditation in some studies, and the insula shows greater thickness and gyration in long-time meditators (although longitudinal studies are required to assess the significance of such comparative data). In particular, both Alcorta and Schachter have suggested that increases in excitatory input from the insula to the nucleus accumbens may explain the euphoria sometimes induced by either meditation or pathological seizures. This process could well provide an alternative to the dopamine disinhibition hypothesized in my target article.

One question I would have with regard to the involvement of the insula would be whether this depends on the type of meditation employed. For example, many forms of meditation involve concentration on the breath as it moves within various components of the body. These types of meditation might be expected to activate the insula, since this region receives interoceptive inputs. One test between the proposed insular activation of the accumbens versus my proposed dopamine disinhibition would be to examine both introspectively reported bliss as well as measured dopamine release during absorptive meditation sessions that variably engage the insula (as judged by both brain-scanning evidence and introspective content).

Ecstasy during seizures may share commonalities with ecstatic experiences during meditation

I thank Schachter for drawing my attention to the phenomenon of ecstatic seizures. This is yet another example of euphoria that occurs in the absence of any external reward substance and that can take on a spiritual significance. The evidence again suggests possible accumbens involvement. It will be interesting perhaps one day to learn whether this has to do with the blockade of usual input patterns to the accumbens, or whether it is due more to direct accumbens stimulation.

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