Exploring vaccine hesitancy spread through social contagion theory: A case study on COVID-19 in the U.S. and implications for public health practice

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Abstract

Vaccine hesitancy, defined as refusing or being reluctant towards available vaccines, is a barrier to the success of public health interventions (WHO). Vaccine hesitancy is influenced by the spread of misinformation via social media and social networks. Misinformation is false information that is shared with others with no harmful intent (Wang et al., 2019). A helpful way to understand the spread of misinformation is through social contagion theory. This theory posits that an individual can model or adopt the behaviors and attitudes of those in their social networks (Konstantinou et al., 2021). In this case study, social contagion theory is used to explore vaccine hesitancy and the spread of misinformation in the COVID-19 pandemic in the U.S. A literature review was conducted to gather and consolidate existing literature on the relationship between social contagion theory, misinformation, and vaccine hesitancy related to the COVID-19 pandemic in the U.S. Vaccine misinformation spreads quickly and is widely disseminated through social media, reaching millions of people, which was mainly seen during the COVID-19 pandemic. Using social contagion theory, it is possible to predict how misinformation spreads through social networks, leading to COVID-19 vaccine hesitancy. Exploring vaccine hesitancy and misinformation through the lens of social contagion theory offers important insights into vaccine hesitancy and how misinformation spread during the pandemic. This improved understanding of how COVID-19 vaccine misinformation spreads through social networks will guide

recommendations for public health practice to maximize vaccine uptake and curb infectious disease threats.

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Preface

I would first like to thank my academic advisor and essay chair, Dr. Sarah Krier. She served as a source of encouragement throughout my time at Pitt Public Health through her guidance on school, careers, and this essay. I greatly appreciate her help in holding frequent meetings to check-in on my essay progress and the time she took to edit and review my essay multiple times.

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Finally, I would like to extend thanks to Dr. Kar-Hai Chu for serving as an essay reader. He provided valuable references and insight into social contagion that was essential in developing my ideas further.

1.0 Introduction

1.1 Vaccines and Vaccine Hesitancy

Vaccines have been around for hundreds of years and have saved countless lives from infectious diseases, from Edward Jenner's cowpox vaccine for smallpox in 1793 to vaccines developed for the COVID-19 pandemic in 2020 (The College Physicians of Philadelphia, 2022). As a result, vaccination is one of the most impactful achievements in public health (Nuwarda et al., 2022). Vaccines protect an individual from a disease or a severe outcome to a vaccine (Mallory et al., 2019). Another purpose of vaccines is to provide population protection from infectious diseases, termed herd immunity (Mallory et al., 2019). Herd immunity aims to vaccinate most of a population to protect those who cannot be vaccinated for various reasons, such as being immunocompromised or not falling within vaccine age requirements (Mallory et al., 2019).

Despite the vast achievements of vaccination, not everyone is willing to get vaccinated or vaccinate their children against vaccine-preventable diseases. This phenomenon is known as vaccine hesitancy. The World Health Organization (WHO) defines vaccine hesitancy as "the reluctance or refusal to vaccinate despite the availability of vaccines" (WHO, 2019). Vaccine hesitancy is influenced by a variety of complex factors, making it a difficult public health problem to address. As a result, levels of vaccine hesitancy have been sustained in the population for generations, setting the circumstances for vaccine hesitancy in modern times. The prevalence of vaccine hesitancy has been increasing in recent decades, leading to the WHO listing vaccine hesitancy as one of the top ten threats to global health in 2019 (WHO, 2019). As more people who could otherwise get vaccinated choose not to, vaccine hesitant populations are challenging herd

immunity, leading to increases in vaccine-preventable diseases (Kestenbaum & Feemster, 2015; Mallory et al., 2019). Since the beginning of vaccination, there has been opposition to vaccines which continues today (The College Physicians of Philadelphia, 2022).

1.1.1 A Brief History of Vaccine Hesitancy

The origin of vaccine hesitancy is traced back to the early 1800's with Edward Jenner's vaccine to protect people against smallpox (Nuwarda et al., 2022). Since Jenner made this vaccine from cowpox, there was concern about growing cow-like body parts after receiving this early vaccine (Nuwarda et al., 2022). This alludes to the concern today, hundreds of years later, focused on the safety of vaccines instead of fearing the risk of contracting a potentially life-threatening disease (Nuwarda et al., 2022). Smallpox vaccines further contributed to vaccine hesitancy in the 1800s through The Vaccination Act of 1853, requiring infants to be vaccinated against smallpox in the United Kingdom (Wolfe & Sharp, 2002). Opposition arose quickly, and when the mandate was adjusted to require smallpox vaccination for children up to 14 years old in 1867, the opponents formally created the Anti-Compulsory Vaccination League in London (Wolfe & Sharp, 2002). This organization was unsettled with the vaccination mandates, and people did not want the government mandating what to put in their bodies (Wolfe & Sharp, 2002). In fact, they cited vaccine mandates as infringing upon personal liberties to decide whether they receive a vaccine or not, a common anti-vaccine sentiment that is expressed still today (Wolfe & Sharp, 2002). A similar situation was happening in the United States (U.S.) as anti-vaccination movements were challenging novel vaccination laws on similar grounds as British anti-vaccination movements (Nuwarda et al., 2022). Despite the several attempts to remove vaccination requirements, the courts continued to uphold the government's right to require vaccinations due to the positive impact that

vaccines have on the health of the collective (Nuwarda et al., 2022). The argument that vaccine mandates violate personal choices and liberties is a justification vaccine-hesitant individuals use to not get vaccinated.

The 1900s saw several vaccine developments, many of which worked to decrease childhood mortality rates, but also saw equivalent anti-vaccine sentiments for these newly developed vaccines (Nuwarda et al., 2022). Jonas Salk created a vaccine for polio in the 1950s. This disease was widely feared due to the risk of paralysis especially in children, and many parents were desperate for a vaccine to prevent polio (The College Physicians of Philadelphia, 2022). However, a manufacturer of the Salk vaccine, Cutter Laboratories, distributed the Salk vaccine that still contained the activated polio virus, leading to thousands of children contracting polio and a few dying (Nuwarda et al., 2022). This occurrence provided evidence for people to be skeptical about vaccines.

More recently, there has been controversy surrounding the Measles, Mumps, and Rubella (MMR) vaccine. In 1998, Andrew Wakefield and others published a paper in The Lancet suggesting that the MMR vaccine may be a causal link to autism in children (Nuwarda et al., 2022). This paper was based on faulty science and was eventually found to not be credible. As a result, the journal retracted the paper in 2010 after finding out this paper was based on faulty science and dubious analysis (Nuwarda et al., 2022). Specifically, there was bias in participant selection and Wakefield was being paid by lawyers to show that vaccination was a harmful practice (Nuwarda et al., 2022). Despite the retraction, significant damage had been done to the public's trust in vaccines, particularly the MMR vaccine. In the years following the Wakefield paper's retraction, measles outbreaks began to appear in areas of the U.S. that had not seen measles on that scale due in years (Nuwarda et al., 2022). The MMR vaccine was not the only one impacted, as Wakefield

and other anti-vaccine scientists created a general distrust in vaccines leading to outbreaks of other vaccine-preventable diseases that were otherwise controlled in the U.S., like pertussis (Kestenbaum & Feemster, 2015). This situation amplified the spread of misinformation related to adverse outcomes of vaccines that is still prevalent today. These historical events helped to lay the groundwork for vaccine hesitancy to thrive today, particularly in the COVID-19 pandemic, through the spread of misinformation, leaving significant impacts on public health.

1.1.2 Impact of Vaccine Hesitancy on Public Health

There is a specific vaccine schedule for children for a reason: vaccines prevent diseases, death, and other serious, negative health outcomes. For example, children who are not vaccinated against pertussis have a 23-fold increased chance of being diagnosed with pertussis, and children who are not vaccinated against chickenpox have a 9-fold increased chance of being diagnosed with chickenpox (McClure et al., 2017). Spatial clusters with higher rates of vaccine hesitancy and unvaccinated children create pockets of susceptibility where vaccine-preventable diseases are more likely to cause outbreaks (McClure et al., 2017). Outbreaks are more common in states with policies allowing for more exemptions from school-required immunizations (The College Physicians of Philadelphia, 2022). Some states allow for philosophical belief exemptions from school-required vaccines, feeding into vaccine hesitancy and leaving more children susceptible to vaccine-preventable diseases (The College Physicians of Philadelphia, 2022).

Furthermore, a national survey found that about half of pediatricians reported spending a significant portion of patients' visits addressing parental concerns about vaccines (McClure et al., 2017). Although it is vital for a trusted professional such as the family physician to address these concerns, these conversations are taking up more time which leaves the parents missing out on

other important health information as visits are only around 18 minutes long (McClure et al., 2017). This increase in vaccine hesitancy has consequences for the uptake of new vaccines. For example, during the COVID-19 pandemic, vaccine hesitancy has led to longer time needed for immune protection to expand across a population, which put lives at unnecessary risk (Alvarez-Zuzek et al., 2022).

1.1.3 Facilitators of Vaccine Hesitancy Today

A variety of reasons potentially exist to explain why vaccine hesitancy exists. Mistrust is a major factor that contributes to vaccine hesitancy. One must have trust in many facets, including in: the government to ensure the vaccine is safe, the pharmaceutical industry to make a vaccine that is efficacious and not just profitable, and healthcare providers to provide accurate information about a vaccine (Kestenbaum & Feemster, 2015). With the widespread use of the internet, most people can find a wealth of information to answer their questions about vaccines. However, anti-vaccine information is also on the internet, and information about vaccines can conflict those who need help discerning factual information from incorrect information (Kestenbaum & Feemster, 2015). Since vaccines prevent diseases so well, many vaccine-preventable diseases are no longer a concern in the U.S. Because of this, the perceived risk of these diseases diminishes, which can lead to people not choosing to vaccinate against these diseases (Kestenbaum & Feemster, 2015). Finally, a significant contributor to vaccine hesitancy is the abundance of misinformation that can influence vaccine perceptions. Although not an exhaustive list, these main contributors to vaccine hesitancy can interplay and are all essential to address when looking to decrease vaccine hesitancy.

1.1.3.1 Models of Vaccine Hesitancy

To better understand the facilitators of vaccine hesitancy in modern times, several models to explain vaccine hesitancy have been developed. The WHO's Strategic Advisory Group of Experts on Immunization (SAGE) created a model to show the interplay of the complexities of vaccine hesitancy and its determinants. This model, called the "3Cs" model, includes the factors of confidence, complacency, and convenience as the determining factors of vaccine hesitancy (MacDonald, 2015). The confidence factor refers to trust in all aspects of vaccines (the safety of the vaccines themselves, the health care professionals that are administering them, and policymakers that determine the need for vaccines) (MacDonald, 2015). The idea of complacency involves the individual's perceived need for a vaccine based on the risk of contracting a vaccine-preventable disease (MacDonald, 2015). The convenience factor involves the availability, affordability, appeal, and accessibility of vaccines (MacDonald, 2015). These determinants are important in understanding how decisions about choosing to vaccinate are made and what influences someone to be vaccine hesitant.

Another model, created by Dubé et al., involves more factors that influence an individual's decision to vaccinate. This model, shown in Figure 1, includes the context around the decision to vaccinate, policy, recommendations from health professionals, and the media (Dubé et al., 2013).
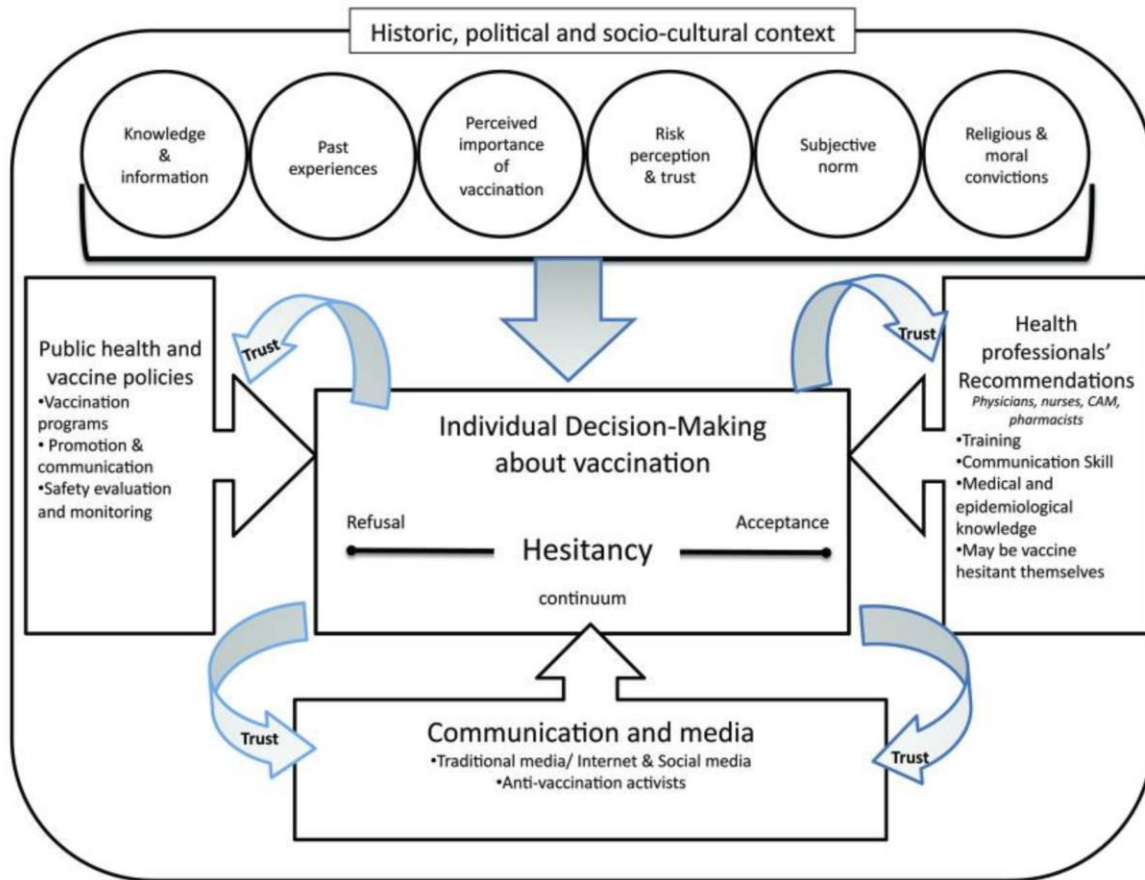
Figure 1: Conceptual Model of Vaccine Hesitancy (Dubé et al., 2013)

An important aspect to this conceptual model is the trust that the individual has in each entity that impact vaccine decision making. It is also essential to note that this model looks at the continuum of vaccination attitudes. Therefore, the same factors that influence someone to refuse vaccine also can influence someone to accept vaccines. These models are helpful to understand what factors influence vaccine hesitancy, while also helping to frame the importance of these factors that can guide public health interventions. Vaccine hesitancy models include factors related to the impact of misinformation and social contagion theory, showing the application of these models to COVID-19 vaccine hesitancy.

1.2 Misinformation

Misinformation is false information that is shared with others with no harmful intent (Wang et al., 2019). A term related to misinformation is disinformation. Disinformation is also false information that is shared with others, but there is an intent to cause harm (Wang et al., 2019). Due to the likeness of these terms and not fully knowing the intent behind a message, it can be challenging to tease out misinformation from disinformation in practice. Therefore, the term misinformation will be used as an umbrella term to encapsulate misinformation and disinformation. Misinformation around health-related topics is widespread and has been recently known as "fake news" and an "infodemic" (van der Linden, 2022). The World Health Organization coined the term infodemic in 2020 to explain an oversupply of information, especially information that is not true and can be misleading (van der Linden, 2022). An infodemic, specifically with health information, is particularly damaging to public health responses by causing public confusion on the correct actions to take in the face of a public health threat (WHO, 2023).

With the internet holding a wealth of true and false information, many people turn to it for health-related answers (Swire-Thompson & Lazer, 2020). Without a high-functioning capacity to discern correct information from misinformation, a person could be harmed by the information they believe to be true (Swire-Thompson & Lazer, 2020). This is incredibly challenging for individuals as studies show that misinformation tends to be more popular on the internet, meaning a person is more likely to encounter misinformation when searching for helpful information (Wang et al., 2019). It is important to know how misinformation spreads to understand the far-reaching effects that misinformation can have.

1.2.1 Spread of Misinformation

Between the internet and social media, information can move extraordinarily fast and on a large scale (van der Linden, 2022). Researchers have looked at misinformation through epidemiological models to understand how it spreads (van der Linden, 2022). Findings show that misinformation spreads more widely and faster than correct information, showing the depth of the issue (Swire-Thompson & Lazer, 2020). For example, a study found that to reach 1,500 people on Twitter, true news stories took six times longer than news based on misinformation (van der Linden, 2022). Furthermore, a small fraction of internet users are responsible for the overwhelming majority of misinformation generated on the internet (Swire-Thompson & Lazer, 2020; van der Linden, 2022). Being exposed to misinformation does not mean that an individual will always believe and re-share what they see (van der Linden, 2022). However, repetition of misinformation can be dangerous as the more an individual is exposed to a statement, the more likely they are to judge that statement as the truth (Fazio et al., 2019). While not explicitly linked to vaccine misinformation, the logical fallacy of argument by repetition has applicability to understand how people believe vaccine-related misinformation. Therefore, with the grand scale on which misinformation is spread, it is more likely to reach people who will view misinformation as fact, whether on the first or a repeated exposure, and share it within their social networks. Exposure to misinformation is heavily reliant on social networks and interactions on the internet and social media, allowing interventions looking to increase vaccine uptake to focus on specific target populations to increase the likelihood of vaccine uptake success.

1.2.2 Misinformation and Vaccines

Of the misinformation in existence, health-related misinformation, especially related to vaccines and infectious diseases, is the most prevalent (Suarez-Lledo & Alvarez-Galvez, 2021; Wang et al., 2019). Vaccine-related misinformation has been a driver of vaccine hesitancy for hundreds of years and continues today. Misinformation about vaccines was printed in books and journals since the 1800s, with one source describing vaccines as a monstrous, dangerous entity (Wolfe & Sharp, 2002). Misinformation about vaccines tends to involve side effects of vaccines (Suarez-Lledo & Alvarez-Galvez, 2021). This plays into the idea that with infectious disease control through vaccination in the U.S., many people do not understand the risks of contracting these diseases and instead focus on amplifying the potential side effects of vaccines (Nuwarda et al., 2022). Misinformation has lasting effects, as studies show that sentiments about the MMR vaccine causing autism, although false, are still spread on social media (Wang et al., 2019). The prevalence of misinformation regarding vaccines on the internet and social media plays into the increase of vaccine hesitancy, which ultimately challenges the achievement of herd immunity (Wang et al., 2019). Misinformation poses an additional threat to new vaccines coming to the market to curb the spread of new infectious diseases, such as vaccines for the COVID-19 pandemic. In turn, understanding how vaccine-related misinformation spreads through social networks will help inform public health practice to increase vaccine uptake.

1.3 Social Contagion Theory

Social contagion theory posits that "an individual can exhibit behavior modeled by another person or adopt the attitudes of members of their social network" (Konstantinou et al., 2021). Researchers have previously applied this theory to understand the spread of various health behaviors and conditions, such as obesity, smoking/drug use, depression, and influenza (Christakis & Fowler, 2013). Social contagion can only extend so far in a social network, as Christakis and Fowler found that influence can typically extend through no more than three degrees of separation in a social network (Christakis & Fowler, 2013). An idea that is related to social contagion theory is homophily, meaning that people typically associate themselves with people who think, act, and have similar attributes (Christakis & Fowler, 2013; Konstantinou et al., 2021). Social contagion depends on the degree of social influence in a social network, as social influence means to influence social contacts (Alvarez-Zuzek et al., 2022). Many studies are looking into influential interactions in social networks while using infectious disease-based epidemiological models to map social contagion spread (Hill et al., 2010). This theory can also be applied to how attitudes about vaccines spread through social networks and are influenced by misinformation.

1.3.1 Social Contagion Theory and Vaccines

A previous review collected studies investigating how people can transmit attitudes about vaccines and vaccine uptake within their social networks. This review found that study participants were likely to reflect positive views on vaccines if their social network had positive attitudes about vaccines and vaccine uptake (Konstantinou et al., 2021). As Figure 1 shows below, significant influencers in social networks included in the studies primarily involved family, friends, and peers

(Konstantinou et al., 2021). Fewer studies investigated the influence co-workers, healthcare providers, and politicians may have on social networks related to vaccines (Konstantinou et al., 2021). People have an increased uptake of vaccines when social networks are mostly made up of family, friends, and peers that have received vaccinations (Konstantinou et al., 2021). This shows a specific application of homophily concerning vaccine uptake and attitudes and relates to the likelihood of vaccine-hesitant people being clustered together. Further along, the evidence will show that social networks can ultimately influence the acceptance, uptake, hesitancy, and refusal of vaccinations (Konstantinou et al., 2021). Since social networks are important for vaccination outcomes, the way misinformation spreads through these networks and is believed by people is vital to understand when combating vaccine hesitancy caused by misinformation.
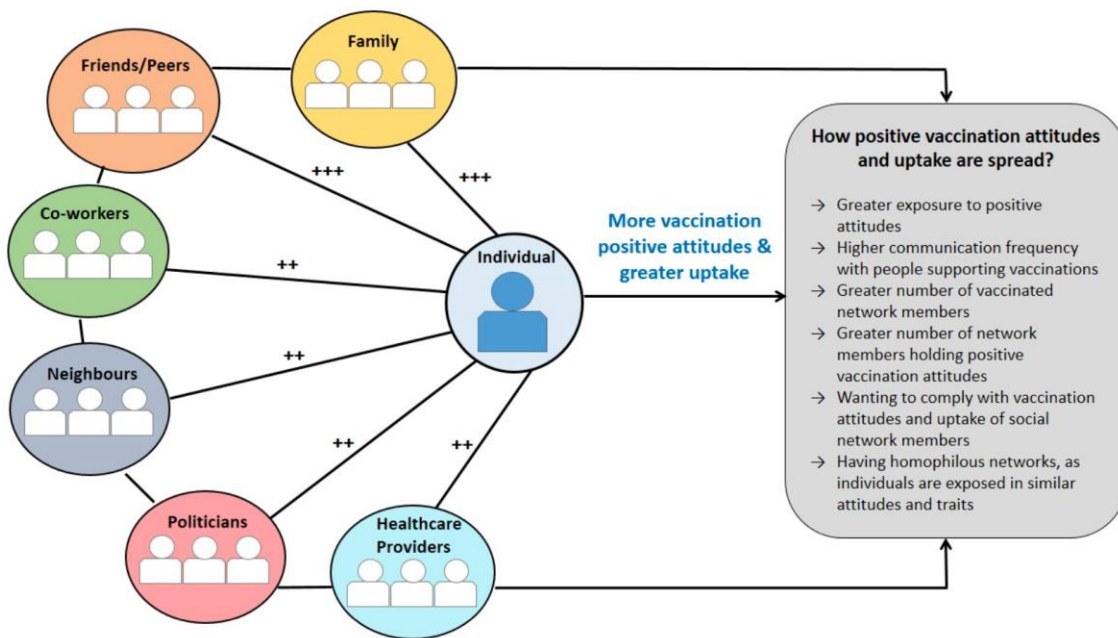
Figure 2: Social Contagion Theory Applied to Vaccine Attitudes and Uptake (Konstantinou et al., 2021)

1.4 Research Gaps and Rationale

With the lengthy history of vaccines and vaccine hesitancy, there is a wealth of research on the subject. In more contemporary times, several reviews have been written on the topic of vaccine hesitancy related to COVID-19. Strategies to improve vaccine coverage have also been well documented in the literature. However, there are research gaps in how vaccine hesitancy is impacted by misinformation spread through social contagion, specifically during the COVID-19 pandemic.

There is a clear relationship between social contagion theory in how misinformation spreads. An important application of this concept is to vaccines and how social contagion theory contributes to spreading vaccine misinformation to increase vaccine hesitancy. Situating these concepts in a contemporary pandemic like COVID-19 in the U.S. will expand the applicability of social contagion theory and help guide public health practice for similar situations in the future, as infectious diseases, vaccines, and misinformation will always exist. This essay will cover a brief background of COVID-19 in the U.S., COVID-19 vaccines, and vaccine hesitancy related to COVID-19 vaccines in the U.S. Additionally, findings explore how COVID-19 vaccine misinformation influences the spread of vaccine hesitancy while applying social contagion theory. The role and responsibility of different stakeholders in mitigating COVID-19 vaccine-related misinformation will also be assessed. Finally, the essay will end by providing public health implications and future directions for public health practice.

2.0 Methods

A literature review was conducted to evaluate the impact of social contagion spreading misinformation, ultimately leading to vaccine hesitancy during the COVID-19 pandemic in the U.S. The databases PubMed and Ovid were used to find sources on the topic. Search terms used in different combinations to find relevant sources included "vaccine hesitancy," "social contagion," "misinformation," 'social networks," "social influence," 'misinformation spread," "COVID-19," and "U.S." The various combinations of these terms yielded a wealth of sources, including reviews, individual interventions, and data modeling. To narrow the results, papers focused outside the U.S. were excluded along with those that were not peer-reviewed. Literature searches were completed from January to March 2023. Information about the COVID-19 pandemic in the U.S. was mostly found on the CDC's website. The papers included had important pertinence to misinformation, COVID-19, and social contagion theory. Table 1 in the appendix shows 17 of the key sources included in this essay.

3.0 Case Study: COVID-19 in the United States

In December 2019, several patients in Wuhan, China presented with a pneumonia-like illness and an unknown cause (CDC, 2022). Eventually, health officials determined the cause to be a novel coronavirus, named the virus SARS-CoV-2, and named the pneumonia-like illness COVID-19 (CDC, 2022; Doctors Without Borders, 2022). SARS-CoV-2 quickly spread worldwide, with the CDC confirming the first U.S. case in mid-January 2020 (CDC, 2022). To curb the number of infections in the U.S., the CDC, Department of Homeland Security established travel advisories with quarantines and screening for those returning from countries with reported cases (CDC, 2022). Despite these efforts, the transmission of SARS-CoV-2 increased substantially in the U.S. and abroad, leading the World Health Organization (WHO) to declare COVID-19 a pandemic on March 11th, 2020 (Doctors Without Borders, 2022).

After the WHO's declaration, the Trump Administration declared a national emergency, and states began to enact stay-at-home orders in March 2020 (CDC, 2022). During 2020 as COVID-19 cases kept increasing in the U.S., there were conflicts between politicians wanting to reopen and public health officials warning against reopening states too soon (CDC, 2022). The introduction of face mask recommendations deepened the divide between those following public health guidance and those who opposed public health guidance, seeing these recommendations and mandates as infringements on personal liberties and freedom. Other factors contributing to a general mistrust in public health and science relating to COVID-19 include having no definitive, initial source of the pandemic, politicians touting false cures for COVID-19 and not following public health guidance themselves, and an overall nationally fragmented response to the pandemic (Leicht et al., 2022). The tumultuous year of 2020 ended with over 11 million COVID-19

infections and over 300,000 deaths from COVID-19 in the U.S. (CDC, 2022). However, the year ended with hope to see the end of the pandemic with COVID-19 vaccines being distributed after a period of development and testing (CDC, 2022).

3.1 COVID-19 Vaccines

As the COVID-19 pandemic began, the search for a vaccine against SARS-CoV-2 started quickly after. Vaccine trials began as early as mid-March (CDC, 2022). There is a rigorous vaccine development and testing process, prioritizing safety at each step (CDC, 2020). Since there are many steps to go through, vaccine development may take several years (CDC, 2020). However, understanding the immediate need for a vaccine, the Trump Administration created "Operation Warp Speed" at the end of April 2020, aiming to develop, test, and approve a vaccine against SARS-CoV-2 in as little time as possible (CDC, 2022). This operation funded mRNA vaccine candidates produced by Pfizer-BioNTech and Moderna (CDC, 2022).

During the late summer of 2020, as the Pfizer-BioNTech and Moderna vaccines were further in development, the government made deals with each company for large amounts of vaccines by the end of the year, contingent on the vaccine being safe and effective (CDC, 2022). As the Pfizer-BioNTech and Moderna clinical trials finished in November 2020, the vaccines proved to be 95% and 95.4% effective, respectively (CDC, 2022). Shortly after, in December, the Food and Drug Administration (FDA) authorized the emergency use of both COVID-19 vaccines (CDC, 2022). The company Johnson and Johnson (J&J) was also working to develop a COVID-19 vaccine that the FDA approved for emergency use by the end of February 2021 (CDC, 2022).

Vaccine administrated happened quickly, with over 100 million doses given in the U.S. by March 13, 2021 (CDC, 2022).

Both the Pfizer-BioNTech and Moderna COVID-19 vaccines used mRNA technology. This method of vaccine development involves creating mRNA in a laboratory setting that includes the instructions for a recipient's cells to create a protein that will induce an immune response against SARS-CoV-2 (CDC, 2022). The J&J vaccine is a viral vector vaccine where the vector virus is not SARS-CoV-2 but rather a different virus manipulated to be harmless (CDC, 2022). The viral vector instructs a recipient's cells to create a protein found in SARS-CoV-2, ensuring that the cells would recognize and fight against SARS-CoV-2 if the recipient became infected (CDC, 2022). These vaccines do not contain the SARS-CoV-2 virus. There are infrequent events of severe reactions or complications from mRNA vaccines (CDC, 2022). However, the J&J vaccines can cause more severe complications that are more common than reactions from the mRNA vaccines (CDC, 2022). As a result, the J&J vaccine is not widely used, and the mRNA vaccines are primarily used in the U.S. (CDC, 2022).

As the pandemic continued, COVID-19 variants arose that spread faster by evading vaccine immunity, showing the necessity of vaccine boosters (CDC, 2022). The Delta variant of SARS-CoV-2 began in June 2021 and quickly became the most prevalent strain in the U.S., causing a new wave of infections (CDC, 2021). By the late summer of 2021, governmental health agencies decided that booster COVID-19 shots would be needed to prevent severe disease from new variants (CDC, 2022). In December 2021, a new variant, Omicron, was detected and was found to be more transmissible than the Delta variant (CDC, 2022). Omicron soon became the dominant strain in the U.S. in the first few months of 2022, and Omicron subvariants were quickly seen that are still causing most COVID-19 infections in 2023 (CDC, 2022).

3.1.1 COVID-19 Vaccine Trends

As of February 2023, over 670 million vaccine doses have been administered in the U.S. (CDC, 2023). The mRNA vaccines (Pfizer-BioNTech and Moderna) have been the dominant two vaccines administered in the U.S. (CDC, 2023). Of the available vaccines, an individual can have completed at least one dose, completed the primary series (2 doses), or received the updated booster dose (CDC, 2023). Over 80% of the U.S. population has received at least one dose of the vaccine (CDC, 2023). Some populations within the U.S. have higher vaccination rates, as 95% of those 65 and older have received at least one dose (CDC, 2023). The percentage of the U.S. population completing their primary series is comparable, with about 70% completing this (CDC, 2023). However, the rate of those who have received an updated booster dose for the COVID-19 variants is significantly lower at only 16% (CDC, 2023). Still, the most vulnerable population in terms of age, those 65 and older, have a higher rate of booster doses at 41.3% (CDC, 2023). Vaccination rates across all doses are typically lower in the southeastern part of the country and higher in the northeast and west coast of the U.S. (CDC, 2023).

3.1.2 COVID-19 Vaccine Hesitancy in the U.S.

Like many past vaccines, the advent of COVID-19 sparked a wave of vaccine hesitancy, but this hesitancy was higher in some populations than others. Vaccine hesitancy levels also fluctuate depending on the public's overall feelings and attitudes toward COVID-19 vaccines (Loomba et al., 2021). Studies show that COVID-19 vaccine hesitancy (both vaccine delay and refusal) is consistently highest in Black/African Americans and Hispanics, females, lower-income individuals, and those with lower education levels (Khubchandani et al., 2021; Rane et al., 2022;

Yasmin et al., 2021). The Department of Health and Human Services (HHS) used data from a Census survey to examine trends in vaccine hesitancy among adults who did not receive a COVID-19 vaccine, including a distinction between those unvaccinated who were willing to be vaccinated and who were unwilling to be vaccinated (Holtkamp et al., 2022). From April 2021-January 2022, rates of unvaccinated adults fell, even among those unwilling to vaccinate (Holtkamp et al., 2022). Those who were unvaccinated but were most willing to vaccinate include younger adults, low-income individuals, less educated individuals, and non-white adults (Holtkamp et al., 2022). This finding differs from previously mentioned studies, perhaps due to the difficulty of obtaining representative and accurate data on vaccine delay and refusal.

The Kaiser Family Foundation monitors the vaccination status of U.S. adults, providing insight into what demographics are likely to be vaccine hesitant. The most recent data from January 2023 from over 1,200 phone survey participants is displayed in Appendix Figure 1. The responses from this survey show that the demographics with the highest rates of people not vaccinated against COVID-19 include people who are uninsured and under age 65, rural residents, Republicans, adults without a college degree, those aged 18-49, those with a household income under $40,000 and under $80,000, and white adults (KFF, 2023). Since this data was collected about two years after COVID-19 vaccines became available, it is plausible to assume that the unvaccinated population had opportunities to receive a vaccine but chose not to. As a result, this data provides key insight into specific vaccine hesitant demographics and to whom to target vaccine encouragement interventions.

The study by the HHS showed that vaccine cost and accessibility were not common reasons why adults were not vaccinated (Holtkamp et al., 2022). This alludes to other factors influencing an individual's COVID-19 vaccination status, including mistrust in the vaccine and concerns about

vaccine safety. People have also cited concerns over the vaccine being another product that vaccine manufacturers will profit immensely on without it having real effectiveness (Zimmerman et al., 2023). In fact, several studies conducted on causes of vaccine hesitancy found mistrust in the government, public health, or the vaccines themselves to be a highly influential determinant in vaccine hesitancy attitudes (Keselman et al., 2022; King et al., 2021; Latkin et al., 2022). Mistrust in these entities leads people to search for other information sources, leaving them susceptible to believing vaccine misinformation.

There are several justifications vaccine hesitant people cite as to why they believe COVID-19 vaccines are unsafe. COVID-19 vaccine hesitancy typically centers around the confidence factor from the WHO SAGE vaccine hesitancy model. Many are concerned with the seemingly fast timeline that the COVID-19 vaccines were developed, which correlated with concerns over severe side effects from the vaccine (Latkin et al., 2022; Zimmerman et al., 2023). Participants who did not believe the COVID-19 vaccines were safe gave reasons such as the vaccines were unnecessary, poisonous, would be used to track people, would give people COVID-19, or would alter their DNA (Kricorian et al., 2021; Neely et al., 2021). The same participants who did not believe the COVID-19 vaccines were safe were also found to be less likely not to understand COVID-19 vaccine information and find it confusing compared to those who believed the COVID-19 vaccines to be safe (Kricorian et al., 2021). This shows the susceptibility of those with a lower level of health literacy to believing misinformation spread about COVID-19 vaccines.

3.2 Misinformation Influences COVID-19 Vaccine Hesitancy

Misinformation about COVID-19 vaccines is prevalent on social media, news, and social networks. While looking into online items relating to COVID-19 vaccines, Islam et al. found just 5% of items to be factual information (Islam et al., 2021). Specific instances of online COVID-19 vaccine misinformation can be found below in Table 1. Misinformation related to the COVID-19 vaccine range from the vaccine causing people to die after receiving it and pushing it through development without proper testing (Islam et al., 2021). Another article pulled over 2,300 items from online sources and found 82% to be false claims, with YouTube and Facebook having the most COVID-19 vaccine conspiracy-themed content (Joseph et al., 2022). COVID-19 vaccine misinformation is clearly pervasive on the internet, and, as a result, misinformation is easily sharable within social spheres through resharing content or personal communications. With the abundance of social media platforms, it is plausible that most U.S. adults have an active account on at least one platform and will be exposed to vaccine misinformation. About 70% of the U.S. report using Facebook, with 43% of the U.S. saying they use Facebook as a means to consume online news (Yang et al., 2021). Additionally, a survey found that 73% of its 600 U.S. adult participants reported at least one exposure to COVID-19 vaccine misinformation in the first six months of 2021 (Neely et al., 2021). The prevalence of COVID-19 vaccine-related misinformation on the internet is concerning as the more people are repeatedly exposed to this misinformation, the more likely they are to start believing those vaccine concerns and become vaccine hesitant (Fazio et al., 2019). With the ease of posting and resharing content online, it is essential to understand the prevalence and spread of COVID-19 vaccine misinformation on these platforms that can lead to vaccine hesitancy.

Table 1: Popular Stories and Claims about the COVID-19 Vaccines (n=600) (Neely et al., 2022)

In the past 6 months, have you read or heard any of the following stories/claims about COVID-19 vaccines	% vaccinated	
	Exposed	Not exposed
COVID-19 vaccines contain a "live strain" of the virus	59.5[a]	67.9[a]
COVID-19 vaccines contain 5G microchips	66.2	63.1
COVID-19 vaccines will be mandated by the CDC	60.1	66.8
COVID-19 vaccines modify people's genes and alter their DNA	61.9	65.7
COVID-19 vaccines may cause infertility	61.4	65.9
COVID-19 vaccines were designed to reduce the world's population	54.4[b]	68.7[b]
COVID-19 vaccines were created before the pandemic started in order to increase vaccine sales	48.7[c]	68.0[c]
The daughter of the Russian president died from the COVID-19 vaccine	44.4[d]	65.6[d]

[a]$\chi^2 = 4.515$; $\varphi = 0.034$; $p \leq 0.05$; [b]$\chi^2 = 11.244$; $\varphi = -0.137$; $p \leq 0.001$; [c]$\chi^2 = 14.881$; $\varphi = -0.157$; $p \leq 0.001$; [d]$\chi^2 = 6.602$; $\varphi = -0.105$; $p \leq 0.05$

One study assessing misinformation on Facebook and Twitter found over 18,000 posts leading to one of 38 links from a single misinformation source (Leicht et al., 2022). Of these posts, Facebook identified all of them as misinformation to their users, while Twitter labeled less than 1% as misinformation (Leicht et al., 2022). Despite Facebook's efforts to label misinformation, these posts had ten times the engagement than Twitter posts, with over 70 engagements on average (Leicht et al., 2022). Although this represents a small snippet of misinformation on the internet, this study shows the extent to which misinformation can quickly spread through social connections. Furthermore, Loomba et al. found that a quarter of U.S. participants exposed to misinformation found the information trustworthy or agreed with it (Loomba et al., 2021). Even

having 25% of individuals believe misinformation raises concern as they can share COVID-19 vaccine misinformation in social circles, further contributing to vaccine hesitancy.

The prevalence of misinformation related to COVID-19 vaccines can impact the level of vaccine hesitancy in the U.S. For instance, a study looking at COVID-19 vaccine hesitancy before and after exposure to misinformation found a significant decrease in overall vaccine uptake willingness among U.S. adults (Loomba et al., 2021). Other studies also found similar results through a negative association between vaccine uptake rates across U.S. states and online misinformation (Joseph et al., 2022; Pierri et al., 2022). This finding was identified through a significant association between increases in online misinformation and a decrease in daily vaccinations (Pierri et al., 2022). Based on the survey analysis by Neely et al., exposure to COVID-19 vaccine misinformation just one time was significantly associated with 10% lower vaccination rates compared to those with no reported exposure to misinformation (Neely et al., 2021). Depending on the "stickiness," or ability for a conspiracy to take root, a single exposure to misinformation can extensively impact vaccine hesitancy (Dow et al., 2021). As a result, sharing content through social ties can further COVID-19 vaccine hesitancy, necessitating a social contagion theory lens.

3.2.1 How COVID-19 Vaccine Misinformation Spreads Through Social Contagion

Social contagion theory (individuals adopting behaviors or attitudes of their social networks) can help explain how COVID-19 vaccine misinformation spreads through social networks leading to vaccine hesitancy (Konstantinou et al., 2021). Dow et al. argues that as COVID-19 created an unprecedented situation, people searched for answers to their uncertainty primarily on online platforms (Dow et al., 2021). This search for answers makes people vulnerable

to believing conspiracy theories that provide easy-to-understand explanations for the complex situation of COVID-19 (Dow et al., 2021). Furthermore, misinformation, or "fake news," headlines are typically written to evoke emotion in the reader, leading them to interact with the piece in some way (reading or sharing the content) (Horner et al., 2021). Thus, as people believe and share conspiracy theories, their social networks, who may be experiencing the same uncertainty, may believe these theories and continue sharing. Additionally, people are not always sharing content they believe to be true but rather content that would be interesting if it were true (van der Linden, 2022). This only increases the influence that misinformation exposure can have on social networks. In the end, conspiracy theories plant seeds of doubt and mistrust, so as COVID-19 vaccines become available, fewer people are willing to receive a vaccine.

Social media also promotes social contagion theory through the positive reward systems of accumulating followers/friends and likes/shares on posts (Dow et al., 2021). Since social media is set up for individuals to seek positive feedback, people will post content to appease their circles. This leads back to the idea of homophily and having social networks comprised of like-minded individuals (Dow et al., 2021). These so-called "bubbles" reinforce shared beliefs among social networks, which have been identified to form around conspiracy theories (Dow et al., 2021). This was specifically seen through an increase in the spread of misinformation by creating Facebook community groups where people with a shared identity can congregate online (Dow et al., 2021). Therefore, as the COVID-19 pandemic began and more people shared vaccine misinformation on social media, the ideal conditions were created for influential bubbles of vaccine hesitant groups.

Relatedly, the concept of echo chambers online also contributes to the social contagion of COVID-19 vaccine misinformation beliefs. A study by Sun et al. involving YouTube comments about COVID-19 vaccines was looking for echo chambers (Sun et al., 2022). This study found that

pro-vaccine users would interact with other pro-vaccine users, while anti-vaccine users would also interact amongst themselves (Sun et al., 2022). This furthers the idea of online congregations of like-minded individuals. As these form through people sharing vaccine misinformation with their social networks, it creates pockets of unvaccinated people and complicates COVID-19 mitigation efforts.

Another factor that influences how COVID-19 vaccine misinformation spreads through social contagion is political affiliation. Horner et al. conducted a study analyzing how different political parties react to fake news headlines and what influences a person to share a piece of misinformation. In general, misinformation tended to be conservative-leaning since political conservatives/Republicans engage with this content more than liberal/Democratic populations (Horner et al., 2021). As a result, this study found that Republicans were more likely than Democrats to believe and share fake news headlines, as the headlines served as a confirmation bias for beliefs Republicans already held (Horner et al., 2021). These results can be applied to COVID-19 misinformation as well. COVID-19 misinformation (in general and vaccine-related) centers more on Republican-leaning beliefs, such as mask-wearing decreases oxygen levels or misinformation that sheds a negative light on Dr. Fauci with examples provided in Appendix Figure 2 (Horner et al., 2021). Understanding that Republicans may be more likely to share misinformation content that is negative towards the opposite political party, along with the process model the researchers made shown below, can help guide public health interventions to reduce COVID-19 vaccine-related misinformation spread.
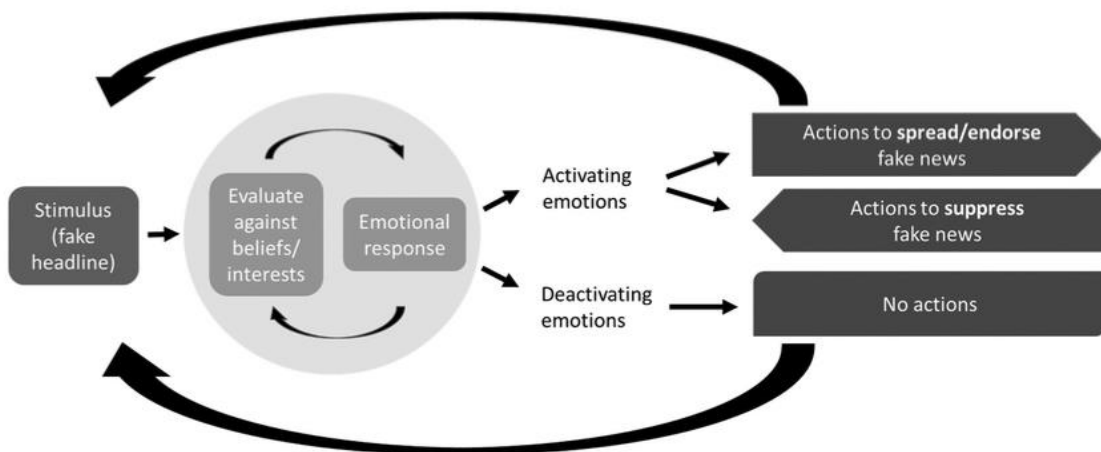
Figure 3: Process Model of Emotional Responses from Fake News Headlines (Horner et al., 2021)

Outside of social media, social contagion still influences COVID-19 vaccine hesitancy. An individual is significantly more likely to be receptive to the COVID-19 vaccine if family or close friends have gotten the vaccine (Hao & Shao, 2022). Conversely, if an individual is exposed to a personal contact expressing caution about the COVID-19 vaccine, they are likely to take on the behavior they are exposed to (Herzog et al., 2022).

3.3 Mitigating COVID-19 Vaccine Misinformation to Increase Vaccine Uptake

COVID-19 vaccine misinformation is clearly an issue that is directly related to COVID-19 vaccine hesitancy. Since COVID-19 vaccine misinformation is shared primarily on social media platforms, these companies have a responsibility to the public's health and a role in vaccination uptake. However, there is still an individual role in mitigating COVID-19 vaccine misinformation, as individuals have power and influence in their social ties to increase vaccine uptake.

3.3.1 Role/Responsibility of Social Media Companies

Since the COVID-19 pandemic began, social media use has increased as people sought social connections during a period of isolation and lockdowns (Dow et al., 2021). The internet and social media quickly became sources of up-to-date information about the pandemic developments while also providing a platform for COVID-19 misinformation to spread (Neely et al., 2021). As such, social media platforms are influential contributors to vaccine hesitancy by allowing users to share and engage with vaccine misinformation.

Social media companies based in the U.S. operate in a self-governing manner, and they do not have a legal responsibility for the content shared on their platforms (Gisondi et al., 2022). However, some social media platforms have taken action, whether by themselves or through public pressure to put warnings on content that may contain misinformation or be misleading about COVID-19 (Gisondi et al., 2022). Inducing cognitive reflection, making the user think about the validity of online content, can help reduce the amount of COVID-19 misinformation spread by social media users (Dow et al., 2021). For instance, Facebook began labeling posts as misinformation which, in turn, substantially decreased user engagement with these labeled posts (Leicht et al., 2022). Although unregulated on the federal level, social media companies are morally responsible for governing what content users share on their platforms during a pandemic where misinformation can harm people's health.

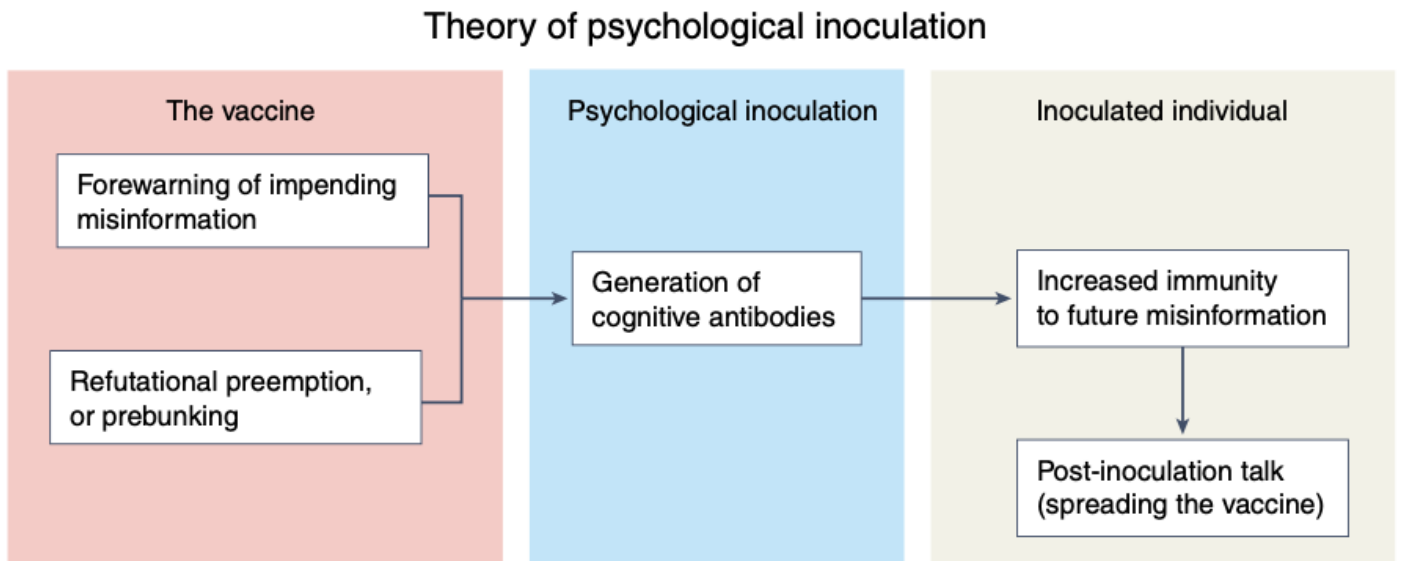### 3.3.2 Role/Responsibility of Individuals and Health Practitioners

Health practitioners have an essential role in promoting COVID-19 vaccine uptake. With most U.S. adults on social media platforms, health practitioners will also have to increase

engagement and content to communicate factual health information (Neely et al., 2021). People build trusting relationships with their healthcare providers. Thus, when faced with misinformation on COVID-19 vaccines and content from a trusted health practitioner, a person may be more likely to absorb the content from the source they already trust (Neely et al., 2021). Increasing the correct health information on video-based social media platforms like YouTube has also been shown to delay the formation of echo chambers (Sun et al., 2022). Health professionals have a responsibility to their patients to optimize their health; so, in the case of COVID-19, they have a responsibility to encourage COVID-19 vaccination and dispel vaccine misinformation.

Although it may seem like a small-scale impact, individuals have a responsibility to themselves and a role in their own social networks to combat COVID-19 vaccine misinformation. Individual social media users must think critically about vaccine content on the internet and not believe it simply because it comes from a verified source. Thinking critically and choosing not to share misinformation in social networks results in fewer exposures to vaccine misinformation for others in the network, reducing vaccine hesitancy (Neely et al., 2021). Furthermore, there is an influence in talking positively about COVID-19 vaccines to family and friends. If people adopt similar attitudes to their social networks, encouraging COVID-19 vaccines can contribute to others' vaccine uptake if they were previously vaccine hesitant (Hao & Shao, 2022). Individuals and healthcare practitioners have a role and responsibility in their social networks to promote COVID-19 vaccines by providing factual information and their influence in their networks.

An important concept to mitigate COVID-19 vaccine misinformation spread is the theory of psychological inoculation. This theory is based on how the immune system recognizes and fights off pathogens through recognition from previous vaccination, except this application is the mind inoculating itself against believing misinformation (van der Linden, 2022). This theory is

visually shown in Figure 3 below. Combining misinformation labeling with positive, truthful vaccine-related content related to COVID-19 would serve as the vaccine. The individual would then have the responsibility to make that connection that the content they are viewing is false and then would be more likely to not believe future instances of misinformation.

Theory of psychological inoculation

The vaccine	Psychological inoculation	Inoculated individual
Forewarning of impending misinformation	Generation of cognitive antibodies	Increased immunity to future misinformation
Refutational preemption, or prebunking		Post-inoculation talk (spreading the vaccine)

Figure 4: Psychological Innoculation as an Intervention Against Vaccine Misinformation (van der Linden, 2022)

4.0 Discussion

A literature review was conducted to evaluate the impact of social contagion spreading misinformation, ultimately leading to vaccine hesitancy during the COVID-19 pandemic in the U.S. There have been several reviews written on the topic of vaccine hesitancy related to COVID-19 that provide strong insight. Strategies to improve vaccine coverage have also been well documented in the literature. However, there is a gap in terms of how vaccine hesitancy is impacted by misinformation spread through social contagion, specifically during the COVID-19 pandemic, that this essay aims to help fill.

The COVID-19 pandemic created an unprecedented situation that caused uncertainty throughout the U.S. During the stay-at-home orders to prevent the spread of COVID-19, people turned to the internet for answers and information about this new disease. Social media provided an outlet to share information through social networks but also created an outlet for spreading misinformation. The development of the COVID-19 vaccines amplified this situation. The fast timeline of getting the COVID-19 vaccines to market, the complicated science behind how vaccines work, the novel mRNA technology, and the growing mistrust of the government all contributed to the seeds of doubt about COVID-19 vaccines, leading to vaccine hesitancy. However, vaccine hesitancy was more concentrated in some populations, with a few being low-income individuals and people without a college degree. The populations more likely to be vaccine hesitant are mostly the ones who would see misinformation as truth and, therefore, share it among their social ties. Confusion and mistrust also allowed vaccine misinformation to be believed and shared within social networks.

Misinformation easily spreads through social media and concentrates in social networks, as explained through social contagion theory. Regarding vaccine attitudes, people are most likely influenced by their family, friends, and peers' attitudes and behaviors. Exposure to misinformation is also a determining factor in predicting vaccine hesitancy. Thus, as misinformation is reshared on social media, it can infiltrate personal social circles. With the influence of social circles, attitudes towards vaccines can be shaped through the exposure to misinformation being shared by a trusted family member or friend who has shared COVID-19 vaccine-related misinformation. Therefore, when looking to increase COVID-19 vaccine uptake, it is imperative to consider how social spheres of influence can shape vaccine attitudes based on exposure to misinformation.

There are a few limitations to this paper to note. The content of the paper focused on U.S. adults, so the conclusions made may have limited applicability beyond this population. Additionally, there is not a wealth of research available to specifically link social contagion theory to COVID-19 vaccine misinformation spread. As such, conclusions are drawn by expanding the findings of previous literature to the current situation. Furthermore, the literature included was limited to two databases, so a more robust literature review search may have yielded additional pertinent articles.

4.1 Public Health Implications and Future Directions

Several implications for public health practice can be drawn from applying social contagion theory to vaccination attitudes. Similar to how people can spread vaccine misinformation and vaccine hesitant beliefs to their social networks, people can also promote vaccines through their social networks. Social contagion theory highlights the importance of

vaccine conversations among social networks, specifically between those that are most influential in transmitting vaccine attitudes (family members, friends, and peers). People who have received a COVID-19 vaccine can start these conversations in their social networks, online or face-to-face, and talk about why they decided to get a vaccine, their experience in getting the vaccine, and help to provide correct information about COVID-19 vaccines to those who have vaccine concerns. This will help to increase the confidence of others in seeking out a COVID-19 vaccine. To help achieve this, encouragement should be given to individuals once they receive their vaccine to share their decision with others and why they chose to do so. It would also be helpful to provide individuals with easy-to-read vaccine information with the encouragement to distribute the information about vaccines with an unvaccinated member of their social networks, prompting a conversation about vaccines. Public health departments can further this by recruiting representative community members to share video clips explaining their reasoning to vaccinate to be shared on social media, along with continually sharing readable vaccine information.

Since misinformation can stem from a general misunderstanding of vaccine science, it is necessary to disseminate vaccine information accessible to a wide range of health literacy levels (Kricorian et al., 2021). Simply telling someone they need a COVID-19 vaccine is insufficient for addressing hesitation, so digestible health information is vital for increasing vaccine uptake. It is also important to reiterate the need for public health professionals to use social media to promote vaccine information. Infiltrating social networks with fact-based information compared to misinformation can help increase positive vaccine attitudes. As such, it is important for people to address vaccine-related misinformation in the moment when they hear it within their social group, since an individual holds a lot of influence in informing others on correct vaccine information among their family, friends, and peers. With the COVID-19 pandemic showing how much people

turn to social media for news, public health professionals should also advocate for social media regulations in terms of misinformation, as Leicht et al. showed that misinformation labeling is not sufficient in reducing misinformation sharing (Leicht et al., 2022).

There is also a great need for public health to focus more on the behavioral/social science side of vaccine hesitancy attitudes. There needs to be more research on the specific pathways misinformation spreads through social networks and leads to vaccine hesitancy. Understanding these social mechanisms will allow for successful interventions to stop the spread of misinformation and increase vaccine uptake.

5.0 Conclusion

Vaccine hesitancy is not a new phenomenon but continues to threaten the success of vaccine-based public health interventions, as seen in the COVID-19 pandemic. Vaccine misinformation drives vaccine hesitancy by creating doubt, fear, or mistrust in vaccines or those who are encouraging them. Many factors determine and individual's decision to vaccinate, including exposure to misinformation and influence from social ties on vaccine attitudes. The uncertainty around the novel COVID-19 created the perfect conditions for spreading misinformation through social media, ultimately leading to vaccine hesitancy through social contagion as people reshare information to their friends and followers. With people being more likely to associate with others of similar mindsets, tracking where misinformation is spread can help predict pockets of vaccine hesitant populations. Although further research is necessary, using the idea of social contagion will help advance the public health field by identifying where interventions are needed to increase vaccine uptake among hesitant populations, such as rural residents, Republicans, adults without a college degree, and low-income individuals. Overall, social conation theory provides a unique and underutilized lens to understand how misinformation influences vaccine hesitancy in the U.S. population.

Appendix A Results

Appendix Table 1: Brief Selection of Papers Included in Review

Citation information	Study design/Methods	Study purpose	Key findings
Dow et al., 2021	Literature review to create a theoretical framework	Help to understand how the COVID-19 pandemic contributes to consuming social media and how social media amplifies COVID-19 conspiracy theories.	Social media usage increased during lockdowns for COVID-19. The internet was used for structure and social connection but had negative effects with spreading conspiracy theories. Social media can be leveraged to be more helpful in the future.
Herzog et al., 2022	Analysis of online survey responses from 300 unvaccinated U.S. adults	Examine how COVID-19 comparison information influences vaccine uptake intentions.	Vaccine intentions were influenced by exposure to those who were cautious. Shows that certain psychological factors can be used to predict some health beliefs.
Islam et al., 2021	Reviewed and analyzed online rumors and conspiracy theories during 2020 on various websites and social media platforms.	Find and understand online rumors and conspiracy theories and their context. Examine different interventions to manage misinformation to increase vaccine acceptance.	COVID-19 vaccine related online content were mostly rumors with some conspiracy theories. The majority (83%) of claims online were false with a small fraction (5%) being true. Rumors around COVID-19 vaccines related to vaccine development, morbidity and mortality, and safety/efficacy.
Joseph et al., 2022	A scoping review of 20 articles	Identify sources of COVID-19 misinformation, the impact of it, and how to limit the spread.	Individual websites and social media platforms help spread COVID-19 misinformation. Social media can also be used to spread evidence-based information to effectively combat misinformation.
Keselman et al., 2023	Survey of U.S. adults (N=140) from crowdsourcing platform with	Explore how cognitive and cultural factors impact COVID-19	Vaccination attitudes were affected mostly by an individual's attitude towards and trust in public health and science. Trust in public health

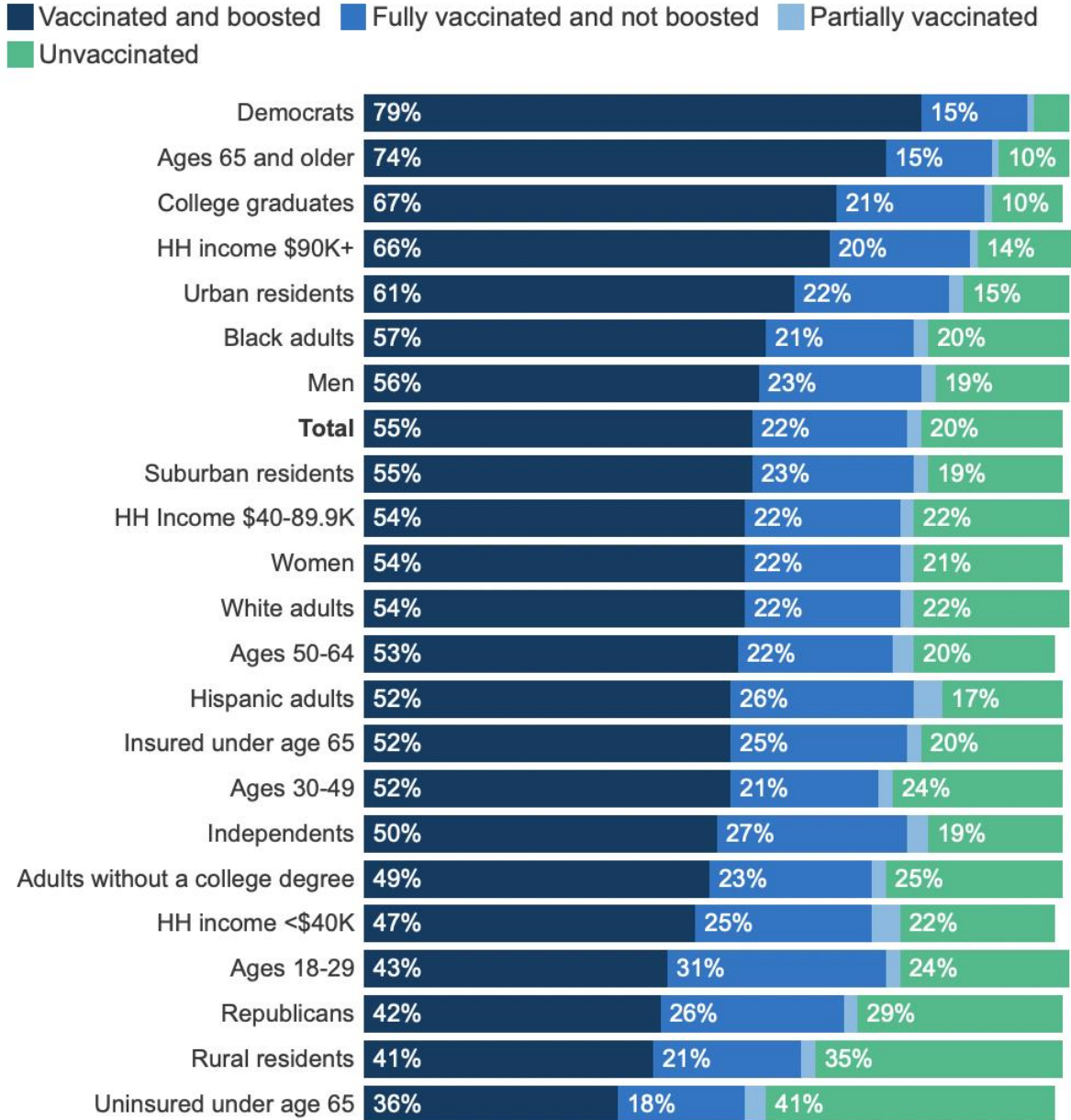|	statistical analyses	vaccination attitudes and uptake.	greatly influenced vaccination status.
Khubchandani et al., 2021	Questionnaire given to 1878 U.S. adults	Determine likelihood of getting COVID-19 vaccines once they become available and what demographics are likely to be hesitant.	Factors related to vaccine hesitancy include having a lower education, lower income, and lower perceived risk of COVID-19 infection. Those who were African American, Hispanic, lived in rural areas, and identified as Republican were also more likely to be less willing to receive a COVID-19 vaccine once they became available.
King et al., 2021	Online survey of U.S. adults over five months (Jan-May 2021)	Find the prevalence of vaccine hesitancy in US adults by occupation and understand why some people are COVID-19 vaccine hesitant to inform vaccine uptake campaigns.	Vaccine hesitancy was shown to decrease during this time span with about 20% of individuals reporting vaccine hesitancy. People with blue-collar occupations were most likely to be vaccine hesitant and believe they do not need a COVID-19 vaccine.
Kricorian et al., 2021	National survey of U.S. adults (N=1,950)	Examine correlation of beliefs and acceptance in relation to the COVID-19 vaccine. Also examine if misinformation is prevalent among those who are not willing to receive the vaccine.	Likelihood of getting a COVID-19 vaccine was associated with believing it is safe. Other significant factors influencing COVID-19 vaccine safety perceptions included sex, race and ethnicity, income, educational level.
Latkin et al., 2022	Longitudinal study online of U.S. adults (N=444)	Find predictors of vaccine uptake to increase COVID-19 vaccine acceptance.	Factors influencing vaccine acceptance included family and friends discouraging vaccines, not trusting vaccine safety, and quick vaccine development concerns.
Leicht et al., 2022	Conducted 2 studies analyzing online data	Study 1: compare misinformation sharing between Facebook and Twitter Study 2: track Facebook user engagement with misinformation,	Facebook labels misinformation better than Twitter. Labeling misinformation posts on Facebook results in these false posts being shared less.

		before and after misinformation labels were added to posts	
Loomba et al., 2021	Conducted an RCT in the UK and U.S. in 2020	Quantify the extent to which online COVID-19 vaccine misinformation exposure impacts an individual's intent to get a vaccine. Findings aim to inform vaccination campaigns to be successful.	Both countries did not show a high enough vaccine intent to reach herd immunity. Exposure to misinformation resulted in a decrease in vaccine intent.
Neely et al., 2021	Used a web-based survey for Florida adults (N=600) in June 2021 and conducted statistical analyses.	Help healthcare and public health professionals understand the current state of misinformation exposure and the common reasons for COVID-19 vaccine hesitancy.	There was a high level of COVID-19 vaccine misinformation exposure in their sample. Misinformation exposure was also correlated with vaccine hesitancy. Political affiliation was another predictor of someone being vaccinated with Democrats more likely to be vaccinated.
Pierri et al., 2022	Used tweets from CoVaxxy dataset to conduct analyses and create regression models based on online misinformation.	Examine how online misinformation impacts vaccination rates/vaccine hesitancy in the U.S.	Found a negative association between vaccine uptake and prevalence of online misinformation. Through a Granger Causality analysis, misinformation strongly forecasts vaccine hesitancy at the county level.
Rane et al., 2021	Interviewed participants involved in a national longitudinal study on COVID-19 and analyzed responses.	Measure vaccine hesitancy trends in U.S. adults and who is less likely to be vaccinated and understand how risk perceptions influence vaccine hesitancy.	The level of vaccine refusal stayed consistent, and refusal decreased slower for participants of color. Racial gaps found were consistent with other paper results. The reasons for COVID-19 vaccine hesitancy stated most frequently surrounded concerns about vaccine effectiveness and side effects of the vaccine.
Sun et al., 2022	Literature review combined with	Understand how the echo chamber effect (ECE) impacts the	People of similar viewpoints tended to interact together, but a weak ECE was found. Social

	data analysis through modeling. Used COVID-19 vaccine YouTube video comments to analyze echo chamber effect.	spread of health misinformation, what factors influence the ECE, and user behaviors because of the ECE and social contagion.	media platforms can be helpful to publish correct information on to stall formations of echo chambers.
Yang et al., 2021	Literature review and data collection from Facebook and Twitter to list sources based on credibility.	Find the prevalence of low-credibility content on Facebook and Twitter, understand if misinformation is concentrated to a small number of accounts, address gaps found in literature review.	The infodemic surged with COVID-19 cases. Of the top 40 accounts posting information, about half were low-credibility sources on both Facebook and Twitter. Misinformation super spreaders are those who get their content reshared by many users. Many low-credibility sources are verified accounts.
Yasmin et al., 2021	Systematic review, 65 studies included	Understand the factors related to vaccine hesitancy in the U.S.	Rates of vaccine acceptance varied greatly between studies (12-91.4%). Factors influencing vaccine acceptance included, age, sex, race, educational level, and income status. Vaccine acceptance was found to increase over time.

Appendix Figure 1: Vaccination Status of U.S. Adults (KFF)

Have you personally received at least one dose of a COVID-19 vaccine, or not? If yes, are you partially vaccinated, meaning you received just one dose of a two-dose vaccine, are you fully vaccinated but have not received a booster, or are you fully vaccinated and have also received at least one booster shot?

■ Vaccinated and boosted ■ Fully vaccinated and not boosted ■ Partially vaccinated
■ Unvaccinated

Democrats	79%	15%		
Ages 65 and older	74%	15%		10%
College graduates	67%	21%		10%
HH income $90K+	66%	20%		14%
Urban residents	61%	22%		15%
Black adults	57%	21%		20%
Men	56%	23%		19%
Total	55%	22%		20%
Suburban residents	55%	23%		19%
HH Income $40-89.9K	54%	22%		22%
Women	54%	22%		21%
White adults	54%	22%		22%
Ages 50-64	53%	22%		20%
Hispanic adults	52%	26%		17%
Insured under age 65	52%	25%		20%
Ages 30-49	52%	21%		24%
Independents	50%	27%		19%
Adults without a college degree	49%	23%		25%
HH income <$40K	47%	25%		22%
Ages 18-29	43%	31%		24%
Republicans	42%	26%		29%
Rural residents	41%	21%		35%
Uninsured under age 65	36%	18%		41%

Appendix Figure 2: Selected Rumors and Conspiracy Theories Related to COVID-19 Vaccines Circulating Online (Islam et al., 2021)

Categories	Claims
Vaccine development, availability, and access	Indonesia is the only country that has been the guinea pig of the COVID-19. Vaccine from China, even though China does not want to test the vaccine on its people.
	COVID-19 vaccine was tested in Indonesia because Chinese laboratories lacked monkeys.
	Putin's daughter was among the volunteers for COVID 19 vaccine trials.
	Dr Anthony Fauci, the nation's leading infectious disease expert, has made a statement" the COVID-19 vaccine should be rushed through development without proper clinical trials".
	Oxford vaccine against COVID-19 will be ready in September.
	COVID-19: Vaccine manufacturers are granted indemnification.
Safety, efficacy, and acceptance	COVID-19 vaccine will cause infertility.
	COVID-19 vaccine may not be effective and has serious side effects.
	Bill Gates explains that the COVID vaccine will use experimental technology and permanently alter your DNA.
	WHO admits COVID vaccines will not work.
	Coronavirus vaccine is ready, able to cure a patient within 3 hours.
	The COVID-19 vaccine "contains DNA modifiers and multipliers.
	Anthony Fauci remarks that vaccines are toxic and can make you worse.
	160 doctors disapprove of the COVID vaccine because it will change our DNA.
	Every fourth American is against taking COVID-19 Vaccine.
	One in six people will refuse a coronavirus vaccine.
Susceptibility due to influenza vaccine	Flu vaccines make people more vulnerable to infections.
	People vaccinated for seasonal influenza face higher chances of catching SARS-COV-2, which causes COVID-19.
	Flu vaccines increase the odds of getting COVID-19.
	Flu vaccine makes kids more vulnerable to coronaviruses.
	Flu Vaccine Kills COVID Patients.
Morbidity and mortality	Two children die from COVID-19 Vaccine in Guinea.
	WHAT??? French Doctors Kill Two in Deadly Vaccine Trials.
	COVID-19 patients died in Guinea after taking a trial vaccine.
	Microsoft founder-turned-philanthropist Bill Gates "admits" in an interview that a COVID-19 vaccine could kill or injure up to 700,000 people.
	The COVID-19 vaccine will kill 50 million Americans.
	American Vaccine against COVID-19 in Ukraine killed 30 per cent of patients.
	All participants in a COVID-19 vaccine trials had side effects.
	Russian President Vladimir Putin's daughter died on August 15th, 2020, after taking a dose of a new COVID-19 vaccine.
	Seven children in Senegal died after being given a vaccine for coronavirus.
	My friend just buried 3 children after getting the Vaccine from China.
	One of the first volunteers of a COVID-19 vaccine trial in the UK, died.
	Vaccines to prevent COVID-19 will modify genes and cause male infertility.

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