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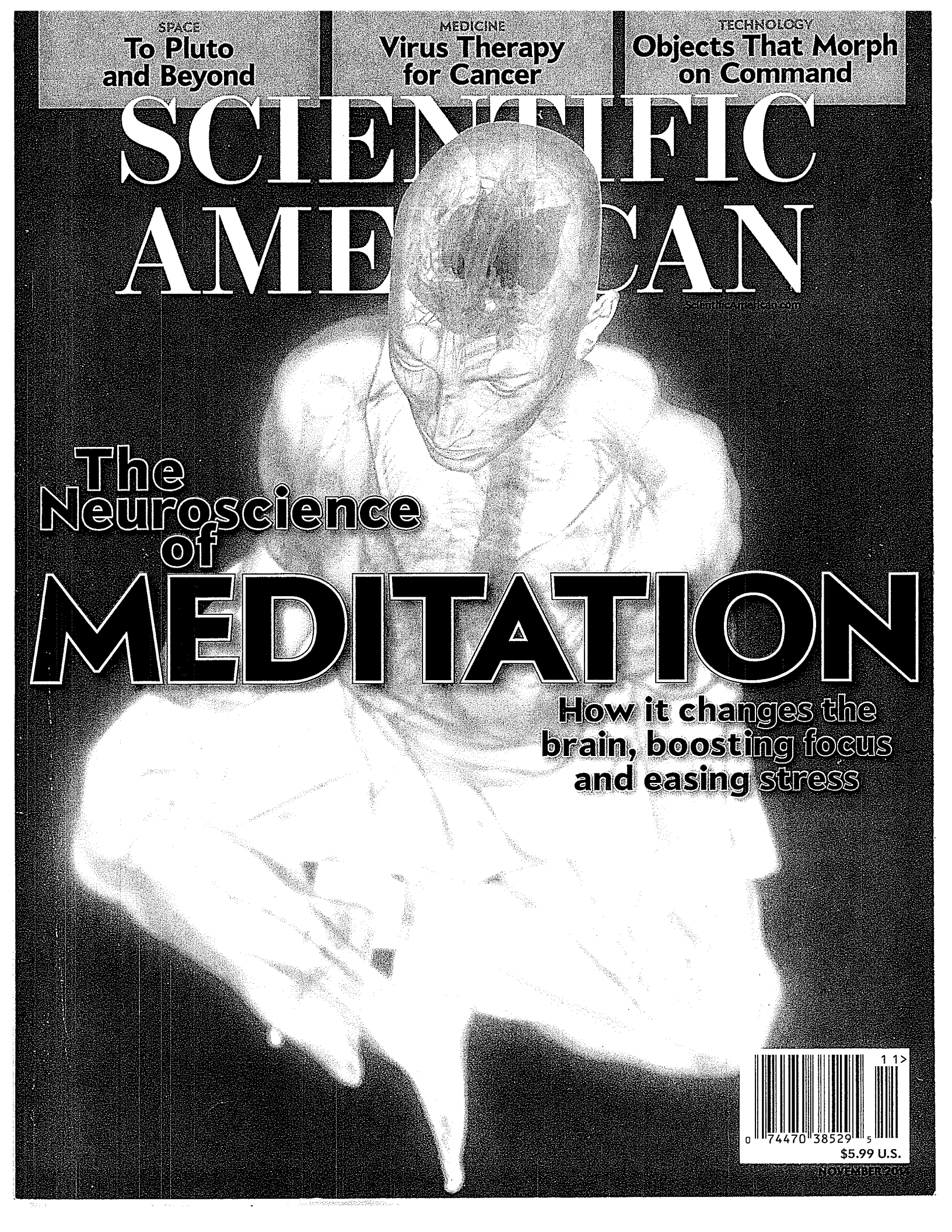

The Neuroscience of MEDITATION

How it changes the brain, boosting focus and easing stress

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NEUROSCIENCE

mind of the meditator

Contemplative practices that extend back thousands of years show a multitude of benefits for both body and mind

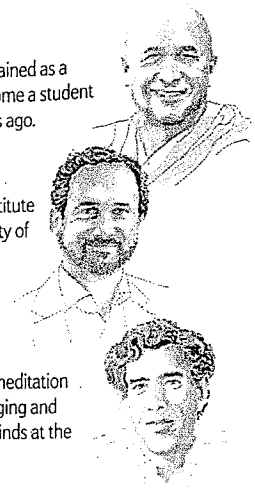
By Matthieu Ricard, Antoine Lutz and Richard J. Davidson

Illustration by Marcos Chin

Matthieu Ricard is a Buddhist monk who trained as a cellular biologist before he left France to become a student of Buddhism in the Himalayas about 40 years ago.

Antoine Lutz is a research scientist at the French National Institute of Health and Medical Research and also works at the University of Wisconsin-Madison. He has been a leader in studying the neurobiology of meditation.

Richard J. Davidson has pioneered the science of meditation as director of the Waisman Laboratory for Brain Imaging and Behavior and the Center for Investigating Healthy Minds at the University of Wisconsin-Madison.



WHEN THE SOCIETY FOR NEUROSCIENCE ASKED TENZIN GYATSO, THE 14TH DALAI LAMA (the leader of Tibetan Buddhism), to address its annual meeting in Washington, D.C., in 2005, a few hundred members among the nearly 35,000 or so attending the meeting petitioned to have the invitation rescinded. A religious leader, they felt, had no place at a scientific meeting. But this particular leader turned out to have a provocative and ultimately productive question to pose to the gathering. "What relation," he asked, "could there be between Buddhism, an ancient Indian philosophical and spiritual tradition, and modern science?"

The Dalai Lama, putting action before rhetoric, had already started trying to find answers to his own question. Back in the 1980s, he had sparked a dialogue about science and Buddhism, which led to the creation of the Mind & Life Institute, dedicated to studying contemplative science. In 2000 he brought new focus to this endeavor: he launched the subdiscipline of "contemplative neuroscience" by inviting scientists to study the brain activity of expert Buddhist meditators—defined as having more than 10,000 hours of practice.

For nearly 15 years more than 100 monastics and lay practitioners of Buddhism and a large number of beginning meditators have participated in scientific experiments at the University of Wisconsin-Madison and at least 19 other universities. The article you are reading, in fact, is the product of a collaboration between two neuroscientists and a Buddhist monk who originally trained as a cell biologist.

A comparison of the brain scans of meditators with tens of thousands of hours of practice with those of neophytes and nonmeditators has started to explain why this set of techniques for training the mind holds great potential for supplying cognitive and emotional benefits. The goals of meditation, in fact, overlap with many of the objectives of clinical psychology, psychiatry, preventive medicine and education. As suggested by the growing compendium of research, meditation may be effective in treating depression and chronic pain and in cultivating a sense of overall well-being.

The discovery of meditation's benefits coincides with recent neuroscientific findings showing that the adult brain can still be deeply transformed through experience. These studies show that when we learn how to juggle or play a musical instrument, the brain undergoes changes through a process called neuroplasticity. A brain region that controls the movement of a violinist's fingers becomes progressively larger with mastery of the instrument. A similar process appears to happen when we meditate. Nothing changes in the surrounding environment, but the meditator regulates mental states to achieve a form of inner en-

IN BRIEF

Meditation is an ancient pursuit that, in some form, is a part of nearly every world religion. In recent years its practice, derived from various branches of Buddhism, has made its way into the secular world as a means of promoting calmness and general well-being.

Three common forms of meditation—focused attention, mindfulness and compassion—are now practiced everywhere, from hospitals to schools, and have increasingly become an object of scrutiny in scientific laboratories worldwide.

Physiological changes in the brain—an altered volume of tissue in some areas—occur through meditation. Practitioners also experience beneficial psychological effects: they react faster to stimuli and are less prone to various forms of stress.

Varieties of Contemplative Experience

Advances in neuroimaging and other technologies have enabled scientists to gain insight into what happens in the brain during three major forms of Buddhist meditation—focused attention, mindfulness, and compassion and loving kindness. The diagram below offers a glimpse into the cycle of events that occurs in the practice of focused-attention meditation—and the corresponding activation of specific brain areas.

Focused Attention

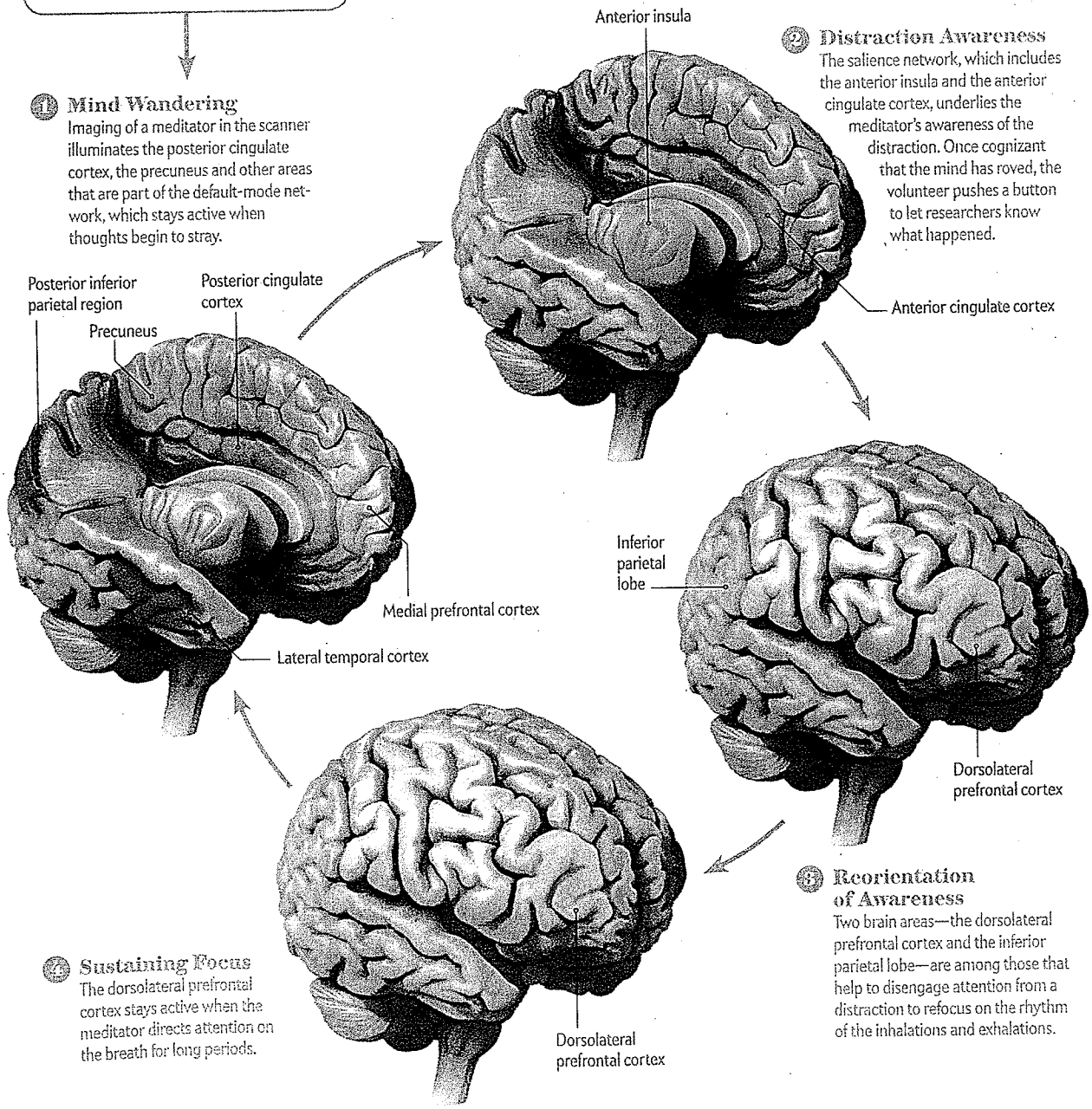
This practice typically directs the meditator to concentrate on the in-and-out cycle of breathing. Even for the expert, the mind wanders, and the object of focus must be restored. A brain-scanning study at Emory University has pinpointed distinct brain areas that become involved as attention shifts.

Mindfulness

Also called open-monitoring meditation, mindfulness entails observing sights, sounds and other sensations, including internal bodily sensations and thoughts, without being carried away by them. Expert meditators have diminished activity in anxiety-related areas, such as the insular cortex and the amygdala.

Compassion and Loving Kindness

In this practice, the meditator cultivates a feeling of benevolence directed toward other people, whether friend or enemy. Brain regions that fire up when putting oneself in the place of another—the temporoparietal junction, for instance—show an increase in activity.



1 Mind Wandering
Imaging of a meditator in the scanner illuminates the posterior cingulate cortex, the precuneus and other areas that are part of the default-mode network, which stays active when thoughts begin to stray.

2 Distraction Awareness
The salience network, which includes the anterior insula and the anterior cingulate cortex, underlies the meditator's awareness of the distraction. Once cognizant that the mind has roved, the volunteer pushes a button to let researchers know what happened.

3 Reorientation of Awareness
Two brain areas—the dorsolateral prefrontal cortex and the inferior parietal lobe—are among those that help to disengage attention from a distraction to refocus on the rhythm of the inhalations and exhalations.

4 Sustaining Focus
The dorsolateral prefrontal cortex stays active when the meditator directs attention on the breath for long periods.

Illustration by David C. Killpack

richment, an experience that affects brain functioning and its physical structure. The evidence amassed from this research has begun to show that meditation can rewire brain circuits to produce salutary effects not just on the mind and the brain but on the entire body.

WHAT IS MEDITATION?

MEDITATION HAS ROOTS in the contemplative practices of nearly every major religion. The prevalence of meditation in the media has given the word various meanings. We will refer to meditation as the cultivation of basic human qualities, such as a more stable and clear mind, emotional balance, a sense of caring mindfulness, even love and compassion—qualities that remain latent as long as one does not make an effort to develop them. It is also a process of familiarization with a more serene and flexible way of being.

In principle, meditation is relatively simple and can be done anywhere. No equipment or workout attire is needed. The meditator begins by assuming a comfortable physical posture, neither too tense nor too lax, and by wishing for self-transformation and a desire for others' well-being and for the alleviation of their suffering. Later the practitioner must stabilize the mind, which is too often disorderly—and occupied by a stream of inner chatter. Mastering the mind requires freeing it from automatic mental conditioning and inner confusion.

We will examine here what happens in the brain during three common types of meditation developed through Buddhism and now practiced in secular programs in hospitals and schools throughout the world. The first one, focused-attention meditation, aims to tame and center the mind in the present moment while developing the capacity to remain vigilant to distractions. The second one, mindfulness, or open-monitoring meditation, tries to cultivate a less emotionally reactive awareness to emotions, thoughts and sensations occurring in the present moment to prevent them from spiraling out of control and creating mental distress. In mindfulness, the meditator remains attentive, moment by moment, to any experience without focusing on anything specific. Finally, another type of practice is known in Buddhist tradition as compassion and loving kindness and fosters an altruistic perspective toward others.

UNDER THE SCANNER

NEUROSCIENTISTS HAVE NOW BEGUN to probe what happens inside the brain during the various types of meditation. Wendy Hasenkamp, then at Emory University, and her colleagues used brain imaging to identify the neural networks activated by focused-attention meditation. In the scanner, the participants trained their attention on the sensation produced by breathing. Typically during this form of meditation, the mind wanders from an object, and the meditator must recognize this and then restore attention to the gradual rhythm of the inhaling and exhaling. In this study, the meditator had to signal mind wandering by pressing a button. Researchers identified four phases of a cognitive cycle: an episode of mind wandering, a moment of becoming aware of the distraction, a phase of reorienting attention and a resumption of focused attention.

Each of the four phases involves particular brain networks. The first part of the cycle, when a distraction occurs, increases activity in the wide-ranging default-mode network (DMN). This network includes areas of the medial prefrontal cortex, the posterior cingulate cortex, the precuneus, the inferior parietal lobe and the lateral temporal cortex. The DMN is known to become activated during mind wandering and to play a general role in building and updating internal models of the world based on long-term memories about the self or others.

The second phase, becoming aware of a distraction, occurs in other brain areas such as the anterior insula and the anterior cingulate cortex, regions of what is called the salience network. This network regulates subjectively perceived feelings, which might, for instance, lead to being distracted during a task. The salience network is thought to play a key role in detecting novel events and in switching activity during meditation among assemblies of neurons that make up the brain's large-scale networks. It may shift attention away from the default-mode network, for instance.

The third phase engages additional areas—among them the dorsolateral prefrontal cortex and the lateral inferior parietal lobe—that "take back" one's attention by detaching it from any distracting stimulus. Finally, in the fourth and last phase, the dorsolateral prefrontal cortex continues to retain a high level of activity, as the meditator's attention remains directed toward an object such as the breath.

In our laboratory at Wisconsin, we further observed different patterns of activity depending on a practitioner's level of experience. Veteran meditators with more than 10,000 hours of practice showed more activity in these attention-related brain regions compared with novices. Paradoxically, the most experienced meditators demonstrated less activation than the ones without as much experience. Advanced meditators appear to acquire a level of skill that enables them to achieve a focused state of mind with less effort. These effects resemble the skill of expert musicians and athletes capable of immersing themselves in the "flow" of their performances with a minimal sense of effortful control.

To study the impact of focused-attention meditation, we also studied its volunteers before and after a three-month retreat with intensive meditation exercises for at least eight hours a day. They received headphones that broadcast sounds at a given frequency, occasionally mixed with slightly higher-pitched sounds. They had to focus on the sounds played in one ear for 10 minutes and react to periodically interspersed high-pitched tones. After the retreat, we found that meditators, compared with a nonmeditating control group, showed less trial-to-trial variation in their reaction times on this highly repetitive task, which lent itself easily to distractions. The result suggested that the meditators had an enhanced capacity to remain vigilant. The brain's electrical responses to high-pitched tones remained more stable at the second session only for the meditators.

STREAM OF CONSCIOUSNESS

THE SECOND TYPE of well-studied meditation also involves another form of attention. Mindfulness, or open-monitoring meditation, requires the meditator to take note of every sight or sound and track internal bodily sensations and inner self-talk. The person stays aware of what is happening without becoming overly preoccupied with any single perception or thought, returning to this detached focus each time the mind strays. As awareness of what is happening in one's surroundings grows,

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INNER PATHWAYS of brain activity register on an electroencephalogram as co-author Matthieu Ricard meditates.

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normal daily irritants—an angry colleague at work, a worried child at home—become less disruptive, and a sense of psychological well-being develops.

With Heleen Slagter, then in our group at Wisconsin, we sought to learn about the influence of this form of training on mental functioning by measuring the participants' capacity to detect rapidly presented visual stimuli—a means to measure mindfulness meditation, which is also sometimes called nonreactive awareness. To perform this experiment, we used a task in which the participants had to detect two numbers presented on a screen rapidly, amid a succession of letters. If the second number appears about 300 milliseconds after the first one, subjects often do not see the second, a phenomenon known as attentional blink.

If the second number appears after a delay of 600 milliseconds, it can be detected without difficulty. The attentional blink reflects the limits of the brain's ability to process two stimuli presented to the observer at close intervals. When too much of the brain's attention is devoted to processing the first number, the second number cannot always be detected, although the observer usually can see it on some of the trials. We hypothesized that mindfulness training could reduce the propensity to "get stuck," or absorbed by seeing the first number. Mindfulness practice cultivates a nonreactive form of sensory awareness, which should result in a reduced attentional blink. As we predicted, after three months of an intensive retreat, the meditators perceived both numbers more frequently than the controls did. This improved perception was also reflected in lessened activity of a particular brain wave in response to the first number. Monitoring the P3b brain wave, used to assess how attention is allocated, indicated that meditators were capable of optimizing attention so as to minimize the attentional blink.

Staying aware of an unpleasant sensation can reduce maladaptive emotional responses and help one to move beyond the disagreeable feeling and may be particularly useful in dealing with pain. In our Wisconsin lab, we have studied experienced practitioners while they performed an advanced form of mindfulness meditation called open presence. In open presence, sometimes called pure awareness, the mind is calm and relaxed, not focused on anything in particular yet vividly clear, free from excitation or dullness. The meditator observes and is open to experience without making any attempt to interpret, change, reject or ignore painful sensation. We found that the intensity of the pain was not reduced in meditators, but it bothered them less than it did members of a control group.

Compared with novices, expert meditators' brain activity diminished in anxiety-related regions—the insular cortex and the amygdala—in the period preceding the painful stimulus. The meditators' brain response in pain-related regions became accustomed to the stimulus more quickly than that of novices after repeated exposures to it. Other tests in our lab have shown that meditation training increases one's ability to better control and buffer basic physiological responses—inflammation or levels of a stress hormone—to a socially stressful task such as giving a public speech or doing mental arithmetic in front of a harsh jury.

Several studies have documented the benefits of mindfulness on symptoms of anxiety and depression and its ability to improve sleep patterns. By deliberately monitoring and observing their thoughts and emotions when they feel sad or worried, depressed patients can use meditation to manage negative thoughts and feelings as they arise spontaneously and so lessen rumination. Clinical psychologists John Teasdale, then at the University of Cambridge, and Zindel Segal of the University of Toronto showed in 2000 that for patients who had previously suffered at least three episodes of depression, six months of mindfulness practice, along with cognitive therapy, reduced the risk of relapse by nearly 40 percent in the year following the onset of a severe depression. More recently, Segal demonstrated that the intervention is superior to a placebo and has a protective effect against relapse comparable to standard maintenance antidepressant therapy.

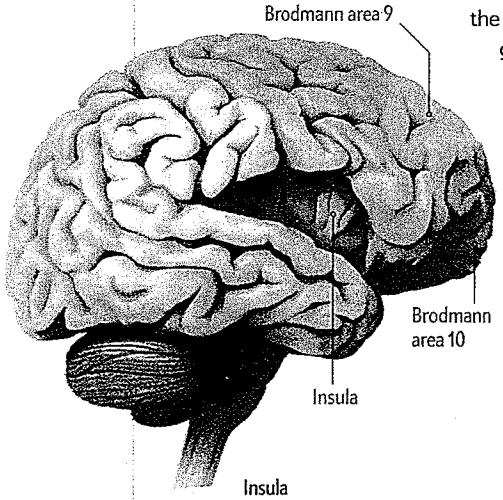
COMPASSION AND LOVING KINDNESS

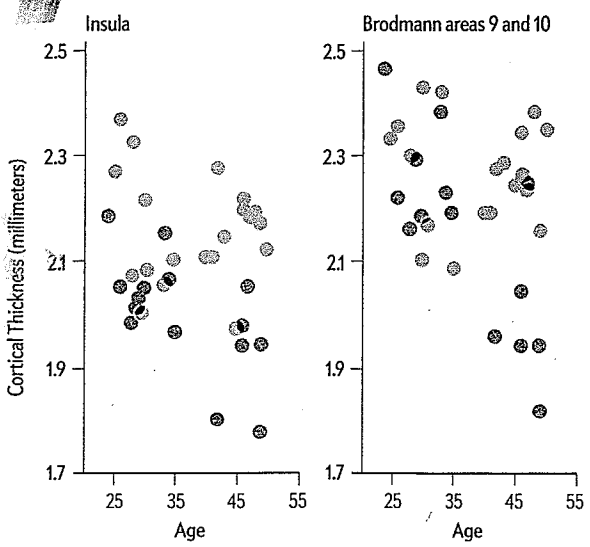
THE THIRD FORM of meditation under study cultivates attitudes and feelings of loving kindness and compassion toward other people, whether they are close relatives, strangers or enemies. This practice entails being aware of someone else's needs and then experiencing a sincere, compassionate desire to help that

A MEDITATION BENEFIT

Grow More Brain

Researchers from several universities explored whether meditation might bring about structural changes in brain tissue. Using magnetic resonance imaging, they found that 20 experienced practitioners of one type of Buddhist meditation had a greater volume of brain tissue in the prefrontal cortex (Brodmann areas 9 and 10) and the insula than a control group did (*graphs*). These regions play a role in processing attention, sensory information and internal bodily sensations. Future long-term studies will be needed to confirm this finding.





SOURCE: "MEDITATION EXPERIENCE IS ASSOCIATED WITH INCREASED CORTICAL THICKNESS," BY SARA W. LAZAR ET AL., IN *NEUROREPORT*, VOL. 16, NO. 17; NOVEMBER 28, 2005

person or to alleviate the suffering of other people by shielding them from their own destructive behavior.

To generate a compassionate state may sometimes entail the meditator feeling what another person is feeling. But having one's emotions resonate empathetically with the feelings of another person does not by itself suffice to yield a compassionate mind-set. The meditation must also be driven by an unselfish desire to help someone who is suffering. This form of meditation on love and compassion has proved to be more than just a spiritual exercise. It has shown potential to benefit health care workers, teachers and others who run the risk of emotional burnout linked to the distress experienced from a deeply empathetic reaction to another person's plight.

The meditator begins by focusing on an unconditional feeling of benevolence and love for others, accompanied by silent repetition of a phrase conveying intent, such as "May all beings find happiness and the causes of happiness and be free from suffering and the causes of suffering." In 2008 we studied experienced volunteers who had practiced this form of training for thousands of hours and found an increase in activity in several brain regions while they listened to voices conveying distress. The secondary somatosensory and insular cortices, known to participate in empathetic and other emotional responses, were more activated for experts than controls in response to the distressed voice, suggesting an enhanced ability to share the feelings of others without reporting any sign of becoming emotionally overwhelmed. The practice of compassion meditation also produced more activity in areas such as the temporoparietal junction, the medial prefrontal cortex and the superior temporal sulcus, all typically activated when we put ourselves in the place of another.

More recently, Tania Singer and Olga Klimecki, both at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany, in collaboration with one of us (Ricard), sought to distinguish differences between the effects of empathy and compassion on meditators. They noted that compassion and altruistic love were associated with positive emotions, and they suggested that emotional exhaustion or burnout was, in fact, a kind of empathy "fatigue."

According to the Buddhist contemplative tradition from which this practice is derived, compassion, far from leading to distress and discouragement, reinforces an inner balance, strength of mind, and a courageous determination to help those who suffer. If a child is hospitalized, the presence of a loving mother at his side holding his hand and comforting him with tender words will no doubt do that child more good than the anxiety of a mother overwhelmed with empathetic distress who, unable to bear the sight of her sick child, paces back and forth in the hallway. In the latter case, the mother may then end up with the common experience of burnout, which, in one U.S. study, beset about 60 percent of the 600 caregivers surveyed.

To further explore the mechanisms of empathy and compassion, Klimecki and Singer divided about 60 volunteers into two groups. One meditated on love and compassion, and the other experimental regimen trained participants to cultivate feelings of empathy for others. Preliminary results showed that after a week of meditation-based loving kindness and compassion, novice subjects watched video clips showing suffering people with more positive and benevolent feelings. The other subjects, who devoted a week to an experimental regimen that just cultivated empathy, experienced emotions that resonated deeply with others' sufferings. But these emotions also brought about negative feelings and thoughts, and this group experienced more distress, sometimes to the point of not being able to control their emotions.

Aware of these destabilizing effects, Singer and Klimecki added training for the empathy group in compassion and loving kindness meditation. They then observed that this additional exercise counterbalanced the detrimental effects of training in empathy alone: negative emotions diminished, and positive emotions increased. These results were accompanied by corresponding changes in the areas of several brain networks associated with compassion, positive emotions and maternal love, including the orbitofrontal cortex, the ventral striatum and the anterior cingulate cortex. The researchers, moreover, were able

Illustration by David C. Killpack (brain)

to demonstrate that a week of training in compassion increased prosocial behavior in a virtual game specially developed to measure the capacity to help others.

A DOOR TO CONSCIOUSNESS

MEDITATION EXPLORES the nature of the mind, providing a way to study consciousness and subjective mental states from the first-person perspective of the meditator. In a collaboration with expert Buddhist meditators at Wisconsin, we have studied the brain's electrical activity using electroencephalography (EEG) during compassion meditation in which the meditators described the well-defined sense of self as becoming less fixed and permanent.

We found that these long-term Buddhist practitioners were able, at will, to sustain a particular EEG pattern. Specifically, it is called high-amplitude gamma-band oscillations and phase synchrony at between 25 and 42 hertz. The coordination of brain oscillations may play a potentially crucial role in the brain's building of temporary networks that can integrate cognitive and affective functions during learning and conscious perception, a process that can bring about lasting changes in brain circuitry.

High-amplitude oscillations persisted throughout the meditation for several dozens of seconds and gradually increased as practice progressed. These EEG traces differed from those of control subjects, in particular, in the lateral frontoparietal cortex. Changes in electrical activity may reflect an increased awareness in expert meditators of their surroundings and their internal mental processes, although additional research is needed to better understand the functioning of gamma oscillations.

Meditation brings about changes not just in well-defined cognitive and emotional processes but also in the volume of certain brain areas, possibly reflecting alterations in the number of connections among brain cells. A preliminary study by Sara W. Lazar of Harvard University and her colleagues showed that among longtime meditators, as compared with a control group, the volume of the brain's darker tissue, its gray matter, differed in the insula and prefrontal cortices—specifically, regions called Brodmann areas 9 and 10, which are frequently activated during various forms of meditation. These distinctions were most pronounced in older participants in the study, suggesting that meditation might influence the thinning of brain tissue that comes with aging.

In a follow-up study, Lazar and her colleagues also showed that mindfulness training decreased the volume of the amygdala, a region involved in fear processing, for those participants who showed the most noticeable reductions in stress over the course of training. Eileen Luders of the University of California, Los Angeles, and her colleagues further observed differences in meditators in the fibers called axons that connect different brain regions, suggesting an enhanced number of brain connections. This observation may support the hypothesis that meditation actually induces structural alterations in the brain. An important limitation of this research relates to the lack of long-term longitudinal studies that follow a group over the course of many years and to the absence of comparisons between meditators and people of similar backgrounds and ages who do not meditate.

Some evidence even exists that meditation—and its ability to enhance overall well-being—may diminish inflammation and other biological stresses that occur at the molecular level. A collaborative study between our group and one led by Perla Kaliman of the Institute of Biomedical Research of Barcelona showed that one day of intensive mindfulness practice in experienced meditators turned down the activity of inflammation-related genes and altered the functioning of enzymes involved with turning genes on and off. A study by Cliff Saron of the University of California, Davis, looked at the effect of meditation on a molecule involved with regulating the longevity of a cell. The molecule in question was an enzyme called telomerase that lengthens DNA segments at the ends of chromosomes. The segments, called telomeres, ensure stability of the genetic material during cell division. They shorten every time a cell divides, and when their length decreases below a critical threshold, the cell stops dividing and gradually enters a state of senescence. Compared with a control group, the meditators who showed the most pronounced reductions in psychological stress also had higher telomerase activity by the end of the retreat. This finding suggests that mindfulness training might slow processes of cellular aging among some practitioners.

A PATH TO WELL-BEING

ABOUT 15 YEARS OF RESEARCH have done more than show that meditation produces significant changes in both the function and structure of the brains of experienced practitioners. These studies are now starting to demonstrate that contemplative practices may have a substantive impact on biological processes critical for physical health.

More studies using well-defined, randomized controlled trials are needed to isolate meditation-related effects from other psychological factors that can influence the outcome of a study. Other variables that may affect study results are the level of motivation of a practitioner and the roles played by both teachers and students in a meditation group. Further work is needed to understand the possible negative side effects of meditation, the desirable length of a given practice session and the way to tailor it to a person's specific needs.

Even with the requisite cautions, research on meditation provides new insights into methods of mental training that have the potential to enhance human health and well-being. Equally important, the ability to cultivate compassion and other positive human qualities lays the foundation for an ethical framework unattached to any philosophy or religion, which could have a profoundly beneficial effect on all aspects of human societies. SA

MORE TO EXPLORE

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