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Welcome to the 5th issue of Scholarly Review, a multi-disciplinary journal providing emerging scholars with a platform to share their work and savor the experience of contributing to an open access peer-reviewed journal. Readers can expect to find stimulating essays to read on a range of topics, and, once again, the standard of submissions has been high. Because there are no processing charges, students are free to submit their work and have it assessed. If a paper is of suitable quality and follows author guidelines, students' work is then peer reviewed by experts on the editorial board. Student authors receive detailed feedback to help them further refine their work, some but not all of which will be selected for publication. As the journal is now well established, the number of submissions is rising, and while this may reduce the chances of being accepted for publication, it ensures the quality of the journal and gives published authors something of which to be proud.

Tina Zhang's paper focuses on audio-visual stimuli and techniques used for acquiring competency in a second language; Rishav Biswas analyzes links between artificial intelligence and social media, using modelling to find early warning signs of suicidal ideation; Thomas Xiong writes about emotional stress leading to 'broken heart syndrome', whereby the heart suffers an acute reaction in response to emotional trauma; Stephanie Zhao examines theories of stress and its impact on cardiac health, looking closely at correlations between coronary heart disease and stress.

Jason Zhang's paper examines the type of neurological damage that occurs in the brain when someone suffers with Alzheimer's Disease and discusses the current limited options for treatment; Inchara Hosanagar takes a measured look at music therapy, assessing evidence in support of its use to improve levels of cognition by increasing neural plasticity; Claire Li writes about using classical music to reduce stress and trigger hormone reactions as a form of self-administered therapy for anyone having episodes of poor mental health, such as were widely experienced during the Covid lockdown; Ghazal Sajeev examines neurological triggers and physical pathologies that predispose someone to having sudden violent outbursts, based around the case of a convicted serial killer from Texas.

Tiffany Zhang's paper demands a degree of scientific literacy, and in writing about space science, she concludes that "future [space] research should investigate smaller and more detailed trends, especially for photometric bands that demonstrate a weak correlation"; Steve Han writes about software engineering and the development of Python language, which "can be used for all sorts of purposes, and one perspective is only a fraction of what the language can do"; Daniel Hu writes about space exploration, looking specifically at the moons of Jupiter and Saturn to see whether these have the potential to support human life.

We look forward to reviewing the next intake of papers and welcome your submissions.

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The Neurological Mechanisms and Possible Treatments of Sporadic Alzheimer's Disease

By Jason Zhang

Author Bio

Jason Zhang is a grade 12 student who is interested in STEM fields, especially neuroscience. He studies at Mulgrave School. A Canadian, he spent approximately 15 years in Shanghai and moved back to Vancouver with his family in 2020. In middle school, he was exposed to the complexity of the brain and decided to dive deep into the field of memory and neuro-diseases. In the future, he hopes to pursue a career studying neurodegenerative diseases and become a neuroscience researcher.

Abstract

Alzheimer's disease (AD) is one of the most common neurodegenerative diseases that accounts for sixty to seventy percent of all causes of dementia. Though Alzheimer's disease was discovered more than 116 years ago, the disease still lacks effective treatment. This paper presents the history of Alzheimer's disease since 1907 when it was first discovered. As a literature review, the paper explores a wide range of studies conducted by global researchers. The major focus of this paper is to illustrate the specific neurological mechanisms of sporadic Alzheimer's disease by looking into the two predominant theories: Amyloid Beta Plaques and Neurofibrillary Tangles. This paper compares and contrasts the two theories and discusses possible directions that could be considered in future studies. Most neuroscientists have focused on the amyloid-beta plaques theory. However, they have failed to conquer the disease by only targeting amyloid-beta plaques. Future research should shift its focus towards TAU tangle theory. This paper also illustrates the potential impact and changes Alzheimer's disease could have on the brain from a neurological perspective. Besides the pathology of the disease, this paper also reviews possible treatments and ways to prevent Alzheimer's disease in a variety of areas including lifestyle, diet, hormones, and FDA-permitted medicines.

Keywords: Alzheimer's disease; neurodegenerative disease; Amyloid Beta Plaques; Neurofibrillary Tangles; Tau Protein Theory; prevention, treatment and medicine; FDA permitted medicine.

Introduction

Dementia is the general terminology used to describe a set of symptoms including poor memory and difficulty learning new information. In most cases, dementia is associated with damaged brain cells which can be caused by a variety of diseases. Alzheimer's disease (AD) is one of the most common neurodegenerative diseases that starts slowly but progressively worsens over time. It accounts for sixty to seventy percent of all causes of dementia (Alzheimer's Association, 2022). AD could directly cause degeneration or loss in neurons in the cortex of the brain.

In 1907, German psychiatrist and neuropathologist Alois Alzheimer reported a case in which a 51-year-old female patient exhibited a variety of symptoms of early dementia. This included loss of recent memory, difficulty performing familiar tasks, and some psychiatric disturbance. Four years after the case was reported, the patient died, and this disease was named "Alzheimer's disease" (Castellani, 2010). By 2022, approximately 44 million people worldwide have been diagnosed with AD, and this number will likely triple to 132 million people by 2050 (Alzheimer's Association, 2022). In the United States of America, AD and other dementia related diseases cost around $321 billion per year. Therefore, AD not only leads to detrimental health outcomes in the patients but also imposes an economic burden on society. This paper explores the neurological mechanisms as well as possible treatments of the type of Alzheimer's now known as sporadic.

Two Types of Alzheimer's Disease

After Alzheimer's disease (AD) is discovered in patients, the disease is categorized into one of two clinical conditions based on the different ages of onset. The two clinical conditions have very different impacts on individuals, and the age of onset indicates the possible causes of AD and needs to be treated differently in terms of pharmacology. In the case of the 51-year-old female patient discussed above, due to the early age of onset, this was recognized as the "presenile" type. This type of AD is mostly familial, suggesting that the causal factor of AD can be inherited from ancestry. In contrast, the more common, older age of onset after 65 years old is recognized as the "senile" or "sporadic" type. This type differs from the presenile type by the older age of onset and its low probability of inheritance; thus, sporadic AD is also the more common type (Rolston, 2010).

In terms of clinical presentation, evidence such as memory loss or impairment in at least one other cognitive domain, as well as evidence of social or occupational function disturbance, is required for the diagnosis of AD. More specifically, patients tend to exhibit symptoms based on the time and brain regions affected, such as deteriorating speech ability, personality, judgment, or sometimes vision. Unfortunately, despite all available treatments, clinical AD continues to advance (Smith, 2010). Over months and years, progressive memory loss continues resulting in a disoriented personality, judgment dysfunction, speech abnormalities, and apraxias. Over time, patients' ability to care for themselves deteriorates. In most cases, pneumonia is the proximate cause of death. This is a devastating illness that strips the patient of their personality and dignity (Castellani, 2010).

Furthermore, AD's impact varies depending on many other factors, such as sex. Females tend to have a higher risk of developing AD and dying from the disease. This is due to the production of estrogen and testosterone (Andrew, 2018). These hormones have neuroprotective mechanisms that help to counter most neurodegenerative diseases. The male tends to have a higher level of estrogen production than female after females experience menopause which results in this different prevalence rate (Tierney, 2018).

Pathology of Alzheimer's Disease

Although the cause of sporadic AD is not fully understood, most pathology discussions focus on two theories — the Amyloid-Beta Plaques theory and the Neuron Fiber Tangles theory. These two theories are both well supported by the observation of patients' brain scans.

Amyloid-Beta Plaques Theory

Amyloid precursor protein (APP) is an integral protein that is found in numerous neuron synapse tissues. It is a cell membrane receptor that regulates synapse formation, brain plasticity, antimicrobial activity, and iron export. APP is

encoded by the APP gene and is controlled by substrate presentation. After this protein is used, it usually gets broken down and recycled for future use. However, during the process of breaking down the used amyloid precursor protein, different secretases are utilized to break down the APP (Huang, 2012). In normal situations, the APP is broken down into a secreted amyloid precursor, a protein alpha, and an 83 amino acid fragment named CTF 83. This process is catalyzed by the enzyme named alpha-secretase or α secretase. Later, the CTF 83 compound is further cleaved by gamma-secretase, which is made up of PEN-2, Aph 1, NCT, etc (Hansson, 2004). This cleavage results in an APP intracellular domain, which is an AICD domain that enters the nucleus and drives the neuroprotection pathways. The remaining sAPPα is secreted from the neuron and enables learning and memorizing (Castellani, 2010).

In contrast, AD patients go through a different process. For patients with AD, instead of alpha-secretase, beta-secretase is used to cleave the amyloid precursor protein into CTF 99 (carbon terminal fragment). The gamma-secretase cuts the CTF 99 compound into an AICD domain and an Abeta 40/42 peptide. The Abeta 40/42 peptide, together with APOE, forms insoluble amyloid-beta plaques (Murphy, 2010). Formed outside of neurons, these plaques block the neuron signaling interaction, which impairs memory ability. The plaques then result in inflammation that damages surrounding neurons and eventually becomes a neurodegenerative disease (Castellani, 2010).

Neurofibrillary Tangles and Tau Protein Theory

In contrast to the Amyloid Beta Plaques Theory, the Neurofibrillary Tangles and Tau Protein Theory (TAU) suggests that the trouble might be within the neurons instead of outside the neurons (Castellani, 2010). Microtubules help transport nutrients and maintain the shape of the neurons, and Tau proteins are a collection of six highly soluble proteins that play an essential role to maintain the integrity of these cellular microtubules (Arendt, 2016). In the case of AD, after amyloid-beta plaques are built, the enzyme kinase is activated and it phosphorylates the Tau protein. The Tau protein then leaves the microtubule and starts to clump up with other phosphorylated Tau proteins which eventually results in neurofibrillary tangles. In AD patients, due to the absence of Tau protein in the microtubules, the microtubules can no longer transport nutrients around neurons (Rolston, 2010). This leads to apoptosis (programmed cell death). As more neurons start the apoptosis process, neuron signaling is significantly impaired and the gyri shrink, which results in severe AD.

External Factors Associated with Alzheimer's

There are numerous external factors that could lead to AD. Though these hypotheses have not been fully proven, these risk factors show a high correlation to the presence of sporadic AD. As previously mentioned, despite the genetic factors that affect the possibility of getting AD, the most significant factor is still age. Between the ages 60-65, AD tends to affect 1% of the total population. The risk increases to nearly 50 % of the age group over 85. Using France as an example, in 2019, around 5800 people within the age range of 55 to 64 were diagnosed with AD. The number increased to 34800 confirmed cases in the age group of 65 to 74 and reached 404,000 cases in the age group of 75 to 84 (Ameli, 2021).

The second factor is the genetic component of AD. Genetics play very different roles in sporadic and familial AD. In terms of early-onset, presenile or familial cases, the genetic components focus on chromosomes 21, 19, 14, and 1 (Castellani, 2010). These chromosomes are inherited from the ancestry history of the family. In contrast, sporadic or senile AD are usually affected by the e4 allele of the apolipoprotein E gene (APOE 4). APOE gene is a cholesterol gene that usually has three forms. The first form is APOE 2, which appears to reduce the risk of AD. The second form is APOE 3, which does not affect the risk of AD. The third form is known as APOE 4, which seems to increase the risk of AD. The three proteins have different sequences by amino acid substitution at different residues (Huang, 2012). Single inherited APOE 4 slightly increases the risk of AD, while two inherited APOE 4 increases the risk of AD to a greater degree. APOE 4 carries the least cholesterol to the neurons in the three forms of apolipoprotein. In addition, APOE 4 degrades quicker, and its ability to clean amyloid-beta is weaker (Mucke, 2012). As a result, the presence of APOE 4 potentially leads to a higher amount of amyloid-beta plaques.

Treatments for Alzheimer's Disease

Though AD was discovered around 115 years ago, there is still a lack of effective treatment. As mentioned above, Alzheimer's disease tends to be a progressive disease whereby once the patient starts exhibiting symptoms of AD, it is usually at a very late stage that synapses function is largely impaired. Thus, most drug developers aim to make drugs or treatments that prevent Alzheimer's disease from progressing into late stages, which also means targeting the formation period of Amyloid Beta Plaques. On the other hand, much of modern pharmacology attempts to slow the progress of the disease. An example of such a treatment is Aducanumab. These types of drugs delay the clinical decline by targeting beta-amyloid plaques and removing ABP to slow down the rate of forming clumps and inflammation. This can successfully delay the formation of amyloid-beta plaques, which leads to a delay in clinical decline (Alzheimer's associations, 2021). By removing some of the amyloid-beta plaques formed around the neurons, the synapse signals will be able to transfer from dendrites to dendrites and perform basic cognitive functions.

The other approach is to treat the symptoms of AD. This alternative approach can temporarily mitigate some symptoms of AD. FDA has also approved drugs that focus on the two categories of symptoms, one being cognitive symptoms, including memory and thinking, and the other being non-cognitive symptoms, including behavioral and psychological symptoms. In terms of cognitive symptoms, FDA has approved drugs like cholinesterase inhibitors and glutamate regulators to treat symptoms related to the cognitive system (Alzheimer's association, 2021). These cholinesterase inhibitors can prevent the breakdown of acetylcholine and support the neurotransmission process. Glutamate regulators on the other hand improve cognitive systems by regulating glutamate, which is a chemical messenger that helps to process information in the brain (Alzheimer's association, 2021).

Despite the pharmacological treatments that were approved by FDA, there are many other treatments or therapies available now that seem to have an impact on AD. One example is hormone replacement therapy. As mentioned above, estrogen tends to lower the risk of AD because of three processes. Estrogen helps to maintain cerebral blood flow, reduce oxidative stress and decrease the formation of amyloid-beta (Andrew, 2018). Population-based studies (Castellani, 2010) have suggested such hormone replacement therapy may delay the onset of Alzheimer's disease.

Another treatment or method to reduce the risk of Alzheimer's disease is known as the Mediterranean diet. Many studies have shown that this diet tends to correlate to the risk of AD. The Mediterranean diet is well known for its "high intake of vegetables, fruit, and cereals; low to moderate intake of saturated fat, high intake of fish and low intake of dairy products and a moderate amount of ethanol" (Rolston, 2010). Many theories and studies have suggested that vitamin deficiency could potentially result in a higher risk of AD. Thus having high levels of vegetable intake such as kale could help people avoid vitamin deficiency, resulting in a lower risk of AD.

Another possible approach is anti-inflammatory drugs, sometimes referred to as non-steroidal anti-inflammatory drugs. As previously mentioned, when amyloid-beta plaques progress to the state of interrupting neurotransmission, inflammation in neurons damages surrounding blood vessels. Recently, there have been many observations (Smith, 2010) that there is a lower than expected prevalence rate of Alzheimer's disease in patients with rheumatoid arthritis. As observed, the long-term treatment of anti-inflammatory drugs might be protective against the development of Alzheimer's disease. The anti-inflammatory treatments can reduce the decline of microglia, astrocytes, and the production of amyloid-beta plaques. According to the Cache County Study on Memory Health and Aging (2013), treatments like NSAIDs could potentially prevent cognitive function decline at a relatively earlier age of onset. On the other hand, in most trials, NSAIDs did not showcase a significant positive impact on the development of sporadic Alzheimer's disease cases. In short, the extent to which anti-inflammatory drugs are effective remains a controversial question that future research could focus on (Castellani, 2010).

Conclusion

In conclusion, though sporadic Alzheimer's disease was discovered over 100 years ago, modern neuroscientists have not yet discovered any effective treatment that targets this disease. The greatest hindrance is a lack of knowledge about the causes of the disease. Until now, there are only hypotheses like Neurofibrillary Tangles and Tau Protein Theory and Amyloid Beta plaques. These hypotheses have been supported in numerous experiments, researches, brain scans, and studies, but the methods of treating TAU tangles and Amyloid Beta plaques remain a mystery. Since 1985, most neuroscientists have focused on the amyloid-beta plaques theory. However, they have failed to conquer the disease by only targeting amyloid-beta plaques. In the future, the research should begin to shift its focus towards TAU tangle theory. If this attempt also fails, other treatments will have to be considered.

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Psychosocial Stress and its Correlation With Coronary Heart Diseases

By Stephanie Zhao

Author Bio

Stephanie Zhao is a senior at Magee Secondary School in Vancouver, Canada. She is very passionate about psychology and interested in biology and hopes to pursue both in the future. In the summer, she was able to take a psychology course at Columbia, which further consolidated her interest in the field of psychology. Aside from being a student, Stephanie is also an athlete. She grew up participating in multiple sports (competitive swimming, traditional Chinese dance, tennis, badminton, figure skating, etc.) and is now playing squash competitively during the school year. Outside of academics and sports, you can find her reading, rewatching Brooklyn 99 for the 10th time, and crying to love songs.

Abstract

Times are becoming increasingly stressful, and cardiovascular diseases (CVDs) are the leading cause of death globally. This article examines the relationship between stress and cardiovascular diseases. We will look into the different theories of stress, including the Life-Events Theory, the Hardiness Theory, and the Social-Support theory. There are also a handful of different types of stressors and how these stressors might have direct and indirect effects on cardiac health. Hypertension, hypercholesterolemia (high cholesterol), and smoking all seem to play the most crucial role when it comes to coronary heart disease (CHD). Although seen as the villain, stress is not all harmful. “Eustress” is a term coined for stress that is actually beneficial to the human body. Regardless, stress is a major issue derived from work, school, and a fast-paced society, leading management methods to be more crucial than ever. One can choose from a plethora of coping mechanisms including exercise, yoga, dietary changes, medications, and relaxation techniques.

Keywords: Cardiovascular disease; stress; coronary heart disease; atherosclerosis; hyperhomocysteinemia; hypertension; life-events theory; hardiness theory; social support theory; psychological stressor; physiological stressor; social stressors

Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally. Cardiovascular disease is defined by various disorders: cardiac muscle and vascular system diseases controlling the heart, brain, and other vital organs (Koolhaas, 20111). Approximately 17.9 million people die from CVDs each year, contributing to 32% of yearly deaths (Steptoe et al, 20122). To put this number in perspective, this is about the same number of people as Ecuador or Guatemala's current population. This has been the case for quite some time. In 2006, cardiovascular disease accounted for the deaths of close to a million people, around 39% of the total deaths in the United States (Gaziano et al, 2006 3). A paper in 2017 by Kivimaki and Steptoe showed that there was a 14.5% increase in deaths from cardiovascular disease from the year 2006 to 2016 (Naghavi et al, 20174). It is not difficult to extrapolate that the number of CVDs will continue to increase, particularly in today's stressful social environment. Numerous works analyzed throughout this paper suggest that there is a correlation between stress and CVDs.

Although a well-known term, recent publications of stress research showed that "stress" as a concept has been broadened to encompass a range of behaviors: everything ranging from a mild response to a small-scale stressor to a severe reaction to a life-altering event. For the purpose of this paper, "stress" strictly refers to the unpredictable and uncontrollable psychological and physiological response where an organism experiences an exceeding amount of environmental demand (Kivimäki et al, 20185).

Like most high school and university students worldwide, stress has become a regular part of life. An increasing amount of fixation on reaching perfection in school, sports, and extracurriculars place most students in pressured environments. Not just students but everyone in society today is significantly impacted by stress. A study conducted by Penn State researchers (Almeida et al, 20206) published in 2020 clearly demonstrated that there is an increase in stress levels when comparing stress levels of adults from the 1990s and the 2010s. In the study, the data was collected by interviewing two groups of participants, one in 1995 and the other in 2012. At the time of the interviews, the participants were the same age. They were interviewed at the end of the day for eight consecutive days. Psychologists then recorded the stressful events and stress levels of each participant in the past 24 hours. The results showed that overall, adults in the 2010s presented a higher amount of stress than did the adults in the 1990s.

Although existing stressors like finances and diseases seem to be shared across all generations, new stressors are constantly emerging. The advancement of technology, social media, increasing work-life imbalance, and more rigorous academic demands profoundly affect how stress is perceived and experienced. For example, after the invention of the internet, new problems like cyberbullying and identity theft arose. More recently, our planet was struck by a worldwide pandemic, which became a common origin of stress.

Though, not all stress is harmful to the human body. The nerves that kick in before public speaking or a test are called "eustress," a term coined by Hans Selye that describes a moderate level of beneficial psychological stress (Marin et al, 20117). Conversely, chronic stress is harmful to the body; it elevates the susceptibility to mental illness and other health issues, and affects cognition (Nabel, 20038) and increases the prevalence of cardiovascular diseases. Cardiovascular disease continues to be the leading cause of death globally; there were approximately 523.2 million cases of cardiovascular disease in 2019, and the numbers are only seeing an upwards trend (Selye, 19579). This paper will look more closely at human coronary heart disease and its relation to stress.

Stress Theories

The Life-Events Theory on stress developed by Holmes and Rahe (Holmes & Rahe, 196710) advances that stress is caused by situations that require more resources than are available. As an example, an individual may experience stress if they walk into a test that they did not study for. Holmes and Rahe designed a stress scale called the Social Readjustment Rating Scale (SRRS) (McEwen & Stellar, 199311) that measures the impact of different life events on a person's stress level. There are a total of 43 accumulated stress events, some of which include the death of a spouse, divorce, marital separation, injury or illness, and retirement.

Another theory revolving around life events is allostasis: a body state that is readjusting to external forces (McEwen & Stellar, 199311). A state of allostasis is described by allostatic load and allostatic overload. Chronic exposure to environmental challenges that cause an individual to react in a particularly stressful way results in chronic allostatic load. Allostatic load increases vulnerability to mental illnesses. According to the theory, stress response mediators, such as glucocorticoids, catecholamines, and proinflammatory cytokines, manifest imbalances as these systems become overtaxed and dysregulated. In addition to causing damage to tissues and major organ systems, chronic dysregulation poses a cumulative physiological risk for disease and disability (Nielsen & Seeman, 200712).

Then there is the Hardiness Theory. According to Maddi and Kobasa (Kobassa et al, 1982; Kobasa et al, 198213-14), hardiness - commitment, control, and endurability - can decrease illnesses that are initiated by stressful life events. Instead of seeing a stressful event as a threat, seeing it as a challenge can decrease the negative impacts such events can have on a person's overall well-being.

Lastly, there is the Social Support Theory. The term "social support" is defined as "an exchange of resources between two individuals perceived by the provider or the recipient to be intended to enhance the well-being of the recipient" (Shumaker & Brownell, 198415). Social supports include but are not limited to emotional support, financial aid, and acts of service. Regardless, social support can help to cope with the event and therefore decrease stress level.

Stressors

There are three environments that can play a role in terms of stressors in life: social, psychological, and physiological environments (Lin & Ensel, 1989 16).

1. Social stressors

Social stressors are defined by Ilfeld, Jr. (Ilfeld, 197617) as life events resulting in situations that are generally perceived as problematic or undesirable. In his article, he discussed how each individual has their own varying responses to stimuli; it is then hard to measure the response rather than the stimulus itself. Similar to Ilfeld's view on the accuracy of measuring stress, Hans Selye (Selye, 195618) believes that diverse external stimuli may induce different physiological and mental responses from different people. This idea initiated the discussion amongst psychologists, therefore leading to studies done in social epidemiology (e.g., Holmes and Rahe 1967; Dohrenwend & Dohrenwend, 1981; Myers, Lindenthal, Pepper, and Ostrander 1972). Researchers have collectively found that stress from social environments influences mental and physical well-being in a significant manner.

It is well known that work causes stress and therefore makes someone increasingly vulnerable to coronary heart disease (CHD) (Brunner et al., 199919). The chances of getting CHD can be elevated through direct causes such as biological responses and indirect causes like lack of exercise (Møller, Peter, Håkan Wallin, and Lisbeth E. Knudsen. 199620). One of the primary stress responses of the body is the activation of the autonomic nervous system (ANS), which contributes to what is known as the "fight or flight" response. When the ANS is activated repeatedly, heart rate variability is lowered, which is a marker for cardiovascular diseases. Some work-related social stress examples include, but are not limited to: excess amount of work, long working hours, experiencing workplace discrimination or harassment, giving speeches or presentations in front of coworkers or superiors, and constant fear of being laid off.

Another rising social stress factor in today's society is school. With the growing obsession with getting into "prestigious" schools, students today deal with more stress than ever. The time that used to be spent on hanging out with friends and doing leisurely activities is now spent on studying and homework. Academic success is actively threatened by challenges, demands, and expectations. For example, a study (Natvig et al, 199921) showed that there is a correlation between psychosomatic symptoms (some include excessive thoughts, digestive issues, headaches, elevated blood pressure, and dizziness) and school-induced stress in 862 Norwegian adolescents (ages 13-15).

2. Psychological stressors

A person's sense of mastery, feelings of competence, self-esteem, and locus of control have been recognized as personality factors that affect their reactions to stressful situations. Psychological stress can increase health problems. In a paper by Mellinger et al.

(Mellinger et al, 197822), psychological stress or "psychological vulnerability" could result in physical illness. In this study, Mellinger et al. conducted a nationwide cross-section survey of U.S. adults. Data was collected on the relationship between psychic distress and life crisis among all ages, races, and demographics. This study used a shortened version of the Holmes-Rahe Social Adjustment Rating Scale, as mentioned above.

3. Physiological stressors

The term physiological stress refers to any condition that changes a cell's or organism's homeostasis. Examples of physiological stressors can include fluctuations in oxygen levels, temperature, and traumatic events. Aside from external stressors, physiological stressors can occur internally as well. For example, organisms can experience physical stress from inner chemistry changes during development (most common amongst adolescents). On top of that, aging is also a common physiological stressor experienced amongst humans. With aging comes molecular damage, which can lead to other health problems, such as decreased effectiveness of the nervous system and immune system.

Stress and its relationship to cardiology health

It is not surprising to learn that stress can cause physical damage to the body, such as heart attacks and strokes (Ueyama et al, 200323). When stressed, people experience increased heart rate variability (Kim, Hye-Geum, et al., 201824), elevated blood pressure, higher cholesterol level, and increased blood volume . These contribute significantly to CHD. Batteries of studies have concluded that three factors - hypercholesterolemia (high cholesterol), hypertension, and smoking - play the most critical role in CHD (Greenberg, 200225). Specifically, hypercholesterolemia and hypertension can easily be influenced by chronic stress.

Although hypercholesterolemia, hypertension, and smoking are the conventional vital factors that may lead to CHD, researchers (Linden et al., 200733) found that half of the patients with CHD do not present any of the above clinical symptoms. In fact, 91% of heart attacks were caused by work-related stress. Therefore, work stress is believed to be a more significant cause of CHD than the conventional risk factors we hear about (Russek & Russek, 197626).

Table 1 shows that 91% of the 100 patients in the "coronary group" have struggled with their jobs, either from long working hours or emotional instability. This is a significant difference compared to the 20% of the control group who had heart attacks due to work-related stress.

Table 1: Incident of various factors in patients who had coronary attacks and in control groups (Russek & Russek, 197626)

INCIDENCE OF VARIOUS FACTORS IN PATIENTS WHO HAD CORONARY ATTACKS AND IN CONTROL GROUPS

	No.	Heredity (Positive)	High-fat Diet	Stress and Strain (Occupational)	Obesity	Tobacco (30 Cigarettes, Plus)	Exercise
Coronary group	100	67%	53%	91%	26%	70%	58%
Control group	100	40%	20%	20%	20%	35%	60%
Ratio		1.7:1	2.7:1	4.6:1	1.3:1	2:1	1:1

In the study done by Henry I. Russek and Linda G. Russek (Russek & Russek, 197626), they concluded that emotional stress is a significant factor in CHD. Interestingly, they talked about the evolution of Homo sapiens and the role natural selection plays in humans' adaptation to new environments. From living in forests to farms to factories, getting used to new environments and lifestyles inevitably takes thousands of years. The Russeks made the connection that CHD might be one mechanism that nature poses as a means of eliminating those who fail to withstand the stress from the new world that we live in. Like learning how to hunt and staying away from vicious animals are skills humans had to learn centuries ago, coping with stress is also a symbolic challenge we would have to learn how to overcome. They also mentioned that even before the turn of the century, scientists have described men with coronary diseases as "ambitious" and "competitive" with "intense emotional drives." Coincidentally, the adjectives that the scientists used tie in with another concept: a correlation was found between CHD and stress and Type A personality. Type A personality is defined as being driven, persistent, involved in work, competitive, aggressive, and time-urgent. This type of behavior suggests that there is a relationship between CHD and stress (Sparacino, 197927).

Stress could induce biological and physiological changes in the body, which can cause additional health issues. For example,

hypercholesterolemia - increased serum cholesterol - is known to clog the arteries (atherosclerosis) and decrease the elasticity of arteries (arteriosclerosis). Cholesterol is a fatty and waxy substance that is a component of all the cells in the body; it is vital for making cell membranes and many hormones. Cholesterol can come from both the liver and the foods we eat. The clogs caused by high cholesterol can later lead to a heart attack or a stroke. Both atherosclerosis and arteriosclerosis overwork the heart muscle, pumping oxygen extra hard to other places and leaving less oxygen for itself. Similarly, increased blood pressure, blood volume, and accelerated heart rate can all lead to an excessive workload on the heart (Félix-Redondo, Francisco J., Maria Grau, and Daniel Fernández-Bergés 201328).

In addition, homocysteine is another biological molecule that stress could affect and influence. Stoney (Stoney, 199929) found a positive relationship found between anger and hostility and homocysteine levels. The production of plasma homocysteine is closely related to CHD. Researchers H. Refsum and P. M. Ueland found that "An elevated level of total homocysteine (tHcy) in blood, denoted hyperhomocysteinemia, is emerging as a prevalent and strong risk factor for atherosclerotic vascular disease in the coronary, cerebral, and peripheral vessels, and for arterial and venous thromboembolism" (Refsum et al, 199830). The amino acid homocysteine is formed by the metabolism of plasma methionine. Hyperhomocysteinemia (unusually high levels of homocysteine) can lead to ischemic injury (caused by blood supply unable to reach muscles, tissues, or organs of the body) and, therefore, CHD. Blood clots, heart attacks, and strokes are also associated with hyperhomocysteinemia.

Stress can affect the heart in indirect ways as well. Someone might have a habit of smoking after a stressful day or skip exercising because of experiencing too much stress. As a result, stress often exacerbates heart diseases by introducing other heart-damaging behaviors into the mix.

Stress management

People often make the mistake of coping with stress by suppressing negative emotions, which is proven to be counterproductive as it increases vulnerability to developing CVDs (Leineweber et al, 201131). Stress levels can be managed by using different strategies. Although no primary coping strategy was established to prevent CVDs, there are some secondary preventive methods proven to be efficacious in patients with congenital heart defects (CHD). Some of these secondary methods are even shown to be effective in reducing myocardial infarction levels (O'Donnell et al, 2008; Linden et al, 200722-33). These techniques include relaxation procedures and cognitive behavioral methods (Whalley et al, 2011; Dixhoorn & White, 200534-35), such as exercise, yoga breathing techniques, changing diets, progressive relaxation, imagery, behavior and anxiety management techniques, or medications (Holmes and Rahe, n.d.36).

Conclusion

Coronary heart disease will continue to be an issue globally, and stress will continue to be present. This study looked into the correlation between stress and CHD. We analyzed the difference between "good" stress and "bad" stress, the different stress theories that other scientists had developed to explain stress, the main types of stressors, and stress' relation to cardiovascular health. We also discussed specific stress management methods that could diminish, not wholly, the amount of stress and its adverse effects on the body.

Through the articles this paper has covered, it is clear that there is a correlation between stress and cardiovascular diseases. Bodily functions such as heart rate and blood pressure can be affected by the amount of stress someone goes through. Furthermore, high cholesterol levels and increased blood volume - which are known to have negative impacts on the heart - can be caused by an increased level of chronic stress. Even though some evidence is not as direct as others, there is still a link between heart health and stress.

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A Review of Takotsubo Cardiomyopathy

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Author Bio

Thomas Xiong is a grade 11 student in Toronto, Canada. He wants to join the healthcare profession in the future, and he is working hard to gain experience in this field. He has completed biology summer programs and is a proud competitor of the British Biology Olympiads. In addition, he has volunteered at multiple cancer organizations, where he has led a team of students to create educational posters and presentation slides on various types of cancers and their treatment options. Outside of this aspiration, he enjoys many hobbies, including Clarinet, band, traveling, reading, and art. Through publishing this article, he hopes to gain experience in research, which includes but is not limited to developing his ideas, discussing them with colleagues, and articulating a comprehensive argument from his thoughts.

Abstract

Takotsubo cardiomyopathy, also known as apical ballooning syndrome, stress cardiomyopathy, and, more commonly, broken heart syndrome, is a temporary heart condition that occurs when an individual experiences sudden extreme emotion that rapidly weakens the left ventricle. This article aims to provide a general overview of takotsubo cardiomyopathy and discuss its history, stressors, clinical and underlying symptoms, populations at risk, clinical studies, and potential treatments. Although rare, these factors are essential to understand, as the effects of Takotsubo could devastate patients' health. By learning about the mechanisms of Takotsubo, effective treatment plans could be implemented quicker and improve prognosis. This article presents that Takotsubo contains many similar qualities to heart attacks, and some treatment options could be considered for both diseases. It is challenging to prevent Takotsubo through medication since the cases are mostly acute and unpredictable. However, treating maladies that often come with Takotsubo could lessen the effects on the patient.

Keywords: Takotsubo cardiomyopathy; apical ballooning syndrome; stress cardiomyopathy; ventricle; cardiac disease.

Introduction

First described in Japan by Hikaru Sato, MD, Ph.D., in 1990, Takotsubo cardiomyopathy derived its name from a traditional octopus trap with a narrow neck and wide base1. The condition causes apical ballooning of the left ventricle, which gives it a shape similar to the octopus trap on a cardiac ventriculogram (Figure 1).

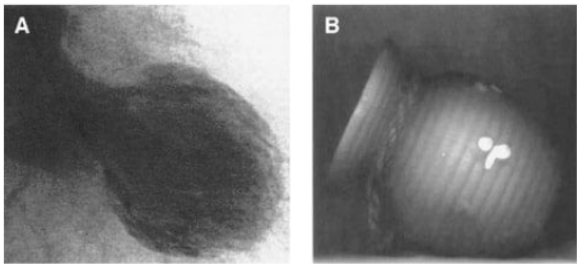

Figure 1. (A) Ventriculogram (B) Octopus pot "Takotsubo"[2]

Interest in Takotsubo cardiomyopathy spiked in 2004 after the Niigata Chuetsu earthquake in Japan, where cases diagnosed in the week following the quake equalled the number of patients diagnosed in the previous decade (1994-2004)1. A rise in rates of Takotsubo also accompanied recent earthquakes in New Zealand. These statistics indicate that physical and emotional stressors may cause Takotsubo. While most people with this condition experience a stressful trigger, around 30% of patients do not have an identifiable trigger3. Emotional stressors of Takotsubo include but are not limited to3,4: Grief, fear, anger, and extreme emotions. Physical stressors of Takotsubo include but are not limited to3,4: High fever, stroke, seizure, difficulty breathing, significant bleeding, and low blood sugar. These stressors are prevalent conditions among populations that have recently experienced natural disasters.

Since 2006, diagnosed cases of Takotsubo have been on the rise5. This could be partly attributed to the increased awareness of Takotsubo, but could also reflect the rising trend of emotional stress and a lack of capacity to deal with such pressures. For example, in the United States, reports of loneliness have increased linearly since the 1970s6. Furthermore, Takotsubo disproportionately affects women. Its prevalence is roughly 2% in patients presenting with clinical manifestations of acute coronary syndrome, but rises to 10% if only women are considered. However, this figure is most likely under-recognized as the condition is sometimes undiagnosed7, but this number is growing. As of 2012, roughly 7000 cases of Takotsubo have been reported in the United States, an increase in incidence of over 20 times7. Moreover, the risk of Takotsubo is often underestimated, and its pathogenesis is unclear.

Hence, further research on Takotsubo needs to be conducted. Many misconceptions about the disease have emerged, partly due to the lack of knowledge and disproven results from earlier reports. As a whole, Takotsubo is incorrectly considered to be a benign disease of "clean" coronary arteries caused by an emotional trigger that can "self-heal." In reality, Takotsubo is not a benign disease7, is not always preceded by an emotional trigger7, and does not require "clean" arteries. Based on the current literature on Takotsubo, this study will focus on presenting a comprehensive view of the disease to reduce some pitfalls and misinterpretations during diagnosis and management.

Post-menopausal women, and women in general, are most at risk of developing Takotsubo, with the risk of development increasing five times after age 557. Up to 90% of Takotsubo diagnoses are of women1. Although the exact reason for this is unknown, it is hypothesized that the female hormone estrogen protects the heart from the harmful effects of stress. For example, estrogen clears up LDL (Low-Density Lipoprotein) and increases the presence of HDL (High-Density Lipoprotein). It also removes free radicals within the blood, which may improve takotsubo symptoms, as it might lower the local oxidative stress1. As women age, their estrogen levels decline, and they become vulnerable to Takotsubo. Other risk factors of Takotsubo include depression, anxiety, or other mental illnesses7.

Despite the disease being described over 30 years ago, the cause of the disease, its exact physiological processes and courses of standard treatment are still unclear. However, with more cases being identified, a symptoms and diagnostic criteria have been established.

Symptoms and Diagnostic Criteria

Symptoms of Takotsubo closely resemble those of a heart attack, for example, sudden, severe chest pain, shortness of breath, intense sweating, and dizziness. However, Takotsubo may be felt within minutes up to hours of the trigger, whereas heart attack symptoms are felt as soon as blood and oxygen supply is cut off8.

The Revised Mayo Clinic Criteria are widely used for the diagnosis of Takotsubo. To be diagnosed with Takotsubo, four of the following conditions must be met9:

1. Transient dyskinesis of the left ventricular mid-segments, with or without apical involvement; the regional wall-motion abnormalities extend beyond a single epicardial vascular distribution, and a stressful trigger is often, but not always, present

2. Absence of obstructive coronary disease or absence of angiographic evidence of acute plaque rupture

3. New ECG abnormalities (ST-segment elevation and/or T-wave inversion) or modest elevation in the cardiac troponin level

4. Absence of pheochromocytoma and myocarditis.

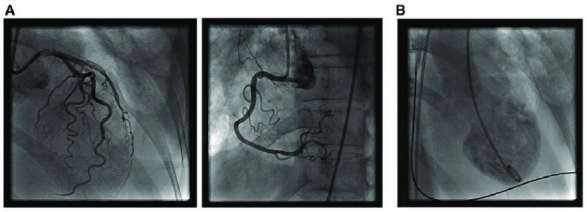

Figure 2. (A) Coronary angiogram demonstrating normal left and right systems. The heart is functioning as normal (B) Left ventriculogram demonstrating apical ballooning consistent with Takotsubo,[10] with the left ventricle being enlarged

In practice, Takotsubo is most commonly diagnosed when cardiac catheterization of a patient with a suspected heart attack reveals no blockage, as shown in Figure 2.

Potential mechanisms of action (MOA)

Although Takotsubo and heart attacks share similar symptoms, their underlying causes differ. A complete or near-complete blockage of a coronary artery generally causes heart attacks. While in Takotsubo, arteries are not blocked, arterial blood flow may be reduced due to a weakened left ventricle.

During Takotsubo, the heart muscle suddenly becomes weakened, and the left ventricle balloons at the heart's apex. The shape change affects the heart's ability to pump blood and may lead to permanent changes to the heart's pumping motion. Takotsubo may delay the twisting motion of the heart, and its squeezing movement may be reduced. Parts of heart muscle were also found to be replaced with fine scars, reducing the heart's elasticity and preventing it from contracting properly. These results may explain why Takotsubo survivors have similar long-term life expectancies to survivors of heart attacks11.

The specific mechanism of action (MOA) leading to Takotsubo is unknown. However, catecholamines, the chemicals released during the stress condition, such as epinephrine and norepinephrine, are hypothesized to contribute to apical ballooning of the heart, leading to Takotsubo. The administration of catecholamines in animal heart models has been shown to cause Takotsubo-like changes1. There have also been reports of humans experiencing Takotsubo after being administered high doses of catecholamines12.
However, it is unlikely that catecholamines are the sole cause of this syndrome, as most humans exposed to stressful situations, which result in the release of catecholamines, do not experience Takotsubo.

Potential treatments

Currently, the standard-of-care for Takotsubo has not been established, as its definitive MOA is unclear. However, a battery of treatments exists to manage the known pathophysiologic consequences and complications after the occurrence of the disease (Table 1)13,14.

Table 1. Complications of Takotsubo and recommended therapies

Complications	Recommended Therapy
Asymptomatic/Normotensive/Normocardic	Supportive care, void anticoagulants, continuous ECG Monitoring for emergence of arrhythmias and QTc prolongation
Angina	Sublingual or intravenous nitroglycerin, organic nitrates, β- blockers
Dyspnea	Monitored closely. Diuretics, nitrates, and β-blockers, depending on the presence/absence of tachycardia, hypertension, bradycardia, hypotension, and evidence of LVOT, mechanical respiratory support
Hypertension	Short or ultrashort acting β-blockers
Hypotension	Monitored closely. Intravenous fluid intake, α_1-agonist
Bradycardia and/or Atrioventricular Blocks	Small doses of atropine
LVEF < 30% and/or Large Apical Akinesis/Dyskinesis	Closely monitored for HF, cariogenic shock, atrial arrhythmias and lethal MA, and thrombus formation
Thrombus and Prevention of Embolism	Unfractionated heparin, low-molecular-weight-heparin (LMWH), vitamin K antagonists, aspirin, and/or P2Y12 receptor antagonists such as clopidogrel, prasugrel, or ticagrelor, or the new oral anticoagulants
Left Ventricular Outflow Tract Obstruction	Intravenous metoprolol, esmolol, or landiolol
Heart Failure	Aspirin, avoid Positive inotropic agents and vasodilators
Mitral Regurgitation	Follow principles of therapy for LVOTO
Right Ventricular Involvement	Monitored for hypotension, RV failure, RV thrombus
Cardiogenic Shock	Estimating or measuring cardiac output, SVR, and organ perfusion
Heart Rupture	Avoided by early employment of β-blockers
Atrial Arrhythmias	β-blockers
Ventricular Arrhythmias	Short-acting β-blockers
Cardiac Arrest	Monitor thoracic ECG signals indicative of stellate ganglia nerve input to the heart
Pericarditis	Thrombolytic therapy, anti- coagulants, and glycoprotein IIb/IIIa inhibitors
Adrenergic Cardiac Innervation	α-lipoic acid therapy

Prevention

When preventing the recurrence of Takotsubo, it has been shown that β-blockers, ACEi/ARB, and aspirin have not prevented a recurrence, lowered its severity, or improved survival. There has also been no clinical data supporting the use of estrogens to prevent Takotsubo13. Instead, endocrinological and malignant comorbidities should be treated to reduce the impacts of Takotsubo.

Case Studies

Three case studies of Takotsubo patients will be examined. Although Takotsubo often presents with other physical stressors, such as illnesses, the disease can appear acutely without warning. The first two patients are presented alongside other stressors, while the third is presented with Takotsubo alone.

The first case study is of a 63-year-old female presented with an 8-10 hour history of progressive dyspnea. She has completed her third cycle of Perjeta plus Herceptin and Abraxane chemotherapy for HER2-positive breast cancer. The high burden of disease in the left breast metastasized to the chest wall, lymph nodes and lungs. Her blood pressure was 142/92 mmHg, her heart rate was 110 BPM, and her oxygen saturation was 91% in room air. She had no preexisting cardiovascular disease except for "white coat" hypertension, which was well-controlled. Approximately two months ago, a baseline acquisition scan about two months ago demonstrated an ejection fraction >65% with no wall motion abnormalities. The patient showed apical ballooning consistent with Takotsubo, and a standard heart failure procedure was initiated while cancer therapy was ceased. The patient chose to pursue comfort care and died approximately one month later15. Combined with the emotional and psychological stress associated with a cancer diagnosis, combination therapy with anti-HER2 antibodies could have contributed to Takotsubos, as it possesses cardiotoxic properties15.

The second case study is of a 66-year-old female with mild coronary artery disease, emphysema, hypertension, and pancreatic cancer who presented to the hospital with worsening dyspnea, chest tightness, and diaphoresis. She recently started Capecitabine as part of her pancreatic cancer treatment and received one dose about three days before symptoms. Her heart rate was 140 BPM, but she was vitally stable otherwise. She was eventually diagnosed with Capecitabine-induced Takotsubo. Capecitabine was discontinued, while heart failure therapy was started. One week later, she recovered16.

Although Takotsubo is rare, it may be potentially devastating to the patient. Whether Capecitabine is a bystander or the offending chemical agent, it must be stopped, and heart failure therapy must be initiated. A new treatment plan must be

created for the patient to improve the prognosis.

The third case study is of a previously healthy 49-year-old female who suddenly complained of chest discomfort stretching to both arms. Her EKG showed ST segment elevation and evidence of possible inferolateral myocardial infarction. A cardiac catheter was inserted but showed no evidence of coronary artery disease that impacted circulation. Her residual ejection fraction was 30%, showing profound left ventricular dysfunction. No physical or emotional stressors were identified, and she was treated with nitrates and ACE inhibitors17.

In conclusion, Takotsubo Cardiomyopathy is a disease that could appear acutely with no previously identifiable stressors. It affects all age groups, but most significantly post-menopausal women, with annual diagnoses rising as the disease becomes more prevalent in scientific literature. Catecholamines are suspected to play a role, and medications exist that reduce complications after an episode. However, this is not enough. The specific mode of action of Takotsubo is still unknown, and an effective standard-of-care for Takotsubo has not been developed. Therefore it is essential to conduct more research into the mechanisms of action of the disease so it can be quickly identified and treated with appropriate medications and so that conditions would not go undiagnosed and potentially recur in patients.

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Music Therapy and Cognitive Function: Exploring the Mechanisms and Potential for Enhanced Care

By Inchara Hosanagar

Author Bio

Inchara Hosanagar is a junior at Newark Academy in Livingston, New Jersey. She has been Captain of the Women's Varsity Fencing Team, president of the Pop-Up Book Club, vice president of the Cancer Awareness Club, and the grade appointed member of the Equity & Inclusion Team as well as the Community Service Council at Newark Academy. Apart from school, Inchara has a deep passion and interest in the STEM field where she spends time on ongoing research projects and internships. This specific research project was under the mentorship of Dr. Roger Worthington, chair of the editorial board (recused from the review of this article). She focused on the cognitive impacts of music therapy as she is deeply interested in the relatively new subject.

Abstract

In a clinical setting, music therapy has been shown to improve cognitive function and improve mental health in some patients who are suffering from psychiatric symptoms. It is one of the non-pharmacological approaches to treating a range of disorders. With a long history of use, music therapy has been shown to improve cognitive function by interacting with a variety of different brain functional networks and cognitive domains. This paper will discuss the various mechanisms of music therapy, the advantages of music therapy's influence on neural plasticity, and some studies that are currently being done about music therapy and cognition in this paper, with an emphasis on an improvement in cognition. Numerous studies have shown that music therapy can slow cognitive deterioration, particularly in the areas of global cognition, psychomotor speed, executive function domains, and autobiographical and episodic memories. A promising intervention for the treatment of various illnesses and disorders is music therapy. However, additional data from prospective, randomized, blinded, consistent, and methodologically focused investigations are required.

Keywords: music therapy; mental health; brain functional networks; cognitive domains; cognition.

Introduction

Music is often considered a form of entertainment; however, there is another angle to approach this subject: that music is used as expressive therapy. Music therapy is essentially an application of music in a clinical environment, where the use of music intervention methods is used to accomplish individualized results. Music therapy is generally administered by a credentialed professional as part of an approved program. Music therapy is used to influence cognition, which can improve language skills. Researching this relatively new therapy, it was clear that music therapy has a strong influence on the brain, which ends up boosting many aspects of the mind and body. It was particularly interesting to see how music therapy does not just change the brain but also lets parts of behavior and function adapt. Because music therapy affects the brain in many different ways, its relevance includes that it can non-invasively enhance cognitive function in a variety of disorders and diseases. In addition to this, it is also able to help alleviate psychiatric symptoms in some patients and improve mental well-being.

Some of the objectives of this paper include describing different aspects of music therapy as well as the distinct functional networks and structural components that are affected. It will also detail how the functional networks translate into positive effects. Furthermore, it introduces future and current research on music therapy by detailing specific case studies that are trying to make the therapy more specialized and individualized. There is a need for therapeutic interventions to provide adaptive strategies to sustain the quality of life, decrease neurologic impairment, and maintain or slow cognitive decline and function due to degenerative neurologic diseases (Mahoney 2013). Musical interventions with adults with cognitive impairments have received increased attention over the past few years, with music being used to decrease agitation and anxiety and aid in certain cognitive functions by forcing neurons to create new pathways for themselves (Cortes, Bartel 2018). These approaches indicate the expanding scope and efficacy of music therapy and the potential mechanisms involved (Cortes, Bartel 2018).

Music therapy is used for many individuals with various disorders and diseases because it has shown significant results in boosting cognition and improving executive functions. This is done by affecting several distinct areas of the brain as it strengthens neural connections and increases brain plasticity. Certain studies are being conducted on how to create a more specialized and individualized music therapy experience. The idea of sound as a healing influence for health and behavior has been prevalent since the twentieth century, during the World Wars, for veterans suffering from physical and emotional trauma. However, music therapy is a relatively new discipline, as it is stemmed from the historically prevalent sound therapy. The earliest known reference for sound therapy was in 1789 when it was used in institutions to alter sleep and wake cycles as a form of psychotherapy (Peng 2013). As it is known to be one of the oldest treatment methods and is used to treat diseases in many different cultures, it regulates physiological functions such as blood pressure and respiratory rhythm and regulates brain oxygenation and blood supply by positively affecting hormones such as serotonin, dopamine, adrenaline, and testosterone (Peng 2013).

Music therapy allows for the objectives of this paper to connect music therapy's impact on cognitive function with how this effect can translate into improved and advanced care for many different disorders and diseases.

Cognition and Music Therapy

Music therapy is regarded as an "expressive therapy," which is when the use of creative arts is implemented as a form of therapy, and unlike some traditional arts, the process of creation is more emphasized than the final product. Music therapy is used in a variety of different places and by different people. It is being used for a multitude of disorders and diseases, so it is used in some medical hospitals, cancer centers, schools, drug rehab programs, psychiatric hospitals, and correctional facilities. Music therapists often use music and its physical, emotional, mental, social, and spiritual facets to help patients improve and maintain their health. Music therapy provides a non-invasive and cost-effective technique that has contributed to improving cognitive function through its cultural role in facilitating social learning and emotional well-being (Fang et al. 2017). As previously stated, music affects many different parts of the brain, which explains why it has so many different benefits (such as improved

memory, motor function, and mood) that cover our entire human experience mentally, physically, and socially. Some of the fallbacks of music therapy include overstimulation, false memories, and anxiety. Music therapy consists of many different factors, such as volume, acoustics, and many instruments, which can sometimes provide overstimulation, causing neurological stress. In addition to this, it can create false memories and anxiety in patients suffering from disorders and diseases like post-traumatic stress disorder (PTSD) and Alzheimer's, which can cause distress (Fang et al. 2017).

Methodology

This project included a literature review and analysis, using search engines like Google Scholar, PubMed, and the National Library of Medicine. When searching for sources, there was a ten-year restriction on the research because new research findings about music therapy and cognitive performance are always surfacing, as it is a relatively new topic of research. While many case studies fell within this timeframe, no sources were excluded that were close to the period because they would still provide new information and insights that would help to add to my analysis. Keywords that were used to locate possible sources include cognitive performance in music therapy, music therapy, cognitive function, music cognition, binaural beats, and music cognition. To categorize this research, multiple case studies were observed and qualitatively analyzed in many resources to notice certain variations and similarities between the sources, which guided the conclusions.

What Is Music Therapy?

While there may be some drawbacks to music therapy being used, its boost in cognitive function over time outweighs the negative aspects, as it is proven to improve multiple domains of cognition, including attention, memory, psychomotor speed, orientation, and executive functions. In addition to this, music therapy can benefit patients by evoking a wide range of feelings that can enhance one's psychological well-being, stress reduction, and quality of life. Also, in terms of perceptions of pain, music can stimulate the release of endorphins, thus improving overall pain management.

For example, in a study by Särkämö, 89 elderly patients with mild dementia, mostly of them were diagnosed with Alzheimer's disease, were randomized to a singing group, a music-listening group, and a usual care group for 10 weeks (Swayne 2014). Compared to usual care, both music listening and the singing group improved orientation, attention, executive function, and general cognition, as proven by an increase in Mini-Mental State Examination (MMSE) scores, a test that is used extensively in clinical and research settings to measure cognitive impairment (Swayne 2014).

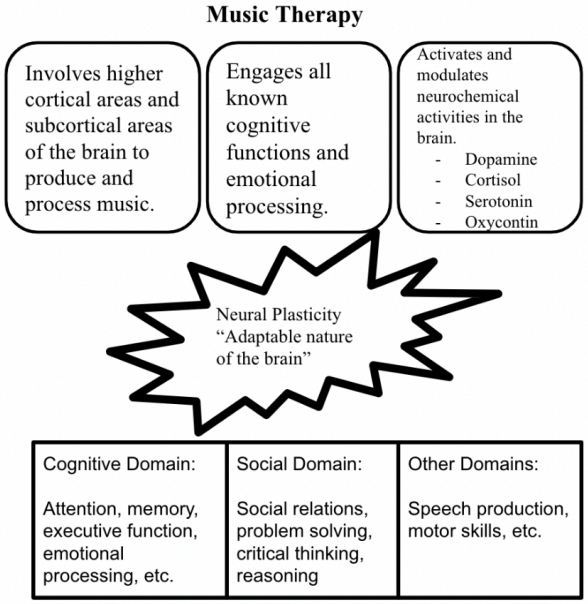

Figure 1: Factors Contributing to Neural Plasticity and Its Effect on Cognitive Domains (Hosanagar 2022)

Functional Networks and Structural Components

Many of the positive effects that music therapy has on these structural components have to do with something called brain plasticity, also known as cognitive plasticity, conveying how the different functional networks and structural components are utilized by music therapy (López-Caballero, Escera 2017). This is the ability of the brain to adapt to certain experiences and interactions by building new neural pathways. Early exposure to music therapy allows for a greater difference in the gray matter, effectively boosting brain plasticity (López-Caballero, Escera, 2017). As shown in Figure 1, music therapy causes

structural and functional changes in the brain through an increase in brain plasticity, which can lead to improved cognition but also growth and changes in brain circuitry and connectivity. Some of the different parts of the brain that are affected are the temporal lobe, which includes specific gyri that help process tone and pitch; the cerebellum, which helps to process and regulate rhythm, timing, and physical movement in music therapy; the amygdala and hippocampus, which regulate and evoke emotions and memories; and the brain's reward system. Cognitive improvement by listening to music has been linked to the relationship between the orbitofrontal cortex and the dopaminergic mesocorticolimbic circuit (Sharma et al. 2018). These parts of the brain vary in function, which conveys how music therapy reaches different audiences and can help with many diseases and disorders because of its extensive reach to different parts of the brain, as well as what all these different parts entail. For example, its effect on the amygdala and regulating emotion has been studied, and there have been clinical studies with patients with depression feeling happier because of music therapy (Sharma et al. 2018).

Comparing two case studies: one was being performed by a research team at UCLA, and the second one was being performed in an elderly home by a team of researchers. And in the first one, an elderly population was only subjected to short-term music therapy, while the second one had two groups that were subjected to short-term and long-term, respectively; generally, the short-term effects of music therapy do not contribute to a boost in cognitive function; it is the long-term exposure that initiates improved cognitive function (Lyu et al. 2018). Short-term exposure to music therapy does not cause growth in cognition, and it can only be done when there is long-term exposure. While we may not be able to revive atrophied tissue from strokes, or developmental, or neurodegenerative diseases, we can activate, or modulate, the signaling in certain areas of the brain involved in emotional processing, cognitive flexibility (or abstract thinking), attention, reward, and motivation (Lyu et al. 2018). Over time, if the brain continues to fire in new ways, it can create new neural pathways.

Translation into Positive Effects

Three factors of how music therapy affects cognition are that it involves higher cortical and subcortical areas to produce and process music, it engages all known cognitive and emotional processing, and it activates certain neurochemical activities in the brain (Stegemöller 2014). These factors contribute to "neural plasticity," where the cognitive, social, and executive domains of the human body are greatly increased. People who are exposed to long-term music therapy are proven to have an increase in brain plasticity as the neural pathways in their brains change as neurons learn how to fire in different ways or strengthen previous connections (Stegemöller 2014). This can be extremely helpful for patients that suffer from neurological diseases like Alzheimer's, Parkinson's, strokes, etc. due to an increase in the gray matter, which leads to improved cognition.

A newer aspect of music therapy and sound therapy includes "binaural beats," which are a part of auditory beat stimulation. Binaural beat therapy makes use of the fact that the right and left ear each receive a slightly different frequency, yet the brain perceives these as a single tone (Kayaaslan, Lok 2019). Auditory beat simulation, a significant aspect of music therapy, allows for certain cognitive functions to be significantly boosted. For example, Wahbeh tested verbal memory performance using the Rey Auditory Verbal Learning Test, where 92 psychiatric and neurological patients, in which 45 of the patients were classified as memory-impaired and the other 47 were classified as non-memory-impaired, are asked to repeat a list of 15 unrelated words over several trials (Smith 2019). They reported that binaural-beat stimulation at 5 Hz, for fifteen-minute sessions, resulted in a significant increase in the number of words recalled post-stimulation, as measured in the Wechsler III Memory Scale (Smith 2019). These results may suggest that prolonged exposure to auditory beat stimulation may affect verbal memory performance and recall (Smith 2019). Due to a lack of research, because it is a relatively new therapy, there are not many studies on how it can boost cognitive function. However, it is more individualized and specialized compared to some of the more traditional aspects of music therapy, like singing and playing instruments. There are five categories of brain waves (delta, theta, alpha, beta, and gamma), in which each brain wave is associated with a different activity (Wilbrecht, Shohamy 2010). For example, gamma waves show promise for helping with increased cognitive flexibility and divergent thinking (Wilbrecht, Shohamy 2010).

By focusing on certain brain waves, different cognitive abilities can be boosted depending on one's needs.

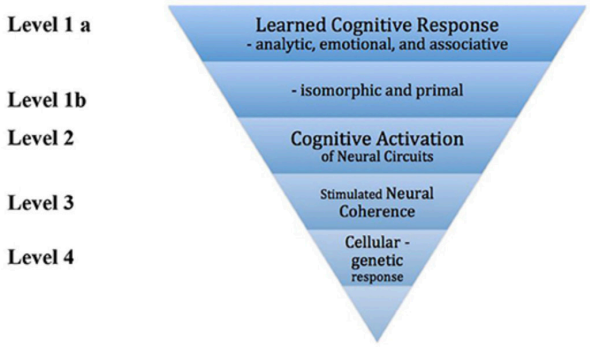

Figure 2: A model of response mechanisms to music (Bartel, Clements-Cortes 2018)

Music is implicated in many different types of interventions relating to health and well-being. It looks at treating the whole person and is broader than music medicine, which can be considered to be more of a prescribed approach to music applications. Some mechanisms are responsible for and involved in the effectiveness of music therapy (Zhang et al., 2019). The cognitive response is oftentimes connected with how one can associate an emotional response with the music they are listening to. As seen in Figure 2, Level 2 in the model involves mechanisms of neural circuitry activated by cognitive processes (Flo et al. 2022). For example, when a person loses the use of language due to a stroke, music with language activates a different circuit in the brain and can thereby rehabilitate language function. This circuit-based approach can focus on movement, speech, language, and other cognitive processes such as memory and critical thinking (Flo et al. 2022). The practice of NMT is based on neural mechanisms for cognitive processes. Levels 3 and 4 are more speculative as they are the responses to music therapy at a vibrational, rhythmic level. Listening to and participating in music therapy allows for these mechanisms to come into play (Flo et al. 2022). As they are being utilized, several different neurons and pathways in the brain are being activated, causing a boost in cognitive and executive functioning as it allows for reinforced responses.

Brain plasticity allows us to be more adaptable and ready to experience new environments, which also causes brain plasticity. This is because music therapy allows for more verbal and emotional fluency. After all, music therapy is interpreted as a new language by the brain. There is research being done on whether certain music types or certain aspects of music therapy can be used to control which areas of the brain can be changed. In addition to this, music therapy can be used to help normalize brain function in states of disease or optimize brain function in states of wellness (Kayaaslan, Lok 2019). This is done because music therapy is shown to better regulate the executive control sections of the prefrontal cortex even in a non-music-related task, and this, along with the altered activation of sensory and motor regions of the brain, translates into an improved cognitive function (Kayaaslan, Lok 2019).

Future and Current Research

Music therapy and its research have mainly been conducted using Western compositions and many classical styles, like Mozart and Bach. While music is oftentimes considered a universal language, it is important to highlight the need to recognize the importance of musical diversity and that musical preferences vary by culture, although there has been little research undertaken into multicultural music therapy. However, researcher Laksmidewi performed a study that involved the Balinese elderly in a retirement home by randomly separating two groups and having Western classical music therapy for one, and instrumental Balinese flute music therapy for the other (Schlaug 2010). As music is linked to one's identity, it can help to connect with a past sense of self. Because of the immeasurable results, it was quite difficult to see if there was a difference in cognition between the two groups.

Some research is being done on whether certain parts of the brain and cerebral circuits can be specifically accessed through music therapy to provide more individualized care. For example, Thaut and Altenmüeller developed a new brain circuit named Neurologic Music Therapy (NMT). NMT uses the perception of auditory structures and patterns in music as specific circuit activators to retrain brain function, which is organized into three main areas: sensorimotor training, speech/language training, and cognitive training (Zhang et al. 2019). A specific example of this is when Poeppel proposed the right hemisphere of the brain is potentially more advanced at handling slowly modulated signals in individuals with expressive aphasia, so the sensorimotor network will be more

easily activated with music therapy, which is exposed to the left side of the body (Schlaug 2010). This is research that has been going on for many years to see if we can optimize what type of music to select to invoke a certain cognitive, motor, or emotional response in a patient by activating certain circuits. This can then allow us to use music to help normalize brain function in states of disease or optimize brain function in states of wellness. For example, in an epilepsy case study conducted by Dr. Ovary (2009), he discovered more about music therapy and its effect on epilepsy specifically. Because patients with epilepsy have different cerebral rhythms and limbic activity, there is more research being done on music therapy and its specific effects on many disorders and diseases, and how to adapt music therapy accordingly.

Conclusion

Music therapy can be considered a non-pharmacological intervention that has the potential effects of reducing cognitive decline and improving neuropsychiatric symptoms. Research has demonstrated that music therapy, while it naturally has some fallbacks, clearly boosts cognitive function. Also, certain mechanisms of music therapy allow for different facets of cognition to be conveyed, especially through an increase in neural plasticity and gray matter. As music therapy is a relatively newer therapy, it is crucial to keep up with current and future research as it aims to provide more specialized and individualized care for individuals, especially those with neurological disorders and diseases. Certain mechanisms and aspects of music therapy can also translate into different effects, as it positively affects individuals and their executive functions. Music therapy causes cognitive function to be increased as it affects different functional networks and structural components of the brain, which relay positive effects on the different domains of cognition. While I was researching for this paper, one particularly interesting aspect of music therapy is that it is constantly changing due to new studies being conducted. It also adapts to each condition that it treats, and while it is crucial to see the benefits that music therapy provides, such as a boost in cognition, it is imperative to modify music therapy as these new studies bring more insight and perspective into how to create more advanced, specialized, and focused care for patients with disorders and diseases.

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The Intersection of Music Listening and Stress

By Claire Li

Author Bio

Claire Li is a senior at Arcadia High School in Arcadia, California. She is particularly fascinated by the intersection of STEM and the arts, as the subjects typically are regarded as separate. At the time of writing, she was the Student Managing Intern for Arcadia Unified School District's Digital Communications Internship, and has been playing piano for many years, invited to play at Carnegie Hall and Zipper Hall. She was also a top 20 finisher in the Southern California Section of the Chemistry Olympiad. In the future, Claire hopes to study an interdisciplinary field that combines arts and science to find new ways to solve traditional problems.

Abstract

The Covid-19 pandemic accentuated a growing concern towards mental health and stress, with reports of stress increasing since the onset of the pandemic. Long term exposure to stress may not only yield health risks but may also add costly financial burdens for society. In more recent years, music listening—especially relaxing or pleasurable music—has been shown to positively affect stress management and relaxation. In specific, classical music was found to have a great effect, and music chosen based on songs popular during a patient's adolescence or early adulthood may help identify music regarded as pleasurable. Though music listening and stress modulate common brain regions such as the amygdala and hypothalamus, they induce different responses. Stress activates the sympathetic nervous system, the body's "fight or flight" response which increases cortisol levels, while music can trigger the "rest or digest" parasympathetic nervous system which dampens the HPA axis and lowers cortisol. Music's ability to regulate the HPA axis, lowering stress biomarkers such as cortisol levels, heart rate, and blood pressure is crucial to its use as a therapy for stress. Traditional stress management or prevention measures are often rather expensive and inaccessible; however, music listening provides a cheaper, non-invasive, and accessible alternative.

Keywords: stress, music, music therapy, music listening, mental health, limbic system, HPA axis, emotion, paralimbic nervous system, amygdala, classical music

Introduction

The onset of the Covid-19 pandemic has brought mental health and stress to the forefront of discussion. American Psychological Association chief executive officer Arthur C. Evans Jr., PhD, commented that Americans are now "reaching unprecedented levels of stress that will challenge [their] ability to cope" (American Psychological Association, 2022).

Stress can be defined as a response to a bodily or environmental demand that disrupts the body's homeostasis (Kumar et al., 2013; Jackson, 2013). Such demands may require physical, mental, or emotional adjustment (Kumar et al., 2013) and may be perceived as either threatening or benign based on whether coping resources are available to an individual (McEwen and Gianaros, 2010). Though not all stress is unhealthy and a degree of stress in everyday life is natural, excessive stress may have an adverse effect on health, behavior, and relationships (Jackson, 2013). Further, the repeated activation of stress responses (chronic stress) has long term effects on the body which may contribute to mental health problems such as anxiety, depression, or and/or addiction as well as physical health risks such as chronic pain and cardiovascular disease (Witte et al., 2019). Because prolonged exposure to stress may lead to substantial financial expenditures for society and traditional stress management measures are rather expensive, cost effective preventative and stress management measures have been sought after (Thoma et al., 2013). Music therapy, an economic, non-invasive, and accessible tool, has recently received great interest in regards to managing stress.

Both music and stress have the ability to modulate the autonomic nervous system, which can be divided into the sympathetic and parasympathetic nervous system. The sympathetic nervous system is responsible for the body's "fight or flight" response, a state of elevated activity and attention. Blood pressure and heart race increase as a result, and nearly all living tissue is innervated (Waxenbaum et al., 2021). Contrastly, the parasympathetic nervous system, which promotes "rest and digest," lowers heart rate and blood pressure, and innervates only the certain parts of the body such as the head (Waxenbaum et al., 2021).

This paper explores the viability of passive music therapy, music listening that eliminates rhythmic movement involved in active music therapy (McPherson et al., 2019), as a means of reducing stress in the post-Covid world. First, the mechanics of music listening and emotional processing are explored; second, the mechanisms of stress are identified; third, the intersection of the brain regions affected by stress and music is analyzed. Subsequently, I propose how music can be used as a therapeutic tool for stress.

Methodology

This paper is a literature review compiled using search engines such as Google Scholar and Pubmed. There was no restriction on the end date of the articles chosen. However, the initial date was restricted to January 1, 2000. Keywords used to locate sources include music, limbic system, neural basis of music perception, music and emotion, mesolimbic system, amygdala, neural basis of stress, and the parasympathetic nervous system. Findings from the articles were then categorized into five main sections: Neural Basis of Music Perception, Emotional Processing of Music, Stress, Music as a Therapy for Stress, and Choosing Music for Stress Relief Music Therapy. This study will focus on the emotional processing of music as it most pertains to the brain's response to stress.

Neural Basis of Music Perception

The sensory system for hearing is arranged in a hierarchical manner, beginning from the neural processing stations in the ear and ascending to stages with growing complexity or abstract features (Warren, 2008). Acoustic information is first translated into neural information within the cochlea (inner ear) (Kolesch and Siebel, 2005), where complex sounds are converted into electric impulse or signals (Särkämö et al., 2013). The information is then transmitted from the auditory nerve to the auditory brainstem (Särkämö et al., 2013), allowing features such as periodicity or intensity of the sound to be processed. From the brainstem, auditory information travels to the thalamus, and is projected primarily to the primary auditory cortex (PAC) and adjacent secondary auditory fields in the temporal lobe, and also to the amygdala and medial orbitofrontal cortex (Kolesch and Siebel, 2005; Särkämö et al., 2013). Within the auditory cortex (AC), more specific information such as pitch chroma, timbre, and intensity are extracted (Kolesch

and Siebel, 2005). In subsequent stages, the cerebral cortex is involved (Warren, 2008).

Following the initial encoding, music triggers cognitive, motor, and emotion processes controlled by both cortical and subcortical areas. For instance, listening to familiar music may activate processing in the hippocampus, medial temporal, and parietal areas—regions involved in episodic memory—while music perceived as emotion may engage limbic and paralimbic areas (Särkämö et al., 2013).

Emotional Processing of Music

Analysis of functional neuroimaging studies (e.g. fMRI and PET) have shown music to modulate activity in brain structures such as the amygdala and nucleus accumbens (NAc) which are crucial to processing emotion (Schaefer, 2017). The structures documented are involved in both the limbic system, a complex network central to emotional processing (Koelsch, 2010).

Limbic System

Virtually all limbic structures are shown through functional neuroimaging and lesion studies to be affected by music-evoked emotions (Koelsch, 2010). Though there is no universal consensus on the total list of structures in the limbic system, key brain regions involved are: the limbic cortex, hippocampal formation, amygdala, septal area, and hypothalamus (RajMohan and Mohandas, 2007). Limbic brain regions communicate back and forth with other regions including the thalamus and midbrain. The limbic system induces emotional responses like fear as well as autonomic and endocrine responses (Rajmohan and Mohandas, 2007). Pleasant music is found to activate both limbic and paralimbic structures such as the posterior hippocampus, nucleus accumbens, and anterior insula (Koelsch et al., 2006). Unpleasant stimuli, based on blood-oxygen-level-dependent (BOLD) responses comparing unpleasant and pleasant stimuli, were shown to inhibit emotional activity in limbic regions. Pleasant music can therefore be favored to alter limbic activity.

The amygdala, a highly differentiated region located near the temporal pole of the cerebral hemisphere (Swanson and Petrovicha, 1998), plays a crucial role in regulating and modulating the emotion network (Schaefer, 2017). After the amygdala receives and processes information from the central auditory system and sensory systems, signals are sent to pathways to the hypothalamus, an area integral to maintaining homeostasis and overcoming stressors (allostasis) (Saper and Lowell, 2014; Schaefer, 2017; Akimoto et al., 2018). When music is processed, projections to the hypothalamic-brainstem structures from the amygdala and hippocampus induce autonomic and endocrine responses (Li, Cheng, and Tsai, 2019). One hormone produced by the hypothalamus is oxytocin. Oxytocin responses occur during music listening after the music stimuli is transferred to the amygdaloid body and the hypothalamus receives information from the amygdaloid body circuit (Akimoto et al., 2018). Some studies suggest that pleasant stimuli increase oxytocin production (Akimoto et al., 2018); oxytocin is said to regulate the hypothalamic-pituitary-adrenal (HPA) axis (Akimoto et al., 2018; Neumann et al., 2000) by reducing the amount of cortisol (C21H30O5) released by the HPA axis (Schaefer, 2017), indicating the hypothalamus can affect the parasympathetic nervous system (Schaefer, 2017).

One pathway related to the limbic system is the mesolimbic system, a dopaminergic reward pathway originating in the ventral tegmental area (VTA) of the brain that projects to the amygdala, NAc, and hippocampus (Cox and Lee, 2016). Functional magnetic resonance imaging (fMRI) conducted by Menon and Levitin (2005), aimed to examine the role of the mesolimbic pathway involving the NAc and VTA, found important dynamic interactions mediated by the VTA to the hypothalamus, insula, and orbitofrontal cortex (OFC) (Menon and Levitin, 2005). The pathway is functionally connected to the AC; for instance, connectivity between the AC and NAc can dictate whether an individual will purchase a song (Schaefer, 2017).

The mesolimbic pathway starts first in the VTA, an area in the brainstem. Mesolimbic dopamine neuron cell bodies are found in the VTA, and are projected to the NAc, a structure involved in pleasure, reward, and addiction located in the ventral striatum (Schott et al., 2008), via the mesolimbic pathway (Menon and Levitin, 2005). VTA and NAc activations were found to be significantly correlated, indicating a link between hedonic music and dopamine release; greater feelings of reward during music listening is

attributed to increased dopamine levels in the VTA and NAc (Menon and Levitin, 2005). The release of dopamine affects pleasure ("chills" are one indication) as well as motivational drives of musical reward (desire to spend money) (Ferreri et al., 2019). Even in the absence of chills, activity changes in the amygdala, ventral striatum, and hippocampal can occur as indicated by a 2006 fMRI study (Schaefer, 2017). This emotional arousal is correlated with increased sympathetic nervous system as measured by a study that examined sympathetic nervous system markers such as heart rate and body temperature following pleasurable music listening (Zatorre and Salimpoor, 2013).

As highlighted by recent studies, key limbic regions affected by music include the amygdala, hippocampus, and hypothalamus. In addition, music is proven to modulate both the sympathetic and parasympathetic nervous systems, with the regulation of the HPA axis correlating with parasympathetic activity and the increase of dopamine associated with sympathetic activity. This indicates that different music may yield different responses, hinting that the specific genre or type of music may be important to examine to achieve the best stress mitigating effects.

Stress

The brain is the primary target for various stressors due to its sensibility to stress-induced situations (McEwen and Gianaros, 2010; Kumar et al., 2013) and is also the location where the stress response begins, as the brain can discern whether a stimulus is threatening (McEwen and Gianaros, 2010). First in the stress response is the perception of a threatening stimulus (Godoy et al., 2018). Stimuli can be generally categorized into either physical (e.g. infection or hemorrhage) or psychological stressors (e.g. failure to satisfy internal drives) (Godoy et al., 2018; Doewes et al., 2021). Different stressors—physiological or psychological—are processed in different brain circuitries, though there may be some overlap (Godoy et al., 2018; Doewes et al., 2021).

The brainstem and hypothalamic regions of the brain are the main structures involved in the processing of physical stressors (Godoy et al., 2018; Doewes et al., 2021). Short-lasting responses such as alertness occur as a result of the sympathetic adrenomedullary system (SAM), the first phase stress processing (Godoy et al., 2018). Activation of the HPA axis occurs as the second phase, resulting in amplified and prolonged secretory reactions (long-lasting responses) (Godoy et al., 2018; Doewes et al., 2021). Apart from the brainstem and hypothalamic regions, limbic regions such as the amygdala, hippocampus, and prefrontal cortex (PFC) have been shown to participate in the stress response for physical stressors by influencing the autonomic response to stress and stimulating the HPA axis (Godoy et al., 2018; Doewes et al., 2021).

Psychological stressors tend to induce physical and cognitive stress responses. Fundamental in the regulation of the stress response for psychological stimuli are the prosencephalic nuclei and limbic regions like the PFC, amygdala, hippocampus, PVN, VTA, and NAc. PFC's significance in the stress reaction is complicated; however, one known role of the PFC is sending major projections to the amygdala, which was initially proven to stimulate corticosteroid synthesis and secretion (Godoy et al., 2018; Doewes et al., 2021).

The HPA axis is activated by both physiological and psychological stressors, signifying that it plays an important role in stress response. Moreover, there is an anatomical overlap between brain regions affected by physiological and psychological stressors and music. For both stress and music, limbic regions were documented as critically involved. Activity within these areas, such as the amygdala and hippocampus, suggest that music has the potential to affect brain areas implicated in stress, and consequently, alter the body's response to stress.

The stress response system is also interconnected with many hormones and neurotransmitters. The HPA axis is critically involved in hormone release, while neurotransmitters involved include serotonin and dopamine (Kumar et al., 2013).
HPA Axis

Activation of the HPA axis is among the most distinguished features of the physiological stress response (Stanwood, 2019). After a stimulus is received in the hypothalamus, the HPA axis is initiated. Corticotropin releasing factor (CRF) is released, which then initiates the release of adrenocorticotropic hormone (ACTH) and beta-endorphin from the pituitary. Released ACTH triggers the liberation of

adrenal steroids such as cortisol and testosterone (Schaefer, 2017; Kumar et al., 2013). High cortisol levels are associated with greater stress, regardless of psychological or physiological stressors (Schaefer, 2017). Once the threat subsides, cortisol levels decrease, and the parasympathetic nervous system lowers the stress response (Weissman and Mendes, 2021).

Understanding the role of the HPA axis in stress and music listening responses is crucial towards understanding the effect of music therapy on stress. Significantly, music and stress alter the HPA axis in opposite ways: stress activates the axis while music can regulate it, inducing the parasympathetic nervous system which lowers the stress response.

Serotonin

Long-standing stress has been evidenced by previous studies to reduce serotonin levels (Kumar et al., 2013). Within the endocrine system, serotonin has a complex effect on the stress pathway as it helps to regulate the HPA axis at many levels (Berger et al., 2009). It was found that oxytocin triggers serotonin release (Lefevre et al., 2017).

Because oxytocin and the serotonin produced regulates the HPA axis, it likely may be an important chemical in the stress coping response. Thus, higher levels of serotonin or oxytocin may be associated with lower levels of stress and may be an indicator towards whether music therapy is beneficial or not.

Dopamine

Preclinical studies have suggested varying dopamine responses to different stimuli. More acute, controllable, or escapable physical stressors were found to increase dopamine release in the ventral striatum, while chronicle, inescapable stressors reduced dopamine levels (Kumar et al., 2013). Further, dopamine facilitates the stress response by coregulating chemical transmitters (Stanwood, 2019).

Interestingly, both stress and music can induce the dopaminergic system. Though dopamine contributes to the stress response, it may also affect the stress coping response (Stanwood, 2019). For instance, midbrain dopamine neurons were found to be capable of regulating the HPA axis as dopamine decreases reduced stress-induced corticosterone secretion (Stanwood, 2019), suggesting music's ability to increase dopamine levels may not necessarily signal an increase in stress, but rather, may help reduce stress.

Music as a Therapy for Stress

In general, music that is considered pleasurable or relaxing is correlated with decreasing stress. The ventral striatum, part of the mesolimbic "reward" pathway, is activated during pleasurable music listening; for instance, music that is found pleasurable because of its familiarity (Chanda and Levitin, 2013). "Relaxing music" (generally including slow tempo, consonant, low pitch, and no lyrics) was demonstrated to decrease stress and anxiety in healthy subjects, pediatric patients undergoing medical procedures, patients undergoing invasive medical procedures (e.g. surgery, dental procedures), and those with coronary heart disease (Koelsch et al., 2006; Chanda and Levitin, 2013). Secretory immunoglobulin A (sIgA) is an antibody involved in immune exclusion, the process of limiting access of microorganisms, bacterial, or antigens (Schaefer, 2017; Corthésy, 2013); high levels of sIgA are associated with positive effects, while low levels may relate to chronic stress (Schaefer, 2017). Relaxing music or musak were observed to significantly increase sIgA concentrations (Schaefer, 2017; Kreutz et al., 2004). A 2004 study found no significant changes in sIgA, but did note a decrease in cortisol levels (Kreutz et al., 2004). Though many studies reaffirmed the benefit of music therapy towards stress, not all studies found a significant change likely because music is very subjective. Taken together, the findings generally indicate that relaxing music can reduce stress. Since the 2004 study did not find significant changes but also did not discover adverse effects of relaxing music, it signals that relaxing music for music therapy may be a good strategy to potentially help patients suffering from stress without the risk of inducing much harm.

Various characteristics of the music presented often impacts the effects of music therapy. Classical choral, meditative, and folk music have been found to greatly lower cortisol levels, while techno music has been correlated with increased cortisol levels (Schaefer, 2017; Chanda and Levitin, 2013). The increase in cortisol level triggered by techno music highlights how certain types of music may actually increase stress levels as opposed to decreasing levels,

thus underscoring the importance of choosing the right music for stress therapy. Unlike the more relaxing music types such as classical, choral, or meditative, techno music is characterized by its heavy bass drum on each beat, snare of clap on the second and fourth beats, and hi-hat on the sixteenth beat. Likely, this strong drumming pattern impairs the relaxing qualities of music. Slow-tempo music has also been shown to increase salivary oxytocin compared with fast-tempo music (Akimoto et al., 2018). Because brainstem neurons generally fire synchronously with tempo, slow music and musical pauses often correlate with lower heart rate, respiration, and blood pressure, whereas faster music increases such parameters (Chanda and Levitin, 2013). Another study compared three pieces of music selected due to their different rhythmic properties: a Strauss waltz (regular rhythm), a modern piece by H.W. Henze (irregular rhythm), and a meditative piece by Ravi Shankar (non-rhythmic).

Though the meditative piece was shown to significantly reduce plasma levels of cortisol and norepinephrine, no effect was concluded for the other two pieces (Chanda and Levitin, 2013). Results from this study indicate non-rhythmic music may be best used as a stress therapy. Additional study explored the effects of 528 Hz music, which has more recently been regarded as "healing" music, and 440 Hz music, music based on the reference tone of tuning. Exposure to 528 Hz soothing piano music significantly reduced mean cortisol levels and increased mean oxytocin levels after 30 minutes, while exposure to 440 Hz music showed slightly decreased mean cortisol levels after 30 minutes. No stress mitigation effect could be confirmed from the 440 Hz condition because there were no significant differences in the mean oxytocin levels or mean levels of cortisol (Akimoto et al., 2018). Taken together, results from these experiments suggest that music is beneficial to treating stress and may share characteristics such as an absence of a strong bass (i.e. classical choral, meditative, and folk music), slow tempo, and pitch based on the 528 Hz tone.

When using music as a therapy for stress, regard for individual music preferences and context factors appear to be significant in mediating the effects of music (Kreutz et al., 2004). Further, some researchers noted that music preferences may vary depending on the listener's mental state (Akimoto et al., 2018). These two factors underscore how music therapy not only varies from person to person, but may even differ in an individual from time to time. Because of this, there may be some disparities in the studies presented, as the music chosen may now have been the most pleasurable or relaxing to all participants. In addition, it highlights the need to carefully examine the individual to find his/her preferences when selecting music used to alleviate stress.

Based on the studies outlined above, I propose that certain types of music, the most optimal generalized as music that people find pleasant and relaxing, which may typically feature characteristics such as familiarity, slow tempo, absence of strong drumming, and non-rhythmic patterns, can be used to activate the parasympathetic nervous system to reduce cortisol and relieve stress. This is especially useful in the post-Covid world where stress has increased and music streaming platforms have made music more accessible than ever. For the best results, individual preference and mood should be taken into consideration as music is highly subjective.

Choosing Music for Stress Relief Music Therapy

Preferential relaxing music best suited for stress relief music therapy often possesses characteristics such as familiarity, slow tempo, and non-rhythmic patterns. Though people's music preferences are shaped by factors such as ethnicity, personality, and/or social class, the most determining factor has been identified as age and nostalgia (Davies et al., 2022). This indicates that finding music released during a person's late adolescence or early adulthood may help when selecting music for music therapy. For instance, for the Baby Boomer generation, one might choose more music under the rock and roll genre, while pop or hip hop might be used more for Generation Z. While familiar, self-selected songs have shown to reduce stress (Labbé et al., 2007), other studies revealed that classical music has a greater benefit (Chennafi et al., 2018). Likely, both the popular, familiar music and classical music can induce oxytocin stimulation, associated with positive, happy feelings; however, the genres most popular amongst generations tend to have a faster, upbeat tempo which is involved more in emotional excitation (Ooishi et al., 2017), contrasting with the physiological relaxation associated with slower tempo music.

In regards to classical music, music from the Impressionist Period may be best suited for passive music therapy when treating stress. Pieces from this period are known for evoking more surreal impressions or feelings, less confined to a traditional harmony or structure. Further, the music often lacks a steady, defined rhythm, unlike music from other periods. Choosing slower tempo Impressionist music can thus fulfill characteristics of relaxing music such as a slow tempo and non-rhythmic pattern known to activate the parasympathetic nervous system.

Conclusion

Of the total respondents in the United States 2022 Pandemic Anniversary Survey conducted online by The Harris Poll on behalf of the American Psychological Association, 56% noted that they could have benefitted from more emotional support since the onset of the pandemic. Music, which can lower stress and stimulate pleasure, may be an effective tool to help address such needs. Stress activates the sympathetic nervous system, stimulating the HPA axis and producing cortisol, while music listening triggers the parasympathetic nervous system which regulates the HPA axis and lowers cortisol production. Before using music as a therapy for stress, though, individual preferences regarding relaxing and pleasant music must be considered to ensure music will alleviate, not magnify stress. Music selections can be made by taking in factors such as the person's age to choose music popular during their adolescence. Classical music was also shown to be amongst the most effective genres to use, and music specifically from the Impressionist Period may be a good selection, fitting characteristics of stress relieving music such as a non-rhythmic pattern. Future studies may analyze music preferences amongst certain age groups or cultural groups to identify genres or songs that are viewed as most pleasurable or relaxing to each category. More research can also be conducted to assess the impact of music therapy in conjunction with other tasks such as exercise as a means of reducing stress.

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Suicidal Thoughts Detection from Social Media Using AI

By Rishav Biswas

Author Bio

Rishav Biswas is a high school graduate from Kolkata, India. He is 18 years old and passionate about AI. Three months ago, he got rejected from every college he applied to, including the safety schools also. He wants all the readers to always dream big but also remember that it will hurt a lot when you fail. Even if it hurts, you will be living with the satisfaction of trying. Through this research, he got to learn so many things which are not taught in his school. He has a dream of reducing the suicide rate in this world.

Abstract

Suicide is one of the leading causes of death worldwide. Early detection and prevention of suicide attempts should be addressed to save lives. Nowadays, people on social media are posting posts that include suicidal thoughts. To detect this kind of post, the author has used an AI model, which can do this by analyzing text. This study is about how the model works and the results of testing the model. The study will cover every aspect of the model. The study also includes an explanation of GloVe, which is used for word embedding. The author has also discussed the weaknesses of the model. There are some pre-existing models for suicidal thoughts detection, but their accuracies are not as high as this model. This model can detect suicidal thoughts with a recall of 0.93 (93 percent) and a precision of 0.94 (94 percent). The author thanks Dr Ganesh Mani, an instructor at Carnegie Mellon University (and editorial board member recused from the review of this paper), and Alfred Renaud for helping him to complete this research project.

Keywords: Machine Learning, AI modeling, suicide, suicidal thoughts, suicide detection, social media, AI, suicidal ideation, suicidal thoughts detection

Introduction

Suicide is among the top three causes of death among youth worldwide. According to the WHO (5. World Health Organization, https://www.who.int/news-room/fact-sheets/detail/suicide), every year, almost one million people die from suicide, and 20 times more people attempt suicide; a global mortality rate of 16 per 100,000, or one death every 40 seconds and one attempt every 3 seconds, on average. The rates of suicide have greatly increased among youth, and youth are now the group at highest risk in one-third of the developed and developing countries.

Due to the advances of social media and online anonymity, an increasing number of individuals turn to interact with others on the internet. Online communication channels are becoming a new way for people to express their feelings, suffering, and suicidal tendencies. Hence, online channels have naturally started to act as surveillance tools for suicidal ideation, and mining social content can improve suicide prevention. In addition, strange social phenomena are emerging, e.g., online communities reaching an agreement on self-mutilation and copycat suicide. For example, a social network phenomenon called the "Blue Whale Game" in 2016 allegedly used many tasks (such as self-harming) and allegedly influenced game members to commit suicide in the end (6. for a journalistic review of the phenomenon, see BBC, https://www.bbc.co.uk/news/blogs-trending-46505722). Suicide is a critical social issue and takes thousands of lives every year. Thus, it is necessary to detect suicidality and prevent suicide before victims end their life. Early detection and treatment are regarded as the most effective ways to prevent potential suicide attempts.

Social media has become an integral part of our lives, especially for the youth. Many people use it to share photos and funny stories, talk about their political viewpoints and catch up with friends. It can also be a place where they feel comfortable talking about struggles or their pain. It may be easier to write about how they feel behind a screen than to share it with someone in person. When they are struggling, they may isolate themselves, and social media becomes one of their only connections to others.

There has been an increase in the number of posts where people are talking about emotional problems. These posts sometimes go one step further where people are expressing their suicidal thoughts. There is a chance that these people may be involved in a suicidal attempt in the future. If I can detect these types of posts, it may help in suicide prevention.

Now to detect suicidal thoughts, I have to take the help of an AI model. The AI model is used for the training and deployment of machine learning algorithms that emulate logical decision-making based on available data. To build an AI model, I need a dataset that can be used for training and testing its purpose. The text involved in a post is the primary source of data to be used as a data set.

In this study, I have taken the dataset from subreddits on the Reddit platform. I have used GloVe for word embedding [3]. In natural language processing, word embedding is a term used for the representation of words for text analysis, typically in the form of a real-valued vector that encodes the meaning of the word such that the words that are closer in the vector space are expected to be similar in meaning. Then the model was created to detect suicidal thoughts.

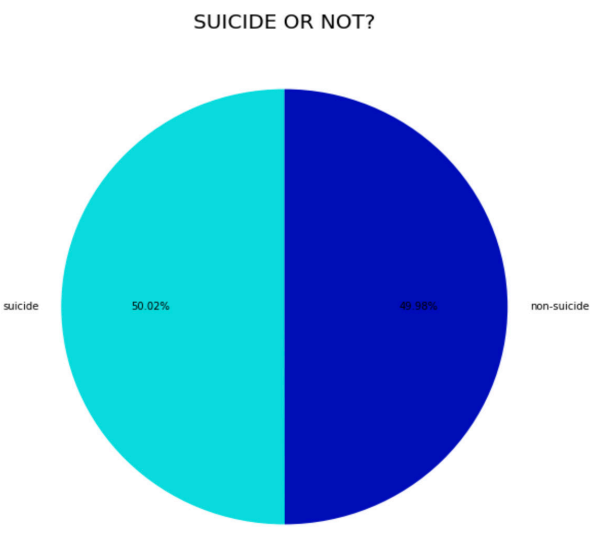
Methods

Data Collection and Preparation

I have collected the data from (https://www.kaggle.com/datasets/nikhileswarkomati/suicide-watch). The dataset consists of 232,074 posts, which are classified into two classes. The two classes are suicide and non-suicide. The dataset is a collection of posts from "SuicideWatch" and "depression" subreddits on the Reddit platform. The posts are collected using Pushshift API. All posts that were made to "SuicideWatch" from Dec 16, 2008 (creation) till Jan 2, 2021, were collected, while "depression" posts were collected from Jan 1, 2009, to Jan 2, 2021. The dataset is illustrated in the table below.

#	TEXT	CLASS
29	yea putting a knife to my wrist didn't give me any hesitation like how it used to, i am free from tha...	Suicide
30	I am ending my life today, goodbye everyone.I am 36 almost 37, I am on disability for PTSD and Rheum...	Suicide
37	Guys I want friends That's it , I'm alone and don't talk to anyone dm me or anything, I'm just tired...	non-suicide
4	Finally 2020 is almost over... So I can never hear "2020 has been a bad year" ever again. I swear to...	non-suicide
25	I'm scared. Everything just seems to be getting worse and worse. I'm young and I think I'm transge...	Suicide

In the above table, there are three columns: the first column is unique values assigned to every text, the second column is text, and the third column is about the class in which a particular text falls. To demonstrate the percentage of text that fall into two classes, there is a pie chart below.



The two classes have almost the same number of data, around 50 % each. This is important for any kind of biased results for my model. There are some changes made to the original dataset due to mismatches of data. This is quite significant for the accuracy of my model.

The dataset was split into two subsets for training and testing of the model. Then, I cleaned the text data by removing special characters or any stopwords (There are a lot of commonly used words, such as 'the', 'is', 'that', 'a', etc., that would completely dominate an analysis, but don't offer much insight into the text in the documents; these words that I want to filter out before analysing the text are called 'stopwords') and converting it to lower case. After that, it was divided into tokens by the process of tokenization (Many TDM methods are based on counting words or short phrases. However, a computer doesn't know what words or phrases are – to it, the texts in your corpus are just long strings of characters. You need to tell the computer how to split the text up into meaningful segments that will enable it to count and perform calculations. These segments are called tokens, and the process of splitting your text is called tokenization).

For pre-processing the text data, I have used the pad_sequence() function from the Keras library [2]. It is done to ensure that all inputs are of the same size. Then I used Label Encoder, from the scikit-learn library, to convert labels (words of the text are labeled) into a numeric form to convert them into the machine-readable form. It will help the model to decide in a better way how those labels must be used.
The data is now collected and prepared for the model to be used.

Word Embedding and GloVe

Word Embedding is the process of converting high-dimensional data to low-dimensional data in the form of a vector in such a way that the two are semantically similar. In its literal sense, "embedding" refers to an extract (portion) of anything. Generally, embeddings improve the efficiency and usability of machine learning models and can be utilized with other types of models as well. When dealing with massive amounts of data to train, building machine learning models is a nuisance. As a result, embedding comes into play.

I have used GloVe for word embedding. GloVe stands for Global Vectors [3]. The GloVe is

essentially a log-bilinear model with a weighted least-squares objective. The main intuition underlying the model is the simple observation that ratios of word-word co-occurrence probabilities have the potential for encoding some form of meaning. For example, consider the co-occurrence probabilities for target words 'ice' and 'steam' with various probe words from the vocabulary. Here are some actual probabilities from a 6-billion-word corpus:

Probability and Ratio	K = Solid	K= Gas	k = Water	K = fashion
P(K|ice)	1.9×10^{-4}	6.6×10^{-5}	3.0×10^{-3}	1.7×10^{-5}
P(K|steam)	2.2×10^{-5}	7.8×10^{-4}	2.2×10^{-3}	1.8×10^{-5}
P(K|ice)/P(K|steam)	8.9	8.5×10^{-2}	1.36	0.96

As one might expect, ice co-occurs more frequently with solids than it does with gas, whereas steam co-occurs more frequently with gas than it does with solids. Both words co-occur with their shared property, water frequently, and both co-occur with the unrelated word fashion infrequently. Only in the ratio of probabilities does noise from non-discriminative words like water and fashion cancel out so that large values (much greater than 1) correlate well with properties specific to ice, and small values (much less than 1) correlate well with properties specific to steam. In this way, the ratio of probabilities encodes some crude form of meaning associated with the abstract concept of the thermodynamic phase.

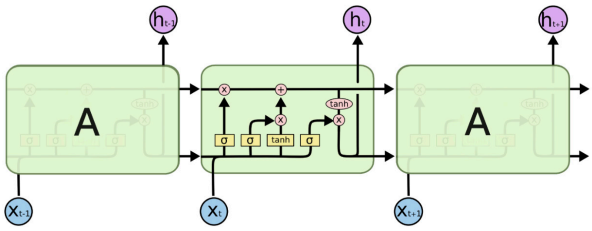
The training objective of GloVe is to learn word vectors such that their dot product equals the logarithm of the words' probability of co-occurrence. Since the logarithm of a ratio equals the difference of logarithms, this objective associates (the logarithm of) ratios of co-occurrence probabilities with vector differences in the word vector space. Because these ratios can encode some form of meaning, this information gets encoded as vector differences as well.

I have used a pre-trained GloVe Embedding taken from(https://www.kaggle.com/datasets/authman/pickled-glove840b300d-for-10sec-loading) to build my model. It was of size 2.3 Gb. It was trained on a dataset of 84 billion tokens(words) with a vocabulary of 2.2 million words and an embedding vector size of 300 dimensions. I can seed the Keras (a library) Embedding layer with weights from the pre-trained embedding for the words in the training dataset. Then I can define the examples, encode them as integers, and then pad the sequence of similar length. Keras provides a Tokenizer class that can be fit on the training data, can convert text to sequences consistently by calling the texts_to_sequences() method on the Tokenizer class, and provides access to the dictionary mapping of words to integers in a word_index attribute.

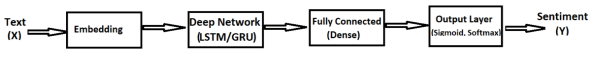
I need to load the entire GloVe word embedding file into memory as a dictionary of words for the embedding array. After that, I need to create a matrix of one embedding for each word in the training dataset. I can do that by enumerating all unique words in the Tokenizer.word_index and locating the embedding weight vector from the loaded GloVe embedding. I will be using this embedding_matrix in my model.

Model Training and Working

I want to build a sequential model with the help of the Recurrent Neural Network (RNN) method. Sequence models are machine learning models that input or output sequences of data. Keras is the main Library that I have used to build this model [2]. To use the RNN method, I have used a built-in RNN layer of Keras (a library) named LSTM(Long short-term memory).



In the above picture, it is a typical LSTM unit that is repeated over the whole length of a sequence. In my model, I first created layers, and with the help of LSTM and embedded_matrix, which was already created, I can train my model. The model performed 20 epochs with a batch_size = 256 on the training dataset. After that, for testing, I used the testing data set. This data set was already split earlier.



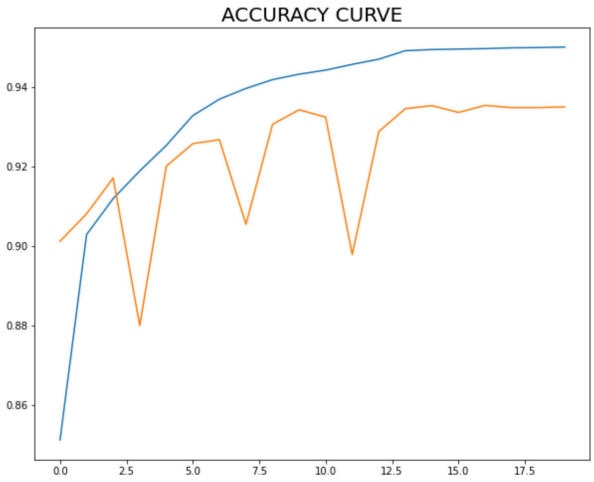
From the above picture, it can be understandable how my model works. At first, there

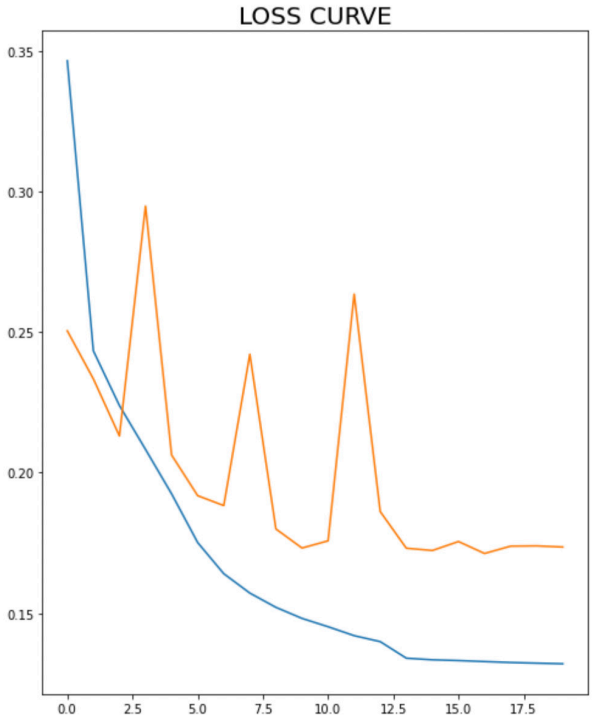
is the text which is the input data, and then there is an embedding layer in which it uses word embedding. Thirdly it has a Deep network (LSTM) that takes the sequence of embedding vectors as input and converts them to a compressed representation. The compressed representation effectively captures all the information in the sequence of words in the text. Fourthly, the fully connected layer takes the deep representation from the LSTM and transforms it into the final output classes. Lastly, it displays its sentiment as either suicide or non-suicide.

Results

In the below graph, the blue line is the accuracy of the training set, and the orange line is the validation set accuracy. The x-axis is for accuracy, and the y-axis is for epoch.

The Model has achieved a weighted average precision of 0.95(95 percent), recall of 0.95(95 percent), and f1-score of 0.95(95 percent) on the training set. For the testing set, the precision, recall, and f1-score are 0.94(94 percent), 0.93(93 percent), and 0.93(93 percent) respectively. The precision for the suicide classes is high than the non-suicide classes for the testing set, while the recall is just the opposite. In the training set, both the precision and recall are the same.





In the above graph, the blue line is the accuracy of the training set, and the orange line is the validation set accuracy. The x-axis is for loss, and the y-axis is for epoch.

Discussion

This study gives a clear picture of how a model is created and how it works. The accuracy of the model is slightly high in comparison to other works on suicidal thought detection. There was a significant change in accuracy when I made some changes to the dataset. My next step will be to analyze the dataset for more scope for improvement in accuracy.

I will be using more datasets in the future to test and improve the accuracy of this model. From the results, it is unclear why there is a difference between precision and recall. I will be looking into that. There will always be uncertainty about the reality of the text means somebody may be for fun posting suicidal thoughts or sarcastically doing this. For these reasons, I should focus on future studies to make a more efficient model. I will also be working on how to reduce the loss of the model during its work.

The ultimate aim of suicidal thoughts detection is intervention and prevention. One of the applications of this study is Proactive Conversational Intervention. Very little work is undertaken to enable proactive intervention. Proactive Suicide Prevention Online (PSPO) [4] provides a new perspective with the combination of suicidal identification and crisis management.

An effective way is through conversations. For enabling timely intervention, automatic response generation becomes a promising technical solution. Natural language generation techniques can be utilized for generating counseling responses to comfort people's depression or suicidal ideation. Reinforcement learning can also be applied to conversational suicide intervention. After suicide attempters post suicide messages (as the initial state), online volunteers and lay, individuals will take action to comment on the original posts and persuade attempters to give up their suicidality.

Conclusion

The study is successfully able to interpret the model. The study also gives every detail about the model building, which will be helpful to beginner students. The model has an accuracy of around 94 percent, which can further be increased. Overall, if you look into the study, it is quite evident that AI can successfully detect suicidal thoughts from social media. Online social content is very likely to be the main channel for suicidal ideation detection in the future [1]. It is, therefore, essential to develop new methods which can heal the schism between clinical mental health detection and automatic machine detection, to detect online texts containing suicidal ideation in the hope that suicide can be prevented.

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Titan and Europa: Candidates as Habitable Moons for Humanity

By Daniel Hu

Author Bio

Daniel Hu is a student at Brunswick School in Connecticut. He is passionate about physics and astronomy, especially astrophysics. He started his own astronomy club at school to inspire people to discover the universe above their heads. Daniel enjoys volunteering at a local observatory, where he operates their telescope and teaches the public about the night sky. He also likes to conduct research on asteroid occultations. He has his own telescope setup, and regularly takes part in astrophotography, particularly nebulae and star clusters. Outside of academics, he is an avid hockey player for his high school team, one of the top in the nation.

Abstract

One major reason humans want to explore potentially habitable extraterrestrial objects is to ensure the survival of our species. Moons of Saturn and Jupiter, such as Titan and Europa, are less known compared to Mars and Venus but have promising features that could make them habitable for humans. Titan has a thick atmosphere similar to Earth's, and Europa is speculated to have a vast subsurface liquid water ocean. However, challenges such as long travel distances and cold surface temperatures are also present on these moons. This paper will analyze features in depth on Titan and Europa that make them ideal candidates as potential places that could support human life. Challenges of exploring and inhabiting these moons are also considered. Two future missions to Titan and Europa, Dragonfly and Europa Clipper, their instruments and information they can gather, and what these new discoveries can mean for human exploration are also discussed.

Keywords: Titan, Europa, Extraterrestrial Habitability, Subsurface Ocean, Atmosphere, Dragonfly missions, Europa Clipper mission, Sensing With Independent Micro-Swimmers

Introduction

On Earth, problems such as global warming, resource depletion, and even human conflict threaten the survival of our species. Although these problems may not lead to immediate catastrophe, they are problems that one should be prepared for. In terms of identifying candidates for habitable planets, Mars and Venus have received a large amount of attention in past and present missions. For comparison, NASA has had 23 missions to Mars (NASA Mars Exploration Program, 2021), while only six to Europa (NASA Europa Clipper, 2014). These two planets seem to have conditions that could have harbored some sort of life in their earlier years: water and more moderate climates. However, Mars and Venus are anything but habitable in the present day. Mars has no atmosphere and freezing temperature, while Venus has a suffocating atmosphere and is hot enough to melt lead (NASA Solar System Exploration, 2022).

Titan and Europa are moons of Saturn and Jupiter, respectively, and have promising features to sustain human life. Heat is important as a suitable amount of it allows extraterrestrial objects to have liquid water. Both Titan and Europa generate heat internally through a process called tidal heating. Tidal heating is the result of the larger planet compressing and contracting the much smaller moon, causing friction inside the planet to generate heat (Lunine, 1997). Europa, for example, is speculated to have an enormous subsurface liquid water ocean as a result of tidal heating (NASA Europa Clipper, 2014). Titan is also believed to have a subsurface ocean, but it also has a thick atmosphere. While the origins of Titan's atmosphere is still being researched, having one is important to sustain life, as will be discussed in this paper. These two qualities make Europa and Titan attractive candidates for habitability. However, these moons also present challenges for exploration and serving as habitable places. These moons are further away than neighboring planets, causing both transportation time and cost to increase dramatically. Jupiter has the strongest radiation belt out of all the planets and consequently its moons receive dangerously high doses of radiation (Roussos, 2022). Surface temperatures are well below freezing and oxygen is not present in the atmosphere (NASA Solar System Exploration, 2022). With all that said, Titan and Europa have conditions that make them ideal candidates as habitable places for humans in the future, and will be explored further in future missions.

Different Moons of the Solar System

Moon Definition

A moon is a type of extraterrestrial object that orbits a larger planet that has not met the three criteria for being classified as a planet: orbit the Sun, have sufficient mass so its gravitational force is enough to form a roughly round shape, and have cleared its path of similar sized objects (IAU Resolution B5, 2006). While Earth's Moon is spherical, the gas giants have moons that are unusual looking and/or irregular. For example, Saturn's Prometheus is extremely elongated while Pan resembles a ravioli (Leleu, 2018). Jupiter has a number of irregular moons that were formed from asteroids captured by its immense gravitational field, and have large, highly eccentric and/or inclined orbits. Saturn's unusual looking inner moons were formed from collisions of similar sized moonlets (Leleu, 2018). These irregular moons are noticeably different from regular moons, which formed along with the parent planet from an accretion disk and have roughly circular and uninclined orbits (Jewitt, 2007).

Earth's Moon

Earth's Moon has been studied extensively in human history, and is a stark contrast to Titan and Europa. The Moon is believed to have formed through what is known as the impact theory. Scientists believe that through evidence between the similarity of lunar rocks and those on Earth, the moon was formed from the debris of an impact by a large body, Theia, on Earth (Jones, 2000). Earth's Moon has been explored extensively by many countries, with much data and information collected. Based on all of the data and research, the Moon is a relatively barren and desolate place. Its atmosphere is so thin that the surface can essentially be considered a vacuum. Because of this lack of atmosphere, the surface pressure is 2.96 x 10^-15 atm (Stern, 1999), compared to the surface pressure of Earth, which is one atm. With no source of internal heat and the lack of an atmosphere, temperatures on the moon's surface range from 127 C to -173 C (NASA Solar System Exploration, 2022). Deadly amounts of radiation from the Sun and outer space also blast the Moon's surface. Water has been found on the

surface of the Moon near the poles, where it exists as rock hard ice inside of permanently shadowed craters. There is so little water discovered on the Moon from missions that the Sahara Desert has 100 times as much. (Wasser, 2020). All in all, the Moon lacks features that make it possible for humans to survive for long periods of time.

Titan

Titan is the largest moon of Saturn, larger than Mercury and similar in size to Mars. Titan is one of the few objects in the solar system that resembles Earth. Its dense atmosphere is made of mostly nitrogen (95%), with hints of methane (5%) and trace amounts of other carbon-rich compounds (NASA Solar System Exploration, 2022). Having a dense atmosphere benefits Titan in many ways. This dense atmosphere, along with Saturn's magnetosphere, protects Titan from dangerous radiation from the Sun. The high density creates a surface that is around 60% more pressurized than Earth's, making Titan the only object which has a similar surface pressure to Earth (NASA Solar System Exploration, 2022). As a result of this high pressure, humans can walk around on Titan without the need of a pressurized suit. Liquid methane lakes and oceans are present on the surface, making Titan the only other object besides Earth to have liquids on the surface. The methane on Titan has a cycle similar to the water cycle on Earth, going through the process of starting as a liquid, evaporating, and then raining back down (NASA Solar System Exploration, 2022). This abundance of methane can potentially be used as a source of energy, as methane is a key natural gas here on Earth. Electricity is generated through methane when the heat produced from burning methane powers a turbine, which in turn generates electricity (Kondaveeti, 2019). Methane in the atmosphere also acts as a greenhouse gas, which heats the moon. Besides the abundance of features above the surface, Titan is also speculated to contain a subsurface liquid ocean as a result of tidal heating. This ocean, along with the rest of Titan, will be studied further in the Dragonfly Mission. The author believes that new discoveries from the Dragonfly Mission will further enhance Titan as a candidate for humans to inhabit.

Disadvantages of Titan

With all of these conditions that are potentially suitable for humans, there are challenges on Titan. The most obvious one is the cold temperature on the surface, with an average of -180 degrees Celsius (NASA Solar System Exploration, 2022). At this temperature, humans can not survive without protection, and any form of shelter would need to be more cold resistant than those used on Earth. While Titan has a robust atmosphere, it is made of mostly nitrogen and lacks oxygen. Oxygen can potentially be split from the subsurface water ocean, but doing so is difficult and energy consuming. Another issue is that Titan only has around 14% of Earth's gravity (NASA Solar System Exploration, 2022). Spending long periods in low gravity environments can cause muscle loss and a decrease in bone density, among other negative impacts (Wolfe, 1992). Titan may also host some sort of life, which can develop into a problem if humans come into contact with them, for example harmful microorganisms. Tholins are a type of organic compounds that form after high energy particles from cosmic rays split apart methane and nitrogen in the atmosphere. These compounds are rich in nitrogen and carbon, which provide the building blocks for life (Waite, 2007). On Earth, bacteria called anaerobic methanotrophs consume methane and single carbon compounds to survive (Guerrero-Cruz, 2021). The liquid methane and tholins on Titan can provide suitable conditions for life to arise. While finding extraterrestrial life forms is exciting, it can also be dangerous for humans to coexist with them on the same moon as humans and these potential life forms can negatively impact each other. All in all, Titan is a great candidate for humans to inhabit in the future with its abundance of promising features, some of which even resemble Earth. However, Titan is not without flaws, and will have to be explored further. NASA is in the works of making a lander mission specifically to explore Titan in more detail than previously.

Dragonfly Mission

The Dragonfly Mission was proposed by John Hopkins's Applied Physics Laboratory to NASA in 2017 and selected as the fourth mission in the New Frontiers program. It is set to launch in 2027 and arrive at Titan in 2034 (JHUAPL Dragonfly, n.d.). The purpose of the Dragonfly mission is to search for extraterrestrial life and habitability on Titan. Dragonfly will be a dual-quadcopter design to take advantage of aerial travel, made easy by Titan's thick

atmosphere and low gravity. Dragonfly can cover tens of miles during the day and recharge during the night. Sunlight does not penetrate Titan's thick atmosphere easily, so Dragonfly cannot use solar panels as an effective power source. Instead, it uses a Multi-Mission Radioisotope Thermoelectric Generator, the same one as on the Curiosity rover on Mars (JHUAPL Dragonfly, n.d.). A Multi-Mission Radioisotope Thermoelectric Generator works by converting the heat generated from the decay of plutonium-238 into electricity using the temperature difference between two different, electrically conductive materials in a closed circuit (NASA Radioisotope Power Systems, 2022). Scientists took data from the Cassini mission and analyzed it to predict the optimal timing for a calm weather period, as well as identifying a landing site. Dragonfly will land at the Shangri-La dune fields, which is similar to the dunes in Namibia and offers a large sampling of materials. After landing, Dragonfly will perform flying missions of more than five miles to reach the Selk impact crater. Along the way, Dragonfly will use instruments such as a mass spectrometer, meteorology sensors, and cameras. These will enable Dragonfly to collect data on both the surface composition and atmospheric conditions, as well as seismic activity to study subsurface activity and structure (JHUAPL Dragonfly, n.d.).

Titan Habitability

Planetary scientist Dr. Amanda Hendrix, a senior scientist at the Planetary Science Institute, expressed her opinions about Titan as a habitable world in her article "Confession Of A Planetary Scientist: 'I Do Not Want To Live On Mars'". The author agrees with most, if not all, of the logical conclusions reached in the paper. For example, the line "these damaging particles cannot make it to Titan's surface; they're absorbed by the atmosphere, meaning that it's a safe environment for humans" (Hendrix, 2017) makes perfect sense as ultraviolet radiation is deadly to humans in space. Titan's thick atmosphere blocks these particles that would otherwise easily make the moon inhabitable. Another point that the author agrees with is the acknowledgement that sending humans to Titan is still a process in the making. Many challenges are in the way, such as low gravity and the lack of a food source. A mission like Dragonfly will allow scientists to gain further knowledge of the moon, and the author believes any more information will only strengthen Titan's candidacy as a habitable moon for humans.

Europa

Europa is a Galilean moon of Jupiter characterized by its large amount of water, both in ice form and liquid form. Europa is around 5.2 AU from the Sun, resulting in sunlight being 25 times fainter there than on Earth and causing temperatures on Europa to average around -160 degrees Celsius (NASA Europa Clipper, 2014). A rock-hard icy water shell, estimated to be 10 to 15 miles thick, covers the entire moon (Nasa Europa Clipper, 2014). However, there is strong evidence from the Galileo mission that Europa has a vast subsurface liquid water ocean. Data gathered from the Galileo mission showed that Jupiter's magnetosphere is disrupted around Europa. The best explanation for this is that Europa is inducing a magnetic field internally, most likely through the rotation of a salty liquid water ocean underneath its ice surface (NASA Europa Clipper, 2014). Similar to Titan, a subsurface liquid ocean water can be made possible by the heat generated through tidal heating. Salty water is not drinkable by humans, but fresh water can be generated through a process called ocean thermal energy conversion (OTEC), a type of technology used on Earth to both desalinate ocean water and generate electricity. OTEC works by using the difference in temperature of salt water, which should be present on Europa. Warm salty water is turned into steam by reducing its pressure. This steam drives a turbine generator to produce electricity, before being turned back into a liquid in a condenser cooled with cold water. While heating and condensing sea water, salt and other impurities are removed to produce fresh water (Ocean thermal energy conversion, n.d.). Besides having a speculated ocean, Europa's surface may hold more than it seems. While the surface appears mostly smooth, images from NASA's Galileo spacecraft revealed jagged double ridges spanning thousands of kilometers and rising hundreds of meters tall (NASA Solar System Exploration, 2022). These double ridges may be formed by warm liquid water rising through the ice, forming a pocket inside the sheet of ice. This pocket of liquid water inside the ice will have temperatures higher than the surface. Almost similar to an igloo, these pockets can protect humans from the frigid cold and high levels of radiation on the surface. Europa also has a thin atmosphere that contains oxygen, but humans cannot breathe without oxygen tanks as the atmosphere is too tenuous.

Europa's biggest strength is its large subsurface liquid water ocean and pockets of warmer water within the icy surface. However, frigid temperatures, high levels of radiation, and a lack of oxygen are among main issues humans face. NASA is planning the Europa Clipper mission to explore the ocean world in further detail.

Europa Clipper Mission

Europa Clipper is a NASA mission set to launch in 2024. It will be the first NASA mission to exclusively study a moon besides Earth's. Europa Clipper will send a spacecraft into orbit around Europa, where it will spend three years flying around Europa 45 times (NASA Europa Clipper, 2014). The spacecraft has an arsenal of instruments to study the icy moon. Its primary mission is to determine if Europa has conditions suitable for life, which scientists highly suspect it does. Europa Clipper's ten instruments can be grouped into four sets based on their function. Cameras and spectrometers create high resolution images and maps of Europa's surface and atmosphere (NASA Europa Clipper, 2014). These images can allow scientists to further explore sections of the surface such as ridges in the ice sheets, as well as identifying areas for future lander missions. Ice penetrating radar, a magnetometer, and plasma sensors allow the spacecraft to explore the ocean and interior of the moon. The plasma sensor studies the distortions of Europa's magnetic field caused by Jupiter, and the magnetometer studies the magnetic field induced by Europa. Scientists will use the data collected by the plasma sensor to factor out any distortion from the data by the magnetometer to achieve a cleaner final result. This final result can produce proof of a liquid water ocean underneath the surface, as well as measure its depth, salinity, and the thickness of the ice shell (NASA Europa Clipper, 2014). A thermal imaging camera will identify regions of warmer ice (NASA Europa Clipper, 2014). By determining where warmer ice exists and if ridges are present at these locations, there is further proof that ice pockets exist underneath these ridges in the ice sheet. A dust analyzer and mass spectrometer measure the chemical properties of particles in Europa's atmosphere (NASA Europa Clipper, 2014). These instruments will provide valuable insight into the possibility of Europa harboring life, and also explore the feasibility of human settlement and future lander missions.

Europa Habitability

Dr. Tom Kerwick stated in his journal article "Colonizing Jupiter's Moons: An Assessment of Our Options and Alternatives" that Europa poses an interesting balance between having many great and also less than ideal qualities. The author agrees with the idea of Europa having a mix between good and bad factors. For example, the line "At 670,000 km from Jupiter, Europa receives 540 rem of radiation per day from the Jovian belts" (Kerwick, 2012, p.12) proves that Europa has harsh surface conditions that would make unshielded living impossible. Other parts of the articles are more optimistic, as in "The abundance of water is significant not only as a source of drinking water, but it could also be broken down to provide breathable oxygen" (Kerwick, 2012, p.12). Europa is an interesting case. It has many features that make it seem perfect for human colonization, yet it also has many that makes it inhabitable. Future missions like Europa Clipper will allow scientists to gain more information to unravel the mysteries of the moon.

Sensing With Independent Micro-Swimmers

Sensing With Independent Micro-Swimmers (SWIM) is a concept in development at NASA's Jet Propulsion Laboratory (Greicius, 2022). As the name suggests, SWIM is a concept that will use tiny swimming robots to explore ocean worlds, such as Europa and Titan. Exploring Europa's ocean in more detail will allow scientists to determine if the ocean already contains life or have conditions suitable for life, such as hydrothermal vents on the ocean floor. The goal of SWIM is to employ wedge-shaped robots around the size of a smartphone. They will be roughly five inches long and three to five cubic inches in volume. Because of their small size, around four dozen of them can be fitted into a 4-inch-long section of a cryobot. A cryobot is a robot that uses a high temperature nuclear battery to melt through layers of ice in order to reach the subsurface ocean. After these robots are deployed into the ocean, they can either swim off to different areas, or conduct research in a group. To achieve this, each individual robot contains a communication, intelligence, power, and sensing component (Greicius, 2022). Using large numbers of tiny robots like SWIM benefits missions by allowing larger areas of the ocean to be explored, and thus

increasing the possibility of finding life or conditions suitable for future human development. SWIM also allows more accurate data to be collected from different parts of the ocean as opposed to collecting data right from the cryobot, which may cause data to be inaccurate as the hot battery can produce chemical changes. SWIM is a very useful piece of technology that is being developed to enhance the productivity of future missions to ocean worlds.

Conclusion

Humans wish to explore habitable extraterrestrial objects to find a safe haven for future generations. While seemingly unlikely candidates in the outer reaches of the solar system, Titan and Europa have features that are promising for future humans to potentially inhabit. Titan has a dense atmosphere and an abundance of methane, as well as a possible subsurface liquid water ocean. Europa is speculated to have a huge liquid water ocean under its ice crust, and may also have pockets of warmer liquid water within its icy surface. NASA is planning to explore these two unique moons with the Dragonfly mission to Titan and Europa Clipper missions to Europa. New technology, such as Sensing With Independent Micro-Swimmers, is also being developed by NASA to increase the productivity of future missions. These missions will provide invaluable information about these moons, and further accelerate humanity's quest to one day live amongst the stars.

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Calibrations of Trumpler 20 Red Clump Stars using the Gaia G-bands

By Tiffany Zhang

Author Bio

Tiffany Zhang is a student at Great Neck South High School and has been part of her school's research program since freshman year. She is interested in astrophysics, computer science, and math. She is the co- founder, website manager, and instructor at AlphaMath, a nonprofit organization that hosts free online sessions to make learning math more accessible and fun during the pandemic. She actively participates in her school's women in STEM club SHE by hosting events and organizing fundraisers. She interned in the ReWild Long Island Summer Program to promote biodiversity, climate change resilience, and food security by reintroducing native plants to attract a variety of animals, following organic and regenerative practices of recycling and composting, and donating grown fruits and vegetables to the hungry. She qualified for AIME, represented her school in various math competitions, and participated in physics and programming competitions. The author would like to thank Dr. Shyamal Mitra, Arnav Sharma, Nicole Spinelli, and Eleanor Liu for their feedback and constant support.

Abstract

Calculating distances to astronomical objects are crucial for measuring absolute magnitude, analyzing evolution, and deriving the Hubble's constant. Different distance methods, such as main-sequence fitting and period-luminosity relations of variable stars, form the distance ladder, in which methods for shorter distances calibrate methods for larger distances. Red clump (RC) stars are not a firmly established distance indicator as the strength of their metallicity-luminosity relation varies between studies. This study investigates broader passbands for more general trends in the relation by using the G-, GBP-, and GRP-bands. Because of its substantial RC, Trumpler 20 was analyzed, and its data was collected from Gaia DR3 and Gaia-ESO DR5. The metallicity-luminosity relations demonstrated weak correlations with the highest R2 of 0.016 ($p>0.05$). However, when calculating the distance to ϵ Tauri, an RC star in the closest star cluster Hyades, the G-band metallicity-luminosity relation yielded the lowest relative error of 2.8%. This study introduces the use of Gaia photometric bands in the RC metallicity-luminosity relations to analyze different correlations for broader passbands. Future studies should further investigate broad passbands to determine if they produce significant results and narrower passbands of photometric bands that weakly correlate with metallicity.

Keywords: distance indicator, red clump, metallicity-luminosity calibration, Trumpler 20, Hyades, G-band, GBP-band, GRP-band, Gaia G-bands, distance ladder, Gaia, Gaia-ESO

Introduction

In an expanding universe, distances are crucial for calculating absolute magnitude, analyzing the evolution of astronomical objects, and deriving the Hubble constant for cosmology, strongly necessitating an improved accuracy of distance methods. Distance indicators rely on the intrinsic properties of astronomical objects and luminosity. However, each indicator can be applied in a limited range. This is because objects might not be present within certain distance ranges or become too faint outside certain distance ranges. Hence, farther distance methods rely on closer distance methods for calibration in the distance ladder. As our understanding of cosmology and evolution progresses, more accurate distance measurements can clarify and confirm the findings.

Red clump (RC) stars could be a useful distance indicator to confirm the distance calculations of other distance indicators. They are core He-burning stars with masses below the He-flash limit MHeF, or the maximum mass of a star that can have a degenerate yet He-burning core to undergo the He-flash (Girardi, 2016). Degenerate cores have similar masses, limiting the irregularity in RC luminosity and effective temperature. As a result, the RC makes up 1/3 of all red giants, creating a prominent clump in the HR Diagram (HRD) shown in Fig. 1—hence its name (Girardi, 2016). Additionally, RC stars' low mass and high metallicity create their characteristic large red convective envelope for fusion. Due to their distinguishability and high luminosity, RC stars are a promising distance indicator.

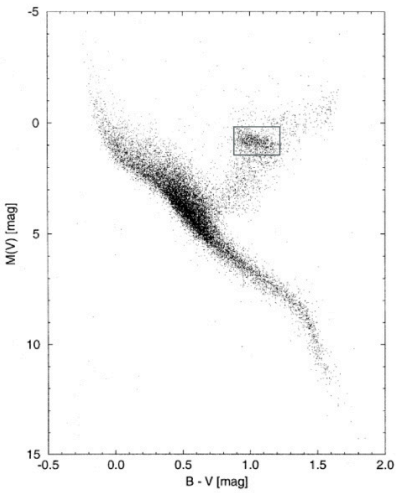


Figure 1: HR Diagram in the B and V bands using Hipparcos data. The grey box marks the red clump in the HRD. This figure is from figure 3 of Lindegren (1997) and edited by the author.

Theoretically, since the RC's luminosity increases as it transitions from mainly H-burning to He-burning over time, the RC should exhibit a metallicity-luminosity relation, which is absolute luminosity represented as a linear function of metallicity, or the concentration of all elements heavier than He relative to the Sun (Girardi, 2016). The distance can be derived by calculating the absolute magnitude from metallicity using the relation and measuring the absolute magnitude as shown

$$m - M = -5 + 5 \log d$$

where m and M are the apparent and absolute magnitudes, respectively, and d is the distance in parsecs.

However, the RC is not a firmly established distance indicator because of systematic errors and unresolved discrepancies in relationships of specific photometric bands, or passbands, with other stellar properties. For example, analyses in the V-band (500 nm - 700 nm) and I-band (700 nm - 900 nm) found unresolvable population effects, which became accepted in the research community (Pietrzyński et al., 2010; Girardi, 2016). Consequently, studies analyzed the K-band (2000 nm - 2300 nm) because of its negligible extinction, which is the dimming of observed light by dust. This was first proposed by Alves (2000) who found a weak correlation between the K-band absolute magnitude and metallicity. Grocholski & Sarajedini (2002) and Van Helshoecht & Groenewegen (2005) found comparable results and a lack of correlation of the K-band absolute magnitude with age. However, models predicted the dependence of K-band magnitudes on age and metallicity (Salaris & Girardi, 2002). These smaller trends in specific passbands may contribute to a larger and stronger trend in a broad passband to yield more accurate distance measurements.

Gaia DR3 collected the most spectrophotometric data to date with a total of 1.8 billion sources, over 1.5 billion sources of broadband photometry, and 470 million sources of their

extinctions (Vallenari et al., 2022). Gaia uses the G-band (350 nm - 1050 nm), GBP-band (330 nm - 680 nm), and GRP-band (640 nm - 1050 nm) as shown in Fig. 2, and the latter two have not yet been used for RC calibrations, despite the large influx of data in parallax and photometry.

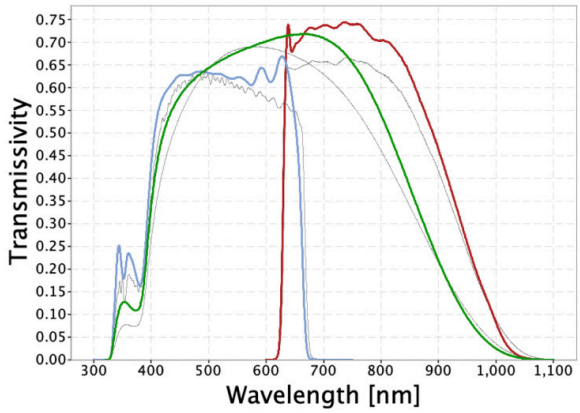
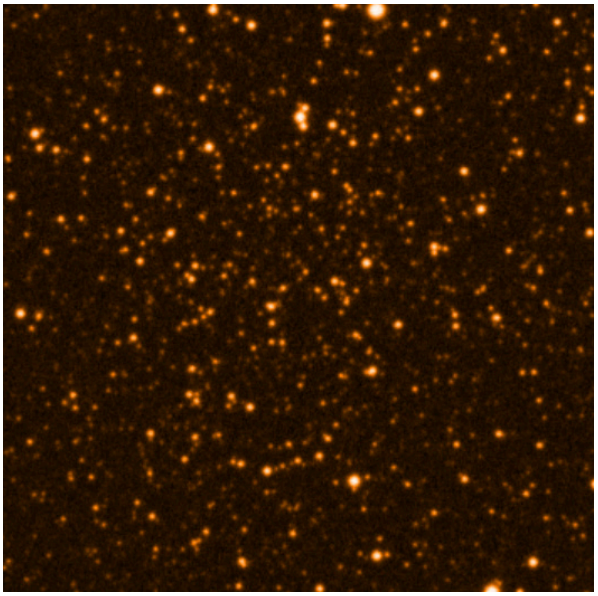


Figure 2: Gaia EDR3 photometric bands G, GBP, and GRP. The green, blue, and red lines represent the G, GBP, and GRP passbands from Gaia EDR3, respectively, and the grey lines represent the passbands before launch. This figure is from figure 24 of Riello et al. (2021).

Few studies investigated the RC in the context of the G-band. Hawkins et al. (2017) and Ruiz-Dern et al. (2017) found disagreeing results for the RC mean G-band magnitude: MG = 0.44 ± 0.01 mag and MG = 0.495 ± 0.009 mag, respectively. Moreover, Ruiz-Dern et al. (2017) analyzed different relations of the Gaia G-band absolute magnitude with metallicity, color G-KS, and effective temperature. However, the studies did not analyze a relation only between Gaia G-band absolute magnitude and metallicity.

Gaia-ESO (GES) DR5 is a large spectroscopic survey with 114,324 sources of open clusters (Gilmore, 2022). Known for its unprecedented high resolution of spectroscopic data, this survey can provide accurate metallicity measurements for the analysis of the RC (Donati et al., 2014).

Trumpler 20 (Tr 20), shown in Fig. 3, is an old open cluster located with a right ascension of 189.88° and declination of -60.63° (Donati et al., 2014; Seleznev et al., 2010). Known for its substantial RC, Tr 20 provides a good starting point for the analysis of the RC stars in the G-, GBP-, and GRP-bands with metallicity.



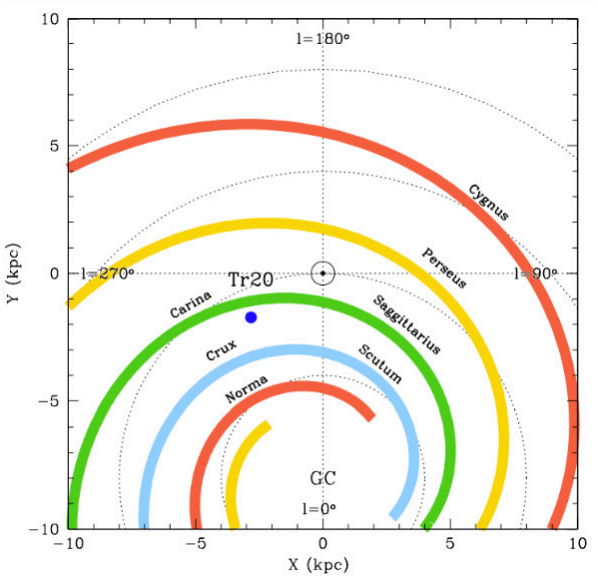


Figure 3: Trumpler 20. The figure on the left is a 10'x10' image of Trumpler 20 from the ESO Online Digitized Sky Survey, and the figure on the right is a graph of Trumpler 20's position in the Milky Way from figure 1 of Donati et al. (2014). The filled blue circle indicates the position of Tr 20 relative to the Sun and the Milky Way's spiral arms denoted by the □ symbol and colored strips, respectively.

The Hyades star cluster is the closest open star cluster. One of its RC stars is ϵ Tauri, which will be used to assess the metallicity-luminosity relation in calculating its distance (Sato et al., 2007).

The goal of this study is to analyze the metallicity-luminosity relation using a broader passband to evaluate larger trends. Section 2 details the data collection of Tr 20 and ϵ Tauri. Section 3 describes the results of the data analyses. Sections 4 and 5 contain the discussion and conclusion, respectively.

Data Collection

2.1. Trumpler 20

Data of Tr 20 was obtained from GES DR5 and Gaia DR3. The stellar parameters of right ascension, declination, and metallicity from all stars marked as members of Tr 20 were collected from GES and right ascension and declination with their respective errors, parallax, apparent magnitudes, extinctions in the G-, GBP-, and GRP-bands, and reddening E(GBP-GRP) from Gaia. Note that the reddening of light occurs due to the scattering of blue light and the passing of red light from dust. The data from Gaia was queried using the right ascension and declination range provided by Donati et al. (2014). All data with uncertainties less than -10 were considered unphysical and removed (Lindegren et al., 2018).

The data from GES and Gaia were cross-matched using right ascension and declination with their respective errors. However, data from GES did not have any measured errors, so an error of 5 arcseconds was used. Since membership was determined for stars from GES, those from Gaia were added to GES data if the rectangles formed by the errors of right ascension (ra) and declination (dec) overlapped. Objects that satisfy that condition are considered neighbors. The best neighbor is selected by the object with the smallest angular distance, calculated as

$$\cos(\theta) = \sin(\mathrm{dec}_1)\sin(\mathrm{dec}_2) + \cos(\mathrm{dec}_1)\cos(\mathrm{dec}_2)\cos(\mathrm{ra}_1 - \mathrm{ra}_2)$$

where θ represents the angular distance, ra1 and dec1 are the right ascension and declination of one object, and ra2 and dec2 are those of the other.

The data were filtered by removing data outside of ±2 standard deviations of both parallax and intrinsic color (GBP-GRP)0, which is calculated as shown

$$(G_{\mathrm{BP}} - G_{\mathrm{RP}})_0 = G_{\mathrm{BP}} - G_{\mathrm{RP}} - E(G_{\mathrm{BP}} - G_{\mathrm{RP}})$$

where GBP and GRP are the GBP- and GRP-band absolute magnitudes, respectively.
Color-magnitude diagrams (CMD) were created to isolate the RC. The absolute magnitude of each photometric band MG, MBP, and MRP was calculated using

$$m - M = -5 + 5\log\left(\frac{1}{p}\right) + A$$

where p is the parallax, A is the extinction, and m and M are the apparent and absolute magnitudes, respectively. The CMD was plotted for each photometric band, and the RC's absolute magnitude and color ranges were determined to isolate the data as shown in Fig. 4. Note that the isolated RC stars are the same amongst the different CMDs, which is expected and helps reinforce the validity of this sample. The data were filtered for outliers by removing data outside of ±2 standard deviations for both parallax and metallicity. The properties of the resulting 84 RC stars are described in Table 1.

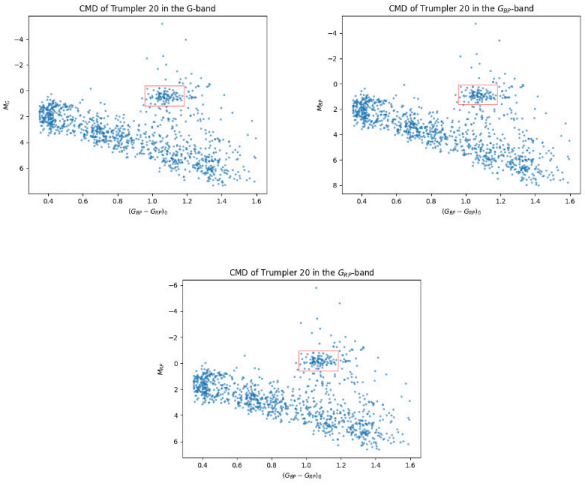


Figure 4: CMD of Trumpler 20 red clump in the G-band. The intrinsic color and absolute magnitude were calculated using Equations 1 and 2, respectively.

The RC is marked by the red rectangle and later isolated using its magnitude and color range.

Table 1. Description of Trumpler 20 Red Clump Stars' Properties. After the data of the RC was isolated and filtered (n=84), the mean, median, and standard deviations of the absolute magnitudes in the G-, GBP-, and GRP-bands, intrinsic color, and metallicity were calculated as shown in the table below. The errors for the mean represent ±1 SEM.

Trumpler 20 Red Clump Stars

	M_G	M_{BP}	M_{RP}	$(G_{BP}-G_{RP})_0$	[Fe/H]
Mean	0.46	0.91	-0.16	1.07	0.07
Median	0.50	0.93	-0.13	1.07	0.08
Standard deviation	0.28	0.28	0.28	0.04	0.11

2.2. ϵ Tauri

ϵ Tauri (HIP 20889) is one of the RC stars in the Hyades cluster (Sato et al., 2007). Its stellar parameters are listed in Table 2. The metallicity was obtained from Table 1 by Sato et al. (2007), and the rest of the properties from Gaia. The intrinsic color and magnitudes were calculated using Equations 1 and 2, respectively.

Table 2. Stellar Parameters of ϵ Tauri Hyades Red Clump Star. The metallicity was obtained from Sato et al. (2007), and the rest of the data (right ascension, declination, and parallax with its respective errors, apparent magnitudes, and extinctions in the G-, GBP-, and GRP-bands, and reddening E(GBP-GRP)) was queried from Gaia. The intrinsic color and magnitudes in each photometric band (G, GBP, and GRP) were calculated using Equations 1 and 2, respectively.

Stellar Parameters of ϵ Tauri

Parameter	Value
Parallax (mas)	22.37 ± 0.17
M_G	0.028
M_{BP}	0.65
M_{RP}	-0.59
$(G_{BP}-G_{RP})_0$	1.24
[Fe/H]	0.17 ± 0.04

Data Analysis

3.1. Regressions of Metallicity-Luminosity Relations

Using the data of the isolated RC, the absolute magnitude was plotted as a function of metallicity. Linear regressions were fitted in the three photometric bands shown in Fig. 8. All the regressions have low R2 values, suggesting a weak correlation, and were statistically similar to the null hypothesis where no correlation is present (p>0.05).

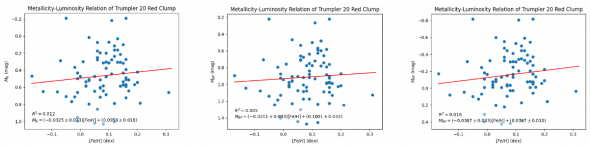


Figure 5: Linear regressions of metallicity-luminosity relation from the RC of Trumpler 20. The linear regression for the G-, GBP-, and GRP-bands are represented by the red line, and its equation and R2 are shown. Errors in the regression represent ±1 standard deviation.

To evaluate the validity of the calibration, the root mean square errors (RMS) were listed in Table 3 and calculated using

$$RMS = \sqrt{\frac{\sum_{i=1}^{N}(x_{\text{measured}} - x_{\text{estimated}})^2}{N}}$$

where N is the sample size. Of the three calibrations, the GBP-band calibration exhibits the greatest RMS of 0.858 while the GRP-band calibration exhibits the least RMS of 0.350.

Hence, in all three photometric bands, a constant RC mean magnitude can be assumed and used to estimate distance, so this was evaluated as a distance method as well. Note that these absolute magnitudes are pairwise significantly different by t-tests (p<0.05). These differences in mean magnitude between different passbands are expected and help reinforce the validity of the sample.

Table 3. Root mean square errors of metallicity-luminosity relations. The RMS of each metallicity-

luminosity relation was calculated using Equation 3.

Root Mean Square Errors			
	G-band	G_{BP}-band	G_{RP}-band
RMS	0.457	0.858	0.350

3.2. Comparing Actual Distances with Calculated Distance

To assess the consistency of the distance calculations relative to the distances measured by Gaia, the derived distances of the Tr 20 RC from each passband calibration and mean magnitude were plotted against actual distances calculated using parallax measurements from Gaia in Fig. 6 and 7, respectively. Equation 2 was used to calculate the distance for the estimated magnitude from the calibrations. The solid black line represents the identity line, and the dotted lines represent it shifted vertically by ±1 RMS of the distances, which was calculated using Equation 3.

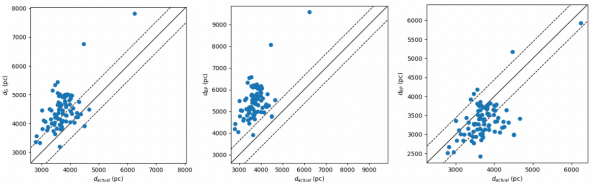


Figure 6: Actual distance vs. estimated distance plots of the metallicity-luminosity calibrations. The G-, GBP-, and GRP-band metallicity-luminosity calibrations were used to calculate the estimated distance for the left, middle, and right plots, respectively. The actual distance was calculated using parallax measurements from Gaia. The solid diagonal line represents the identity line, and the dotted lines represent ±1 RMS, which was calculated using Equation 3

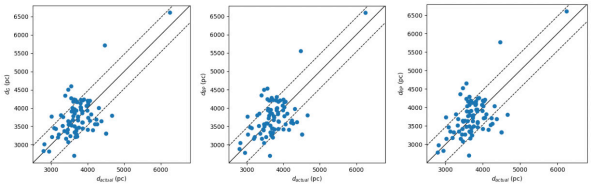


Figure 7: Actual distance vs. estimated distance plots of the mean magnitudes. The G-, GBP-, and GRP-band mean magnitudes from Table 1 were used to calculate the estimated distance for the left, middle, and right plots, respectively. The actual distance was calculated using parallax measurements from Gaia. The solid diagonal line represents the identity line, and the dotted lines represent ±1 RMS, which was calculated using Equation 3.

3.3. Distance Estimations to ϵ Tauri

To assess the accuracy of the distance methods, the absolute magnitude estimates were calculated and the obtained apparent magnitudes and extinctions from Gaia were used to derive distances using Equation 4. All the calculated distances were compiled in Table 4. The relative errors (RE) were calculated as a percent using

$$\mathrm{RE} = \frac{|d_{\mathrm{actual}} - d_{\mathrm{calculated}}|}{d_{\mathrm{actual}}}$$

where dactual and dcalculated are the actual and calculated distances, respectively. The distance calculated using the G-band calibration resulted in the smallest RE of 2.8% while using the GRP-band calibration resulted in the largest RE of 26.1% in Table 4.

Table 4. Distance estimates to ϵ Tau. Using the parallax measurement from Gaia, the true distance is 44.71 pc. Estimates of the absolute magnitude in each photometric band were derived with the regressions and metallicity and used to calculate distance using Equation 4. Since the linear regressions cannot reject the null hypotheses (p>0.05), a mean absolute magnitude was assumed and used to estimate distance as well. The relative errors (RE) of each calculated distance were derived as a percent using Equation 5.

Distances to ϵ Tau						
	G-band	RE_G	G_{BP}-band	RE_{BP}	G_{RP}-band	RE_{RP}
Mean magnitude	36.65	18.0%	39.61	11.4%	36.68	18.0%
Linear regression	43.45	2.8%	39.6	11.4%	33.02	26.1%

Discussion

The goal of this study is to analyze the metallicity-luminosity relation in the context of a broader passband, specifically the G-, GBP-, and GRP-

bands, for a larger trend.

4.1. Analysis of Calibration Data

The metallicity-luminosity relations of RC stars in the Gaia photometric bands G, GBP, and GRP demonstrated insignificant and weak correlations ($p>0.05$) as shown in Fig. 8. The GBP-band calibration exhibited the weakest correlation and largest RMS, which is inconsistent with Bilir et al. (2013) where the V-band (500 - 700 nm) magnitude, which composes half of the GBP-band wavelength range, strongly correlated with metallicity ($R = 0.971$). Tr 20's large distance possibly caused the discrepancy, increasing the possibility of obscuration by dust, and GBP-band range's short wavelengths, causing greater sensitivity to extinction and scattering. Moreover, studies found that the I-band (700 - 900 nm), which composes half of the GRP-band wavelength range, and V-band magnitudes are susceptible to unresolvable population effects (Pietrzyński et al., 2010). As a result, the G-band composing of the GBP- and GRP-bands' wavelength ranges may have caused its lack of correlation.

Because of the insignificant regression results, the mean magnitudes were evaluated as distance methods. This study found a mean RC G-band magnitude of $MG = 0.46 \pm 0.28$ mag as presented in Table 1, which is consistent with Hawkins et al. (2017) who found $MG = 0.44 \pm 0.01$ mag and with Ruiz-Dern et al. (2017) $MG = 0.495 \pm 0.009$ mag, but only because of the large error. This large spread of the G-band magnitudes is likely due to the sampling of one cluster.

4.2. Applicability of Calibration and Mean Magnitudes

To assess the reliability of distance calculations with the mean magnitudes and metallicity-luminosity calibrations, both actual distance vs. calculated distances graphs and distance estimations to ϵ Tauri were used.

The actual distance vs. calculated distance graphs for the calibrations exhibited systematic tendencies as shown in Fig. 9, especially for the GBP-band where most of the stars were skewed towards greater distances and only two of the stars fell inside ±1 RMS from the identity line. The distance estimations by the G-band calibration were also skewed to greater distances while those by the GRP-band calibration were skewed to closer distances. This was probably due to uncorrected systematic errors in extinction or reddening as the susceptibility of each wavelength varies. However, the actual distance vs. calculated distance graphs for the mean magnitudes exhibited no systematic tendencies as most of the points fall within ±1 RMS from the identity line. This may have occurred because the mean fits the systematic tendencies of the data. Hence, these distance methods must also be evaluated with other stars that are not part of the sample to assess their reliabilities.

The Hyades RC star ϵ Tauri was used to evaluate the validity of these distance methods. As presented in Table 4, the GRP-band calibration calculation exhibited the highest RE of 26.1%, while the G-band calibration calculation exhibited the lowest RE of 2.8%. The calculated distances from mean magnitudes were found to have REs smaller than 20% but are less accurate than the distance calculated with the G-band calibration. Using the mean G-band magnitudes from Hawkins et al. (2017) and Ruiz-Dern et al. (2017), the calculated distance to ϵ Tauri is 36.99 pc and 36.06 pc, which were 0.9% greater and 1.6% less than that calculated using this study's mean G-band magnitude. However, the calculated distance using the G-band calibration was relatively more accurate than using G-band mean magnitude as used by previous studies.

4.3. Limitations and Future Research

The data collected was susceptible to various systematic errors. Since Tr 20 is a rather distant open star cluster, the small parallax measurements can be easily influenced by parallax errors. Moreover, the position of Tr 20 makes it susceptible to pollution by unwanted stars in the CMD (Donati et al., 2014). Unaccounted extinction and reddening may also have contributed to systematic errors since the photometric bands used in this study are easily obscured by dust.

The analysis of larger passbands produces moderately weak results because the various smaller trends seem to strongly influence it, so an overall trend was not apparent. This result may be similar to the

weak correlation between metallicity and luminosity in specific photometric bands caused by analyzing too broad a range of wavelengths that should be broken down into smaller ranges for analysis. For instance, one past study clarified the relation of RC stars with luminosity, metallicity, and age in the K-band by separating them by age: in older RCs (>~2 Gyr), the K-band magnitude was shown to be sensitive to age but not metallicity while in younger RCs (<~2 Gyr), the K-band magnitude was shown to be sensitive to metallicity but not age (Grocholski & Sarajedini, 2001).

Future research should continue investigating novel calibrations, especially those that look at more detailed trends rather than overall trends. Other stellar parameters can be analyzed similarly to the age analysis by Grocholski & Sarajedini (2001) to uncover more detailed trends. Additionally, analyzing an entire spectrum of wavelengths to reveal trends of different smaller wavelength ranges can possibly determine the optimal wavelength range in which a metallicity-luminosity relation is strongest. However, studies should also clarify the RC luminosity relations in the G-, GBP-, and GRP-bands by collecting data from a variety of star clusters and analyzing various parameters to improve correlation and significance.

Conclusion

The goal of this study was to analyze the metallicity-luminosity relation in larger passbands to analyze overall trends in luminosity. The relations in the G-, GBP-, and GRP-bands exhibited weak correlation and statistical equivalence with the null hypotheses ($p>0.05$). Moreover, systematic tendencies in distance calculations were observed in each band, particularly the GBP-band. This suggests that smaller photometric trends strongly influenced larger photometric trends, so future research should investigate smaller and more detailed trends, especially for photometric bands that demonstrate a weak correlation. However, the distance calculated from the metallicity-luminosity relation in the G-band to ϵ Tauri had a low RE, better than using the mean magnitude G-band magnitude as implemented by previous studies, so other relations in the G-band should be explored. These results set a new path in the calibration of the RC's luminosity relations to derive more accurate distance measurements for calibration in the distance ladder.

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Python Library Dependency Analysis

By Steve Han

Author Bio

Steve Han is a motivated student in Toronto who is highly interested in computer science and research. He is engaged in many volunteer and internship opportunities to enhance his coding skills. He hopes to improve people's daily lives by researching various issues to support his community.

Abstract

Python is a high-level programming language used by software engineers, computer scientists, and mathematicians. The purpose of this research is to help with the future development of the Python language, such as the optimization of the PIP manager and choosing built-in packages for Python. The main goal of this research is to analyze the pattern in the dependency network and how it changed after 2016. Using the official API provided by PyPI, a network of all related packages was made. After filtering any incomplete or irrelevant nodes, the entire graph is 10x larger than the research done by Kevin Gullikson in 2016. By ranking the number of edges, connectivity, as well as degree distribution of the nodes, a shift into machine learning and data analysis can be seen in the Python community. Some required packages shifted and reflected the current technological trend in recent years, such as Numpy for machine learning and Django for web development. Future studies are recommended to further investigate any particular changes in the usage of Python.

Keywords: Python; Graph analysis; PIP; NetworkX; Web-scraping; Graphing; PyPI; Data Parsing.

Introduction

Python has developed a huge package dependency tree throughout the years. To install a Python package, one only has to type the package's name and press enter. It was often thought to be a simple download from the library archive. However, when a package is installed, it does not just install one package in most cases. Every package has a requirements list that includes packages and versions of the packages that it requires to run.

While using the Python language, it would be very inefficient to code everything from scratch. For example, a data analyst uses mathematical libraries to do complex arithmetic on a large scale of data and graph drawing packages to present their results in a readable format. While possible, it would waste valuable time to reimplement these pre-existing codes for every occasion the user needs them. Users can package the codes they wrote and publish them on the Internet and then simply use Python's package manager to reuse the code so that people can focus on their analysis and research.

Python uses PIP to manage packages. PIP is a recursive acronym for "Pip Installs Packages." Recursive acronyms are a common feature in many computer programs, where the acronym is found in the full name. PIP simplifies many of the problems that might occur during the installation of packages. For example, import loops (where package A requires B, but B requires A, creating a loop) and dependency resolution (picking the right version of a package when multiple packages require a different version of the same package) are all handled during the installation process. We can visualize the data as a graph based on the packages' requirements. A detailed definition of Dependency Analysis can be found in the IBM documentation (IBM Documentation, 2021).

PIP searches the dependencies required by the package and automatically installs them. PIP is a smarter tool than most people think it is. The relationship between packages can be represented on a directed graph. Python's dependency network will be analyzed in this paper.

The dependency requirements between packages can also be represented as a directed graph. A graph, or a network, shows the connection (edges) between many individual things (nodes). For example, addresses and streets are a network where buildings are connected through many streets. However, graphs can be virtual as well. Bitcoin wallets and transactions are also a form of network, and social media accounts and subscribers can also be represented as a graph. In this case, every node represents a python package, and a directed edge represents the required dependency a package needs. A directed graph means that the connections between nodes are one-way only. It is a directed edge or connection because the relationship can not be reversed. If package A requires package B to function, then the directed relationship would be A -> B, but saying B -> A would not make much sense because B works fine without package A. For the simplicity of the research, the required versions of dependencies are ignored. An example of a library that visualizes module dependencies and checks for circular dependencies is Madge, but it's designed mostly for Javascript and CSS instead of Python (Github, Pahen/Madge, 2021).

For this paper, the researchers analyzed a few aspects of a network. The degree of a node is the number of connections a node has. In this case, the degree will represent how frequently a package is used. The PageRank algorithm shows each node's relevance, similar to how Google ranks its search results. The connectivity of a graph is the minimum number of elements that need to be removed in order to separate the graph into two separate ones. Communities are defined as a subset that is densely connected to other nodes in the subset and loosely connected to other communities in the graph.

People use Python due to its simple syntax and universality, which was made possible by the hundreds of thousands of different packages available on PyPI. This research ranked the commonly referenced packages in the dependency network through different measurements. This research also compared the current data with Kevin Gullikson's results in 2016 to see if anything has changed over time (Gullikson, 2016). It is predicted that low-level packages will have the highest usage because of their functionality. This analysis aims to help the development of the Python language by integrating some of the common functions into Python itself, as well as gain insight into how people use the language and help with many Python Enhancement Proposals that currently exist.

Methods

The first step would be to rerun the program to fetch the newest dependency data from PyPI using the same program provided in Gullikson's analysis. However, this is no longer feasible because PyPI discontinued the search function long ago, meaning the program no longer works. Articles of analysis for other languages were examined to form a solution for this problem during the research. Another solution found during the research is the Simple Repository API provided by PyPI. It is a simple index page for all Python packages formatted for program use. The PyPI-simple library was used to retrieve the list of packages, and the PyPI JSON endpoint was called to collect the dependency data of each library.

```
from pypi_simple import PyPISimple
import json
import requests

'''
with PyPISimple() as client:
    index = client.get_index_page()
    print('done')
    with open('2022.json', 'w') as f:
        f.write(json.dumps(index.projects))
'''

with open('2022.json', 'r') as f:
    index = json.loads(f.read())
    url = 'https://pypi.org/pypi/{}/json'
    with open('fetch.csv', 'w') as f:
        for project in index:
            data = requests.get(url.format(project))
            if data.status_code != 200:
                continue
            data = data.json()
            if data['info']['requires_dist'] is None:
                continue
            data = [x.split(' ')[0] for x in data['info']['requires_dist']]
            for each in data:
                f.write(project + ',' + each + '\n')
```

Figure 1, code used to download data from PyPi

The Python code in Figure 1 scraps data from the PyPI website and makes a list of dependencies. After generating the file, the data lists all of the packages on the left side of each line and their dependency on the right. In the case of multiple dependencies, there will be multiple lines of the same package with different dependencies. The graph is relatively large, and some of the analyzing methods might be too inefficient; this problem will be addressed later in the article. This paper uses NetworkX and other data visualization tools to analyze this graph and provide evidence to prove or disprove the hypothesis. The main analyzing approach would be relatively similar to older articles related to this topic, but with the more recent dataset to see how the dataset has shifted after their analysis.

The first noticeable change is that the network has grown significantly since 2016. Back in 2016, Gullikson was able to process 20,522 out of around 74,000 packages. The current graph includes 179,565 out of 383,450 packages and 788,318 edges. Python has likely grown drastically over the years. This became an issue due to the required time to fetch the entire network, but the script was eventually able to download a good portion of the data. During the process, packages that do not require other dependencies are excluded from the graph. It is understood that there are exceptional packages without any required dependencies, such as BeautifulSoup4 (an HTML parsing library), but they do not affect the graph as a whole. Versions of the required packages are also omitted since they are not the main focus of this research.

NetworkX and Matplotlib were used to analyze the data. NetworkX is a Python library for creating and manipulating graphs. It has many built-in methods that simplify the work, and it does all the heavy lifting math behind the scenes. Matplotlib is a plotting library that works very well with NetworkX. Kevin Gullikson's program was rerun for connectivity, degree distribution, and communities of the new graph. The code in Figure 2 is the process of generating the "betweenness" of a dataset.

```
bc = nx.betweenness_centrality(dep_graph)
sorted_dict = sorted(bc.items(), key=operator.itemgetter(1))[::-1]

N = 10
x = np.arange(N)
y = np.array([d[1]*100 for d in sorted_dict[:N]])
xlabels = [d[0] for d in sorted_dict[:N]][::-1]
fig, ax = plt.subplots(1, 1, figsize=(7, 7))

ax.barh(x[::-1], y, height=1.0)
ax.set_yticks(x + 0.5)_ = ax.set_yticklabels(xlabels)
ax.set_xlabel('Betweenness Connectivity (%)')
fig.subplots_adjust(left=0.32, bottom=0.1, top=0.95)

fig.savefig('Figures/Betweenness.png')
```

Figure 2, code used to calculate the betweenness by Kevin Gullikson (2016)

Several plots were generated and compared to the original graph. The analysis showed related results to the older analysis, but new changes were also found in the new graph, demonstrating how Python has evolved in the past few years. Produced charts will be shown in the following section, as well as some analysis and interpretation. However, it is worth noting that the JSON API used in this research might not be

100% accurate and up to date. These errors are small enough to be ignored in such a large dataset.

Results

This analysis came to many interesting conclusions. First, both the network from 2016 and the one from 2022 showed similar results for the degrees of nodes, as can be seen in Figure 3 and Figure 4.

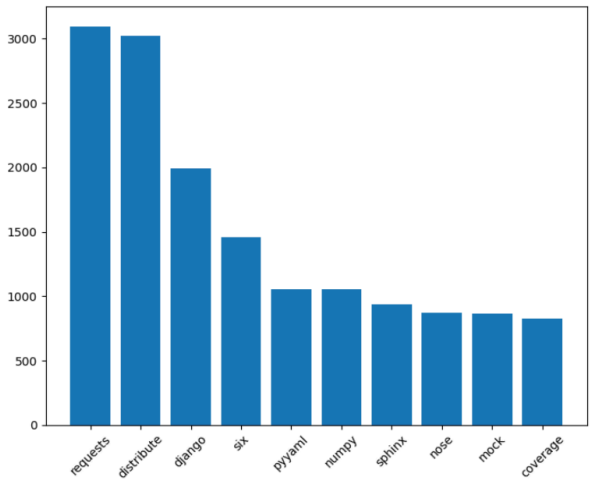

Figure 3, Graph degree in 2016

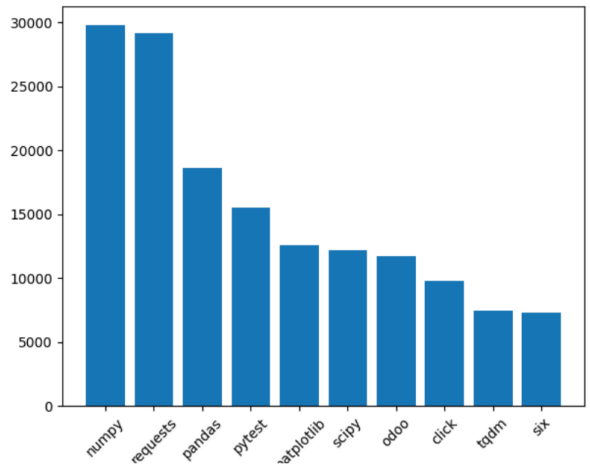

Figure 4, Graph degree in 2022

The data relatively stayed the same, and the degree count showed relatively the same trend. Even though the size of Figure 4 is 10 times bigger, the graph showed a decreasing trend of degrees within the first few packages, which is relatively similar to previous data. However, the major difference is that NumPy became very popular in the last six years, and Django is no longer seen in the plot.

Although the most popular package is still the requests package, other scientific analysis packages such as Numpy and Pandas also rose their rank to the top. A possible reason can be the new breakthroughs and discoveries in AI and machine learning, causing more and more companies and users to get into the field. Further studies are required regarding this hypothesis.

Testing packages also had a high rank in data from both times. Testing packages are mainly to ensure high-quality code and measure production metrics. Examples of these packages would be pytest, coverage, and mock. It is understandable that these universal tools are used quite often since most software in production uses these tools to assist with the development process.

The betweenness connectivity of the graph, the percentage of shortest paths between every two nodes that go through each package, is analyzed next. Figure 5 and Figure 6 showed both graphs' connectivity in 2016 and in 2022.

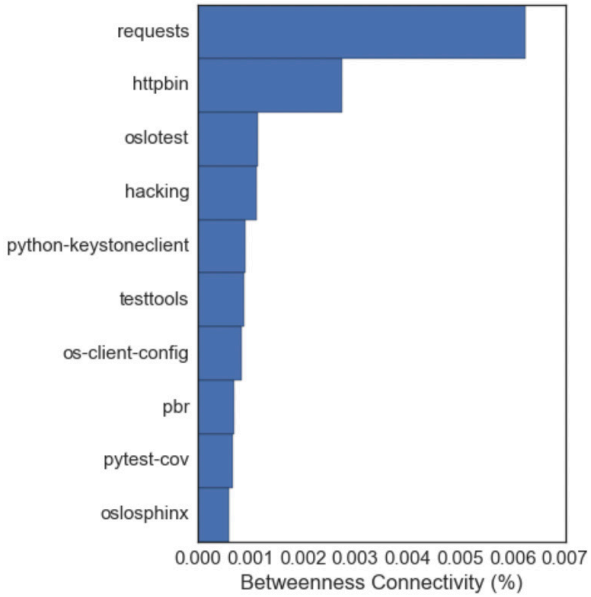

Figure 5, Connectivity in 2016

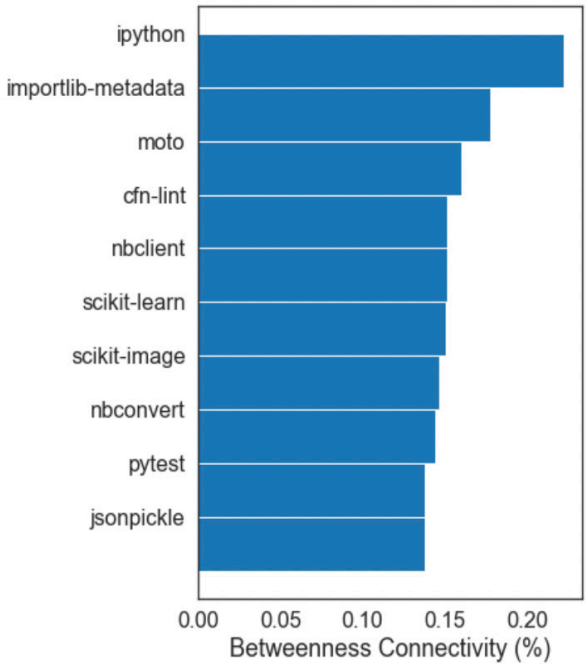

Figure 6, Connectivity in 2022

In Figure 6, the decreasing trend is significantly less dramatic. The Requests package was widespread in the dataset, but IPython and other testing libraries are replacing it. It is possible that the reasons why people use Python have shifted over the years or that the older data has been filtered out of the traditional data. Keep in mind that the network in this research is also significantly larger, which might also give us a more accurate result.

The last plot that was produced in this research is the degree distribution. A degree distribution plot describes how many packages require how many dependencies. The data from 2016 and 2022 are shown in Figure 7 and Figure 8.

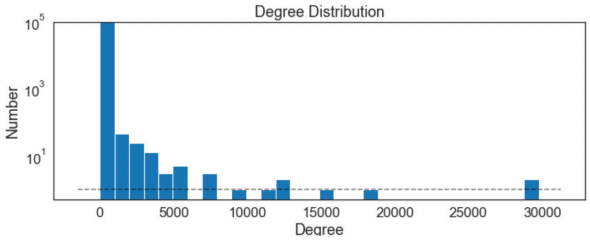

Figure 7, Degree distribution in 2022

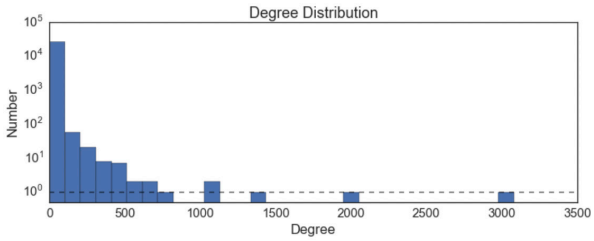

Figure 8, Degree distribution in 2016

The plot showed a similar decreasing trend, with fewer packages requiring more dependencies. It showed that most packages require 0 to 700 packages recursively. As Gullikson mentioned (2016), "A likely explanation is a 'rich get richer' scenario: packages that already have lots of stuff that uses them show up high on Google search results, and so new package developers use them too. For example, almost all scientists use the matplotlib plotting package, and so their code all requires matplotlib".

Conclusion

The results of this research revealed a great deal of exciting data indeed. The first difference is how the size of the graph grew through the years, to nearly 10x its 2016 size. This is strong evidence that Python's popularity has been growing drastically. With more tools being developed, more users will be attracted to the language, and more effort will be put into it. Python has a healthy community that is constantly growing, and this research predicts that it will continue to dominate the programming field.

Many important packages can be seen in this research. The most popular package is the Request package, which can be seen on the top in many plots. One possible reason is that web scrapers usually use Python to write their scripts, and requests became an essential dependency because it allows users to send HTTP requests and simulate actual browser headers easily. However, it still should not be a built-in package because there are many use cases for Python that have nothing to do with networking or web requests.

Python also seemed to become universal over the past six years. Even though the exponential trend still exists, it is seen in many plots that the trend is flattening between the top first few packages. One way

to interpret this is that Python has shifted from web-related development to many other fields. However, this could also be due in part to incomplete data or incorrectly filtered results, which caused biased data. It is best to reexamine this issue before further research is concluded.

It is worth noting that the relations between packages do not completely represent a package's popularity. For example, a library meant for end-user usage might not have a lot of packages depending on it, but it doesn't mean that it is an unpopular package. However, dependencies can show, to some degree, some low-level package's importance in the community and its importance. To fully investigate the popularity of packages, other metrics such as Github stars and the number of pull requests might better represent such topics.

In conclusion, the data analyzed in this research shows many exciting results, and the hypothesis mentioned at the beginning is mostly correct. There are more packages that showed significant usage than expected, but it also revealed how Python is used for all sorts of purposes, and one perspective is only a fraction of what the language is capable of doing. Based on the more detailed results, it is recommended that more research be put into this graph in order to decide whether some packages should be included in Python.

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Effects of Engagement with Different Authentic Audiovisual Stimuli on the Listening Proficiency of Higher-level and General Second Language (L2) Learners

By Tianyi (Tina) Zhang

Author Bio

Tianyi (Tina) Zhang is a student at Syosset High School in New York. She found her passion in linguistics when she found herself loving the process of learning different languages in school and at home. She is fluent in English and Mandarin Chinese and semi-proficient in French and Japanese. She plans to study linguistics in college with the ultimate goal of becoming a linguist, translator, or diplomat. Outside of school, she is a nationally ranked fencer who has been fencing competitively for seven years. She is an only child in her family and has a mini brown pet poodle named Frankie. During her free time, she enjoys hiking and knitting.

Abstract

The term "audiovisual" pertains to a combination of both the hearing and sight senses, and different audiovisual stimuli have diverse effects on listening proficiency. Establishing the effectiveness of various audiovisual stimuli on language learners is essential to optimizing secondary language acquisition. This study examines how engagement with audiovisual programs impacts the listening proficiency of second language (L2) learners, and which type of audiovisual program is optimal for higher-level learners to improve their proficiency. By reviewing relevant studies and comparing their results, this study finds that engagement with audiovisual stimuli significantly enhances the listening proficiency of L2 learners. Moreover, there is no strict hierarchy of sources that best help higher-level learners because of the variable interplay of factors such as speech styles, the learners' first languages and the languages being learned, their topic familiarity, and their level of interest. However, there is a widespread preference for TV news as the optimal material for higher-level L2 classrooms, because they contain a high degree of redundancy that facilitates listeners' understanding of vocabulary. Furthermore, the TV news has been suggested to be most helpful for building higher-level L2 comprehension if certain features could be adjusted: effectively juxtapose spoken and visual texts, present less ambient noises and clear enunciations, and include more disfluencies as well as greater combinations of voiceovers and visuals instead of talking heads. Teachers are suggested to incorporate more audiovisual sources, especially the TV news, into L2 classroom learning.

Keywords: Audiovisual stimuli; Listening proficiency; Second language acquisition; TV news; Higher-level learners; Second language classroom; Authentic audiovisual sources; EFL/ ESL; Features that influence listening comprehension

Introduction

It is not uncommon for non-native speakers to attempt to learn English by watching American TV shows. For instance, Korean rapper RM from the boy group BTS attributes his English proficiency to the sitcom Friends (Pirnia). However, TV shows are not the only audiovisual, a term pertaining to a combination of the hearing and sight senses, sources available. There are many mass media programs, and they have presumptively variable effects on second language acquisition. Establishing the effectiveness of various audiovisual stimuli on language learners is essential to optimizing secondary language acquisition. Consequently, this present study will examine the impacts of engagement with audiovisual mass media programs on the listening proficiency of second language (L2) learners and ascertain the type of audiovisual program optimal for higher-level L2 learners.

Studies show that engagement with audiovisual mass media programs significantly enhances the listening proficiency of L2 learners. Moreover, there is no strict ranking of sources that best help higher-level learners due to the variable interplay of factors such as speech styles, the learners' L1 and L2, topic familiarity, and level of interest. However, there is a widespread preference for TV news as the optimal material for higher-level L2 classrooms, as they contain a high degree of redundancy that may facilitate listeners' understanding of vocabulary. Furthermore, research has favored TV news for building higher-level L2 comprehension if certain characteristics are prevalent: effectively juxtaposed spoken and visual texts, narrative text, and a combination of voiceovers and visuals.

To better understand audiovisual stimuli, it is essential to recognize how to analyze and measure their effects. Four primary skill sets are used as empirical indicators of language proficiency: reading, writing, speaking, and listening. However, listening is the least thoroughly researched due to a traditional overemphasis on reading and writing, which is unfortunate because listening is an important skill in evaluating the language proficiency of L2 learners (Rubin 198). As a result, this present study delves into the listening proficiency of L2 learners in an attempt to expand and spread knowledge in the area of listening comprehension.

Interlocutor, task, listener, process, and text characteristics in audio are the five main factors which affect L2 listening comprehension (Rubin 198). To start, interlocutor characteristics are primarily concerned with gender bias and the perceived language proficiency of speakers by listeners (Rubin 205). Task characteristics are concerned with the nature of the task, such as whether the task includes multiple choice, choose-a-picture, matching, or free response questions (Rubin 204). Additionally, listener characteristics deal with the impacts of the listener's language proficiency level, ability to recall, amount and span of attention, age, gender, background knowledge of the topic, and the possibilities of learning disabilities on listening proficiency (Rubin 206). Next, process characteristics are those that influence listeners' interpretation of the audio based on prior or unknown knowledge (Rubin 211). Finally, text characteristics are time-related variables, including speech rate, frequency of pauses and hesitation; perceptions of stress and rhythmic patterns; differences in syntax, such as the length of each sentence; prevalence of redundancies; and the order of the words (Rubin 202). These characteristics are presented in different audiovisual programs. Philips displayed the main types of audiovisual sources, ranging from standard features such as weather reports through soft news, news, and short documentaries (Philips 348). These audiovisual programs differ in the proportions of text/speech to image components and may have correspondingly varying effects on L2 learners' listening proficiency (Philips 349).

During my research, I conducted a literature review of studies on the effectiveness of various audiovisual sources in L2 acquisition and proficiency using JSTOR and Google Scholar. Subsequently, I evaluated relevant studies and compared their results and conclusions. Over the course of my paper, I will explore the effects of general audiovisual sources on L2 learners' listening proficiency, and then delve into the most helpful audiovisual sources for improving their listening skills. Next, I will examine specific source and L2 listener features — speech styles, learners' L1 and L2, their topic familiarity, and interest — that influence their listening comprehension, and at last focus on the TV news as a type of audiovisual program while detailing certain elements that could be adjusted to maximize listening comprehension.

Analysis

Effects of Audiovisual Programs on L2 Learners

To determine the relationship between listening ability and general foreign language proficiency, Feyten assayed a group of students enrolled in a summer intensive language learning program and requested them to respond to a video version of the Watson-Barker Listening Test (WBLT) in the beginning and end of the program (176). Feyten finds statistically significant positive correlations between listening ability and overall foreign language proficiency, indicating that advances in listening proficiency results in improvements in overall language proficiency (French, $r = .41$; Spanish, $r = .39$; $p < .05$) (Feyten Table I, 177). Graham & Zhang's study further supports this conclusion by demonstrating that Chinese L2 learners of English with little preexisting vocabulary knowledge and high listening proficiency gain expertise in English most effectively, proposing that listening proficiency influences vocabulary input, thereby impacting foreign language proficiency (1042).

The positive correlations found between listening ability and overall foreign language proficiency enables us to better understand how auditory and visual stimuli interact to produce the effects of audiovisual programs on L2 learners. Rubin, who investigated the listening comprehension of beginner Spanish students who watched dramas on video compared to that of their counterparts who didn't, discovered that the students who watched the videos improved significantly over their counterparts (102). Her findings signify that auditory input augmented with visual support may enhance listening proficiency. Rubin's conclusion is further supported by Herron et al., who, while exploring the impact of video on the listening comprehension of university students in French, learns that listening proficiency improves to a greater extent after exposure to an audiovisual source than to a text and audio-only source (Herron et al., Table IV, 786). Based on these results, we can conclude that exposure to audiovisual programs may significantly enhance L2 learners' listening proficiency.

Hierarchies in the Effectiveness of Different Audiovisual Sources

Philips contrasts the French A2/TF1 weather forecasts that consistently visualize speech with mobile graphics, gestures, and speech, with the Mexican Noticias ECO (Empresa de Comunicaciones Orbitales) weather forecast programs that show stationary maps while the discussions go into much greater detail (348; 349). As Philips' weather forecast example demonstrates, the same type of audiovisual program may have varying degrees of correspondences between visuals and texts depending on the country. It has been previously established (Meinhof; Arnold & Brooks) that improvements in listening proficiency partially rely on how much the text and the visuals complement each other. Specifically, the greater the correspondence between the visuals and texts in an audiovisual program, the likelier that the source will improve L2 learners' listening proficiency. Hence, it would be difficult to generalize which blanket category of audiovisual source might best enhance L2 learners' listening proficiency, as this improvement relies on variable internal features of the auditory and visual components of a given source. Philips raises advertisements as another example, as they have different combinations of the visual, musical, and language components as well, which further insinuates that there may be no strict hierarchy of audiovisual sources in terms of how much they help L2 learners to improve their listening skills, because the degrees of correspondences between the two components differ across the same audiovisual program (Philips 351).

Philips' position is supported by Bell, who studied news broadcasts that conduct street interviews with the vox populi, who display a great variation of "accents based on region, age, socio-economic, class, race, and ethnic identity" and the use of slang or in-group language (8). Bell finds that familiarity with the vox populi's accents facilitates comprehension, while a lack of it creates greater processing difficulties (8). On that account, the extent to which L2 learners understand a news broadcast varies based on their familiarity with the speaker's accent. Therefore, it is very difficult to determine which audiovisual mass media program is most effective for improving L2 learners' listening proficiency because improvements or lack thereof are entirely arbitrary depending on their experiences with the speaker's accent.

Furthermore, Bell finds that the amount of time that "talking heads" versus voiceovers occupy on TV news broadcasts differs across network

news (9). Notably, according to Bell's coverage of Gunter's study, listening comprehension is the lowest for "talking head" segments. Thus, since TV news broadcasts have differing amounts of time that display talking heads and mixed formats of video presentation and audio, L2 learners' listening proficiency may rely on a variety of particular features of audiovisual mass media programs. Consequently, it is not likely that there is a particular hierarchy of audiovisual sources.

Audiovisual and Listener Features that Influence Listening Comprehension

Philips asserts that a combination of "formats and speakers highlighted factors not previously apparent," suggesting that the matter of ascertaining the type of audiovisual program that best benefits the L2 learners' listening proficiency is not simple (351). One factor, for instance, is individual speech styles in the programs. Rubin finds that the speaker's pause phenomena, speech rate, and hesitation in audiovisual sources all play a role in listening comprehension (199). She cites Blau, expressing that blank pauses, hesitations, and a delayed speech rate in audiovisual sources facilitate listening comprehension (9). The trend described may be reflected on many other kinds of audiovisual sources, as they have a variety of speech styles that affect L2 learners differently depending on the frequencies of pauses and hesitation and speech rate. Consequently, it is very difficult to determine which type of audiovisual source is best for improving L2 learners' listening proficiency.

Furthermore, according to Glisan, who examines the effect of Spanish word order patterns in listening comprehension of English-speaking students learning Spanish, there is a hierarchy of comprehension difficulty associated with word order (465). Glisan finds that subject-verb-object sentences may yield lower comprehension compared to verb-subject-object and object-verb-subject sentences (Glisan Table 3, 460). Her study reveals that various word orders spoken in audiovisual programs have differing effects on L2 listening comprehension. Hence, since each type of audiovisual source is composed of multiple sentence structures and word orders, it impractical to ascertain the specific kind that best benefits L2 listening proficiency. As a result, it is highly likely that there would be no strict ranking of audiovisual sources.

Another factor that influences listening proficiency of L2 learners is their familiarity with the topic discussed in the audiovisual sources. Long, as summarized by Rubin, finds that participants who had prior knowledge about the topic displayed higher comprehension, demonstrating a positive correlation between background knowledge and listening proficiency (209). Moreover, according to Rubin's account of Schmidt-Rinehart's study, L2 learners recall significantly more information from listening to a familiar topic, and their improvement in listening comprehension is higher compared to that after listening to an unfamiliar topic (209). Their research denotes that improvements in learners' listening proficiencies vary based on topic familiarity, meaning that listening comprehension progress is likely independent of the type of audiovisual program.

A learner's interest in the audio topic is also a significant variable affecting comprehension. L2 learners' interest determines the amount of attention they pay to audiovisual sources, which affects their comprehension to a larger degree than the type of audiovisual source. According to Rubin's account of O'Malley et al.'s study, more interested listeners "seemed to be aware when they stopped attending and made an effort to redirect their attention to the task" while less interested readers "usually just stopped listening or failed to be aware of their inattention" after encountering an unknown word or phrase in a listening text (428). These observations pinpoint that the level of interest affects attention which, in turn, affects how much information the second language learners absorb and recall, implying that the type of audiovisual programs may not really affect the listening proficiency improvements of L2 learners. Moreover, according to Schwartzstein, the phenomenon of selective attention can lead a listener to consistently fail to recognize important sentences or words and hold incorrect beliefs about certain things because they have absorbed only partial information (1449). Schwartzstein's finding supports the conclusion that inattention or selective attention is harmful to L2 learners' language acquisition and listening proficiency. Since their improvements in listening proficiency vary based on the level of attention they give to each topic, it is likely that there is no strict order of audiovisual sources.

Finally, the linguistic relationship between

the first and new languages of L2 learners' affects their listening proficiency. Philips claims that improvements in listening proficiency are associated with the degree of similarity between an individual's L1 and L2: the closer their L1 is to their L2 linguistically, the more accessible or easier those improvements are (351). Furthermore, according to Nation, the L1 provides a familiar and effective way of "quickly getting to grips with the meaning and content of what needs to be used in the L2" when the languages are relative to each other, further expressing that having similar L1 and L2 may help the learners to enhance their foreign language and listening proficiency (5). Both studies illustrate that there is a significant positive relationship between proficiency in L1 and L2, especially when they are interrelated or similar to each other. As a result, it would be difficult to determine a ranking of audiovisual sources when there are numerous variations in the L2 learners' L1 backgrounds.

News: The Optimal Audiovisual Source for Higher-level Language Learners?

These complexities notwithstanding, several studies suggest that TV news may be a more effective audiovisual source to improve higher-level language learners' listening proficiency than other audiovisual stimuli. For example, strong correlations are found between the listening proficiency improvements of upper-intermediate-level learners with exposure to their preferred type of program (news broadcasts: correlation coefficient = 0.334, p-value = 0.004), but no correlations exist between low-level L2 learners' language proficiency improvement and exposure to their preferred audiovisual source (cartoons: correlation coefficient = 0.122, p-value = 0.906) (Bahrani & Tam Sim 2012a, 56). Bahrami and Tam Sim's finding conveys that news broadcasts may be more effective in helping higher-level L2 learners and cartoons less effective for lower-level L2 learners .

In another study, Bahrani finds statistically significant improvements in all four areas of language proficiency with the second greatest difference in listening proficiency for higher-level L2 learners of English who are exposed to TV news in Malaysia (Bahrani 2013, 155). Bahrani studied the results of the International English Language Testing System (IELTS) tests. He employed the Pairwise comparison with Bonferroni correction to find that the improvements in listening proficiency ($M = 0.50$, $SD = 0.72$) are statistically significant ($p = 0.01 < 0.05$) (Bahrani 2013 Table 4.28, 153). His findings reveal that TV news may be an effective medium for higher-level L2 learners to use to enhance their listening comprehension skills.

These findings correspond with a third article by Bahrani and Tam Sim, where lower-level L2 learners spent the most time watching cartoons (18,038 min.), and higher-level L2 learners spent the most time watching news (16,648 min.) during their study (Bahrani & Tam Sim 2012b Table 2; 3, 356). They find that exposure time to news broadcasts significantly correlates with upper-intermediate level L2 learners' language (listening) proficiency improvement (t statistic = -3.20, p-value < 0.05), yet the same does not occur for low-level L2 learners with cartoons (t statistic = -0.25, p-value > 0.05) (Bahrani & Tam Sim 2012b Table 5, 358). Their findings contend that higher-level L2 learners who prefer news programs are more likely to improve their listening comprehension, contrary to lower-level L2 learners with their preferred type of audiovisual program (cartoons).

Further evidence in support of these studies is provided by Bell, who expresses that news items may be "suitable pedagogical material for the second language classroom" because TV news contain a high degree of redundancy (15). Bell raises an example of the Carry-on Luggage TV news item, which contains many repetitions and synonyms: carry-on baggage, carry-on bags, bags, carry-on luggage, luggage, and carry-on to insinuate that TV news may be useful in the L2 classroom (9). These redundancy features of repetition, paraphrase, and synonyms are generally understood to help higher-level L2 comprehension (Chiang & Dunkel 373). Moreover, according to Brinton & Gaskill, the "amount of recycling of vocabulary in episodic news items" and high-frequency idioms used by anchors and correspondents lead to better comprehension and allow viewers to gain knowledge in specialized vocabulary (410). Therefore, it is very plausible that higher-level L2 learners' vocabulary development is enhanced significantly when they are exposed to TV news, indicating that the TV news is beneficial for higher-level language learners.

Enhancing the Effectiveness of News as an Authentic Audiovisual Stimulus

It may be possible to adjust specific features of TV news, to make it more effective at enhancing the listening proficiency of L2 learners (Bell 15). One element is the juxtaposition of spoken and visual texts. There are three ways that text and images are said to interrelate: overlap, when words and pictures are identical; displacement, when words and pictures mark cause and effect of an action, or when images are used to comment or draw inferences from the text; and dichotomy, where words and images refer to different actions altogether, and the input may be misleading or unhelpful (Bell 10). Of the three ways text and images interrelate, the overlap relation is established to be most effective in improving L2 learners' language (listening) proficiency (Bell 11). The overlapping relationship is most effective in allowing L2 learners to map the visuals shown on TV to the meaning of the words, as it enables learners to acquire new vocabulary and improve their listening comprehension (Bell 11). Further evidence is provided by Philips, who finds a positive association between the frequency of visual and text correspondences in audiovisual programs and improvements in L2 learners' listening proficiency (351). These findings demonstrate that engagement with TV news items with higher degrees of correspondences between texts and images allow for greater listening proficiency improvements in L2 classrooms.

Another important detail subject to change is exposure time to narrative text versus non-narrative text. Bell's coverage of Brown's study suggests that narrative texts are easier for L2 learners to listen to and recall than expository events. Moreover, stories with a clear narrative story line tend to be easier processed than those without it for L2 learners, conveying that a shift from a non-narrative to more narrative text may help to better improve listening proficiency (9). Additional support is provided by Bullock et al., who reasons that because of narratives' basic organization compared to non-narratives, the content is more structured and easy to understand, making narratives useful devices for organizing events, illustrating relationships, and providing examples (10). Since narrative texts are processed more easily, they lead to better comprehension and could be more influential in persuading L2 learners. Consequently, increasing exposure to narrative texts in TV news is likely to produce beneficial effects on learners.

Furthermore, the clarity of enunciation and absence of ambient noise could be adjusted. According to Bell, the vox populi interviewed in TV news may not enunciate every word clearly, creating difficulties for the L2 listeners to understand. In addition to ambiguous enunciations, most interviews with vox populi take place on streets filled with various background noises, rendering speech more difficult to comprehend for L2 listeners as the background noises overpower the vox populi's words. Additionally, Sarampalis et al. finds that noise reduction in programs reduces listening effort and allows cognitive resources for other tasks, including performance on the word-memory task and responses in visual reaction times, hinting that noise reduction in the TV news may prompt better L2 listener recall on words and quicker responses to visuals. Consequently, it becomes crucial for TV news programs to effectively eliminate background noises and improve the clarity of the vox populi's enunciations during the editing process to improve L2 learners' listening proficiency.

Additionally, the amount of hesitation and disfluency shown in the TV news influence L2 listening proficiency. Anchors and correspondents on the TV news tend to have planned discourses, resulting in an absence of hesitations and repairs. Although this tendency serves to make TV news seem smoother and easier to predict, the absence of pauses and hesitations may lessen L2 listeners' comprehension (Rubin 201). Rubin indicates that hesitations and pauses tend to lead listeners to focus great attention on the source, which could result in better listening comprehension (201). Therefore, the lack of those disfluencies could lead to less comprehension. Corley et al. further supports Rubin's finding by expressing that disfluencies are more likely to be remembered by listeners, implying that TV news could incorporate greater occasions of disfluencies to lead to better recall by the L2 learners. The study also demonstrates that hesitation affects the way in which listeners process spoken language, and that these changes are associated with longer-term consequences for the representation of the message. As a result, it is important to depict more hesitations and pauses in the TV news in order to enhance L2 listening proficiency.

Finally, TV news could adjust the time covered on talking heads versus voiceovers. From

Bell's coverage of Gunter's study, decreased coverage of talking heads and increased voiceover features on the TV news may lead to more recall and comprehension by L2 learners (9). Bell hints that talking heads may lead to less viewer concentration in general due to a lack of enticing features and consequently less recall and comprehension. On the other hand, voiceovers paired with visuals may result in more concentration and recall due to engrossing visuals. Brosius' study elaborates on the ineffectiveness of talking heads and proposes a new suggestion to improve comprehension. Brosius finds that understanding of TV news is enhanced by the "use of film as opposed to 'taking heads' only and by mixing up formats", entailing that decreased coverage of talking heads and increased combinations of film items with mixed format news broadcasts may best benefit L2 learners and help them to improve their listening proficiencies (399).

Identifying L2 Students Who May Benefit Most From TV News

Higher-level L2 learners who possess higher vocabulary significantly benefit from TV news (Bahrani & Tam Sim; Bell; Brinton & Gaskill). According to Saraswatys, a major setback in listening comprehension for L2 learners is that they often do not have sufficient vocabulary or their vocabulary is too poor to understand (146). Since TV news tends to have a greater range of and more difficult vocabulary than cartoons and films, it is crucial for listeners to have knowledge of at least some of the words. L2 teachers could try to expand students' vocabulary by asking them to guess meanings of words used in the listening context before explaining to them: when students could relate what they have already known to what they are supposed to listen for, they are more likely to listen more attentively and comprehend better (Saraswatys 146). It is no surprise that higher-level learners tend to benefit more than lower-level learners from the TV news, since they tend to have greater vocabulary.

On top of this, knowledge of precise pronunciations of words by native speakers may be another criterion for determining the type of L2 students who benefit most from TV news. Saraswatys indicates that incorrect pronunciation hinders students from listening comprehension and that students' own accurate pronunciation of words is of great help for them in listening acquisition (146). Saraswatys' finding communicates that without knowledge of the proper pronunciation of words, it is very difficult for the listener to determine the meaning of the text. Therefore, higher-level L2 learners who are knowledgeable in the correct pronunciations of words could greatly benefit from the TV news.

Lastly, L2 learners who are not easily distracted by visuals may benefit more from TV news than those who do. According to Bell, although audiovisual sources could help to enhance listening proficiency, it is possible that some L2 listeners become distracted by the visuals (7). When they are distracted by the visual component of the TV news, they tend to focus less on comprehending speech, which may hinder or have no effect on the improving progress of their listening proficiency. Consequently, L2 learners who exhibit greater attention to the text and are less likely to be distracted by visuals may benefit most from TV news.

Conclusion

Engagement with general audiovisual mass media programs could significantly improve the listening proficiency of L2 learners. Furthermore, there is likely no strict hierarchy of audiovisual stimuli types that most effectively enhance higher-level L2 learners' listening comprehension, as the speech styles presented, the relationship between the learners' L1 and L2, topic familiarity, and interest and attention vary for each audiovisual source and differs from person to person. This finding indicates that enhancement of listening proficiency is likely to depend more on listeners' internal factors or audiovisual sources' features instead of the type of program. Nevertheless, there is a widespread preference for TV news as the optimal material for higher-level L2 classrooms due to its high degree of vocabulary redundancy, which facilitates the understanding of vocabulary. Moreover, if certain features of TV news could be adjusted — display more narrative texts, adequately juxtapose spoken and visual components, limit ambient noises and present clearer enunciations, and include more disfluencies and combinations of voiceovers and visuals — they could be very effective for building L2 comprehension. There has even begun a general trend of American TV news leaning towards framing news

stories dramatically and conversationalizing TV news discourse, which is likely to produce beneficial effects for L2 learners and their listening proficiency (Bell 9).

This paper's findings present implications for L2 classroom learning, suggesting that teachers could start by incorporating more audiovisual mass media programs into L2 classroom learning to better their students' listening comprehension. Additionally, although there may not be a strict hierarchy of audiovisual sources, certain features of TV news may render it a more useful medium for L2 classroom learning, especially for higher-level learners. As a result, teachers could use a checklist for some factors in TV news to select the most appropriate and effective ones for L2 learning and listening proficiency enhancements. Moreover, this paper identifies higher-level L2 learners who have higher vocabulary, knowledge of proper pronunciations of words, and do not get easily distracted by the visuals as the students who benefit most from exposure to TV news. Consequently, teachers in L2 classrooms could start by expanding their students' vocabulary and expose them to more varieties of accents and speech styles to prepare them for audiovisual or audio-only stimuli. In addition, teachers may help their students become more familiar with the precise and correct pronunciations of native speakers. By doing so, the students' own pronunciation capacity is improved, which will help them find listening to native speakers to be less challenging. Furthermore, L2 teachers could help their students develop listening strategies for effective listening. Listening strategies such as self-monitoring, elaborations on what has been heard, and inferencing may lead to better listening comprehension. Active implementation of those listening strategies may also reduce the chances of getting distracted by visuals or irrelevant observations. Additionally, providing audiovisual materials corresponding to students' interests and backgrounds may also serve a purpose, as they motivate students to actively concentrate on audiovisual sources and better understand speech.

Nevertheless, this present study also raises new questions. For example, if all the internal factors in the listener or in the audiovisual program could be taken into account, could we determine if there is truly an optimal audiovisual source for L2 language learning? Moreover, we discover that the TV news could be most effective for higher-level L2 learners if certain features are adjusted, but what about the types of audiovisual stimuli that could be most effective for lower-level and intermediate-level learners? Lastly, it would be interesting to investigate more features in the audiovisual program such as the speed of the speech as well as the age of the listener and how they could impact L2 language and listening proficiency.

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The Texas Tower Shooter: An Analysis of Charles Whitman

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Abstract

This application paper will examine common attributes of serial killers, such as biological impairments in their brains and other aggravating factors: experiencing child abuse, having violent fantasies, and fitting into the categorization of organized/disorganized killing. These factors will be analyzed to determine how accurately they apply to serial killer Charles Whitman and to what extent they influenced his decision to commit a mass shooting. Information from empirical studies on serial killers, review articles on neurological defects concerning violence, and book chapters were assessed to establish what aspects relate to Charles Whitman. The results indicate that Charles Whitman had common traits of a serial killer, such as undergoing an abusive childhood, being classified as an organized killer, and having violent thoughts. The research supports the fact that Whitman had a neurological defect, a tumor on his amygdala that could have contributed to his actions. The overall findings suggest that further neurological research on how biological elements impact violent actions can contribute to a better understanding of preventive measures regarding violence in serial killers.

Keywords: Charles Whitman, serial killer, neuroscience, brain tumor, amygdala, biological, school shooting, murderer

Introduction

The study of the most dangerous and feared criminals, serial killers, is a prevalent topic of interest today. Whether it is by criminologists or the general public, most people want to know the why behind a serial killer's actions; what causes a human being—like them—to be able to commit such atrocious and unimaginable acts to others without any evident empathy? Research on serial killers is necessary for society as it can provide more information on understanding them and offer insight into the question of how their actions can be prevented. Unfortunately, understanding the motives behind a serial killer's actions is not a straightforward process due to the complexity of their behavior. However, many different theories exist to attempt to explain their behavior. Investigating a serial killer's childhood, mindset, environmental influences, and/or biological processes of their brain are different approaches that can help further analyze the actions of a serial killer.

There are specific proven factors in all of these theories that certain serial killers exhibit. Crime and the brain are linked because there is evidence that certain parts of the brain can be linked to aggression and violence, like the amygdala and prefrontal cortex. Along with neurological influences, research has shown that the environment a serial killer grew up in could affect their future actions. Suffering from child abuse and witnessing domestic violence are examples of harmful childhood experiences that could increase the likelihood of violence in the future. While identifying risk factors is essential, acknowledging existing traits in a serial killer's personality is also necessary. A distinguishable factor of serial killers is their type of killing being labeled as organized or disorganized. Another feature attributed to serial killers is fantasizing about violent thoughts. This paper will discuss how these factors are present in serial murderer Charles Whitman and how they can be applied to his actions. Moreover, various research findings on these topics will be utilized to comprehensively explain specific characteristics of serial killers and how advancing neuroscience knowledge can contribute to a better understanding of biological impacts.

Charles J. Whitman and the Murders

Charles J. Whitman would be described as a mass murderer, someone who has killed four or more victims at one location on a single occasion. He committed a mass school shooting at the University of Texas in 1966 by shooting and killing 14 people while wounding 32 others. Earlier on the day of the shooting, Charles Whitman murdered his mother and wife as well.

Charles Whitman's childhood consisted of being raised in a middle-class home in Florida by his mother and father, Margaret and C.A. Whitman. He was described as a healthy young boy who regularly attended Mass with his mother and two brothers and did well in school. He joined the Boy Scouts of America and enjoyed playing piano and hunting. However, his father was abusive to him, his brothers, and his mother. He suffered from harsh expectations his father set for him to succeed in all aspects of life, like his extracurriculars and school. Additionally, he continually witnessed and experienced the violence his father inflicted on the family (Lavergne, 1997).

Two weeks after he turned eighteen, Charles Whitman left his home, joined the Marines, and eventually went to college at the University of Texas where he met his future wife, Kathy Leissner. As the years progressed, he began complaining about headaches and stress. He was referred to a psychiatrist, and had a session with him in which he discussed his frustrations with how his father treated him in his childhood, his attempts to treat Kathy well, and his fantasy of going up the clock tower at the university and shooting people (Lavergne, 1997).

The day before the murders, he wrote a note and again admitted to having violent fantasies by stating that he was a "victim of many unusual and irrational thoughts," even though he was "supposed to be an average reasonable and intelligent young man." He wrote about his plan to kill Kathy and his mother and discussed how he was prepared to die. Whitman explained that he could not pinpoint "any specific reasons" for his actions. He then requested an autopsy after his death to reveal if there was anything physically wrong with him due to the severe headaches he had been having. Whitman briefly mentioned seeing the doctor for what he called his "overwhelming violent impulses" but believed it didn't help as he stated he was left to fight his "mental turmoil alone" (Lavergne, 1997).

Around midnight on August 1, 1966, Charles Whitman went to his mother's apartment and murdered her. Right after her death, he wrote a note stating that he had taken his mother's life and believed he had relieved her of her suffering on Earth. He mentioned his hatred of his father and how his mother had suffered because of his father for far too long. Then around 2:30 AM, he returned to his apartment where his wife Kathy was asleep. He stabbed her five times in her sleep. In his previous note, he mentioned that he planned to kill Kathy as "painlessly as possible" and that he loved her a lot. Then he wrote a note requesting that if his life insurance policy was valid, to pay off his debts and "donate the rest anonymously to a mental health foundation," proposing that "maybe research could help prevent tragedies of this type" (Lavergne, 1997).

After the murder of his wife and mother, Whitman carefully planned the shooting that would take place that very same day. It was clear the shooting was organized and carefully planned. Charles Whitman had the intent to murder as many people as possible. He entered the clock tower at the University of Texas by posing as a janitor and brought along several different guns, ammunition, and other supplies. Once he reached the top, he shot at victims near the observation deck and barricaded himself inside, beginning the mass shooting. His experience in the Marines undoubtedly assisted with his ability to shoot individuals from the tower that rose over 300 ft above the campus. He shot at anyone in his view, including students, a pregnant woman, and young teenagers. He ultimately killed an unborn child and thirteen people that day, the fourteenth victim dying a week later from their injuries. Charles Whitman had injured 32 other people in the shooting as well. Eventually, he was shot and killed in the tower by the officers of the Austin Police Department. Upon his request, an autopsy of his death was performed, and a tumor was found in his brain. This tumor caused speculation about what impact it could have had on his actions (Lavergne, 1997).

Analysis of the Murders and Tumor

The murders Charles Whitman committed were surprising to his friends and family. His father believed he had lost his mind and other close relatives attributed his actions solely to the tumor. He was said to have a good relationship with his mother and wife. He was also described as an ordinary young man by people who knew him. There is a lot of speculation about what ultimately motivated his actions. Approaching the study of Whitman's actions from a biological approach can help to scientifically analyze what he was experiencing. Several parts of the brain, such as the prefrontal cortex and amygdala, have been proven to be associated with violence upon damage.

In Charles Whitman's case, he had a tumor called a glioblastoma which was in a region of his brain beneath the thalamus, on the hypothalamus, and in a position that caused it to compress and over-stimulate the amygdala (Eagleman, 2011). The amygdala is a small almond shaped part of the brain that is associated with emotion regulation. It is activated in humans, especially in situations regarding fear and aggression (Eagleman, 2011). A University of Baltimore Law Review Article examined the role of Functional Magnetic Resonance Imaging and how it can be used in a court of law (Donahue, 2013). Functional Magnetic Resonance Imaging, or fMRI, is a process researchers use to monitor a human brain and identify impairments. The research done on fMRI does not fully support it being utilized for lie detection; however, the article proposes that fMRI should be considered to be eventually taken into account in court hearings by the jury and judge because it can provide evidence displaying how specific impairments of the brain are linked to violence and aggression. The article analyzes fMRI studies and presents the findings that support the claim that the amygdala functions in the brain directly increase or enhance anger and aggression. Several fMRI studies examined the role of fMRI with the prefrontal cortex and amygdala, regions of the brain that can affect how well an individual can fully understand the culpability of their actions. The article claims that since these neurological impairments can be identified from fMRI, they should be considered when assessing a criminal's actions in court. Based on the article, present evidence from fMRI can demonstrate that in Charles Whitman's case, his seemingly unexplainable actions could be due to the overstimulation of his amygdala that he was experiencing. Findings show that over-stimulation of the amygdala would result in "uncontrollable violent behavior" and an inability to comprehend this criminal behavior.

The information presented in the Law Review Article simply recognizes the link between Charles

Whitman's brain tumor on his amygdala and how that could have led to increased violence and aggression. However, neuroscience research and how accurately it can be used to explain criminals' actions is still advancing. Whitman's tumor could provide a potential explanation for the motives behind the murders. Still, there is evident uncertainty in this research about the extent to which he was personally responsible for his actions. The tumor affecting his amygdala did not necessarily indicate he had no control over his actions. Additionally, other aggravating factors would need to be considered as it would not be realistic to identify one sole cause. Charles Whitman had risk factors and experiences that have also been identified in other serial killers, such as experiencing child abuse.

A systematic review was conducted by Allely et al (2014) in which mass and serial killers were studied to analyze the number of serial murderers with neurodevelopmental disorders like autism spectrum disorder (ASD) or a head injury. The study investigated psychosocial risk factors in relation to these disorders as well. The research was conducted by searching for studies and books on internet-based biological databases related to associations between mass/serial killers and brain injury or ASD. 239 serial killers were finalized to use for the study. The analysis displayed that 21.34% (N = 51) had had a definite or suspected head injury, and 28.03% (N = 67) had definite, highly probable, or possible ASD. Out of the 106 killers with ASD and/or head injury, 55% (N = 58) had experienced psychosocial stressors such as physical, psychological, or sexual childhood abuse. Additionally, a definite head injury was defined as a situation where a brain scan revealed damage to the brain or head trauma (Allely et al., 2014).

These findings suggest that there could be a relation to head injury and psychosocial stressors in serial killers, which applies to Whitman. The autopsy suggests there was damage to the amygdala in his brain because of his tumor. Moreover, during the time he spent in the marines, there was also an incident in which he and his friend fought with other marines, and he was kicked in the head, leading him to be treated for headaches and dizziness. The systematic review indicates that over 55% of eligible killers in the study had experienced psychosocial stressors. Charles Whitman experienced the psychosocial stressor of child abuse. He was physically abused by his father growing up, who had admitted to spanking his kids, using a belt, his fists, or a paddle to instill his sense of discipline. When Whitman was almost 18 years old, he arrived home intoxicated. In anger, his father threw him into the swimming pool, causing Whitman to almost drown. Whitman's father physically abused Whitman's mother frequently. His family was very broken, and Whitman witnessed his mother's abuse while growing up. He also had a lot of pressure placed on him by his father; his good grades, activities, and sports throughout his childhood were generally a result of force from his father, who he lived in fear from. Whitman suffered from both psychological and physical abuse from his father. The review acknowledges that in several studies and reports, psychological and/or physical abuse was a pervasive characteristic of serial killers' childhoods (Allely et al., 2014). Overall, the child abuse Whitman suffered related to the findings indicating that a high percentage of mass/serial killers with a head injury had psychosocial stressors like child abuse.

The child abuse that Whitman suffered manifested itself in some of Whitman's own explanations for the murders. In a note he wrote after killing his mother, he discussed that she experienced his father's abuse for too long, and by killing her, he was "relieving her suffering" (Lavergne, 199). Similarly, he claimed that since he was ready to die, he killed Kathy because he did not want her to suffer alone (Lavergne, 1997). While his words do not explain the mass shooting, it displays how witnessing abuse growing up led him to offer it as a reason behind one of his many murders.

Organized and Disorganized Killers

Whitman's actions can be analyzed and studied to learn what type of killer he was. Organized and disorganized are two common characteristics employed to describe murderers based on their behavior before, during, and after the crime. A study from the National University of Public Service, Hungary, analyzes several cases of serial killers to identify and cluster the most common traits of serial killers. The study looked at their general attributes, psychological risk factors, biological effects, and common ways serial killers can be clustered. It identified several specific characteristics that applied to organized serial killers, such as having a rough family history involving abuse and being of above-average intelligence. The description of being methodological,

socially adequate, and a white male was also included. Other characteristics were employment struggles and several suicide attempts (Simon, 2015).

In contrast, the study explained that the disorganized serial killer would have a low IQ and murder impulsively and without a plan. They would generally lack friends or significant others, live alone, and be described as having odd personalities. These killers were also typically sexually perverted and would deform the corpses of their victims. While these categories have several other factors, those listed summarize the general idea of what an organized or disorganized serial killer would be (Simon, 2015).

Based on the study, many factors regarding the "organized killer" section would apply to Whitman, whereas many of the characteristics related to the "disorganized killer" do not apply to Whitman. Whitman reportedly had an IQ of 138, suggesting that he had above-average intelligence, similar to organized killers. The shooting he committed could be described as methodological and premeditated. He had planned how to get into the tower by pretending he was a janitor. He also created a way to hide the several guns and ammunition he carried with him by using a trolley. It was well thought out and not an impulsive decision— which would have been a trait of a disorganized killer. Whitman was also socially adequate because he had a wife and many friends. He experienced abuse and had an unstable family history, both experiences that were described as typical characteristics of organized killers. Additionally, there was no evidence that he was sexually perverted or that he deformed the corpses of his mother or wife, indicating that the disorganized characteristics did not apply to him.

While Whitman did not have every single trait listed under the organized category, his actions identified mainly with being an organized killer compared to a disorganized one. Whitman was intelligent and had a detailed plan to conduct the shooting. He was socially adequate because he was known as friendly and had built relationships with people in his life. Of the two most common ways of identifying a killer, Whitman was an organized killer.

Along with experiencing child abuse and being classified as an organized or disorganized killer, another general characteristic of a serial killer is experiencing violent fantasies. A study analyzing a typical serial killer's thought process, from having a fantasy of murder to committing murder, explains how experiencing violent thoughts is a component that leads to the ultimate murder of the serial killer's victims. While it is unclear how the data was collected, the article compiles information from several articles related to serial killing. Eventually, it identifies serial homicide behavior as being characterized by socio-environmental, relational, and individual factors. An essential aspect of an individual factor of a serial killer is listed as "Imaginative Life (fantasies)," which indicates that one of the factors involved in serial homicide is having fantasies of murder, such as wanting "destruction of other people" for "personal gratification" (Malizia, 2017). The article explains that typically before the killing, the serial killer will fantasize about it in his imagination and eventually feel obliged to satisfy the fantasy by actually murdering the victims. The article reviews all aspects of the killer's mindset and attributes childhood, biological predispositions, and personality as factors that strengthen the role fantasy plays in the murders (Malizia, 2017).

Whitman discussed his own frustration with violent fantasies he experienced in the notes he wrote before his death. He explained that he did not understand himself and experienced uncontrollable violent urges and unusual thoughts. He also spoke of the shooting fantasy beforehand. During his first and only session with the psychiatrist, he sometimes thought about "going up on the Tower with a deer rifle and shooting people"(Lavergne, 1997, 71). Whitman's own college dorm residents recalled him mentioning how he would like to go on top of the University of Texas clock tower and shoot people (Lavergne, 1997). The psychiatrist and residents never suspected that Whitman could be serious about such an idea. Like the serial killers discussed in the article, Whitman experienced violent thoughts and eventually acted on them by turning them into reality and becoming a serial killer.

Conclusion

Charles Whitman—the Texas Tower Shooter—committed one of the first school shootings in American history on August 1st, 1966, at the University of Texas. He took the lives of fourteen

people that day, including his own mother and wife. He wounded 32 more and was finally shot to death by police. Whitman's impact on the University of Texas and the United States understanding of school shootings was dire. Rarely had the American public been exposed to such a violent crime inflicted by an individual in a mass murder spree. The victims' families suffered greatly, and the injured civilians, students, and staff at the university were horrified by the event they had gone through.

Perhaps the most perplexing part of Whitman's killings was his motivation behind them. Many people could not understand why a former university student and an intelligent, seemingly happy man would want to go on a murder spree. Despite being the most favored theory, the uncertainty regarding the impact of Whitman's tumor reveals the necessity of modern neurological research; it could help researchers understand current cases similar to Whitman's. A review of research on biological connections to violence by Ling et al. (2019) examined the brain mechanisms discovered in serial killers and psychopaths in comparison to the rest of the population. It was determined that the amygdala in serial killers generally had stimulated hyper or hypoactivity. A maldevelopment involving the amygdala defers it from its typical role of detecting distress or threat cues; and it no longer discourages criminal behavior. With continuing analysis of the brains of serial killers, several differences are being identified in the limbic system of the brain, prefrontal cortex, and striatum region. (Ling et al., 2019). Existing studies involving fMRI, PET scans, and analysis of brain autopsies help to inform society about a definite understanding on neurological aspects in violence. A clearer understanding of the perpetrators self control may be revealed, thus assisting with the application of legal policy in murder cases. Additionally, with more attention on analysis through a biological lens, the proper treatments and prevention methods may eventually be discovered and implemented correctly.

The purpose of this paper was to analyze several aspects of serial killers and demonstrate how they could be applied to Charles Whitman. Studying his case has proved the significance in focusing on advancing studies, research, and biological findings that will allow the public to better comprehend the mindset of serial killers. With an increase in the knowledge of the neurological influences behind murder, there will be highly probable prevention of violence, pain, and fear of victims that serial killers cause worldwide.

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