Love in the Brain: A Social Neuroscience Review

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Abstract

Love is all around us whether we want to believe it or not. This feeling is more than just an emotional one; it is a complex biological one. Romantic love shows neuronal correlations in all stages: falling, being, and breaking up with love. Love can be obsessive, and it can also be nonexistent. Looking into these emotions and behaviors, we learn more about ourselves.

Key terms: Social neuroscience, Biology, Chemistry, Love, Romance

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Chapter 1: Introduction

Researchers have just begun diving into what Horstman describes as “what in our brains makes our hearts go pitter-patter with love and lasting love–with the whole smorgasbord of emotions” (Horstman, 2012). Everyone experiences love throughout their life whether it is maternal love, unconditional love, or romantic love. Biologically, it is hardwired in our brains. Despite love being within us from the beginning of life, we do not fully understand it. We have had evolutionary and psychological theories of love and in recent decades, neuroscientists have begun diving in to understand the biological basis of love. Although the investigation is rather new, there has been much progress in these efforts. Long the domain to art and literature, today neuroscientists are studying love and what it does to the brain.

This mass composed of human flesh, nerve connections, and fluid is more emotional and complex than many of us, including the ones researching it know. Neuroscientists have proposed that the brain in love “uses an entire pharmacy of chemicals and chemical actions and reactions, calling forth a tsunami of neurotransmitters and hormones” (Horstman, 2012). To see the very basic structure of the human brain see Figure 1 (By, 2023). Biological and neuronal correlations correspond to the fact that love does alter the brain's activity and chemical reactions. So what exactly is love and how does it relate to the biological mechanisms of our brain?

Knowing what love is and how it relates to evidence found in the brain only gets us so far. There are dozens and dozens of studies done investigating this topic of love in the brain. As there are different types of love ranging from maternal to unconditional to romantic, the data is immeasurable. Consequently, for this study, research will be based on passion, also known as romantic love. It is your boyfriend or your girlfriend or your partner whom you want to see;

romantic love changes your brain's chemistry and in turn your behavior. What exactly is romantic love and what does it do to the brain?

Again, such a generalized question leaves us thinking about a lot. Thus, the real question is what love does to the brain through stages. Immediately through research we can see how romantic love interacts with the brain, but it raises the question of how deep the love is. This study proposes that we look at romantic love in all its stages including falling in love, being in love, and experiencing heartbreak. The obsessive nature of falling, the comfort of being, and the hostility of breaking up will be investigated. Through this, the behaviors that we see on the outside will associate with much of what is going on inside.

Background

Social neuroscientists investigate love through technology, something that was difficult to come by dozens of years ago. Predominantly, studies of love have been done on animals, but today human experiments are proliferating (Young, 2009). The study of love is new and forthcoming. Think about it: years ago, we did not have the technology we do today to explore such areas of science. Much of what we know about the neurobiology behind love is derived from imaging techniques and experimental studies. It is a game of estimating, evaluating, looking, and theorizing (Zeki, 2007). We can now look at what the brain in love looks like through new technology. Researchers use EEG (electroencephalograph), CAT (computed axial tomography), X-Ray (electromagnetic radiation), PET (positron emission tomography), SPECT (single-photon emission computed tomography), MRI (magnetic resonance imaging), fMRI (functional magnetic resonance imaging), MEG (magnetoencephalography), and DTI (diffusion tensor imaging) to study love in the brain (Horstman, 2012). Each of these tools is used in some way or another to investigate the actions and reactions in the brain. Technology has been able to narrow down the mechanisms and neural correlates in our brain to connect activity to actions and feelings, thereby hypothesizing that there is meaning there (Horstman, 2012). At times these techniques are used alone or in combination during research studies. Researchers have been able to identify the locations in which love alters the brain's activity through such tools (Cacioppo et al., 2012).

Technology is not the only way in which love is researched, as love still displays as a feeling not just the representation of neurons firing. Researchers may directly ask individuals with interviews, which can be subjective. They can conduct observations with animals or people. Laboratory tests can be conducted measuring bodily tissue and fluids as well. Humans produce neurochemicals and hormones that correlate to certain feelings such as stress and love, which gives researchers some insight (Horstman, 2012). When done on individuals, interviews or self-reports are conducted on participants who are deeply in love. The participants are shown stimuli related to their loved one as well as a control target such as a friend where brain activity should be distinctly different. Chemical and physiological reactions are examined during these studies. These experiments are then compared against people who are not in love, thus researchers find the differences between the reactions and activity of those in love versus those not in love (Clark-Polner & Clark, 2012).

As we learn about love in the brain, what is love? Some might think this is easy to explain, but as it is not simply within the definitions portion of this thesis, it is apparent that it is not. In no way is love easy to define. Different people view love differently and it depends on the contexts in which it is used, thus there are countless interpretations of it. Love has been called all sorts of things from “exhilarating, but also as involving a sense of calmness and security” and at times “wonderful, but the same relationship may also cause pain” (Clark-Polner & Clark, 2012).

Love has existed since human development started as mammals began adapting more meaning to their relationships (Francesco & Cervone, 2014). Neuroscientists specifically propose that love is a basic need and thus humans find pleasure in it (Horstman, 2012). Romantic love is an extremely rewarding experience that has biological, neural, and evolutionary bases (Zeki, 2007). As the brain is formed to protect the body, it tells us how to further increase our ability to survive and pass those advantageous genes. Similar to Darwin's theory on Natural Selection, our brain has evolved to follow the same sort of mechanisms. The theory goes that evolutionarily, love began as a way for men to ensure offspring were his and for women it was to keep the male to care for the offspring (Horstman, 2012).

Parental love is one of the most essential relationships for developing human children as humans are not able to care for themselves from birth like some other animals are able to do. This is what tends to set the stage for how we love in the future, though it is not set in stone. There are a lot of mysteries surrounding this idea of love, but there is no question about our desire to be loved (Horstman, 2012). Our question is thus related to what happens after that love is conceived. Biologically and emotionally "we crave the comfort of others…[and] people will kill, die, starve, and commit crimes for love" (Horstman, 2012).

At some point in evolution love arose from this mate preference, and it became more than just reproduction. Passionate love is a complex idea that has been defined most consistently by Stephanie Ortigue as "the existence of an emotional state involving chemical, cognitive, rewarding and goal-directed behavioral components that evoke basic and complex emotions" (Cacioppo et al., 2012). This definition holds precedence over the many other variations. A very important distinction to highlight is that love and sexual desire are not the same thing. Though one might necessitate the other depending on circumstances, the terms cannot be used interchangeably (Cacioppo et al., 2012).

Overview of Study

Secondary research of articles and books were used to obtain evidence relating to the biology of love and the studies that correspond to it. Information regarding the nature of love in the brain through the three stages was examined. Any appropriate evidence relative to that was recorded such as seen with addictive behaviors related to love. Each source was analyzed and contrasted to the others to obtain a more decisive idea of the picture of love in the brain.

Significance

Although social neuroscience and its dive into love on the brain is relatively new, the implications of it can be far reaching. The topic of love's biology is all of the following: relevant, important, interesting, and different. From the beginning to the end of life, we experience love. For example, at birth our mothers produce oxytocin; we then go on to feel paternal love, then romantic love, and heartbreak of some form which all produce this same chemical. As we all experience love in some way or another, despite not always seeing or seeking it, we can all relate to it. Whether we lack knowing how to love or love too obsessively, there is a place and a need to know about it. If we wish to explain love, we do so by studying its interactions with the brain and cultivating meaning from that (Francesco & Cervone, 2014).

As love is a large part of our lives, it is important we know about it from different spheres of influence, not just psychology. Seeing how love acts in the brain shows us how embedded it truly is and why we are hardwired for love and relationships. A sneak peek into the research indicates that love is an impending factor in one's health. Having healthy love in your life helps lower your chances of dementia and cardiovascular issues, while the absence of love can increase one's chances of health complications (Horstman, 2012). In the spirit of this literature, answers shall wait until we learn about what can happen when you lose love. The point is, we all want to be healthy and much of that begins with learning about love.

Definitions

- *EEG (electroencephalograph)*: electrical impulses are recorded from electrodes placed on a person's scalp (Horstman, 2012).
- *fMRI (functional magnetic resonance imaging) scans*: creates images of the brain detecting functions, anatomy, activity, and abnormalities in the brain (Horstman, 2012).
- *Social neuroscience*: is defined as "the study of how genes, chemicals, and brain areas contribute to social behavior" (Kalat, 2018).

Limitations

There are a few things to remember about the underlying basis of this study. The study of love in relation to the brain is a new field of study as it is no easy subject to study and some skepticism around the neural basis of love still exists (Cacioppo, 2022). Not every answer has been determined in this scientific pursuit of love. For instance, though love does seem to reduce stress and aid health, we do not know what the data exactly means for applicable knowledge in all areas (Esch & Stefano, 2005). The "'ingredients' of the love phenomenon" are just getting dug into (Esch & Stefano, 2005). The biology and neural basis behind love has only recently hit the foreground for study in research. The implications of the research are still speculative as scientists are just beginning.

Other domains such as psychology have studied love for centuries, but the neurobiological take is different (Esch & Stefano, 2005). Scientists warn that "knowledge on the neurobiology of love has yet to evolve" (Esch & Stefano, 2005). Though neuroscientists have not been able to determine the specifics of the brain and love's relationship, they are gaining a better understanding of the brain's activities related to this concept (Horstman, 2012). While advancements have been made, it is still new so no rash conclusions should be made necessarily. It is unclear whether specific parts of the brain are active during experiences of love that directly correlates with a meaning or if there is more going on. It does not always mean cause and effect. Neuroscientists "are still trying to figure out much of what goes on between your ears" (Horstman, 2012).

Besides not having an entire map of the neurobiology behind love, this research in general suffered some consequences mainly because of its short time frame. It is difficult to conduct an in-depth evaluation of the secondary sources that are out there. With dozens of studies and literary reviews on this topic, fifteen weeks is a minuscule time frame to handpick each one. I was limited to only skimming the first few pages of my searches as roughly seven thousand could not be scanned by me alone. Also important to note is the fact that with only being supplied Anna Maria databases, a lot of the information was not available. Often, articles would appear that focused on the narrow topic needed but without access there was no way to gather that data. With limited sources and time, the plethora of information was constricted.

Chapter 2: Methodologies

For this thesis research articles and books were read and synthesized to comprise an analysis of what love does to the brain through the phases of falling in love, being in love, and falling out of love. The databases used were Gale in Context: Science, SocINDEX with Full Text, Gale Onefile Psychology, PubMed Central (PMC), and Google Scholar. All books except two were found through looking at books written by academic scholars that were in the bookstore. One exception was found while reading an article review about a particular book. The other was found through my advisor, Robert Pijewski, as he taught his neuropsychology course with it, which was the inspiration for the whole thesis.

While going through these sources search terms such as “love,” “biology,” “neuroscience,” “breakup,” “brain,” “heartbreak,” “biology of love,” and “social neuroscience” were included in different combinations (See Appendix Figure 2: Methods Chart). Exclusion criteria included any articles before 2000, those not in English, those not full text by Anna Maria College’s descriptions, and those not peer-reviewed. Thus, only articles after 2000, full text, peer reviewed, and in English were reviewed. There were no strict exclusions on sample size as this topic is new and some data can be limited.

The initial search yielded 66,188 results but after exclusion information was used, 58,952 articles were cut out. The remaining number was 7,236 articles. The first few pages of those 7,236 articles were then skimmed by title and year. Only 15 articles were corresponding to my topic. From those 15 articles, a few of their references proved useful as 5 more articles were gathered from here for further research. From the databases, 20 articles were gathered and 2 books were found from recommendations and popular books. These 22 sources were included in this literature review.

The articles and books were critically analyzed and compared in relation to one other and the overall topic of the brain in love. A benefit of this research methodology was that the databases helped narrow down the more specific topic I was to find in my thesis as much of it was scientifically based; there was a broad range of articles and books available by scholarly sources. A pitfall of this methodology was that there was a lot of digging as narrowing articles down came more from peeking at articles and sifting through them. It took a lot of trial and error finding the right key terms and often once an article was found in relation, the references there proved to be the most direct. Another issue was that when finding appropriate articles, often the most useful ones were often unavailable.

Chapter 3: Results

As new technologies have risen to study love in the brain, social neuroscientists hope to determine what areas and chemicals in the brain associate with specific behaviors and emotions seen during love. Technology such as fMRI scans "allow scientists to see brain activity in real-time in a live, thinking, feeling, loving (or sexually excited) brain" (Horstman, 2012). The question is what happens to your brain when it is in romantic love? What does romantic love look like in all its stages including falling in love, being in love, and experiencing heartbreak?

Since love comes with an array of emotions that have biological standings, we shall flip through its pages. The first step is to investigate falling in love through brain mechanisms and behavior. Then we will see what it is like being fully immersed in love and what it does to the brain. The last stage of heartbreak will be seen as it has detrimental health effects.

Falling in Love

Carey has compared new love to a mental illness, "a blend of mania, dementia, and obsession that cuts people off from friends and family and prints out-of-character behavior—compulsive phone calling, serenades, yelling from rooftops—that could almost be mistaken for psychosis" (Carey, 2005). Biology begins by playing a role in whom someone falls in love with. Hormones in the autonomic nervous system (ANS) and central nervous system (CNS) increase and decrease dramatically during this time like a literal roller coaster so that healthy relationships can thrive. The act of falling in love can make us feel euphoric and out of this world.

Scientists speculate that we are essentially primed to seek certain types of love, meaning obsessive love patterns may be the result of childhood experiences. During the early stages of love, the lover often idolizes their lover and sees them as unique (Fisher, 2000). Such an experience is related to the fact that one cannot feel romantically for more than one person, although some see controversy in this, scientists believe it to be true (Fisher, 2000). When we begin falling in love, our brain releases multiple neurotransmitters and chemicals to evoke specific reactions. The beginnings of love feel good and are euphoric.

This act of falling in love kickstarts the ventral tegmental area (VTA) which is ironically shaped like a heart (Cacioppo, 2022). This area stimulates dopamine release into the reward circuit of the brain. Physiologically, a number of processes occur including an increase in heart rate, your extremities feel warm, your face becomes flush, your pupils dilate, and you increase the release of stored glucose to increase energy production (Cacioppo, 2022). Early experiences relate to the flush of saturated dopamine in the brain's central nervous system (CNS) (Fisher, 2000). The mesolimbic dopamine system in the central nervous system (CNS) grasps the most attention for its role in motivation, especially the pleasurable and rewarding behaviors (Esch & Stefano, 2005). Not only do these early feelings relate to emotion, but they also compare to goal-oriented motivation and attention (Fisher, 2000).

Dopamine regulates emotional and motivational states and thereby plays a crucial role in the states associated with falling in love. For instance, diarrhea can be linked to the increased dopamine release when falling in love as there is a psychosomatic connection (Esch & Stefano, 2005). As Dr. Cacioppo discussed the meeting with her husband through a biological lens, she “felt euphoria—from the rush of dopamine” and “blushed–a sign of adrenaline” (Reese, 2022). Dopamine is a prominent force in the feelings of love and so is adrenaline.

When we fall in love, we are also often in the so-called “honeymoon phase” and biologically this is because of the release and activation of those euphoric neurotransmitters, namely dopamine and adrenaline (Reese, 2022). Adrenaline, which is produced by our adrenal glands, fuels that exciting flow of feelings as it keeps us alert and attentive, a key biological feature of our flight-or-fight reflex, but also in non-stressful situations as well (Horstman, 2012).

This period also consists of over-attentive behavior towards the individual's positive qualities. As mentioned earlier, we begin seeing this individual as unique. One often neglects to look at the negative qualities found in the person. Specific events and material objects may also become associated with the person. These feelings and memory enhancements relate to the distribution of dopamine and adrenaline in the brain's central nervous system (CNS) (Fisher, 2000).

Other stress hormones, such as the primary stress hormone cortisol are also elevated during the beginning stages of romantic relationships as your body is going through something new (Verhallen et al., 2021). Chemicals such as these are evident in high-stress situations as a normal physiological reaction. Have you ever noticed how stressed you are when beginning a relationship? In studies of females, high cortisol levels along with low follicle stimulating hormone (FSH) levels indicate signs of stress because of the new social situation (Esch & Stefano, 2005).

The new social situation also creates some odd behaviors as a result of a special system. As Cacciopo described, she and her husband John began acting similarly to one another when they met as the brain's mirror neuron system began taking shape (Cacioppo, 2022). Mirror neurons play a crucial role in our human connections of love as they allow us to mimic and model responses we gather from others. As they got closer physically to each other, this was a sign that the mirror neuron system was working (Reese, 2022). Mirror neurons allow us to literally experience what others do and feel (Horstman, 2012).

Mirror neurons also evaluate how we look at intent which is a building block to relationships. Mirror neurons are found in the premotor cortex, inferior parietal areas, the medial temporal cortex, and the insula (Horstman, 2012). Parietal areas relate to perception and movements while the medial temporal cortex and the insula relate to how we understand other people's feelings and express language (Horstman, 2012). There is also this contagion effect that is created by the mirror neuron system. Scientists have developed theories regarding the connections between mirror neurons and behavior. They suggest that this may explain "why fat people have fat friends, and happy people have happy friends" (Horstman, 2012).

While eye contact might stimulate the mirror neuron system, physical touch like cuddling releases oxytocin (Cacioppo, 2022). Oxytocin is also essential to love as it is present throughout each stage (Esch & Stefano, 2005). Oxytocin is known as the cuddle hormone and it is released in nursing mothers, newborns, and following an orgasm. Many of the hormones involved between mother and child are also present during romantic love (Esch & Stefano, 2005). Despite seeming like a mainly female hormone, it is also found in men. Oxytocin supports love and it is the "hormone of love, trust, and attachment and is involved in every kind of human and mammal bonding" (Horstman, 2012). Often more necessary later, but also given early in a relationship, oxytocin aids in forming trust and nurturing loyalty.

There is evidence that oxytocin and its similar chemical, vasopressin play a role in reward systems as well. Both chemicals are linked to dopamine, the reward chemical in the brain. There are however a few differences between these two chemicals. Oxytocin is released during mild stress, care of babies, and helps stabilize romantic relationships through support and tenderness (Acevedo et al., 2020). Vasopressin is related to the behaviors necessary to protect a partner such as with vigilance and mobilization (Acevedo et al., 2020). Vasopressin and oxytocin work together to create your ideal image of a partner and promote pair bonding. Dopamine also aids this interaction of pair bonding as research has found it to be elevated during early and long lasting love (Acevedo et al., 2020).

Pair bonding and love are still closely aligned with the chemicals oxytocin and vasopressin. For oxytocin, bonds are often made through the brain dopamine reward systems. These hormones together play an immense role in determining what kind of partner someone wants to be with as found through prairie vole and sheep studies. Studies on prairie voles found that when injected with oxytocin and vasopressin, the voles remained more faithful and monogamous than without the chemicals (Francesco & Cervone, 2014). Similarly, through staining the hypothalamus in voles showing no social attachments, their brains had lower vasopressin levels (Kalat, 2018). In a study of sheep it was ascertained that the odor built because of oxytocin and vasopressin also relates to the reward part of meeting a partner. Visually, mothers of baby sheep become more maternal as oxytocin is released when the baby is born. If the gene for these chemicals is no longer available, forming a profile and connection becomes difficult (Zeki, 2007).

As we saw, dopamine regulates our ability to fall in love in many ways. Another neurotransmitter we have not yet considered is serotonin. The activity of serotonin is also involved, but not in the ways you might think (Sternberg, 2014). Increases in dopamine relate to decreases in serotonin which regulates one's emotions and appetite (Zeki, 2007). Since there is a serotonin deficiency, falling in love is often correlated to disorders defined by low serotonin levels. For instance, anxiety, stress, and intrusive thoughts are quite common (Francesco & Cervone, 2014). Once these behaviors and mannerisms begin to take place, obsession and intrusive thinking may begin to form. It is proposed that low serotonin levels relate to such ways of thinking during love.

The love-possessed experience is associated with "psychophysiological responses including exhilaration, euphoria, increased energy, sleeplessness, loss of appetite, trembling, a pounding heart, and accelerated breathing…anxiety, panic, and/or/ fear…mood swings" (Fisher, 2000). At times, it can feel obsessive, and you may only find yourself thinking of the one you love. Blood tests of people in love show similar and lower levels of serotonin that is seen in obsessive-compulsive disorders, anxiety, and depression. Low levels of serotonin are linked with depression and obsession while too much is linked with a decrease in sexual desire (Horstman, 2012). Thus, love reminds us of a rollercoaster of emotions with feelings that do have a biological precedent.

In Love

The early stages of romantic love demand a grave amount of attention from our metabolism and disrupt our normal function. When in love, the beginning stages appear similar to obsession but this eventually reduces with time (Sternberg, 2014). Our genes determine the baseline levels in our brain of chemicals and neurotransmitters in our brains; love disrupts these distributions. For instance, endorphins are released in high volumes during love. These chemicals assist in the reduction of pain and work to increase pleasure, and they can be described as "your body's natural narcotics" (Horstman, 2012). However, this is not the only neuronal change in our body during love.

When we are fully immersed in love, experiences feel like the reaction of "biological fireworks" as our heart rate and levels of oxytocin continue to increase (Reese, 2022). Oxytocin influences how we love and how we are loved by others (Shih et al., 2022). Often referred to as the "love-enhancing or love-magnifying hormone," studies indicate that oxytocin increases already standing love and trust for an individual, but it does not magically create love out of nowhere (Kalat, 2018).

Safety is achieved through building bonds and attachments with others. Oxytocin fuels commitment along with vasopressin as they work to equal out the intense effects of testosterone, adrenaline, and dopamine (Horstman, 2012). Oxytocin acts on its receptors in the ventral tegmental area (VTA). Oxytocin and vasopressin are essential for the maintenance of social bonding and the acquisition of memory and learning during love (Zeki, 2007).

Dopamine is another chemical that continues playing a role, specifically in subcortical areas of the brain (Cacioppo et al., 2012). Dopamine "provides the over-the-moon high that rivals heroin in its orgasmic and addictive kick…the fire in your fireworks" (Horstman, 2012). The release of dopamine is associated with euphoria, decreased appetite, extreme activity and mental activity, delayed fatigue, a lower need for sleep, fear state, anxiety, and panic (Fisher, 2000). Understandably, it makes sense that many of these feelings and changes in behavior are associated with love. Dopaminergic neurons in the ventral tegmental area (VTA) of the brain influence motivation and reward behaviors. Evidence suggests that the ventral tegmental area (VTA) regulates cognitive and reward-based behaviors especially those relating to love (Shih et al., 2022).

The dopamine reward system works with hormones such as oxytocin and vasopressin. This combination is what makes love feel and look rewarding. Oxytocin and vasopressin are vital to the understanding social cues (Francesco & Cervone, 2014). Dopamine works to activate the learning and habituation of reinforcements and rewards. As these systems work together, pair bonds are formed where we often see the tendency to like a specific type of partner or in return to the same partner. Such dopaminergic areas aid the inner social brain network (Francesco &

Cervone, 2014). Beyond chemistry, studies reveal that the regions of the brain associated with dopamine are activated when mothers look at photos of their child and when people look at images of their lover (Young, 2009).

In one study for instance, it was found that 72% of men and 84% of women remembered the monumental situations in their relationship regarding their lover. Out of these individuals, 82% of men and 90% of women stated they tended to remember these events over and over in their heads (Fisher, 2000). Henceforth suggesting that much of our attention goes to disregarding the bad and meaningless information while more is devoted to the overtly good experiences. Such studies reveal that dopamine is again strongly influential in the experience of love because high levels of dopamine relate to high levels of attention.

It also makes sense that adrenaline is involved as high activity of this chemical in the central nervous system (CNS) relates to the remembrance of new experiences and imprinting (Fisher, 2000). Adrenaline activity increases which results in blushing which is the representation of our cheek capillaries (Reese, 2022). Another common experience of being in love is the fact that time moves fast. This is also a result of an increase in adrenaline (Cacioppo, 2022). Increased stimulation of this chemical is evident as this neurotransmitter leads to bodily symptoms such as “a pounding heart and elevated blood pressure, both of which are associated with being in love” (Sternberg, 2014).

In a recent study by Vico (2010), the behavioral effects of adrenaline are visible. Vico had a group of 30 females between the ages of 20 and 27 who were to view black-and-white pictures of faces that were in five specific categories of certain kinds of people. For instance, they were divided by loved ones and unknown people. The central and peripheral data were significantly different between the images of loved ones and the images for other categories. When looking at the images of loved ones, the participant particularly experienced a “higher heart rate, skin conductance, and zygomatic activity” (Cacioppo et al., 2012). There were also discrepancies between the groups of loved ones as such responses spiked higher in intensity in reaction to romantic love versus familial love (Cacioppo et al., 2012). Looking at a loved one produced a physical response in relation to one’s bodily function.

Serotonin is also relevant during love as it continues to decrease in activity. Serotonin “helps regulate memory, emotion, sleep, appetite, and mood, among other functions” (Horstman, 2012). As serotonin helps regulate eating and anxious ideas, we often experience over-worry and appetite changes while in love. Serotonin levels deplete, hence the presence of appetite changes, anxious thoughts, and behaviors similar to disorders (Cacioppo, 2022).

The chemical changes in the brain with oxytocin, vasopressin, dopamine, adrenaline, and serotonin aid the formation and maintenance of romantic love (Shih et al., 2022). The chemicals that are highly stimulated, along with the inhibition of serotonin work to train us to become addicted to the one we love. As the production occurs, they work to balance out our brains and behaviors (Horstman, 2012). The chemical transmissions influence the effects of love so that “it becomes a basic need, such as hunger or thirst–so powerful it can feel like an obsessive-compulsive disorder” (Horstman, 2012). In comparison, Dr. Cacciopo described romantic love as “a superpower that makes the brain thrive” (Reese, 2022). The consequences if lost are extreme.

Love expansively impacts all sorts of stimulation throughout the brain regions in basic and complex areas. Both subcortical and cortical areas of the brain are highly stimulated during love which constitute the emotional brain (Zeki, 2007). Love is more than just a feeling, as many regions of the brain are influenced. Love is not just basic; as we will see, it involves complex feelings and stimulation. For instance, looking at pictures of someone who you deeply love also activates regions in the brain related to memory and cognition, such as the hippocampus (Kalat, 2018).

Romantic love shows an increase in activity in subcortical areas of the brain. Subcortical areas include parts of the striatum and nucleus accumbens, which together comprise critical regions of the reward system (Zeki, 2007). This area of the brain is also connected with euphoria and motivation, and is rich in the release of dopamine. Its specific activity is found in the ventral tegmental area, caudate nucleus, and the putamen (Cacioppo et al., 2012). During passionate love, the retrosplenial cortex, a key area for a variety of cognitive functions such as future planning, also increases in activity (Diamond & Dickenson, 2012).

Bartels and Zeki were the first to study the effects of passionate love on the brain with fMRI scans. Participants looked at a picture of their partner and then interchanged the image with pictures of friends. Bartels and Zeki then analyzed the brain scan images finding passionate love to show an increase in activity in the subcortical areas of the brain including the ventral tegmental area (VTA), caudate nucleus, and the putamen (Cacioppo et al., 2012). Such areas contain dopamine and oxytocin receptors meaning they are rich in these chemicals (Shih et al., 2022).

Aron and his colleagues also found an increase of activity in the ventral tegmental area (VTA) and the right of the caudate nucleus (Diamond & Dickenson, 2012). Ortigue and his colleagues later supported Aron's work as they found the caudate nucleus and the ventral tegmental area (VTA) played a key role in love. They reflected along with Arons's idea that romantic love is "a dopaminergically-mediated motivational state" as the one you love often becomes one with your concept of self and representation (Diamond & Dickenson, 2012).

Similarly to drugs, romantic love activates the dopamine filled reward system (Brewer, 2018). To see how all of these prominent studies are laid out in a more manageable format, see Figure 3 (Cacioppo et al., 2012). Be aware that it does also look into maternal love, but this is to show the distinctions between the two types of love.

The ventral tegmental area (VTA) contains a lot of cells producing dopamine, some of which are released to the caudate nucleus. This area is also part of the reward system in the brain meaning it is related to motivation, pleasure, and arousal (Sternberg, 2014). This area is essential for love and for feelings of desire, reward, and the decision-making processes (Shih et al., 2022). Romantic love is highly linked to activity in bilateral ventral tegmental areas (VTA), which correlates to the natural reward we gravitate from human relations because of its connections to the brain's reward system (Shih et al., 2022).

As it is bilateral, the hemispheres show distinct differences because each side of this brain region regulates different functions. We see the “right VTA associated with the behavior of ‘wanting’ and the left VTA associated more with ‘liking’” (Shih et al., 2022). This means that there are both wanting and liking behaviors present during love. In comparison, for maternal love there is only left hemispheric activation so liking is the only feeling.

The retrosplenial cortex, which is in the cortex and subcortex, is related to episodic memory and future planning (Diamond & Dickenson, 2012). The putamen and caudate nucleus relate to motivation and reward processes. The caudate nucleus is also related to goal-oriented behaviors (Sternberg, 2014). The caudate nucleus and putamen are some of the most common areas of the brain stimulated during positive and negative emotions (Bartels & Zeki, 2000). The activity in the caudate nucleus and putamen is comparable to localized dopamine release in the striatum from video gaming, though more research is necessary on this topic.

Love also activates cortical areas of the brain, including the precentral gyrus, occipital cortex, superior temporal gyrus, and structures involved in higher-order thinking (Cacioppo et al., 2012). Other areas include the medial insula, anterior cingulate, hypothalamus, and hippocampus (Zeki, 2007). The insula and the anterior cingulate cortex are linked to emotion and insula activity is found to be more prominent especially in women (Cacioppo, 2022) The insula regulates a lot of different emotional functions and abnormalities can result in deficiencies of visual information interpretation. Negative emotional situations are related to the anterior insula. It was also found that "attractiveness of unfamiliar faces was reported to correlate positively with blood flow in the left insula" (Bartels & Zeki, 2000). Meanwhile, the anterior cingulate cortex regulates emotional functions and many emotions. These can range from happy feelings to attentiveness of one's state of mind and others. The hypothalamus is active in romantic love but not maternal love, suggesting that this is the reason for the erotic behavior (Zeki, 2007).

Locations in the brain that are deactivated are also important, Bartels and Zeki find that the balance of activation and deactivation may be dictated by the nature and strength of the emotion itself (Bartels & Zeki, 2000). Areas deactivated in the cortex include the right locations of the prefrontal cortex, parietal lobe, and middle temporal cortex, and the posterior cingulate gyrus and medial prefrontal cortex. In the subcortex, the amygdala, an important area for fear, is deactivated (Bartels & Zeki, 2000). Areas in the occipital lobe and fusiform gyrus that contribute to facial attention were neutral as they were neither stimulated nor deactivated (Bartels & Zeki, 2000).

Aron and his colleagues found that in studies done with humans in love, activity in the amygdala was decreased (Diamond & Dickenson, 2012). Similarly, in Bartels and Zeki's study, love was found to deactivate the amygdala and medial prefrontal cortex, which are involved in judgment and negative emotions (Shih et al., 2022). Since the amygdala, also known as the fear circuit, is deactivated it implies a decreased sense of fear. As the frontal cortex is deactivated this suggests a lack of judgment and assessment. The parietal and temporal lobes deactivation suggests our avoidance to critically assess the ones we love as these areas are related to negative emotions (Zeki, 2007).

Heartbreak

All of this wild activity begins to settle no matter if the couple remains intact or breaks up (Carey, 2005). Dr. Helen Fisher stated when you are in love '"it's overwhelming, you're out of control, your irrational…And when rejected, some people contemplate stalking, homicide, [or] suicide"' (Carey, 2005). Studies have shown that loosing love has led to rejection, violence, and even suicide (Horstman, 2012). If the love ends in a breakup or some other cut-off, individuals may experience a flat affect or become depressed (Fisher, 2000). Evidence suggests that losing love, whether from breaking up or death, can have severe consequences. So what can happen if that love is stripped from you?

Helen Fisher evaluated a study by Rutgers University from 2006 to explain how there are two main stages following a breakup no matter the cause. The first is the protest stage where rejection is observed as people try to win the other back. Individuals often try to dissect the relationship in obsessive ways to figure out how to get it back (Horstman, 2012). Such reactions can become embarrassing, aggressive, and dramatic. Biologically, this stage is seen by "unusually heightened, even frantic, activity of dopamine and norepinephrine receptors in the brain, which has the effect of pronounced alertness" (Horstman, 2012).

When entering the despair stage, dopamine-producing neurons in the midbrain decrease their activity which correlates with lethargy, despondency, and depression (Horstman, 2012). If one's efforts in this stage do not work, the second stage of heartbreak or resignation/despair occurs. When all options have been resorted to, the individual eventually must return to feelings of loneliness and hopelessness. At times the old protest stage ideas may return, but for the most part people wallow in their sadness and defeat. This stage can look a lot like the withdrawal from drugs as the process of love almost mirrors drug abuse with the spikes and sudden losses of dopamine production (Horstman, 2012).

The feelings of loneliness which are the opposite of love, can have detrimental effects on an individual's physical and mental well-being. The brain will actually send signals necessitating the need for social interactions (Reese, 2022). These internal reactions are evident externally, such as the experience of being thirsty. Though the consequences go deeper than this too. We have seen people go mad in solitary confinement, or even die of loneliness or the emotional blow of a broken heart (Horstman, 2012)**.**

Without love, humans do not fend very well. A meta-analysis in 2010 of 148 studies evaluated how and why people may experience death. The top factor was found to be loneliness, thereby suggesting that "a lack of relationships can be as deadly as well-established risk factors for death such as smoking and alcohol, and it is even greater than other risk factors such as obesity" (Horstman, 2012). Other studies have indicated that lonely people have an increased risk for sickness, depression, earlier death, and memory loss. The opposite is true for people with loving relationships in their lives as they may have higher rates of longevity and balanced health (Horstman, 2012).

Helen Fisher further explained how some people may even die from a broken heart which may be caused by their depression resulting in heart attacks or strokes. One such condition, the widowhood effect, where a surviving spouse dies soon after the death of their mate was supported by a study from St. Andrews University in Scotland. Based on data from 58,685 married men and 58,415 married women who were of perfect health, it was found that the remaining spouse had an increased risk of death. Either on the same day or within ten days after the death of a spouse, 40% of widowers and 26% of widows died (Horstman, 2012). Scientists studying the connections between mirror neurons and behavior propose that these neurons may be why "long-time spouses often die soon after the death of a loved one—the so-called widowhood effect" (Horstman, 2012).

The other such condition, broken heart syndrome, also known as stress cardiomyopathy is another phenomenon associated with dying related to a broken heart. It is when cardiac arrest occurs in healthy people as a result of trauma. The cause is clearly emotional while the effect is physical (Horstman, 2012). After Dr. Cacciopo's husband died, she said that she experienced psychological and physical pain as her heart burned for weeks and she lost an extreme amount of weight. The twenty-four-hour period after a loved one dies is related to a 21 to 28 percent higher heart attack risk (Cacioppo, 2022). Stress hormones such as adrenaline and cortisol directly influence the function of one's heart. People with heart complications or postmenopausal women are the most likely to experience this.

After a breakup, brain scans indicate the areas linked to love such as the subcortical and cortical areas are still high, sometimes even higher than before. Dr. Fisher noted this concept as the "frustration-attraction" as the feelings seem to increase (Carey, 2005). Fisher continued her research using fMRI studies to evaluate the regions of the brain during heartbreak. She found that even after despair hits, the nucleus accumbens, a structure involved in the reward system, still was stimulated when looking at an image of their ex. Areas relating to obsessive-compulsive thoughts, anger, and stress were stimulated during this time thinking about the lost love. The stress brain areas that were ignited during this time related to areas of the brain involved with cocaine addiction like the ventral tegmental area (VTA) (Horstman, 2012). Other areas such as the amygdala are overactive as well (Cacioppo, 2022).

When we go through a heartbreak the connections from the anterior cingulate cortex which regulates emotions, increase its response to the vagus nerve, relaying the information. When too much information is being relayed to the vagus nerve, we experience bodily reactions such as nausea and increased heart rate (Horstman, 2012). Your emotional brain takes over for your thinking brain and the hormones and chemicals related to love operate chaotically. During this experience “your cortisol stress hormones rise, your serotonin levels sink, and your dopamine levels see-saw and then plummet” (Horstman, 2012). Breakups can be extremely stressful to individuals and they can even lead to symptoms of depression even if the person was healthy before.

Both depression scores and cognitive alterations rise in people experiencing a breakup. As a result of depressive symptoms, working memory appears to fade in efficiency (Verhallen et al., 2021). Often there is a deactivation in precuneus activity, which is an area that regulates working memory. Such deactivations and working memory-relating brain networks correlate to depressive symptoms. A larger sample size would be needed to prove more concrete evidence between heartbreak, depressive symptoms, and memory problems, though a link is still there.

Even when a death or breakup occurs the power of love may still hold. For reference, “you can stay connected with others even if you are physically alone in a room” (Reese, 2022). In other cases, after a breakup stimulation eventually decreases in the brain, allowing people to go searching for love with someone else. Either way, efforts have been made to relieve people of the pain that arises. Many of the efforts to relieve the damage of heartbreak come from neurological data. For instance, one suggestion is to eat dark chocolate. This advice stems from the fact that it reduces "blood pressure, stimulates endorphins, and contains the mood-leveler serotonin" (Horstman, 2012). Situations of heartbreaks mirror withdrawal symptoms from an addiction and suggestions for moving on even include modeling the twelve-step program in Alcoholics Anonymous (Horstman, 2012).

A study on prairie voles who were raised in a lab proposed another interesting idea regarding broken hearts. When the female voles mated with specific males consistently, the levels of dopamine in the nucleus accumbens increased by half. When an antagonist for dopamine was injected in the brain region, the vole no longer wanted that male. As the author proposed, "if we could do this in humans, might we be on the way toward finding a cure for broken hearts" (Sternberg, 2014)? But would curing heartbreak be a good thing or do we need to hurt and heal to be human?

Chapter 4: Discussion

Summary

This new scientific pursuit of the brain in love is an innovative one and while there could be an intense analysis regarding all types of love, romantic love is at the core of this assessment. Despite picking one area of focus, motherly and parental love influences the way one loves romantically as it lays the groundwork for the motivations and behaviors of romance (Esch & Stefano, 2005). Later abilities to create bonds and attachments often stem from the types of attachments built between infants and mothers during the sensitive period of development (Shih et al., 2022). With this said, it is not the end all be all because of neuronal plasticity. Later secure and healthy forms of attachment can modify early insecure ones, meaning the destiny of your love is not fixed because of your parents.

As there is room for change in how one loves, love can just as similarly change directions. Romance is not linear; henceforth, the process can be divided into stages. Through a systematic review of secondary research, the essence of falling in love, being in love, and experiencing a heartbreak is evaluated. Through synthesizing research on love, a more complete picture of love through these periods is visible. The good and the bad behaviors associated with love interact to create the blend we call love.

Conclusions

Romantic love ignites fireworks in the brain. As Stephanie Ortigue once said, “‘it’s all about how that network interacts,’” and the cognitive functions “‘are triggers that fully activate the love network’” (Horstman, 2012). When we usually think of love we just think of it as an emotional feeling. It is care and love for another human; we simply just feel it. However, through literary research on this topic, it is indicated that love is not just a basic emotion. Rather it is this complex state in which cognition is also a factor. We have become hardwired to love through our biology and human evolution. Love has become who we are. Life as we know it would be unrecognizable without love.

Anyhow, love has been proven to activate and deactivate specific brain regions, chemicals, and systems through all its stages (See Appendix Table 1: Chart of Stages). Studies have shown that specific chemicals and regions are activated when falling in love. This stage is related to increased release of the chemicals dopamine, adrenaline/epinephrine, cortisol, oxytocin, and vasopressin. Serotonin levels actually begin dropping during these beginning stages. Regions of the brain like the ventral tegmental area (VTA), activate especially during this time period as this is the area initiating that boost of dopamine. The mirror neuron system is also engaged as we fall in love and we see that behaviorally through modeling and mimicking patterns.

Similarly to the beginning stages of love, the actual presence of being in love involves similar chemicals. Chemicals such as dopamine, adrenaline/epinephrine, oxytocin, and vasopressin are all engaged during this period of time. The main difference is that more changes in brain regions are visible when someone is fully injected in love. There are clear subcortical and cortical areas being stimulated such as the ventral tegmental area, caudate nucleus, putamen, retrosplenial cortex, precentral gyrus, occipital cortex, superior temporal gyrus, medial insula, anterior cingulate, hippocampus, bilateral fusiform areas, and angular gyrus. There are clear indications that love is complex with emotional regions and higher-order thinking areas engaged. Areas deactivated such as the prefrontal, parietal, and middle temporal cortex, and in the posterior cingulate gyrus, medial prefrontal cortex, and amygdala are just as important to note.

The reason for this is that lacking activity in regions implies a defect in function. Stimulated functions are just as essential as destimulated ones.

The last stage of heartbreak can also be seen through biology and it has dangerous health effects. Activity in regions of the brain corresponding to love is still high during a breakup or heartbreak of some form. For instance, the nucleus accumbens and the ventral tegmental area (VTA) still produce activity. Other areas jumped in activity such as the anterior cingulate cortex. As for chemicals related to love, their activity is still influenced just not in the same way. Cortisol and norepinephrine/noradrenaline continue rising higher than seen with love, serotonin drops even more, and dopamine remains high for a while but eventually drops dramatically all of which oppose love's neural actions.

Also important to note about heartbreak is the fact that depression scores increase and cognitive impacts such as working memory deficits rise. Despite not searching for this information, the unintended findings dive into just how deep love can damage the brain physically. Along the lines of what harm love can produce, significant studies on the widowhood effect and broken heart syndrome were found as people can actually die from losing the love in their life. Since data drove the analysis here, resolutions for heartbreak were also found through neuroscientific data, dark chocolate and acetaminophen can help.

All in all, the research indicates why universally we fall in love, stay in love, and how heartbreak can break us on the neurological level. It might sound like nonsense and gibberish. You might even be asking yourself, why does any of this matter? It matters because we can learn why we crave love past just the emotional sense of wanting love, we can see that love is more complex and engaging than we ever knew. Such findings and studies can be incorporated into therapy and inevitably we can learn how to build healthier relationships, brains, behaviors, and bodies. Love can be strenuous to keep, difficult to let drift away, and physically and psychologically impactful to lose. Learning about love can help us reduce stress and anxiety so that in the long run we can live a healthier and happier life. There is perhaps “no better way of realizing our brain’s full cognitive potential, than by being in love” (Cacioppo, 2022).

Limitations

To people not in the science field, a lot of the words within this paper might appear to be meaningless jargon. However, in neuroscience it is about the function of such brain areas. For instance, remember how love deactivates the amygdala? That one change alters an individual's whole conception and reaction to fear. The impacts on the brain impact behavior as well. With this said, a lot of these studies are speculative and while there may be correlations, they do not imply causation. Something to be very wary about when learning about the brain in love is that the research is still very early. More research and studies need to be done to truly associate points A to B. The chemicals and regions have been determined, but the meaning of those connections has only lightly been touched upon.

While this paper gives an overview of the basics of the science behind love, this is just it, it is a basic overview. This research is new, but this paper could extend over hundreds of pages. There is still a wide array of information on this topic. With more than fifteen weeks to work on this project, the wealth of knowledge and along with all of the articles could have been explored. The intersections between love, lust, trust, sexual desire, and other types of love could have been discussed for instance. A broader characteristic of love could have been looked into with more time. More time may have also allowed a new study to be created by me. Though this would have been a whole process of its own as brain studies are not easy and IRB is not a quick system. As a lot of the studies done on love are evaluated in the same manner, much of the research is already laid out. Other research platforms could have also been used as a lot of the articles found were not available through Anna Maria College's database platform.

Recommendations for Future Research

The investigation into love could really go on forever. My original inspiration for this paper came from a short essay I wrote in a neuropsychology class as I wanted to keep the topic going. I wanted to incorporate more work and more evaluations on the topic but I did not have the time. Another semester has been devoted to the biological study of love, and still, it feels unfinished. The study of love in the scientific direction can go in more ways than one. For instance, we have seen how love has been compared to that of a drug. Researchers propose that "rather than the cause of addiction, perhaps love is the drug for treating addiction" (Hostetler & Ryabinin, 2012). We might also dive into what it is like not to experience love. It is clear that there are so many directions this work could take someone.

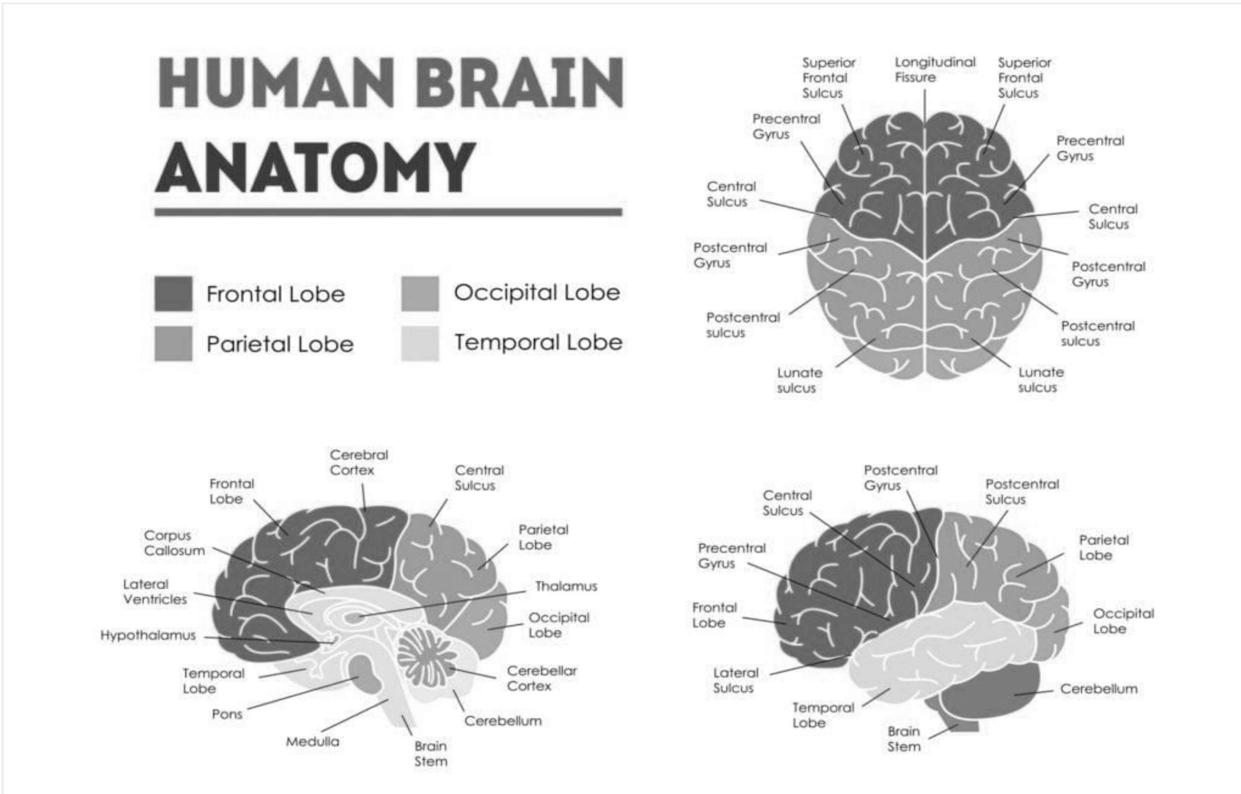
In the spirit of my own literature review, an article stood out to me that could also be a new way to take this topic. The article elaborated on the importance and implications of mindful awareness. Mindful awareness "appears to promote neural plasticity, implying that practicing meditation can actually change the structure of the brain" (Snyder et al., 2012). It was found that mindfulness influences similar areas to ones impacted by relationships. For instance, the mirror neuron system is associated with this, as this system was mentioned in our investigation of love we know it connects. Practicing mindfulness in early relationship situations sets the path for the entire relationship outcome. One might be able to take mindfulness research and put it in romantic situations to investigate if it did indeed optimize the relationship function.

Another investigation into relationships leads us towards the more negative side of things. Despite love being a part of humanity in all standpoints ranging from evolution to psychology, there are still many instances in which criminality arises from love. For instance, roughly 25 percent of homicides in America are related to romantic relationships. There is abuse, jealousy, divorce, battering, adultery, suicide, depression, and homicide associated with love. Consequently, further investigations into love, rejection, and neuroscience may shine some light on why deviance occurs (Fisher, 2000). Also, might mindfulness connect and help this issue in any way?

This example brings us to the inevitable question of why. The biggest thing scientists can do to further their research findings associated with the biology of love is to find out why. The neural correlates and chemical reactions in our brain might sound as if it does not matter. Nonetheless, if we relate it to meaning then more people might find a place in enjoying this topic. Regions in our brains do influence our behavior as we see with lesion studies as injured areas produce effects. There is a correlation and speculation for what the amygdala not being activated during love for instance does, but what does that really mean for behavior? What do all of the biological correlations mean for the nature of love?

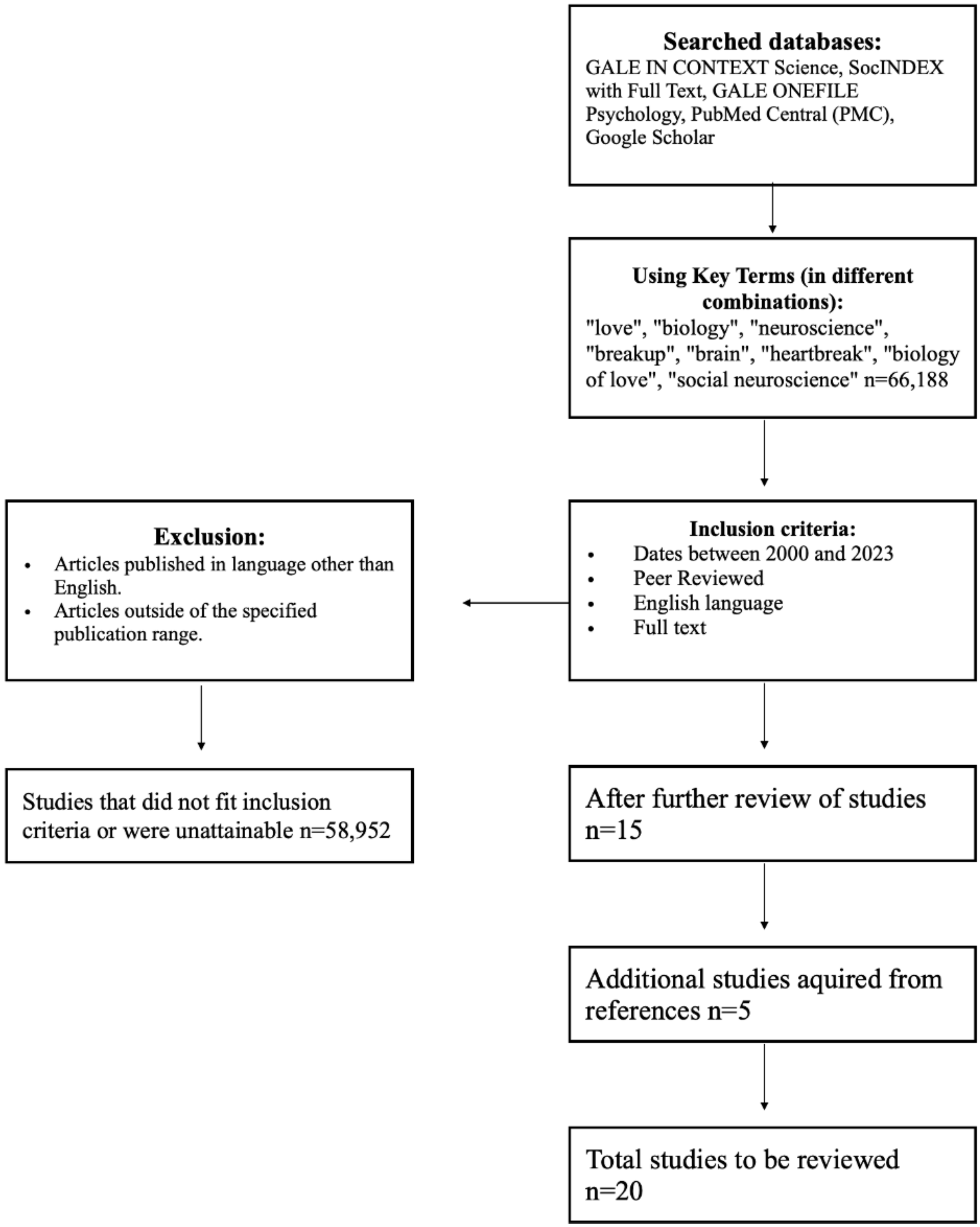
Appendix

Figure 1: Human Brain Anatomy Basics



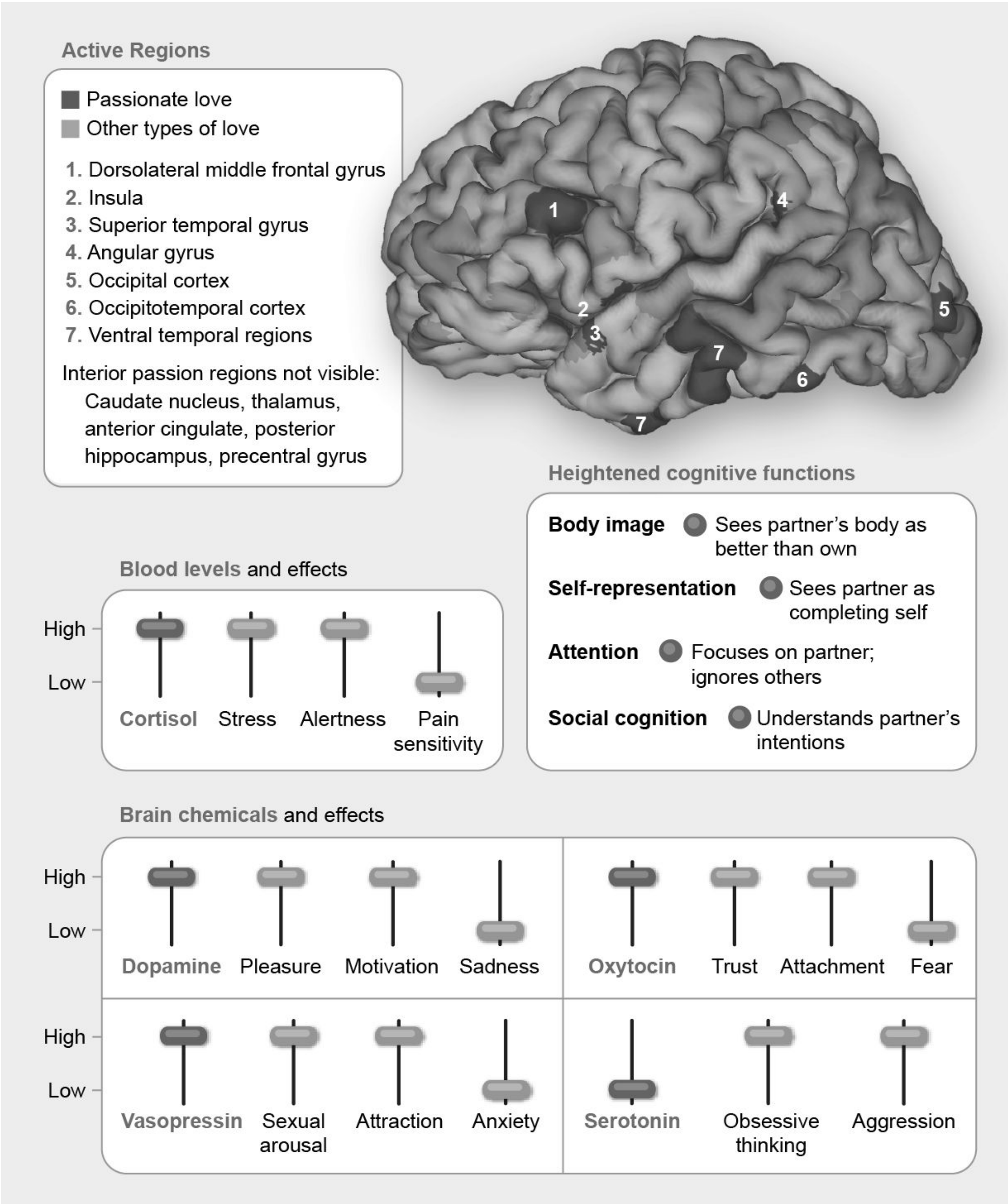
Basic structure of the brain (By, 2023).

Figure 2: Methods Chart



Methods used to survey the literature following the PRISMA Checklist.

Figure 3: Passionate Love vs Maternal Love



Pictured are the main regions of the brain and chemicals that are engaged during both maternal and passionate love (Cacioppo et al., 2012).

Table 1: Chart of Stages

Stage	Chemicals	Regions	Systems/Other
Falling in Love	cortisol, adrenaline, dopamine, oxytocin, vasopressin, and serotonin	ventral tegmental area (VTA)	mesolimbic reward system and mirror neuron system
In Love	adrenaline, dopamine, oxytocin, vasopressin, endorphins, and serotonin	ventral tegmental area (VTA), caudate nucleus, putamen, retrosplenial cortex, precentral gyrus, occipital cortex, superior temporal gyrus, medial insula, anterior cingulate cortex, hypothalamus, hippocampus, amygdala, prefrontal cortex, parietal cortex, middle temporal cortex, and posterior cingulate gyrus	mesolimbic reward system
Heartbreak	cortisol, noradrenaline*, dopamine*, and serotonin *noradrenaline sporadically high *dopamine sporadically high then drops	ventral tegmental area (VTA), nucleus accumbens, anterior cingulate cortex	mesolimbic reward system, widowhood effect, broken heart syndrome, depression symptoms, working memory

Key: increased activity and decreased activity (NOTE: colors do not mean "good" or "bad")

Depicted here are the stages of love and each category of reactions that they produce according to synthesis of the articles.

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