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Biology: Your Brain In Love

By Helen Fisher
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Have you just fallen madly in love? Thus began the announcement I posted on a bulletin board for psychology students on the Stony Brook campus of the State University of New York. I had come to believe that romantic love is a universal human feeling, produced by specific chemicals and networks in the brain. But exactly which ones? Determined to shed some light on this magic, I launched a multipart project in 1996 to collect scientific data on the chemistry and brain circuitry of romantic love.

My working hypothesis was that three related chemicals in the brain — dopamine, norepinephrine and serotonin — play a role in romantic passion. I speculated that the feelings of euphoria, sleeplessness and loss of appetite as well as the lover's intense energy, focused attention and increased passion in the face of adversity might all be caused in part by heightened levels of dopamine or norepinephrine in the brain. Similarly, I believed that the lover's obsessive thinking about the beloved might be due to decreased brain activity of some type of serotonin. I also knew these three compounds were much more prevalent in some brain regions than in others. If I could establish which regions of the brain become active while one is feeling romantic rapture, that might confirm which primary chemicals are involved. Perhaps these data would help explain the evolutionary roots of romantic love, why we choose one person rather than another, even how people can find and sustain this glorious passion.

My Plan

After a conversation with a neuroscientist at the Albert Einstein College of Medicine, I developed a scheme. I would collect data on brain activity while love-smitten subjects performed two separate tasks: looking at a photograph of his or her beloved and looking at a "neutral" photograph of an acquaintance who generated no positive or negative romantic feelings. Meanwhile, I would use a functional magnetic resonance imaging (fMRI) machine to take pictures of the subject's brain. The fMRI machine records blood flow in the brain. It is based in part on a simple principle: brain cells that are active use more blood than quiescent brain parts in order to collect the oxygen they need to do their job. I had already invited Lucy Brown, a neuroscientist at the Albert Einstein school, to interpret the scanning results. But I had one concern about the design of the experiment. I knew that lovers have a hard time not thinking about their beloved. I was afraid that the lovers' passionate romantic thoughts, generated as they looked at the photo of a sweetheart, would carry over and contaminate their passive thoughts as they looked at the neutral photo. Art Aron, a research psychologist at SUNY Stony Brook, who joined our team, along with graduate students Deb Mashek and Greg Strong, recommended that we use a "distraction task," a standard psychological procedure to wash the brain clean of emotion. We settled on a particular "distraction task" that amuses me to this day. Between looking at the photo of the sweetheart and the photo of a boring acquaintance, subjects were shown a large number (like 8,421) on the screen and asked to mentally count backward in increments of seven. The point: to cleanse the mind of strong feelings.

The Experiment

Now we were ready to gather our subjects, using word of mouth and the HAVE YOU JUST FALLEN MADLY IN LOVE? poster. Just and madly were the operative words. We sought only candidates who were so intensely in love that they could hardly eat or sleep, people whose romantic feelings were fresh, vivid, uncontrollable and passionate.

They were not difficult to find. Students immediately began to call Aron's psychology lab to volunteer. Mashek weeded out those who had metal in their heads (such as lip, tongue or nose jewelry or braces on their teeth) that would affect the magnet in the fMRI machine. She also excluded those who were claustrophobic, those taking medication that could affect brain physiology, and men and women who were left-handed. Brain organization can vary with handedness, and we needed to standardize our sample as much as possible.

At this point, I interviewed each candidate. My first question was always the same: "How long have you been in love?" My second question was the most important: "What percentage of the day and night do you think about your sweetheart?" Because obsessive thinking is a central ingredient of romantic passion, I sought only participants who thought about their beloved almost all their waking hours. I also looked for men and women who laughed and sighed more than usual during the interview.

If a potential subject showed signs of passion, I invited him or her to participate. We acquired two photographs: one of the beloved and one of an emotionally neutral individual. Generally the latter was someone the subject had known casually in high school or college. Then we set a date to put each subject into the brain scanner.

The Brain-Scanning Procedure

The procedure was simple but not easy. First Mashek and I made the participant as comfortable as possible in the scanner — a large, horizontal, cylindrical, cream-colored plastic tube that is open at both ends and extends from above the head to about the waist. After taking preliminary scans to establish basic brain anatomy, the 12-min. experiment started. First the subject looked at the photograph of the beloved on the screen for 30 sec. as the scanner recorded blood flow in various brain regions. Next the subject was shown a large number and asked to count backward for 40 sec. The participant then looked at the neutral photograph for 30 sec. while the brain was scanned again. Finally the subject was shown another large number and asked to count backward again, this time for 20 sec.

This cycle (or its reverse) was repeated six times — enabling us to collect 144 scans of different brain regions for each participant. After the experiment was over, I interviewed all the subjects again, asking how they felt and what they were thinking about during all parts of the test. To express our gratitude, we gave each participant $50 and a picture of his or her brain.

The Brain in Love

Before we could understand the results of our scanning, we had to make an in-depth analysis of the brain pictures. The fMRI machine that we were using shows only blood-flow activity in specific brain regions rather than the chemicals involved. But because scientists know which kinds of nerves connect which kinds of brain regions, they can often surmise which brain chemicals are active when specific regions begin to glow.

Many brain parts became active in our love-struck subjects when they focused on their beloved. However, two regions appear to be central to the experience of being in love. Perhaps our most important finding concerned activity in the caudate nucleus. This is a large, C-shaped region that sits deep near the center of your brain. It is very primitive — part of what is called the reptilian brain because it evolved long before mammals proliferated, some 65 million years ago. Our brain scans showed that parts of the body and the tail of the caudate became particularly active as a lover gazed at the photo of a sweetheart.

I was astonished. Scientists have long known that this brain region directs bodily movement. Only recently have they come to realize that it is also a key part of the brain's "reward system," the mind's network for general arousal, sensations of pleasure and the motivation to acquire rewards. Not only did our subjects exhibit activity in the caudate, but also the more passionate they were, the more active their caudate was.

We discovered this in a curious way. Before our subjects entered the brain scanner, we asked each to fill out several questionnaires, including a survey designed by psychologist Elaine Hatfield and sociologist Susan Sprecher called the Passionate Love Scale. We wanted to compare the brain activity of each subject to what that subject reported on a questionnaire. We found a positive correlation: those who scored higher on the Passionate Love Scale also showed more activity in a specific region of the caudate.

We also found activity in other regions of the reward system, including areas of the septum and a brain region that becomes active when people eat chocolate. Chocolate can be addictive. I maintain that romantic love is addictive too.

The Dopamine Mother Lode

Another striking result from our FMRI experiment concerned activity in the ventral tegmental area (VTA), a central part of the reward circuitry of the brain. This result was what I was looking for. As you know, I had hypothesized that romantic love is associated with elevated levels of dopamine or norepinephrine. The VTA is a mother lode for dopamine-making cells. With their tentacle-like axons, these nerve cells distribute dopamine to many brain regions, including the caudate nucleus. And as this sprinkler system sends dopamine to various parts of the brain, it produces focused attention as well as fierce energy, concentrated motivation to attain a reward, and feelings of elation — even mania — the core feelings of romantic love.

No wonder lovers talk all night or walk till dawn, write extravagant poetry and self-revealing e-mails, cross continents or oceans to hug for just a weekend, change jobs or lifestyles, even die for one another. Drenched in chemicals that bestow focus, stamina and vigor, and driven by the motivating engine of the brain, lovers succumb to a Herculean courting urge.

The Drive to Love
All these data had a definite effect on me — they changed my understanding of romantic love. For many years I had regarded this wonderful experience as a constellation of related emotions that ranged from elation to despair. But psychologists distinguish between emotions and motivations — brain systems oriented around planning and pursuit of a specific want or need. And our colleague Art Aron was wedded to the idea that romantic love was not an emotion but a motivation system designed to enable suitors to build and maintain an intimate relationship with a preferred mating partner.

Indeed, because of Aron's dedication to this idea, we had begun our brain-scanning project with two hypotheses: my hypothesis that romantic love is associated with dopamine and other closely related neurotransmitters in the brain, and Aron's theory that romantic love is primarily a motivation system rather than an emotion.

As it turns out, our results suggest that both hypotheses are correct. Romantic love does seem to be associated with dopamine. And because this passion emanates from the caudate nucleus, motivation and goal-oriented behaviors are involved.

Love's Complex Chemistry
We are coming to some understanding of the drive to love — and what an elegant design it is! This passion emanates from the motor of the mind, the caudate nucleus, and it is fueled by at least one of nature's most powerful stimulants, dopamine. When passion is returned, the brain tacks on positive emotions, such as elation and hope. And all the while, regions of the prefrontal cortex monitor the pursuit — planning tactics, calculating gains and losses, and registering one's progress toward the goal: emotional, physical, even spiritual union with the beloved. Nature has produced a powerful mechanism to focus our precious courtship energy on a special other — an evolutionary miracle designed to produce more humans.

"The brain is wider than the sky," wrote Emily Dickinson. Indeed, this 3-lb. blob can generate a need so intense that all the world has sung of it. And to make our lives even more complex, romantic passion is intricately enmeshed with two other basic mating drives, the sex drive and the urge to build a deep attachment to a romantic partner. Ah, the web of love. How these forces feed the flame of life.

A Little Help From Serotonin

BY **ANNE UNDERWOOD** ON 12/28/97 AT 7:00 PM

FOR RHESUS MONKEYS, LIFE IN THE WILD IS A little like high school. Some animals--call them losers--slouch around looking aggrieved. They're volatile and bellicose, slow to form alliances and loath to reconcile after a spat. One in five dies during the passage to adulthood. But while the losers scrap over bits of chow, other animals--call them winners--stay busy grooming each other. They maintain wide networks of allies. They deflect challenges without resorting to violence, and 49 out of 50 survive to produce offspring. Why do they fare so well? The answer is no doubt complicated, but the monkeys' spinal fluid provides an intriguing clue. In study after study, researchers at the National Institute on Alcohol Abuse and Alcoholism have found that the winners' nervous systems are loaded with serotonin.

As the 20th century winds down, we humans seem increasingly convinced that serotonin is the key to a good life--and it's easy to see why. This once obscure neurotransmitter is the secret behind Prozac, the drug that revolutionized the pursuit of happiness 10 years ago this winter. Prozac and its mood-altering cousins all work by boosting serotonin's activity in the brain. So do Redux and fenfluramine, the blockbuster diet drugs that were pulled off the market this fall due to safety concerns. Even Imitrex, the hot new migraine treatment, works its magic via serotonin. Somehow serotonin is implicated in just about everything that matters to us--from winning friends and wielding power to managing anxiety and controlling appetites and impulses. So what is serotonin? How does it work? And why is it in such short supply? Those issues are still murky, but science is yielding some clues.

Serotonin is so basic to life that even worms and sea slugs make it. The substance abounds in our bloodstreams, but our brains produce separate supplies via cells known as raphe nuclei. Rooted near the base of the skull, these specialized neurons extend like branching vines through the brain and spinal cord, each one maintaining links with a half-million target cells. When a nerve impulse reaches a branch ending, the neuron releases serotonin into a tiny space, or synapse. Serotonin molecules then lock into receptors on the target cell, transmitting a message that travels through the nervous system. Microseconds later, the neuron that released the chemical takes it back in--a process known as reuptake.

What does serotonin say during its moment in the synapse? It depends on the target. Our nervous systems harbor at least 14 classes of serotonin receptors, each tailored to a distinct piece of the molecule. Since different types of brain cells sport different receptors, their responses to serotonin vary widely. Serotonin excites the motor neurons, which govern muscle activity, but it quiets the sensory neurons that mediate hunger and pain. It also pacifies neurons in the limbic system, the brain's Department of Animal Instincts. ""Serotonin puts the brakes on primitive behaviors like sex, aggression and excessive feeding," says Dr. Larry Siever of New York's Mount Sinai School of Medicine.

Small wonder, then, that high serotonin can foster social success. In a classic series of experiments with vervet monkeys, UCLA scientists Michael McGuire and Michael Raleigh found that males who had achieved high rank within a group's social hierarchy had nearly twice as much serotonin in their blood as low-ranking males. But that's not to say they were born leaders; further analysis showed that social standing had as much effect on the animals' serotonin as serotonin had on their status. If an alpha male was displaced by a challenger, his blood count would quickly plummet--and when an upstart came into power, his serotonin level would surge. Raleigh and McGuire found they could deplete a leader's serotonin simply by keeping him behind a one-way mirror, where his peers couldn't acknowledge his dominance displays.

People's social lives are more complicated than monkeys', but not entirely different. When Raleigh and McGuire analyzed blood samples from 48 UCLA fraternity boys, the average serotonin level was nearly 25 percent higher among officers than among members. And when Raleigh compared his own serotonin count with that of his lab director (McGuire), the boss's was 50 percent higher.

Rising to the top may involve some scrapping, but serotonin doesn't foster aggression. ""Serotonin provides a restraint mechanism, a kind of behavioral seat belt," says Dr. John Mann of Columbia University. Whether you look at monkeys, dogs, horses or humans, the most aggressive individuals are typically those with the lowest serotonin levels. Drugs that boost serotonin's activity tend to dampen a wide range of impulses (including sexual ones that need no dampening), and they can help violent people get a grip. Yasmin Hamani has seen it happen. When her autistic daughter was 8 years old, her annoying repetitive behaviors turned violent. If Hamani turned her back, the child would sneak up and sink her nails into an exposed piece of flesh with swift pinches that drew blood. She would kick people in church and grab at women's hair in the supermarket. One of her schools confined her to a four-foot pen to protect the other kids. When the child was 11 and increasingly uncontrollable, Dr. Edwin Cook at the University of Chicago tried treating her with Prozac. The drug didn't cure her autism, but violent outbursts stopped. ""Everyone loves her now," says Hamani.

Violence is one possible consequence of low serotonin, but there are many others. Without the chemical's leveling effects, we grow more vulnerable to all kinds of impulses--whether to gamble, buy things, steal things or eat things. And low serotonin can have devastating effects on mood. It plays major roles not only in depression and suicide but in premenstrual syndrome (PMS), seasonal affective disorder (SAD) and routine morning grumpiness (RMG).

You might conclude from all this that more serotonin is always better. But just as a serotonin deficiency can unleash destructive impulses, an overly active serotonin system can leave a person paralyzed by obsessions and compulsions. People with compulsive disorders become hyperaware of potential threats--possibly because serotonin is overstimulating the receptors involved in planning and vigilance--and they develop bizarre rituals for managing their anxiety. Incessant cleaning and checking are the classic manifestations, but there are many others. Hypochondria, once dismissed as an annoying bid for sympathy, is now viewed as a type of obsessive-compulsive illness. So is body dysmorphic disorder (BDD), a grim fixation on some flaw in one's appearance. Dr. Eric Hollander of New York's Mount Sinai has seen people undergo two dozen surgeries to correct perceived defects. ""This isn't a trivial illness," he says. ""There is a high rate of suicide among these patients."

Prozac would seem an unlikely remedy. Its job, after all, is to amplify serotonin's effect, by slowing its removal from the synapse. Yet Prozac and the other ""selective serotonin reuptake inhibitors" (SSRIs) are proving as useful against compulsive disorders as they are against impulsive ones. How could the same drugs alleviate such disparate problems? Most experts credit the body's drive to maintain equilibrium. If a neuron is responding poorly to serotonin, blocking reuptake may simply compensate for the shortfall. But if a neuron is already overstimulated, it may compensate for the extra exposure by responding less vigorously. ""It's a leap to think "I hate my nose so I'll take Prozac'," says Dr. Katharine Phillips of Butler Hospital in Providence, R.I. ""But it can make a difference."

Domination is Linked to Chemical in the Brain

By HAROLD M. SCHMECK Jr.
Published: September 27, 1983, New York Times

STUDIES of monkeys and college students suggest that social status is reflected in the chemistry of the brain.

Scientists say studies show that the dominant males in colonies of vervet monkeys had twice as much circulating serotonin in their blood as any other males. Serotonin is a neurotransmitter, a chemical used in sending information from cell to cell in the brain.

And when a dominant monkey was put by himself, his blood serotonin level dropped. In a solitary situation he had no need or opportunity to show dominance. With the dominant male removed, scientists at the University of California in Los Angeles found, another male soon assumed the role. His blood serotonin also rose to about twice the normal level.

When the original dominant male returned, however, he became dominant again; the level of serotonin in his blood went up and that of his rival went down.

Just what serotonin has to do with animal dominance is unknown, but the scientists found hints of something similar in humans. Measurement of blood serotonin levels in a college fraternity showed that officers had higher levels than the others.

The scientists said social interactions seem to influence serotonin levels. They studied circulating blood levels because direct measurements in the brain would have been extremely difficult. The findings imply that the ability to convert food substances efficiently into serotonin help an animal achieve dominance. Serotonin, one of the most-studied neurotransmitters, is found in several brain areas, including those involved in emotion.

"We don't believe for a moment that serotonin is the only factor," said Dr. Michael T. McGuire. of U.C.L.A.'s Neuropsychiatric Institute. "But we just can't find out what else is going on." The differences have been shown clearly in 40 different vervet monkey groups in seven years of study, Dr. McGuire said.

His colleagues in the work are Dr. Michael J. Raleigh, Dr. Gary L. Brammer and Dr. Arthur Yuwiler of U.C.L.A. The monkeys are being studied at Sepulveda Veterans Administration Hospital's nonhuman primate laboratory in Los Angeles and at St. Kitts Island in the Caribbean.

The team plans to study humans further next summer with the help of a 17-man Swedish yacht crew who will be contestants in an around-the-world sailing race out of London. The men will be monitored for leadership roles, and blood samples will be taken as the yacht nears Cape Horn. The blood will be packed in ice and flown to U.C.L.A. for serotonin measurements.

"The basis of all this research is what we call socio-pharmacology," said Dr. McGuire, a psychiatrist. "We are especially interested in how social situations affect body chemistry and physiology. We know that psychotropic drugs have different effects in different situations."

Psychotropic drugs are drugs that alter a person's perceptions or mental state. It has often been observed that the effects of such drugs on an individual vary markedly depending on the user's social situation at the time.

Other Serotonin Study Summaries

Serotonin and Risky Male Behavior in Monkeys (Higley et al., 1996)

1. Aim: Is serotonin related to taking risks?
2. Method: A field study where they followed male monkeys who were migrating to new social groups
    a. Measured the serotonin by extracting cerebrospinal flluid by placing needles in their spines
3. The independent variable was dividing the monkeys into high, mid-high, mid-low and low serotonin groups
4. The dependent variables were how aggressive the monkeys were observed to be, number of scars they had and death
5. Results: 11/49 of the monkeys who died had low serotonin levels
6. Conclusion: Monkeys with low levels of serotonin are more likely to take risks like fighting with other monkeys
7. Evaluation: This field study has high ecological validity but lacks the control of lab experiments
    a. Sex difference - What about female monkeys?
    b. External validity - Do these results generalize to human males?

Serotonin and Risky Female Behavior in Monkeys (Westergaard et al., 1999)

1. Aim: Is serotonin related to taking risks for females?
2. Method: Observational study of captive monkeys
3. The independent variable was the species of monkey: rhesus monkeys or pigtailed macaques
    a. Rhesus monkeys are known to be aggressive
    b. Pigtailed macaques are known to be friendly
4. The dependent variable was the level of serotonin they measured in the cerebrospinal fluid like Higley et al., 1996
    a. Another dependent variable was how aggressive the monkeys behaved and how many wounds they had
5. They placed each monkey in same sex groups to see how they behaved
6. Results: Rhesus monkeys were more aggressive and had more wounds. Rhesus monkeys had less serotonin than pigtailed macaques
7. Conclusion: Serotonin inhibits risky behavior in females as well
8. Evaluation: This field study has high ecological validity but lacks the control of lab experiments
    a. External validity - Do these results generalize to human females?

Serotonin and Gambling Monkeys (Long et al., 2009)

1. Aim: Test if serotonin levels are related to gambling risks in a controlled environment
2. Method: They manipulated the amount of serotonin the monkeys could produce by forcing a certain type of diet
    a. Tryptophan is the raw material required to produce serotonin and is found in certain foods
3. The independent variable was the tryptophan level of the diet which was high or low in tryptophan
    a. High tryptophan meant more serotonin should be produced than the low tryptophan diet
4. The dependent variable was the choice the monkey made in the gambling task
5. In the gambling task the monkey could choose a safe option which would guarantee they would get a normal amount of juice
    a. There was a riskier option where they could get a low or high amount of juice
6. Results: The low tryptophan group chose the risky option whereas the high tryptophan group chose the safe option
7. Conclusion: Levels of tryptophan as determined by diet can affect serotonin levels and risky behavior
8. Evaluation: Lab experiment had a high amount of control but a small sample size (only 3 monkeys) and low ecological validity
    a. Do these results generalize to humans?