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Serotonergic Modulation of Socially Affiliative Behaviors in Dominant Individuals in Social Hierarchies: A Literature Review

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Abstract

This systematic literature review endeavors to investigate core neuronal issues that affect organizational psychology. It seeks to understand critical neuronal mechanisms that direct human behaviors in the area of social hierarchies. Hierarchies seem to be one of the core driving forces of human interactions, which leads towards optimal health and survival as humans. Interestingly, serotonergic interactions seem to be correlated to many of these behaviors. This systematic literature review seeks to understand if and how serotonin modulates affiliative behaviors in dominant individuals in these hierarchies. This literature review will investigate the current state of research and will suggest future areas of investigation.

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Problem Statement

Organizational psychology's raison d’être is to develop optimal organizational structures that mutually benefit all workers, managers, and consumers (*Industrial Psychology Provides Workplace Solutions*, 2013). To that end the field has created grand organizational theories, such as systems theory, contingency theory, and quantitative theory to name a few (Becker et al., 2011; Knudsen & Tsoukas, 2003; Murray & Antonakis, 2019). However, there seems to be a gap in organizational psychology research. Research moves from broad theory to productivity testing effects (Murray & Antonakis, 2019). These theoretical systems have scant analysis of the neurobiological systems that are innate to humans (Becker et al., 2011; Murray & Antonakis, 2019). The *Oxford Handbook of Organizational Theory*, a comprehensive literature review of the field of organizational theory, consisting of 619 pages of scholarly articles (Knudsen & Tsoukas, 2003), does not contain a single reference to serotonin or any other neurological process related to hierarchies. Current surveys of employee engagement, like Gallup’s 2022 Q12 employee engagement survey, of nearly 60,000 workers, shows that engagement dropped by 2% to 34% while actively disengaged employees rose to 18% (Harter, 2023). This would suggest that current organizational theories have not operationalized the mechanisms that would modulate optimal organizational behaviors broadly in society and specifically in the organizational and corporate realm (Harter, 2023). This indicates the great need for further research into this problem and a need for effort to uncover the mechanisms that lead to positive engagement in the workplace.

The emerging discipline of organizational neuroscience aims to bring new insights and previously unexplored lines of inquiry into the broader field of organizational psychology (Becker et al., 2011; Murray & Antonakis, 2019; Pareek & Satapathy, 2021). This systematic literature review seeks to address the lack of neurological processes used in forming current organizational theories by assessing the current state of understanding of neurobiological mechanisms that lead to optimal states human social organizations. Rather than using meta-theories that look at macro behaviors and theorizing what would be optimal, there is an opportunity to examine the neurobiological pathways that modulate organizational outcomes. This might lead to new insights and methodologies for further research.

Serotonin’s role in social behavior seems to be particularly significant. Serotonin and the nuclei that it projects to and modulates seem to correlate with optimizing social interactions as a species (Bubak et al., 2014; Crişan et al., 2009; Crockett et al., 2013; Kanen et al., 2021; Kiser et al., 2012; Lucki, 1998; Rogers, 2011; Schafer & Schiller, 2022; Seymour et al., 2012). The study of serotonergic processes shows promise in illuminating the understanding of optimal interactions in humans. It would be reductionistic to say that serotonin is the only system involved in this complex process in human brains (Berends et al., 2019; Carré et al., 2011; Chen & Hong, 2018; Donaldson & Young, 2008; Froemke & Young, 2021; Lefevre et al., 2017; Teed et al., 2019). Additionally, it is reductionistic to say that macro theories are unimportant in the understanding of human interactions (Becker et al., 2011). However, the study of serotonergic activity seems essential for the refinement of functional organizational theories. Understanding serotonergic processes might even play a role in how humans work together in broader ecological interactions with all living beings. This literature review will therefore investigate this correlation with the broad operation of social hierarchies which seem foundational to human survival and interactions as humanity.

Could understanding the neural mechanisms that lead to optimal groups be illuminated so that humans can interact with each other on levels that optimize neurophysiology collectively? Could understanding the individual neurobiology that creates socially affiliative, homeostatic, sustainable, organizations lead to new methods of engaging with workers in the workforce? Could organizational psychologists then succeed in guiding people in organizations to more optimal methods of interaction? Serotonin seems to be at the center of this neural mechanism. This literature review will examine how serotonergic systems might be the key to unlocking greater understanding of our fundamental programing as humanity.

Introduction

The broad focus of this review will be to examine the neurobiological pathway of serotonin, which is a neuromodulator that affects the human brain, the brains of higher primates, and the brains of mammals (Dwortz et al., 2022). Specifically, this review will explore the connection between this single neuromodulator, *serotonin*, and its relationship to dominant individuals in social hierarchies that behave in socially affiliative ways. In colloquial terms the question is: are leaders of organizations affected by high serotonin levels to promote healthy reciprocal relationships in the organizations they lead?

This literature review does not address all the neurological modalities that contribute to affiliative behaviors. The limitations of this literature review are reduced to the effect of serotonin alone due to scope, but it should not be assumed that serotonin alone modulates affiliative behavior (Miczek et al., 2002; Watanabe & Yamamoto, 2015). There are complexities beyond the scope of this literature review that require investigation. This literature review will seek to elucidate the role of serotonin primarily in socially affiliative behaviors to encourage further research and understanding of this neurotransmitter. This limitation is also due to the fact that serotonin has vast influence over social behavior (Kiser et al., 2012; Watson et al., 2009; Young & Leyton, 2001, 2002).

This literature review explores a narrow population of dominant individuals in social hierarchies. Dominant individuals are required for hierarchies to exist (Casto & Mehta, 2019; Chen Zeng et al., 2022). However, dominance requires the acquiescence of the subordinate population (Casto & Mehta, 2019; Cummins, 2005) and serotonin seems to play a role in the social learning of the subordinate individuals to that end (Collins et al., 2022; Terranova et al., 2016). This literature review also explores the current knowledge of this specific pathway of serotoninergic modulation of the creation of dominant hierarchies and, more narrowly, those that lead to socially affiliative behaviors within those hierarchies. Serotonin is theoretically associated with the modulation of stable groups called *dominance hierarchies*. Serotonin seems to modulate the creation and elevation of dominant individuals in these social constructs (Janet et al., 2022; Lahn, 2020).

While non-affiliative behaviors, like aggression, manipulation, and inequitable resource distribution exist (Ang & Manica, 2010; Glomb, 2002; Hagenbeek et al., 2016; Korzan et al., 2006; Montoya et al., 2012; Muller et al., 2021; Poulin & Boivin, 2000; Romero-Martínez et al., 2022; Sapolsky, 2005), these will not be explored in depth except as an apophatic clarification of the path that leads to affiliative behaviors. Exploration of what leads to adverse outcomes requires exploration, but it is beyond the scope of this review. It is necessary to acknowledge that these issues exist and need to be explored as well. Still, this literature review will primarily examine the narrow pathway of social affiliation that has great potential utility in leading humanity down societal organization pathways that lead to the best outcomes for society in general (King et al., 2008; Puga-Gonzalez et al., 2009).

Therefore, the goal of this literature review is to explore the serotonergic modulation of socially affiliative behaviors in dominant individuals in social hierarchies. This review will also endeavor to answer the following questions: Does serotonin modulate socially affiliative behaviors in dominant individuals in hierarchies of humans, primates, and other animals? Can it be generalized that dominance, hierarchies and serotonergic modulation are part of a coherent system that might give rise to socially affiliative behaviors? Can innate serotonergic systems be used to create optimal outcomes for human organizations for all individuals? In pursuit of the goal and to answer the questions above, this review will survey the extant literature according to the methodologies outlined below.

Methodologies Used in This Literature Review

Use of Animal Studies

There is a broad consensus that non-human primates, mammals, and humans have neurological homologies of neurological functioning and that these homologies are true of serotonin (Lickliter & Bahrick, 2000; Stoesz et al., 2013). Indeed, serotonin is a neurotransmitter that is found in most living organisms, from ameba to humans (Bamalan et al., 2022; Howell et al., 2007). While functions are complex and varied between species and even within the human brain, this literature review will use animal studies to generalize about behaviors in humans where appropriate. Preference was given to human studies, then subsequently to non-human primate studies, and finally, mammalian studies. Studies of other species are mentioned as well but make up the minority of literature selected.

Research History in this Domain

The research history related to the core question regarding the serotonergic modulation of socially affiliative behaviors in dominant individuals in social hierarchies, must be addressed. It will affect the research methods of this review's literature selection. The research has a complex relationship with human and animal populations, time, and methodologies. As with most psychological and neurological research, it starts with animal studies (Redhead & Power, 2022). Uniquely, this literature review's core question deals with qualitative and quantitative research simultaneously. Qualitative research is used to determine dominant individuals in hierarchies (Casto & Mehta, 2019). In animal field studies, qualitative studies for primates require massive observations in the field that can take years (De Waal, 2007; Sapolsky, 2005). Quantitative studies were used to measure the levels of serotonergic activity. These quantitative studies measuring serotonin were often done with invasive methods not ethical on human subjects like cerebral spinal fluid taps (Higley et al., 1996; Mehlman et al., 1994, 1995; Virkkunen et al., 1995), electrode brain stimulations, certain pharmacological interventions, and genetic manipulations (Kramarcy et al., 1984; Lewejohann et al., 2010). This animal research was done in the 1980s and 1990s, and early 2000s and achieved scientific consciousness and is still often cited in recent literature studies (Koski et al., 2015). It took some time to duplicate these studies in humans due to the invasive nature of the quantitative study of serotonin levels. Therefore, in humans, quantitative serotonergic measurements required the development of more sophisticated methodologies in humans that began to take place in the past few decades. These methodologies do not lend themselves easily to field studies as animal studies could, since they require fMRI, PET scans, pharmacological, or genetic tools. There are key studies that link the qualitative and quantitative nature of this literature review's core question. Yet there are few in-vivo human studies that accomplish all that animal studies have done to date. This led to some unique criteria in the literature selection for this review. First, the axiomatic studies done from the 1980s to 2010 are considered foundational to the question from an animal study perspective, so these studies were selected for this review. The human studies confirming the conclusions of the animal studies in human populations are more recent, and those that combine the quantitative and qualitative measurements are few. Therefore, this literature review is using a wide swath of time from 1980s to the present for study selection.

Preference was given to literature that combined both the qualitative determination of hierarchical behavior and the quantitative serotonergic data. Literature that discussed qualitative and theoretical research into hierarchies and the related mechanisms, but without quantitative research were included but was deemed as supportive literature. Additionally, literature that discussed the function of serotonin without connection to hierarchical constructs was considered supportive material as well. Some organizational theory literature was selected to clarify the need for this line of research as well.

Research was done primarily using the Mendeley database. Additionally, the reference lists of other literature reviews and empirical studies listed in the reference list below were part of the search resources used. Peer reviewed studies from respected journals were selected primarily. Some theoretical literature is selected from respected edited collections for broad theoretical consideration. Approximately 1200 articles and sources were considered and 188 were selected for this literature review (Snyder, 2019).

Definitions of Terms

It is essential to begin this literature review by defining terms as we will be using them in this review. Not all authors in this literature review or people in everyday parlance use the terms precisely in this manner, but this review will limit the semantic range of these terms for clarity's sake.

Hierarchy

A *hierarchy* is a structured population. Specifically, this population has a grading of individuals within it that is a type of numerical rank order. Those individuals with higher rank order have more access to resources and have control over the distribution of resources. The individuals of higher rank order draw the attention of the other individuals, showing them deferential behavior (Franz et al., 2015; Gutleb et al., 2018; Kappeler & Van Schaik, 2002; Lee et al., 2021; Lewis, 2022; Tiddi et al., 2012; Vervaecke et al., 2000). The hierarchies seem to be modulated instinctively and form quickly and spontaneously in a self-organizing manner (Hickey & Davidsen, 2019). Hierarchies can shift over time in size and internal definition of rank order (Lee et al., 2021; Vervaecke et al., 2000). However, they tend to resist change overall and provide stability to the individuals in the group (Ang & Manica, 2010; Hickey & Davidsen, 2019; Higley et al., 1996; Knight & Mehta, 2017). Hierarchies are theorized to form around the basic need to distribute resources that have some scarcity. Some examples of these resources are food, procreation, protection from aggression both internally and from out-group threats, the primacy of selection, and services of subordinates in the hierarchies (Akkawi et al., 2020; Fulenwider et al., 2022; Hu et al., 2015; Meloni et al., 2017; Nilsen, 2020; Smith & Codding, 2021; Strauss & Holekamp, 2019).

Rank

Rank is a linear order of the social grading system. The individual in the first rank is considered dominant and typically has the first access to resources. They will be able to influence the behaviors of others and will have more attention than others lower in the order. As rank descends access to these social advantages diminishes. Rank operates within a social hierarchy (Desmichel & Rucker, 2022; Fitzgerald et al., 2022; Griffiths et al., 2022; Leclair et al., 2021; Lerena et al., 2021; Rueger et al., 2021; Varholick et al., 2019). Rank computation in the human brain is mapped to areas of the brain called the inferior parietal sulcus which is typically used for the mathematical ranking of numbers (Chiao et al., 2009).

Dominant

Dominant is a term used to refer to an individual within the hierarchy who stands high or highest in the rank order of the hierarchy population (Dwortz et al., 2022). These individuals can become dominant by overt signaling in violent competitions, by size, by musculature, and by the production of valuable activity for the group (Desmichel & Rucker, 2022). The signals can be more subtle as well, including length of gaze, gestures, behavior displays, comportment, and physical location in the group. Other more social methods that dominance is achieved is by kinship with a dominant individual, by social alliances, or by dint of age (Akkawi et al., 2020; Desmichel & Rucker, 2022; Fulenwider et al., 2022; Hu et al., 2015; Leclair et al., 2021; Meloni et al., 2017; Smith & Codding, 2021; Strauss & Holekamp, 2019). Humans have other markers that are far more cognitively constructed and displayed. Humans that are dominant can confer dominance ranks within their hierarchies by fiat. Humans can display rank order by positions, clothing, and rituals that are far more involved than in non-human species (Brand & Mesoudi, 2019; Desmichel & Rucker, 2023). This is by no means an exhaustive list of criteria that are used to define and to code in qualitative studies of groups to determine who the dominant individuals are within a hierarchy.

Serotonin

Serotonin is a monoamine that is used in many systems of animals, including the brains of humans. Primarily it directs behavioral responses within organisms (Chamberlain et al., 1987; Kötting et al., 2013; Lee & Goto, 2018; Moskowitz et al., 2001; Young & Leyton, 2001, 2002). It is often called a neurotransmitter in its role in synaptic connections (Bamalan et al., 2022). It is additionally referred to as a neuromodulator which is a neurotransmitter that has longer-term effects on brain systems. In this role, it couples with GPC receptors that induce systemic changes on neurons that are longer lasting than a single action potential (Baez et al., 1995; Julius, 1991). Serotonin has even been demonstrated to change the regulation of DNA expression, thus giving rise to an even more profound effect on neuronal activity, behavior, mood of the individual and social decision making (Lee & Goto, 2018). In humans and primates' brains it originates in the dorsal raphe nuclei on the brain stem (Huang et al., 2019; Matthews et al., 2016; Mlinar et al., 2016) and its neuronal expression is pervasive throughout the subcortical and cortical systems. Thus, serotonin has a large area of expression in the human brain, influencing many subsystems of behavior and perception (Matthews et al., 2016; Matthews & Tye, 2019).

It is important to understand for this literature review a few details on how serotonin is measured or variably increased in a study subject. Genetically, individuals with the rh-5HTT s-variant allele have impaired serotonergic transport and therefore have lower serotonergic activity than their conspecifics in the population (Freudenberg et al., 2016; Lesch et al., 1997; Michopoulos et al., 2014; Surtees et al., 2006). These individuals were studied and compared to the non-impaired population. Serotonin levels in the brain can be measured in the cerebral spinal fluid by measuring for the serotonin metabolite 5-HIAA. This requires a spinal tap which is done under sedation and is an invasive procedure (Higley et al., 1996; Mehlman et al., 1994, 1995; Virkkunen et al., 1995). Serotonin levels can be increased pharmacologically by using selective serotonin reuptake inhibitors (SSRI) (Lorman, 2018; Masand & Gupta, 1999) or by administering tryptophan, which is a chemical building block for serotonin, which results in greater serotonin production. (Beacher et al., 2011; Bjork et al., 2000; Chamberlain et al., 1987; Colzato et al., 2013; Henry et al., 2022; Moskowitz et al., 2001a, 2001b; Moskowitz· et al., 2003; Moskowitz et al., 2011; Reuter et al., 2021; Ward et al., 2017; Wood et al., 2006; Young et al., 1985; Young & Leyton, 2002; Zamoscik et al., 2021). An fMRI can detect activity in the dorsal raphe nucleus, signaling serotonergic activity in areas of the brain that produces serotonin and begins the signaling process (Chiao et al., 2008). Therefore, these measurement methods are referenced in this literature review.

Socially Affiliative Behaviors

Socially affiliative behaviors are social behaviors that promote cooperation and provide mutual benefit between individuals. It usually involves mutually beneficial actions on the part of two individuals in a hierarchy (Jasso del Toro & Nekaris, 2019). For example, in primates, there are mutual grooming behaviors that take place or agreements to protect the children of individuals or mutual protection pacts (Garcia et al., 2018; Puga-Gonzalez et al., 2009). In humans, these can be verbal agreements to work together or they can be affirming behaviors of gaze, communication, and positive regard (Stoesz et al., 2013). Essentially these behaviors are constructive and neither individual feels threatened but rather values the engagement (Stoesz et al., 2013). Dominant individuals who successfully cultivate these types of socially affiliative behaviors often fare better than the aggressive, dominant types (Lesch, 2007). This strategy of behavior is more successful by and large in creating stable hierarchies (Ang & Manica, 2010; Hickey & Davidsen, 2019; Knight & Mehta, 2017; Morris & Vollmer, 2020). These behaviors predict the success of the hierarchy as a group and the dominant individuals within that group (King et al., 2008; Puga-Gonzalez et al., 2009). It tends to increase the access to resources for all involved in these types of behaviors (Lesch, 2007).

Theoretical Framework Used in This Literature Review

Serotonin Modulates Hierarchical Behaviors

Many of the studies that are examined in this literature review have the theoretical understanding that serotonin is one of the primary modulators of hierarchical behaviors like dominance, aggression, social learning, and social affiliation. Many of the studies sought to confirm this theoretical point of view (Chen & Hong, 2018; Grossman et al., 2022; Hofmans & van den Bos, 2022; Janet et al., 2022; Lischinsky & Lin, 2020; Matthews & Tye, 2019; Noonan et al., 2014; Olsson et al., 2020; Redhead & Power, 2022; Watanabe & Yamamoto, 2015), but it is not universally accepted (Duke et al., 2013). This review will seek to operate from and assess this theoretical perspective.

Hierarchical Behavior Systems are Preserved Due to Optimization

Another theory that is prevalent in the studies reviewed in this literature review is that the behaviors like dominance, formation of hierarchies, and social affiliation have some sort of optimal functionality for them to be preserved within the populations of humans and animals being studied. It is not assumed that this optimization is uniform for each individual, but it is functionally optimal for the group as a whole and by extension the most optimal possibility for the individuals of the hierarchy (Perret et al. 2020; Redhead & Power, 2022; Watanabe & Yamamoto, 2015).

Review of the Literature

Hierarchies

This literature review will begin by investigating how groups of individuals come together to form hierarchies. Later it will examine how individuals within these hierarchies rise to dominate them. In both instances the role of serotonergic mechanisms in the modulation of these behaviors will be examined.

Innate Nature of Hierarchical Formation. There are many species that live in social groups such as insects, birds, and especially mammals (Cronin et al., 2015; van der Kooij & Sandi, 2015). Primates are particularly prone to living in social groups (Munuera, 2018; Sapolsky, 2005). This is true of humans as well (Yamaguchi et al., 2017). These social groups are not mere gatherings of individuals, they form hierarchies (Koski et al., 2015). In 1922 Schjelderup-Ebbe first described the pecking order of chicken hierarchies, and since then hierarchies have been understood as a common social phenomenon among multiple animal taxa (De Waal, 2007). Furthermore, the formation of hierarchies seems to be an innate behavior in these species and not a behavior that is learned (Koski et al., 2015; Lee & Dugatkin, 2002). There are abundant observational studies that show that hierarchy formation is spontaneous and self-organizing. Thus, the spontaneous and self-organizing nature of the hierarchy forming behaviors would suggest the innate nature of this behavior across species (Franz et al., 2015; Gobel & Miyamoto, 2023; Hickey & Davidsen, 2019). Due to the innate nature of this behavior, it would follow that specific neuronal mechanisms are responsible for this behavior and that there might be homologies between the species that exhibit these behaviors (Brand & Mesoudi, 2019; Ligneul et al., 2017). This is valuable to understand. This literature review will further explore if the attempt to work against the innate nature of human instinctual wiring could be disadvantageous, and or impossible, if human brains seem to innately default to the hierarchical model of behavior.

Hierarchies Distribute Resources. Hierarchies have an apparent functional utility that gives a competitive advantage to the individuals and species that exhibit this behavioral tendency (Silk, 2007). Effectively hierarchies solve the problem of the distribution of limited resources (Perret et al., 2020). Typically, the resources that are affected by the hierarchy in non-human groups are food, propagation, and protection from attack (De Waal, 2007). In human hierarchies, psychological benefits are added to the aforementioned categories (Desmichel & Rucker, 2023; Gobel & Miyamoto, 2023). This distribution effect has a positive effect on those higher up the hierarchy in rank, and negatively affects the individuals at the lower ends of the hierarchy relative to the higher ranked (Sapolsky, 2005; Weinstein & Lane, 2014). However, there is some indication that being highly dominant individuals can exhibit increased cortisol and have a shorten lifespan as well (Hellhammer et al., 1997; Watanabe & Yamamoto, 2015). However, when one compares this to the survival rates of individuals without hierarchies in the same species population the isolated lower ranked individuals, outside of a hierarchy, often fall victim to poor health outcomes as well (Reissmann et al., 2021; Xia & Li, 2018). Lonely, isolated individuals that are isolated from social hierarchies also show adverse effects on immunity, tumors, and lower brain derived neurotropic factors (Begni et al., 2020; Farbstein et al., 2021; Matthews et al., 2016; Nakagawa et al., 2019; Shirenova et al., 2021; Song et al., 2021; Xia & Li, 2018). There seems to be a lack of comparison in the literature between individuals of low rank in a hierarchy versus individuals isolated without a hierarchy. Perret et al. (2020) surmise there is a benefit for individuals on the lower end of the hierarchy to remain in the hierarchy rather than merely leave the hierarchy. Their hypothesis is that hierarchy has a functional advantage for even the lower ranking individuals and thus has been preserved as a persistent behavior in humans. Their models were largely mathematical and correlated to resource production and distribution but were not corroborated in large field studies (Perret, Hart, et al., 2020; Perret, Powers, et al., 2020; Powers & Lehmann, 2014). Instinctual survival benefits inherent in the structure of hierarchies perhaps keep lower ranked individuals in hierarchical societies. This systematic literature review will further investigate if there is a neurological mechanism that keeps social species returning to the hierarchy as a behavioral norm.

Reduction in Aggression. Hierarchies have the functional advantage of providing a societal structure that reduces the need for aggressive altercation over resources (Ang & Manica, 2010; Bond & Cleare, 1997). Studies correlate a reduction in aggression as another key component of the functional outcome of hierarchies (Ferreira-Fernandes & Peça, 2022). It is speculated that the functionality of hierarchies reduces the need for aggression around resource allocation within groups as once dominance is established it does not need to be challenged often (Hobson et al., 2021; Klein et al., 2008). The learned rank order of dominance within a hierarchy reduces the need for violent challenges and exchanges whenever resources are scarce, providing positions of safety for the subordinate and dominant individuals in the hierarchy (Davis & Reyna, 2015). Violent aggression occurs less frequently, and the hierarchical group can efficiently get on with the varied tasks of everyday living and survival, thus preserving the energy of the group by greater efficiencies (De Waal, 2007; Perret, Hart, et al., 2020; Qu et al., 2017). This literature review will also examine how serotonin modulates the reduction of aggression in dominant individuals when we examine dominant individuals later in this review. The point here is to understand that the reduction of aggression is a property of hierarchies on a macro level that has a function that leads to the preservation of the hierarchy behavior (Perret, Hart, et al., 2020).

Serotonergic Modulation of Hierarchies

It is important to first examine the broad relationship of the serotonergic modulation of the social behavior of the creation of hierarchies as a meta-behavior. Hierarchy formation is made up of more acute behaviors like aggression, social affiliation, and social learning (Lesch, 2007). Serotonin’s involvement is more acutely demonstrable in the specific behaviors, like aggression, affiliation, and social learning that make up the macro-behavior of hierarchical social structuring. These details will be examined later after this first broad overview.

Serotonergic Modulation of Hierarchies in Non-Human Species

Quality research was done on several species linking the formation of hierarchies with serotonergic modulation (Best et al., 2020). Many research studies refer to it axiomatically (Best et al., 2020; Chen & Hong, 2018; Chiao, 2010; Lee & Goto, 2018; Qu et al., 2017; van der Kooij & Sandi, 2015; Wei et al., 2021), however there needs to be more research in this area broadly, as many of the more recent literature reviews refer back to studies done decades ago with a few exceptions (Ferreira-Fernandes & Peça, 2022; Watanabe & Yamamoto, 2015).

Foundational work was done by Raleigh et al. (1991). They worked with vervet monkeys that were all adult males from 12 social hierarchies with each of the hierarchies having at least three males and three females. Raleigh and his team established five observation times in the study where they would remove the dominant male from the group and would randomly treat the one of the remaining males with a pharmacological intervention to reduce serotonergic functioning or enhance their serotonergic functioning. They did this in a way that would alternate between the subjects being studied as the control and the manipulated variable. Each time the intervention was done the individual with elevated serotonin levels would become the dominant male. They had no deviation from this pattern in all their testing. This led them to infer a strong positive correlation between serotonin and the creation of hierarchies (Raleigh et al., 1991).

Noonan et al. (2014) studied a similar pattern in macaque monkeys. Using MRI scans of 25 individuals, three of whom were females, they sought to examine brain structures associated with the serotonergic system like the dorsal raphe nucleus. Through observations they ranked the individuals in their hierarchy. Noonan and team performed an fMRI scan on these individuals and found that there was a strong positive correlation between the serotonergic related nuclei and social dominance. Their findings demonstrated the serotonergic modulation of hierarchies and dominance in this species of macaque (Noonan et al., 2014).

Matthews et al. (2016) experimented with rodents. Their research was more detailed and more complex. They were able to use optogenetics to activate and inhibit the dorsal raphe nucleus of their test subjects. Their study involved times of social isolation and the monitoring of dominance and social approach behaviors. There were several variables being tested in this study. One of the generalized conclusions drawn from their data was that the dorsal raphe nucleus and serotonin do indeed play a role in the approach and dominance seeking that make up the hierarchical behaviors (Matthews et al., 2016).

Lee and Goto (2018) also experimented with rodents and social dynamics similar to hierarchies. They devised several behavioral experiments to test dominance, like food access tests and conflict tests. They used fluoxetine, which is an SSRI, to increase serotonin levels in certain test subjects to see how this would affect their behavior. Rodent society is simpler, and it is theorized that aggression is critical to dominance in these groups. When the serotonin was elevated in the test subjects, they became less dominant, less aggressive and socially obedient. Their test suggests a positive correlation between serotonin and the broader hierarchy related behaviors (Lee & Goto, 2018).

Serotonergic Modulation of Hierarchies in Humans. Human studies demonstrated the homologous serotonergic pathways active in the modulation of hierarchies within human populations (Chiao, 2010). Though humans are more difficult to study due to methodological restrictions due to ethics and invasive techniques, this is still an active research domain in human subjects. Chiao (2010) highlighted the effects of serotonin on the formation of hierarchical systems in humans. Chiao discussed many systems in the mind that relate to the perception and formation of hierarchies in human social populations. Chiao indicated an indicator of serotonergic modulation of the hierarchy behaviors in humans is the s-variant and the l-variant of the 5-HTT gene. There is a strong correlation between the l-variant, which leads to an increase in serotonin, and higher social rank in hierarchies. Whereas, the s-variant correlates to lower serotonin and depression and increased life stress (Chiao, 2010). This might indicate that some of the differences between individuals of rank are innate neurological mechanisms and not due to just sociological environmental situations.

Schafer and Schiller (2022) in their literature review claimed that hierarchies are foundational to social life and that competition is an inevitable consequence of living in large groups. They asserted that serotonin plays a critical role in the establishment of hierarchies in human social structures (Schafer & Schiller, 2022).

Janet et al. (2022) recently conducted a novel study of 32 human males. They used a reinforcing learning computer program that offered participants two different learning situations. One was a social learning situation where they were pitted against simulated competitors that the participants thought were real. They would compete and artificially lose to these simulated participants or win based on the reinforcing computer model. They were then asked to choose opponents showing the participants ability to understand their ranking in the social competition hierarchy. The second game was not against people but was a simple computer game where they made nonsocial ranking decisions. This was all done in real time inside an fMRI and PET scan. The serotonergic pathways including the dorsal raphe nucleus were examined for activity during the two game simulations. It was only during the social ranking game that the serotonergic pathways showed enhanced activity. Through statistical analysis of the data Janet et al. demonstrated a positive correlation with the serotonergic systems and hierarchical behavioral activities.

van der Kooij et al. (2015) discussed another indication of the serotonergic modulation of hierarchies in human populations. They pointed out that the SLC6A4 allele, which affects the serotonin transport and use in neurons, is a genetic marker that points to less hierarchical behaviors in humans. Interestingly, countries where there are higher hierarchical structures there are less of this variant and countries where there are more of this variant there tends to be lower incidence of hierarchical behavior. Twenty-eight countries were studied, and this correlation was statistically relevant. These indications from the SLC6A4 genetic mutation, that is unique to some populations, would indicate that serotonin plays a role in the hierarchical behavioral formation (Fischer, 2013; van der Kooij & Sandi, 2015).

Humans, like other animal species, instinctively form hierarchies and seem to be neurologically predisposed to do so (Redhead & Power, 2022). Hierarchical behavior must have a functional benefit to human survival for it to have such a persistent appearance across species. Serotonergic pathways are strongly associated with hierarchy formation behavior according to the research covered in this literature review. This is significant as hierarchical behavior seems to be a pervasive neuro mechanism in humans for survival purposes.

Summary of Hierarchy Exploration. This examination of hierarchies points to a persistent functional effect that has a homologous effect across social species. It seems to be an optimized methodology for organizing diverse genetic individuals with a variety of strengths and weaknesses into a collective unit that is not perfect yet optimally constructed for functional benefits to all the individuals. It confers a positive survival effect on the individuals within the groups in hierarchies. There does seem to be an uneven distribution of resources and health benefits to individuals. Highly dominant individuals seem to suffer with elevated stress levels, and this shortens their life span (Ferreira-Fernandes & Peça, 2022). Those on the lowest ranks also seem to have diminished survival responses, and diminished health benefits as well (Sapolsky, 2005). However, those in the lower and higher ranks seem to collectively survive better than they would without the hierarchical structure. This might suggest that a hierarchy is incapable of universal equity of resource distribution but represents an optimized functional unit for all the individuals within the hierarchy. Further on this systematic review will examine more about social affiliative behaviors within hierarchies that seem to functionally improve a hierarchy to its most optimal level, creating the most optimized outcomes for all individuals within the hierarchy and the most optimized outcomes for the hierarchy as a whole.

Dominant Individuals in Hierarchies

This part of this systematic review will be dedicated to investigating dominant individuals within hierarchies. dominant individuals are of particular interest as their behavior seems to affect the hierarchy disproportionately (Chen Zeng et al., 2022; Ohtsuki & Ujiyama, 2022; Redhead & Power, 2022). From an organizational psychology perspective these individuals represent leaders within an organization. Research from Carasco-Saul et al. (2015) demonstrated that leaders have a disproportionate effect on the subordinate individuals within an organization. This literature review will investigate the relationship to serotonergic modulation for this behavior within hierarchical social systems.

Dominant Individuals Have Higher Levels of Serotonin Than Subordinates. Dominance is the fundamental organizing behavior within hierarchies and it is the dominant individuals that shape the existence of hierarchies (van der Kooij & Sandi, 2015). Serotonin seems to modulate the dominance of individuals within a hierarchy (Moskowitz· et al., 2003). There seems to be a correlation between the level of serotonin and the rank of an individual in a hierarchy and appears to be the case in both animal and human studies.

Dominance in Animal Studies. Many studies show that elevated serotonin levels in dominant individuals in several different social species including fish, rodents, birds, non-human primates, and humans (Franz et al., 2015; Moskowitz· et al., 2003).

Lee and Goto (2018) studied 32 mice and have shown that mice who have lower levels of serotonin exhibit dominant behaviors in lab studies utilizing SSRI pharmacological methodologies to manipulate the levels of serotonin in individual mice. They did 50 rounds of repetitive trials using tests like the tube test which pits two mice in a tube to see which one yields to the dominance of the other. They found that there was a statistically positive correlation between lower serotonin and dominance behaviors (Lee & Goto, 2018). Rats also were studied by de Boer et al. (2009) and they replicated these findings that elevated serotonin modulated dominance in that species. They found that in their studies of 20 rats that decreased serotonin increased aggression. It is theorized that in rodent populations dominance is primarily characterized by aggressive behavior, whereas in primates and humans this is reversed, and aggression is a behavior associated with less dominant individuals (Caramaschi et al., 2007; de Boer et al., 2009; Lee & Goto, 2018).

In a study mentioned earlier, Raleigh et al. (1991) researched vervet monkeys using cross-over and counter-balanced methodologies. The focus was on a limited population of 36 adult males and was a qualitative field study with a measurable pharmacological intervention of an

SSRI. Vervet adult males were observed to acquire social dominance when their levels of serotonin were elevated. Interestingly their data showed that 100% of the males with pharmacologically elevated rates of serotonin all became the dominant male after the pharmacological intervention. This demonstrates a strong positive correlation between elevated levels of serotonin and dominance behavior (Raleigh et al., 1991). The same study also found that the converse was true, that monkeys with low levels of serotonergic activity were observed to have a lower rank in the same hierarchies (Raleigh et al., 1991).

In new world monkeys there was also a perceived correlation between serotonin and dominance behaviors. Reales et al. (2018) collected blood samples from 27 individuals for genetic testing for serotonergic genetic markers of the 5-HT3A receptor. They noted that serotonin modulated dominance, but did not articulate the exact role of the serotonergic mechanisms (Reales et al., 2018).

Howell et al. (2007) did a longitudinal study of 104 macaque monkeys. Over the lifespans of these individuals they performed cerebral spinal fluid tests on their f-HIAA levels. This is a highly accurate methodology for testing serotonin levels in the brain. They observed that elevated serotonin in the cerebral spinal fluid had a strong positive correlation with dominant ranks in the hierarchies in macaque monkeys. What is more, those low in serotonin behaved impulsively, were aggressive and had shortened life spans. This study is significant in this domain of research because it is a field study, using a highly accurate quantitative methodology, in a well-studied social species using standardized quantitative coding, and observing over a long period of time. Howell et al. found a very strong positive correlation between elevated serotonin and elevated dominance in the population studied.

Dominance in Human Studies. Human studies reinforce the view that serotonin pathways modulate dominance in individuals within human social hierarchies (Redhead & Power, 2022). Qu et al. (2017) in a comprehensive literature review, found that dominance is an impulse that is foundational to the neurobiological make up of humans. They also found that the serotonergic pathway had a modulator effect on dominance seeking behaviors. Additionally, the literature review found that the evidence developed by studies about humans is more sparce than in the studies about animal and non-human primates (Qu et al., 2017; Watanabe & Yamamoto, 2015).

A seminal study done in 2001 sought to establish the same link between dominance and serotonin that had been established in animal studies (Moskowitz et al., 2001). Moskowitz et al. (2001) completed a double-blind crossover study with 98 human participants. They alternated 12 days of placebo and 12 days of tryptophan in the study subjects. Tryptophan is a serotonin precursor, and one gram was administered daily. Tryptophan intervention is a well-researched methodology for modulating serotonin and has been used for decades reliably. The fact this was a crossover study with a sizable sample size helps the credibility of this study. The researchers concluded that there was indeed a strong positive correlation between dominance and increased serotonin resulting from the tryptophan (Moskowitz et al., 2001).

In a 2017 study, Shalaby (2017) examined 24 leading administrators in the sports field. They were tested for several traits including dominance, serotonin levels, genetic, and psychometric studies. Shalaby used blood tests to test for blood serotonin levels and found that the test subjects had higher levels of serotonin than the general population. They speculated that this might not be causative of the dominance but might be a result of increased physical activity. However, they did not rule out the affects of serotonin on the dominant behavior exhibited in these men. The study was limited in scope, yet corroborated other similar findings (Shalaby, 2017).

In a separate study the social effect of serotonin correlated with the cues to dominant behavior causing the subjects to be more aware of dominance cues (Beacher et al., 2011). Another, literature study also showed a correlation between dominance and serotonin (Kiser et al., 2012). The authors of this literature review were also led to the conclusion that serotonin was one of the contributors to dominance behaviors in humans (Van Der Westhuizen & Solms, 2015). Again, the issue with this literature review is that they cite older studies and animal studies. This points to the need for further human studies in this area. There are many theoretical qualitative studies, but few qualitative studies focused on the serotonergic system and dominance specifically in humans.

Types of Dominant Behaviors. There are several ways to categorize dominant behavior. The two methodologies we will examine are similar. Hobson et al. (2021) categorized two different groups of aggression. They named their first group the *simple pattern* which was aggressive only to those who were direct competitors to the dominant individual of high rank. The direct competitor would also be of high rank or just slightly lower (Hobson et al., 2021). The second group was the *complex pattern*. This was aggression to those of rank further down the hierarchy and bullying which was aggression towards the lowest ranks (Hobson et al., 2021). Their work was done primarily in animal populations. Their methodology was primarily focused on social information, meaning how clear was the rank of the other individuals as a determinant for which group they would fall into. Their observations were governed by strict coding methods that allowed for comparisons and generalizations across species. The largest group was the simple pattern which comprised 77% of the groups studied. The remaining complex pattern group saw 13% in the further distant rank sub-category and only 9% in the bullying sub-category (Hobson et al., 2021). These patterns are similar to what Kalmal et al. (1993) observed earlier in human populations.

Likewise, two types of dominance was identified in a qualitative study by Kalma et al. (1993). These two types are *sociable dominance* and *aggressive dominance* (Kalma et al., 1993). They were identified by using questionnaires. All of their work was done with 115 human individuals who were students with the average age of 21. Interestingly these insights are paralleled in the quantitative research by Hobson et al. (2021) mentioned above, which saw dominance built on either aggression or social affiliative behaviors as well as by other researchers (Chen Zeng et al., 2022; Redhead & Power, 2022). While the methods used in the research mentioned here are not identical, rough patterns emerge for further investigation. It seems that the serotonergic pathways modulate a differentiation of the dominance pattern as well. This literature review will examine these two pathways to achieving dominance and how they are related to the serotonergic pathways.

Aggressive Dominance. Typically, we often think of dominance as resulting from aggressive types of behaviors. Behaviors like the bullying categories mentioned above and the aggressive categories observed by Kalma et al. (1993). Aggressive dominance is characterized in animal behaviors such as violence, attacking, and aggressive posturing (de Boer et al., 2009). In humans aggressive dominance can also take on psychologically manipulative behaviors to get others to conform to their will, or by unsympathetic deprivation of resources (Buades-Rotger et al., 2021; Fast & Chen, 2009; Garandeau et al., 2011; Wong & Balshine, 2011). Interestingly, dominant individuals who exhibit what would be characterized as aggressive dominance are lower in serotonin as concluded by the following studies.

Aggressive Dominance in Animal Studies. This was first observed as early as 1991 in vervet monkeys by Raleigh et al. (1991) They used fluoxetine to modulate serotonergic activity and found that lower serotonin led to an increase in aggressive behaviors (Raleigh et al., 1991). It was observed again by Mehlman et al. (1994) in a population of macaques. They observed that there was an inverse correlation between high levels of cerebral spinal fluid measurements of serotonin and aggressive dominant behavior (Mehlman et al., 1994, 1995). Higley et al. (1996) corroborated these findings a year later in rhesus monkeys. They also found that higher cerebral spinal fluid measurements of serotonin modulated aggressive dominant behaviors (Higley et al., 1996). Howell et al. (2007) later observed that lower serotonin led to aggressive impulsive behavior in macaque populations. Lower serotonin also correlated with earlier death rates. Audero et al. (2013) used genetic knock outs that lowered serotonin production in mice, and this also confirmed the connection between lower serotonin and aggressive behaviors. Takahashi and

Miczek (2015) confirmed this again in 2015 in similar experiments in mice. They found that mice that have a knockout gene for the 5-HT1BR serotonin 1B receptor, increased impulsivity and aggression is exhibited. This suggests that the serotonergic pathway modulates this behavior, where lower serotonin leads to aggression (Nautiyal et al., 2015)

Aggressive Dominance in Human Studies. Human studies, though fewer in number, find the same pattern where low serotonin correlates with aggressive behavior and high serotonin with more sociable dominance. Moskowitz et al. (2001) found that low levels of serotonin correlated with individuals who behaved externally aggressive, and exhibited self-directed violence like suicidality. Higley et al. (1996) found that human subjects were also given to the same pattern. Low serotonin led to aggressive violent behaviors (Higley, Mehlman, et al., 1996). Virkkunen et al. (1995) also observed this pattern in their findings in human subjects as well. Mann (1995) also found the serotonergic pathway modulated aggression. Bond (2005) found strong associations between serotonergic activity using antidepressant pharmacological interventions where there was a correlation between raising serotonin and lowering aggressive behavior. Zamoscik et al. (2021) found that reduced tryptophan or 5-hydroxytryptophan correlates with impulse control issues and elevated aggressive behavior.

The 5-HT1BR serotonin receptor is linked to impulsive and aggressive behavior. This receptor is linked via serotonergic receptors to the nucleus accumbens in a regulatory fashion that further modulates impulsivity (Desrochers et al., 2022; Nautiyal et al., 2015). The serotonin 1B receptor is a G protein coupled receptor and acts as a neural modulator for other transmitters that have inhibitory or excitatory properties, acting in a cumulative way to dampen impulsivity (Desrochers et al., 2022). G protein receptors are longer acting than ion receptors and thus have long-acting effects on the brain lasting for months (Schonenbach et al., 2015; Yang et al., 2021). The serotonin system has far reaching modulatory effects on so much of the brain from the brain stem to almost every part of the prefrontal cortex (Kocsis et al., 2006; Mlinar et al., 2016).

Summary of Aggressive Dominance and Serotonergic Modulation. Studies with varying methodologies all confirm the linkage between the serotonergic system and the modulation of aggressive dominance behavior. It is confirmed by pharmacological methodologies, as well as genetic, and cerebral spinal fluid testing. This confirmation by multiple methodologies, and repeated testing goes far to demonstrate the validity of the hypothesis that serotonin plays a modulator role. While other processes are certainly involved in this complex behavior, serotonin’s role cannot be denied. Additionally, the repetition of this line of experimentation confirming these conclusions also points to the reliability of these findings in non-human studies. Interestingly, aggression is conversely related to dominance in primates and humans. The lower the serotonin in an individual the higher the aggression and the lower the dominance rank in the hierarchy.

Sociable Dominance. Interestingly those with higher levels of serotonin correlate with less aggressive behavior. How do they achieve dominance over the aggressive and manipulative types of domineering individuals? This literature review will demonstrate that socially affiliative behaviors are more affective behavior than chaotic aggressiveness in achieving dominance. Serotonergic processes drive dominant individuals to exhibit more of this socially affiliative type of behavior. Many of the same studies that prove low serotonin leads to aggression also show that the converse is also true.

Sociable Dominance in Animals. In the 1980s Raleigh et al. began studying the effects of serotonin on the behavior of vervet monkeys using pharmacological interventions to modulate serotonin. They found that increased levels of serotonin promoted socially affiliative behaviors like grooming, and drawing near to other members of their troop (Raleigh et al., 1980). Nearly a decade later in 1991 in vervet monkeys Raleigh et al. (1991) used fluoxetine to increase serotonergic activity and found that this decreased aggressive behaviors and increased affiliative behaviors.

Variations of macaques have different levels of hierarchies (Thierry, 2000). Seven different sub-species of macaques have been studied extensively (Judge et al., 2006). Interestingly, the rhesus macaques have the least sociable form of dominance of all seven species. This sub-species also has the highest amounts of allelic expressions of the rh5-HTT (Lesch et al., 1997). The rh5-HTT gene disrupts the serotonergic system lowering the overall serotonin in the systems of the rhesus monkeys in contrast to the other seven sub species which show much more socially affiliative behaviors within their hierarchies. This solidifies a connection between the modulator effect of serotonin on socially affiliative behaviors (Lesch, 2007). Interestingly, there is an additional modulating effect on the expression of this gene into aggressive or sociable dominance. That of being reared by an attentive mother who is socially dominant, and the amount of rough and tumble play that the juvenile monkey is afforded in their life (Barr et al., 2003). Play could be seen as a form of sociable dominance training (Barr et al., 2003). And the mini hierarchy of mother and child an additional form of training that seems to effect genetic expression and ultimately sociable behavior in macaques (Barr et al., 2003).

Hunter et al. (2022) confirmed the linkage between the rh5-HTT allele of the s-variant and connections to aggressive and conversely socially affiliative behaviors. This study confirmed the conclusion of earlier studies that this genetic predisposition leads to aggressive dominant displays. Interestingly, this study added an additional layer of detail by examining the effects on males and females of the species (Caramaschi et al., 2007; Higley, Mehlman, et al., 1996; Liu et al., 2023; Mehlman et al., 1994; Michopoulos et al., 2014; Zhelyazkova-Savova & Zhelyazkov, 2003). Hunter et al. (2022) found that across the sexes the rh5-HTT s-variant increased aggression in the males towards non-members of the troop introduced to the troop. Whereas, for females with the rh5-HTT s-variant it increased aggressive dominance mostly towards other females of the same troop rather than strangers (Hunter et al., 2022; Wang & Deater-Deckard, 2020).

Sociable Dominance in Humans. A 2001 study focused mostly on dominance in humans also showed the possibility that serotonin influences social affiliative behaviors. This study used tryptophan to manipulate serotonin levels and it saw an initial rise in social affiliative behaviors, however, this persisted in the placebo condition of the crossover study. This might be because the increased serotonin levels were more persistent than expected (Moskowitz et al., 2001a)**.**

Colzato et al. (2013) did a study that showed that interpersonal trust increased when the serotonergic systems were stimulated. They did this by a double-blind study using tryptophan supplements to increase serotonin levels. They then had participants in the study use the psychological test designed for trust called the *trust game* (Colzato et al., 2013).

Similar to indications found in macaque monkeys (Barr et al., 2003), evidence that human individuals with the rh5-HTT allele results in lower levels of serotonin and links to impulsivity and reactivity (Canli et al., 2005). This was found in studies that used fMRIs in a small study of 16 adults with this specific genetic allele. The fMRI revealed that areas associated with fear and reactivity in the limbic areas like the amygdala were activated in behavioral tests inside the fMRI machine (Canli et al., 2005). The study also showed decreased inhibitory activity from the medial prefrontal cortex which processes emotional stimuli (Canli et al., 2005). Based on this background information concerning the s-variant from the rh5-HTT allele, Nakamura and colleagues studied the Japanese culture and how it has developed a culture of sociable dominance based on this 5-HTT variant research (Nakamura et al., 1997).

Stoesz et al. (2013) set out specifically to find the neurological mechanisms responsible for social affiliative behavior in humans. Using a comprehensive literature review they sought to answer this question. While they identified some other processes that added to social affiliative behaviors like upbringing with parents and healthy social environments, they also emphasized the role of serotonergic pathways in the modulation of social affiliative behaviors in humans (Stoesz et al., 2013).

Tse et al. (2002) investigated the serotonergic modulatory effects on the combination of social dominance and affiliative behaviors in 20 humans. This would be a very direct examination of sociable dominance. They used a pharmacological intervention, citalopram, which is a selective serotonin reuptake inhibitor, which raises serotonin in the subjects studied. They also administered a placebo in this double-blind crossover study. They followed this with standardized social interaction tests and observational studies. They found that those in the non-placebo condition showed higher levels of social affiliative behaviors. They drew the conclusion that a link between higher levels of serotonin and social affiliative behaviors, and dominance existed (Tse & Bond, 2002).

In a survey of recent literature on the connection between dominance and social affiliation, Shafer et al. were able to conclude that social affiliative behaviors help lower conflicts and have a beneficial survival effect on populations. They went further to conclude that dominance and social affiliation co-occur and are modulated by serotonergic control mechanisms (Schafer & Schiller, 2022).

Summary of Social Dominance. Ample studies seem to support the conclusion that serotonergic processes modulate social affiliative behaviors in hierarchies. There was a diversity of methodologies deployed in studying both humans and other animals all confirming the same conclusion. Homologous serotonergic systems and effects on behavior exist in human and animal studies. Dominance and social affiliation arise from elevated levels of serotonin and this serotonergic effect is actively modulating both dominance and social affiliation simultaneously.

Social Learning Modulated by Serotonin.

Social learning is the ability of an individual to infer their rank within a social hierarchy (Schafer & Schiller, 2018). It is also concerned with the amount of attentional attunement an individual has towards studying their social environment (Reed et al., 2010). Once again, serotonin seems to play a role in the modulation of this process as well. This instinctual behavior exists in all individuals for both humans and most social animal species (Lesch, 2013; Terranova et al., 2016). Those individuals with higher levels serotonin seem to be better social learners than those with lower serotonin (Janet et al., 2022). While all individuals have some sense of social cognition or social learning, having a greater acumen in social learning seems to lead to more stability, dominance, better survival, and affiliative behaviors (Garcia-Nisa et al., 2023). All these tendencies combine to be a powerful social function that seems to help all the individuals within a hierarchy achieve survival benefits (Garcia-Nisa et al., 2023). This literature review will now examine these concepts and see how they are reflected in the literature.

In their literature review Wang et al. (2020) noted that studies showed that infant macaques struggled with social learning when they had the rh5-HTT allele, resulting in lower serotonin. This effect of lower serotonin and lower social learning was even lower in individuals that were not raised by their biological parent (Champoux et al., 2002; Wang & Deater-Deckard, 2020).

In another literature review, Lesch (2007) observed that serotonergic pathways related to imitation effects social learning as well. When compared with the rh5-HTT allele low serotonin results in a reduced internal representation of the social world. These individuals cannot process the complexities of society around them as well as their non-impaired cospecies (Lacoboni, 2005; Lesch, 2007; Marshall & Meltzoff, 2014).

In a study conducted by Reuter et al. (2021), the conclusions about the link between serotonin and social learning were tested further. Their methodology involved a tryptophan rich diet which has been shown to increase serotonin levels. In a non-placebo group, there was a statistically significant pattern of increased social cognition skills including the recognition of emotion on faces and answering a validated test on social norms (Reuter et al., 2021). Once again confirming the modulator role that serotonin plays in the social learning process in humans.

Schafer and Schiller (2018) linked what they called social mapping to the hippocampus, which retains ranking as a memory. Those with more dominant ranks also exhibited an upregulation of serotonin, thus enhancing this cognitive social learning ability (Schafer & Schiller, 2018). Janet et al. (2022) used fMRI to examine the activity in the dorsal raphe nucleus, the key nucleus for the initiation of the serotonergic pathways in the brain. This study demonstrated that social learning was modulated by serotonin and was enhanced in social contexts (Janet et al., 2022).

All these studies support the connection between serotonergic modulation of social learning. Increased serotonin appears to lead to increased social learning. Social learning helps in the establishment of dominance and hierarchies as well as overall wellbeing of individuals that have high social learning abilities.

Stability of Hierarchy and its Effect on Individuals

Social Hierarchy Instability and Isolation Leads to Lower Levels of Serotonin and Aggression

Knight and Mehta (2017) compared the effects of a stable and unstable social hierarchy on human subjects. The study showed that an unstable hierarchy reverses the benefits of social dominance and increases stress hormones in the dominant individuals (Knight & Mehta, 2017).

Losecaat Vermeer et al. (2020) in a novel experiment tested the effect of stable versus unstable hierarchies on aggressive dominant behavior. They found that when hierarchies were unstable there was more competitive aggressive behavior in the males they tested in their study. They also showed that more dominant individuals showed less tendency towards aggressive behavior over those in less dominant ranks in the hierarchies even when the hierarchy was unstable (Losecaat Vermeer et al., 2020).

Barr et al. (2004) found that individuals who had the rh5-HTT s-variant were even more prone to stress releasing adrenocorticotropic hormone. Additionally, these individuals were prone to more aggressive challenges when they were chronically separated from their social groups and then returned (Barr et al., 2004). This made a link between social disconnections and challenges to dominance in hierarchies.

These studies provide some insights that stably dominated social hierarchies lead to more socially affiliative behaviors in both dominant and subordinately ranked individuals and seem to lower critical stress markers in both the dominant and subordinate individuals. Again, this stable situation seems to be linked to a group effect of serotonin on the network as a whole.

Summary of Findings About Hierarchies.

These findings from the studies reviewed above concerning hierarchies point to a positive feedback loop of stable affiliative hierarchies. Specifically, higher levels of serotonin apparently modulate several behaviors in the creation and sustenance of hierarchies in humans and many animals. These behaviors include the formation of hierarchies, dominance, social affiliative dominance, social learning and stability in hierarchies. Additionally, there is a positive correlation between stable affiliative dominance and higher levels of serotonin.

Discussion

The Serotonergic Modulation of Socially Affiliative Behaviors in dominant Individuals in Hierarchies

This literature review presented a broad view of the state of research into serotonergic modulation of socially affiliative behaviors in dominant individuals. The generalized pattern of nearly all the studies presented here is that serotonin indeed modulates socially affiliative behaviors in dominant individuals in the context of hierarchies. What is more, serotonin apparently has a broad role in defining meta behaviors in social species including humans. Serotonin seems to play a key role in the health and well-being of individuals and collective communities of individuals.

Serotonergic Modulation of the Domain of Hierarchical Behaviors. What is unique about this literature review is that it shows the modulatory intervention of the serotonergic system in much of the domain of hierarchy formation and preservation. While other studies and reviews present one element of the hierarchical domain. This review connects several processes in the social hierarchy domain to the serotonergic system. This literature review shows the modulatory effect of serotonin on the creation of dominant individuals, the creation of hierarchies, the promotion of socially affiliative behaviors, the suppression of aggression, the action of social learning, and the promotion of stability in hierarchies. This broad domain of social behaviors is found in many species and is modulated by the same serotonergic systems in very similar homologous brain functions and structures according to this literature review. While it is reductionistic to say that serotonin is the only brain system or neurotransmitter at work in this process, it certainly is not (Lesch, 2007), it does seem to have a significant modulatory influence that needs to be noticed and studied further.

Serotonergic Modulation of Dominance. This literature review present**s** a broad picture of human and animal studies that demonstrate homologous serotonergic systems at work promoting dominance in individuals. Individuals with high rank and dominance seem to have more serotonergic activity relative to their rank dominance. The studies covered several species from mice to non-human primates to humans showing a similar pattern across these species. The studies used a wide array of methodologies from pharmacological interventions, fMRI procedures, genetic isolation processes, and cerebral spinal fluid measurements. All methods confirmed the modulator effects of serotonin in the dominance rank status and behaviors of individuals in all populations studied. Other literature studies seemed to treat the modulation of serotonin as axiomatic in the area of dominance (Lesch, 2007; Redhead & Power, 2022). It seems reasonable to generalize that serotonin indeed modulates dominance in individuals in hierarchies. However, more studies should be done in this area particularly in humans in field studies. There is much more detail to understand about exactly how behaviors and the serotonergic systems interact. This literature review points to the great potential this area of study has to offer to our understanding of the role of dominance or leadership in colloquial terms in our society.

Serotonergic Modulation of Hierarchy Formation*.* This literature review presented the activity of serotonergic pathways in promoting hierarchy formation in populations of social species. Once again serotonin seems to play a disproportionate role in the formation of hierarchies. This seems to be true for humans and a variety of social species confirming the validity of the connections between serotonin and hierarchy formation. Multiple studies over many decades, using diverse methodologies confirm the reliability of the connection between hierarchies and serotonergic systems. The pervasiveness of this system seems to show great utility of hierarchies to bring stable ecosystems where individuals with a broad valance of survival abilities are united into a network that does not deliver uniformly equitable results, but perhaps brings optimally best results for all individuals in the hierarchy. Perhaps this is why this system **is** repeated in nature due to its functional optimization. Additionally, the fact that this system is wired into the neural networks of social animals seems to make hierarchies self-organizing and an inherent trait. It would be like trying to make bees not live collectively in a hive. The brains of social animals utilizing serotonergic systems learn rank order and dominance as **innate** behavior. Working with these tendencies and creating stable hierarchies seems to be most optimal for human health and wellbeing.

Serotonergic Modulation of Social Affiliative Behaviors. This literature review connects the same serotonergic pathways that enable dominance behaviors and hierarchy forming behaviors with socially affiliative behaviors. This literature review links dominance, elevated serotonin levels, and social affiliation. Conversely, it shows the opposite behavior of aggressive antisocial behavior as related to low levels of serotonin and lower dominance. Social learning seems to increase with increased serotonin. This too appears to lead to more affiliative behaviors. Additionally, the studies show that hierarchies that are stable, and that non-isolated individuals preserve the socially affiliative behaviors more, and that this too is related to the serotonergic pathways. Again, studies across social species, using diverse methodologies seem to reinforce the theory that serotonergic modulation is critical for sociable dominance to occur in individuals in social species. What is more, social affiliative behaviors seem to be the optimal form of hierarchy and dominance, promoting homeostasis, and suppressing aggressive violence in social hierarchies. This opens an interesting area for further studies. Little is known about the exact modalities of interactions between behaviors and neural serotonergic systems. More field studies, especially in humans, need to be done to isolate the exact behaviors that interact with serotonin between individuals.

Are Dominance Hierarchies the Optimal Design?

One question that this study theoretically approaches but does not answer due to limitations is the optimal nature of hierarchies. Sapolsky (2014) rightly pointed out that individuals of low rank in hierarchies do not fare as well in many measures of health and well-being. However, not enough studies measure hierarchies against non-hierarchies. Would an individual isolated from a hierarchy have greater health or well-being? Or would it turn out that stable socially affiliative hierarchies are best for the low ranked as well as the high-ranking individuals, and that a more optimal organization of social species groups is not obtainable? Perhaps future research could investigate optimal sizes of hierarchies for the benefit of individuals of lower rank. Further studies that involve neurological correlates as well as macro-observational studies seem to be in order. It seems however that millennia of trials have preserved this behavior in many species giving indications that dominance hierarchies have optimal functional utility.

Human Field Studies for Hierarchy Optimization

This author is baffled why there have not been more human field studies related to this whole domain. Hierarchies in the workplace, military, religious groups, clubs, and schools abound, there is no shortage of field study opportunities. Yet there is a paucity of literature examining the neural mechanisms of the human brain function related to social behaviors in the field. Opportunities abound to enhance human cooperation and well-being that would seem to greatly impact huge spheres of optimal human existence and reduce violent aggression. Studies in these areas could improve the health of thousands. Specifically, there needs to be studies of rank dominance and social affiliative behaviors' effect on the subordinate ranks. Studies on optimal size of hierarchies so that the distance to a dominant individual would be best for all ranks. Behaviors need to be independent variables and neural mechanisms the dependent variable. Behaviors like social affiliation, focused time attention, or even play. Currently most studies have this pattern reversed. Future studies of social hierarchies should be tied to neural mechanisms rather than mere social theories, because it seems that humans have a pre-programmed neural system that needs to mesh with operational organizational theories to be optimally effective.

Studies of hierarchies throughout society need to be a focus. Right now, the United States has the highest rate of single parent homes at 34%. That rate rises to 64% in minority communities. This is the highest rate in the world for any country (*Annie E. Casey Foundation Data Center*, 2023). Studies indicate that family hierarchies play a key role in the expression of the serotonergic system, affecting dominance, resource allocation, health, and affiliative behaviors. However, it is not known what the exact effects of family hierarchies have on children. This is another area of hierarchical studies that could greatly benefit individuals of future generations.

Methodological Advancements

There is a desperate need for methodological advancements. One of the issues slowing the research into hierarchies and neural mechanisms like serotonin is the lack of parsimonious methodologies. Pharmacological interventions fail to reproduce actual field conditions. fMRI studies limit studies to the lab due to the size and confinement of an fMRI. It is hard to study social interactions within a two-foot tube with a megawatt magnetic field generator surrounding the subject. Genetic studies are difficult as well as genetic alleles in a population are limited and not universal, again making field studies difficult. Finally, there is the cerebral spinal fluid methodology, which is incredibly invasive and unethical in human studies. Some sort of quick and real time brain imaging or blood testing would need to be developed to really advance this area of study. Until new methodologies are developed this area of study will remain somewhat handicapped. New measurement technologies should be a priority for the research community.

Limitations

In addition to the limitations mentioned already, the largest limitation is the limited number of empirical studies in this research domain as a whole, particularly in the area of human field research. The connection of qualitative research on rank and dominance coupled with quantitative measurements of neuronal activity is greatly lacking. It is surprising that more research was done in the past than has been done recently. This limited a deeper evaluation. Methodologies hold back quantitative research as was mentioned above. Another limitation is that neuroscience in general is highly complex, and resists being reduced to a single process. There are so many nuclei and transmitters interacting that it is difficult to have a focused controlled study and thus difficult for this literature review to focus on a single process.

Conclusion

In this literature review of the current literature a correlative pattern seems to emerge. Serotonin seems to be implicated in the modulation of many of the social hierarchy systems. These systems include the key behaviors in humans like the strong tendency to create hierarchies, the tendency for dominant individuals to arise within these networks, the ability and instinct for individuals to use social learning circuits to rank individuals and the self within these hierarchies, and for dominant individuals to manifest affiliative behaviors. When functioning optimally, it appears that hierarchies increase human optimization for living collectively. It seems to minimize the negative effects of imbalances of innate survival strengths. Of course, there is a need for much more research in this area focused on the neuronal functioning of individuals and how this affects the collective interactions. Cultures and societies will be served greatly by this endeavor.

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