THEORETICAL ANALYSIS OF THE BIOLOGICAL BASIS FOR SERIAL KILLERS' COOLING-OFF PERIODS

by

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A THESIS

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Although serial killers have been meticulously studied, there is still much to be learned about particular behaviors exhibited by these offenders. In particular, minimal research exists on the phenomena of serial killers' cooling-off periods. Most definitions of serial killers mention the temporal separation between crimes that distinguish them from other kinds of multi-victim murders; however, due to a lack of empirical research it has been difficult to determine the function or cause of cooling-off periods. There has been a recent uptick in research published on cooling-off periods as interest in the neural activity of serial-killers has increased and as brain scanning technology has become more accessible. However, due to the inherent limitations of brain scans, there exists demand for an alternative method to understanding the function and cause of cooling-off periods. First proposed by M.V Simkin and V.P. Roychowdhury in 2014, it is hypothesized that cooling-off periods may be compared to the refractory periods of neurons during the propagation of action potentials. This approach is considered analogical and will remain as such until definitive evidence is produced showing a biological linkage between the two phenomena. This thesis applied this hypothesis to ten cases of prolific serial killers and looked to verify trends seen in previous research on cooling-off periods. It was concluded that the previous observed patterns were not applicable across all killers and the connection between refractory periods and cooling-off periods will remain speculative until further empirical research is done.

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Introduction

> "Most violent criminals are impulsive, disorganized, and easily caught. The vast majority of homicides are committed by people known to the victim and, despite game attempts to throw off the police, these offenders are usually identified and arrested. It's a tiny minority of criminals, maybe 5 percent, who present the biggest challenge--- the ones whose crimes reveal preplanning and unremorseful rage."
>
> – Michelle McNamara, true crime author

Historians and criminologists speculate that serial killers have been present throughout history, although interest in their behavior has seen a spike in recent decades. Robert Ressler, a former FBI Special agent, is credited with coining the term "serial killer." During a lecture in 1974 he used the phrase "serial homicide," which eventually transitioned into the more colloquial "serial killer" (Ressler & Schachtman, 1993). By the most comprehensive definition, a serial killer is an individual that commits three or more murders over a significant period of time (Adjorlolo & Chan, 2014). According to FBI statistics, serial killers account for less than one percent of all homicides. Though their crimes are rare, these individuals have been incredibly well studied and are the predominant cause of the layman's fascination with true crime. Understanding how serial killers differ from other killers is imperative to understanding how they came to be and who has the ability to become a killer.

There are three main types of killings that involve multiple victims: spree, mass, and serial. In each case an individual murders at least two people; however, the key difference between them is the temporal separation between crimes. A mass murderer commits their crimes simultaneously, as in the case of bombings and mass shootings. A spree killer tends to exhibit a small amount of time between their crimes, often not

exceeding more than a few hours. What differentiates serial killers from spree and mass murders is the extended temporal separation between their crimes. Referred to as the cooling-off period, the separation between crimes is thought to allow the killer to both recover from the crime from an energetic perspective as well as to plan their future endeavors (Osbourne & Salfati, 2015). This recovery period varies anywhere between a few days up to several years.

Recovery periods are present across numerous biological processes. A phenomenon that is aligned particularly well with the cyclical nature of the serial killer's behavior are the propagation of action potentials in neurons. Similar to serial killers, neurons undergo a refractory period after they have fired, or expelled an action potential. This period functions similarly to a recovery period in that it returns the neuron to its resting state where it is able to fire again once a particular stimulus threshold is met.

This thesis will present the current understanding of the biological mechanisms behind the cooling-off period of serial killers, examine the adaptation of these periods across 10 unique killers' careers, and ultimately attempt to establish a connection between the functionality of refractory and cooling-off periods.

Background

Since the establishment of the FBI's Behavioral Science Unit in 1972, the actions of serial killers have been meticulously studied to understand what causes a person to act in such a heinous manner. Often, however, a killer's cooling-off period is the least studied of the behaviors. Serial killers are characterized by their "signatures" or *modus operandi*, which include the manner in which they commit the crime and the shared characteristics across their victims. Researchers tend to focus on these aspects of the crimes because they are the easiest to compare across killers (Edelstein, 2020). Outside of research, the motivations and victimology of each killer are the main focus of the cultural obsession with true crime.

What aligns the research conducted by behavioral scientists with that of true-crime enthusiasts is the approach taken to understanding how a person becomes a serial killer. The accepted technique is to determine who was killed, how they were killed, and ultimately why they were killed. A murderer's victimology, *modus operandi*, and motivation do provide considerable insight into the mind of the killer; however, they do not provide a definitive answer as to why they killed.

Why Someone Becomes a Serial Killer.

Criminal psychologists attempt to answer the "why" behind murders in two ways (Brogaard, 2012; Gillette, 2019). The first is by identifying any traumatic experiences from the killer's childhood or adolescence that may have led to either a behavioral imprint or a brain injury. Most murderers present with some history of trauma, although the extent varies greatly. It is widely accepted that some combination

of neural injury and traumatic environments play a role in the development of a killer (Alley, Minnis, Thompson, Wilson, & Gilberg, 2014).

The second approach is based on the actual biology of the killer with a particular focus on biochemical imbalances, genetic predispositions, and abnormal brain activity. Traditionally, researchers begin by looking for irregular levels of particular biochemicals that are associated with aggressive or violent behaviors. Abnormal serotonin and dopamine levels are thought to be involved in the underlying mechanism that causes impulsive aggression. These neurotransmitters are believed to compound on one another to cause increased aggression, with serotonin exhibiting hypofunction while dopamine shows hyperfunction (Seo & Patrick, 2008). It is believed that serial killers may inherently require a larger stimulation in order to feel the same satisfaction as non-violent offenders, causing them to exhibit more violent and risky behaviors. (Ramsland, 2006). The basis for this conclusion is the prevalence of low dopamine levels in serial killers that may make them more susceptible to addictive or compulsive pleasure-seeking behaviors (Johnson, 2004). Furthermore, irregular serotoninergic activity is present in many serial killers, with low levels associated with impulsivity (Soderstrom, Blennow, Manhem, & Forsman, 2001) and high levels linked to increased aggression (Baron-Cohen, 2011; Bell, Abrams, & Nutt, 2001). These biochemical imbalances can either compound on one another or be aggregated by neurodevelopmental complications, potentially causing an increase in desire and reduction in control of pleasure-seeking behaviors, which may contribute to an individual's decision to kill (Ramsland 2006; Sharma, 2018).

Recently, researchers have attempted to identify genetic predispositions that may be associated with increased aggression and violence. The focus has primarily been on low activity levels of monoamine oxidase A (MAO-A), which is involved in the breakdown of dopamine and serotonin (McDermott, Tingley, Cowden, Frazzetto, & Johnson, 2009). Individuals with low activity levels may be predisposed to increased levels of aggression (Heide & Solomon, 2006). There is still a lot of speculation regarding genetic components that predispose individuals to having violent tendencies; however, further research may lead to the identification of genetic similarities between serial killers that provide further insight into their progression into murder.

The final components of the approach focused on the underlying biology of serial killers are neurodevelopmental complications and abnormal neural activity. Abnormalities in brain structures have been linked to serial killers, although the extent of the atypicality varies greatly. The most common neurodevelopmental complication across killers is thinned tissue in the subcortical regions of the brain, including areas thought to be involved in emotion and decision making (Gansler et al., 2009). Since similar neurodevelopmental markers also exist in non-violent people, they cannot be the sole cause of violent behavior. However, considering the link between behavior and neural activity, it is presumed that some combination of neural damage or aberrant activation must be present in order for a serial killer to murder (Yap & Greenberg, 2018).

Existing Research of Brain Function of Serial Killers

Atypical neural activity in serial killers has gained interest recently, as scanning technologies and understanding of the brain advances. Four common types of

neuroimaging methods are computerized axial tomography (CAT) scans, positron emission technology (PET) scans, magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI). Each scan lets neurologists look at either the structure or function of the brain; however, all four have limitations that restrict the extent of the conclusions that can be drawn from them. CAT scans are used to identify any major structural issues within the brain, as x-ray images are compiled to construct a fairly low-resolution image that shows any tumors, injuries, or intercranial bleeding in the brain. Alternatively, PET scans are used to look at brain function. Patients are injected with a radioactive substance, most often radioactive glucose, that emit positrons. When these particles collide with electrons within the brain tissue, they emit gamma rays that are picked up by the scanner. Since the radioactive substance is delivered intravenously, PET scans are imaging movement of blood through the brain. Areas with increased activity are the most pronounced on the scan.

MRIs use a combination of magnetic fields and computer-generated radio waves to create a high-resolution structural image of the brain. A computer is able to render 3-D images of the brain by compiling data of how different parts of the brain responded to the magnetic fields and radio waves produced by the MRI machine. Hydrogen atoms in the brain respond to the magnetic fields emitted by the scanner, allowing the scanner to identify which part of the brain it came from. fMRIs are similar to MRIs, however, the scans are primarily based on the different responses of oxygenated and deoxygenated blood to the magnetic fields and radio waves. fMRIs use blood oxygen level dependent contrast to detect changes in blood flow to the brain and subsequently identify which parts of the brain are the most active.

Using these methods, researchers have been able to more thoroughly study the brains of violent offenders; however, due to the logistical complications of getting a serial killer into a scanner, there is still a lack of data regarding the brains of serial murderers. Of those able to be scanned, it was found that many serial killers exhibit low activation in left subcortical regions, which include the amygdala, hippocampus and thalamus (Sajous-Turner et al., 2019). Considering the inherent issues with brain scans, researchers can only speculate whether this discrepancy in activation levels is somehow related to the violent behavior of killers. Identifying how brain activity relates to certain behaviors may be imperative to finally understanding how someone becomes a killer.

In addition to measuring abnormal activation levels and brain function, scans may also identify structural issues that may relate to violent behaviors. In terms of examining serial killers' brains, scans have revealed a reduced presence of grey matter in the murder's brains when compared to other violent and nonviolent offenders (Image 1).

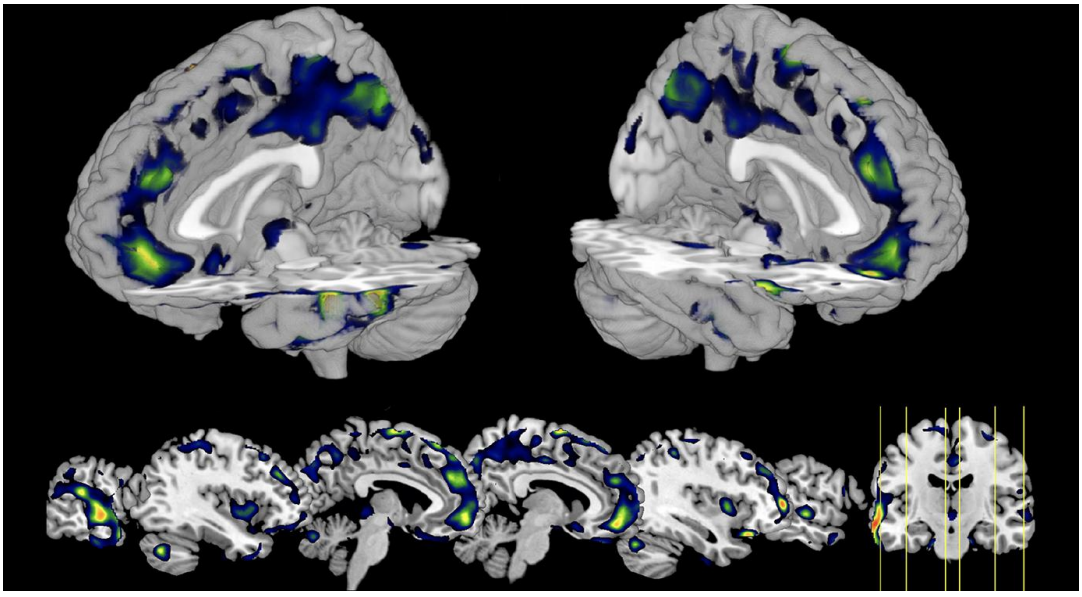

Image 1: Composite of brain regions exhibiting reduced grey matter in murderers as compared to other violent offenders. Reprinted with permission from Sajous-Turner (2019).

The reduced grey matter is primarily localized in regions of the brain thought to be involved with emotional processing, behavior control, and social cognition (Sajous-Turner et. al, 2019). While the researchers managed to acquire an impressive sample size of 800 incarcerated men in one study, we cannot conclude that there is a causal relationship between reduced grey matter and predisposition to homicidal considering the presence of reduced grey matter in non-violent individuals.

The most limiting factor of these scans is that the results are restricted to when someone is in the scanner. This means that any structural or functional abnormalities were not observed at the time of a crime. Although individuals are presented with comparable stimuli in the scanners in order to activate portions of the brain that are presumably involved in specific behaviors, the stimuli are not identical to those experienced outside of the scanner (Roache, 2014). In one fMRI study, ninety-six violent male offenders were given computer tasks meant to test their decision making while simultaneously inhibiting their impulsive reaction. The researchers noted that individuals who exhibited low activity in the anterior cingulate cortex tended to reoffend, though they were unable to definitive link the abnormal activity level to subsequent violent behaviors (Kiehl, Liddle, & Hopfinger, 2000).

The speculative approach of combining genetic makeup, presence of brain damage, and the murderer's interactions with their environment in order to yield a holistic view of the causes behind their violent behaviors has been used extensively be researchers (Aharoni, Vincent, Harenski, et. al, 2013). Scientists combine these data with functional neuroimaging methods, with a keen interest in determining which parts of the murderer's brain are the most integral to their violent behavior. Most of this

research remains speculative, although it has been readily misused as definitive findings. Arguably the most famous example of this approach is the work of Dr. Fallon.

James H. Fallon is a neuroscientist at the University of California, Irvine. His work focuses on the underlying genetic and neurological factors that cause particular behaviors. Through his work Dr. Fallon has examined more than 70 brains of nonviolent and violent offenders and applied the aforementioned approaches to figure out what causes a person to become a serial killer (Stromberg, 2013). At a neurological level, he found that every male offender that he studied presented with some form of damage to their orbitofrontal cortex. The orbitofrontal cortex is involved in decision-making behavior and is believed to be an integral part of the brain's reward system. Even-though damage to the orbitofrontal cortex was present across all killers, the extent of the damage varied widely, indicating that the damage alone was likely not the sole cause of the killer's murderous tendencies. Furthermore, damage in the orbitofrontal cortex is not unique to violent offenders so it cannot be conclusively linked to increased likelihood to commit a homicide.

Fallon proceeded to look at the genetic make-up of each killer with a particular focus on whether they had acquired a mutation causing low activity of the MAO-A gene, which is often referred to and misrepresented as the "warrior gene" (Tiihonen et al., 2014). This mutation is characterized as a low activity variant of the variable number tandem repeat (VNTR) region of the MAO-A gene. Individuals with this low activity variant often show heightened levels of aggression (Gupta, Khan, Sasi, & Mahapatra, 2015). The VNTR mutation in the MAO-A gene is sex-linked on the X chromosome, which is thought to be the basis for why serial killers are predominantly

male (they only have one copy of the X chromosome). Fallon broadened his genetic analysis to include non-violent people and found that the mutation was also present in non-violent people, signifying that some additional factor must be present in the murderer's life to cause them to become killers.

Fallon concluded that in order for the MAO-A gene to be expressed in way that produces massively violent behavior, such as murder, an individual must experience some form of trauma in their adolescence (Naik, 2009). Criminologists have routinely debated whether the root cause of an offender is based in nature or environment, but Fallon's findings indicate that it is some combination of the two. Most serial killer's experience some kind of environmental issue during their childhood and are subject to some form of abuse, whether physical or sexual (Hasselt & Hersen, 1999). Fallon believes that experiencing such violence at a young age causes them to act in a comparable or more extreme violent manner to what they experienced in childhood. This compounded by the presence of the low activity MAO-A mutations creates the speculated genetic basis for a violent offender (Naik, 2009).

What is missing from Fallon's explanation of what causes an individual to become a serial killer is evidence of specific brain activity or a particular stimulus that makes the individual murder someone.

Existing Research on Cooling-Off Periods

Because brain scanning data cannot provide definitive answers about causation, researchers are left working backwards to figure out the underlying biological causes of certain behaviors. While many researchers have focused on a serial killer's *modus operandi* (M.O.), a few have focused their attentions on a more obscure aspect of serial

killers' behavior, the cooling-off period. To date, no one has been able to determine why serial killers have cooling-off periods. The complexity of this behavior and the lack of empirical data have left researchers only able to speculate about the cause and purpose of cooling-off periods (Edelstein, 2020).

The earliest comprehensive study on the phenomenon of cooling-off periods was published in the journal *Nonlinear Dynamics, Psychology, and Life Sciences* in 1999. Dr. Rense Lange was the sole author of the work. Titled "A Cusp Catastrophe Approach to the Prediction of Temporal Patterns in the Kill Dates of Individual Serial Killers", Lange (1999) used mathematical models to examine the cooling-off periods of eleven serial killers. His models did not incorporate any additional elements besides the temporal gap between crimes. He was able to derive an equation that was moderately effective ($R^2 = 0.53$) at predicting the changes in the duration of cooling-off periods between successive murders. The unique time series of each killer exhibited a cyclical pattern, although there existed discrepancies in the patterns such that particular phase portraits exhibited either attractor or repeller patterns. Lange eventually showed how each killer could be identified by the unique characteristic of their time series. He concluded that the cyclical nature of the time series indicated an underlying biological cause that required the serial killers to partake in a cooling-off period between crimes.

More than twenty years after Lange published his findings there are no readily available baseline statistics on the cooling-off periods of serial killers. This is most likely due to the lack of empirically supported theoretical explanations (Edelstein, 2020). The most recent study that attempted to empirically define cooling-off periods was conducted by Mikhail Simkin and Vwani Roychowdhury from the University of

California, Los Angeles. They utilized stochastic models to analyze the patterns of elapsed time between Andrei Chikatilo's murders. This kind of model is used when randomness or uncertainty is present in the study sample, and these models tend to be more realistic than deterministic models when working with a small sample size. Their study, "Stochastic modeling of a serial killer", was published in the *Journal of Theoretical Biology* in 2014.

Simkin and Roychowdhury (2014) found that the distribution of the time intervals between Chickatilo's crimes followed a power law with an exponent of 1.4. This means there was a proportional change between the cumulative number of victims and the time elapsed between crimes. They speculated that the probability that a serial killer will commit a new murder depends on the time elapsed since the previous murder. Using stochastic modeling, they found that the probability of a new murder was higher than the killer's average murder rate immediately after he committed a murder. The probability of a new murder dropped below the average rate once 100-days had elapsed. Simikin and Roychowdhury concluded that this observation could be indicative of a characteristic time scale in the distribution of crimes. They also noted, however, that this observation may have been the result of statistical fluctuation due to the smallness of their sample size ($n=1$).

Although research on the cooling-off periods of serial killers is scarce, there have been some important findings. Researchers have found that, contrary to popular belief, a longer interval between murders actually decreases the probability of another murder, and most of the time, the interval between murders is fairly consistent (Edelstein, 2020; Yaksic, 2018). Additionally, the instances where the interval is not

consistent with the killer's pattern are usually related to some external circumstances that inhibits their ability to find a victim, ranging from a move to an arrest (Edelstein, 2020; Lange, 1999).

Arguably the most important finding of the existing research on cooling-off periods is the similarity in duration between killers. Most killers require at least two-weeks between murders, with many exceeding four-weeks (Edelstein, 2020; Yaksic, 2018). This pattern suggests that there may be some underlying cyclical biological process that causes the serial killers to take a cooling-off period. The identity of that particular biological process is yet to be determined; however, there are other biological mechanisms that it can be compared to in order to further the understanding of why this behavior occurs. The obvious comparison is to the action potential in neurons because of the presence of a refractory period, which is presumably functionally similar to a cooling-off period.

Neurons are electrically polarized cells that maintain a resting membrane potential of approximately -70 mV. This charge is controlled by ion pumps and channels that regulate the movement of ions across the cell's membrane. Electrical signals are passed through and between neurons by way of an action potential (AP). An AP is a temporary reversal in membrane potential due to depolarization and hyperpolarization. When a neuron releases chemical messengers called neurotransmitters into the synaptic cleft, or space between neurons, the neurotransmitters begin to bind to receptors on a neighboring neuron, causing it to depolarize. This makes the neighboring neuron's membrane potential become more positive and approach the neuron's threshold potential of -55 mv. When the membrane

potential reaches it threshold, sodium channels begin to open and allow a rapid influx of positively charged sodium ions into the neuron. This causes a mass depolarization of the neuron as the membrane potential passes zero and becomes more positive. This is referred to as the rising phase of the AP.

The depolarization of the neuron causes the AP and allows the electrical signal to move across the neuron. Sodium channels close once the AP reaches its peak and potassium channels begin to open. This causes the cell to repolarize as the positively charge potassium ions move out of the cell. This is referred to as the falling phase of the AP as the membrane potential becomes more negative. Potassium channels do not immediately close once the membrane potential reaches its resting state, causing the cell to hyperpolarize. The subsequent phase is known as the refractory period, where potassium channels slowly begin to close and the neuron's membrane potential returns to its resting state. While the neuron is undergoing it refractory period it is incredibly difficult to cause another AP. Due to the infrequency of short cooling-off periods, Simkin and Roychowdhury first hypothesized that cooling-off periods were similar to neural refractory periods because they believed that it is difficult for a serial killer to be stimulated enough to murder while in their cooling-off period.

For this thesis, ten serial killer cases were examined to verify the previously observed trends that longer intervals decrease the probability of another murder, that external circumstances cause inconsistent intervals, and that serial killers' cooling-off periods are longer than two weeks on average. The intention of this thesis work was to compare the cyclical nature of each offender's behavior to the propagation of an action potential.

In particular, this thesis focuses on the similarities between the neural refractory period and a murderer's cooling-off period in an attempt to align the two and to gain more insight into the purpose of a cooling-off period.

Methods

To look at how cooling-off periods evolve through the offender's criminal career, 10 case-studies were conducted on prolific serial killers. In order to standardize the sample set, the following criteria were established. Firstly, the crimes must have been committed solo. Partnerships introduce external motivations and pressures that likely impact the killer's ability to partake in a cooling-off period. Secondly, there could be no incentive behind the murders (i.e., no murder for hire). This removes any external motivations that may have encouraged the killer to act. Thirdly, all crimes must have been confirmed by both the killer and law enforcement to ensure accuracy. False confessions can skew the intervals between murders, so a two-step verification will mitigate potential falsities. The final requirement is that all killers must have been male. Female serial killers do exist; however, they are rare in comparison to males. Only 15% of known serial killers are women (Farrell et al., 2011). Since less research exists on these offenders, this thesis focuses on male killers.

On top of the previously mentioned selection criteria for killers, this research was conducted under a few assumptions. The first assumption is that murders are committed after neural excitation exceeds a particular threshold. However, murders cannot necessarily be committed immediately after the threshold is surpassed. The second assumption is that murders function as sedatives, causing the killer to partake in a cooling-off period that functions similarly to a refractory period (Simkin & Roychowdhury, 2014).

Each of the ten offenders' crimes were chronologically logged in Excel and the interval between each crime was calculated in terms of elapsed days. In instances where

there were multiple murders in one day, the circumstances surrounding each murder were considered when calculating the elapsed days. When it was found that these murders happened in the same event, as with familicide, no elapsed time was inputted between the murders. When multiple murders happened on the same day but across different events, a zero was inputted for the elapsed time indicating that the cooling-off period was less than a day. Statistical analysis was used to identify the mean interval between crimes, the standard deviation of the interval between crimes, the longest and shortest interval between crimes, and if there were any outliers. The interquartile range of the values was used to create outlier fences, with the lower fence limit being 1.5 IQR less than the bounds of the first quartile, and upper fence limit being 1.5 IQR more than the bounds of the third quartile. Any values found to be outside of the fence limit were considered outliers. If outliers were present, the data were re-analyzed without the outliers to recalculate the mean and standard deviation of the interval between crimes. The dates of the crimes were graphed against the cumulative number of crimes using a Cantor function, yielding step lengths that pertain to the elapsed amount of time between crimes. If the offender committed additional crimes (burglary, sexual assault, etc.) the previous steps were repeated with the addition of these crimes.

Case Studies

Case Study I: Joseph James DeAngelo (aka EARONS, Golden State Killer)

Image 2: DeAngelo's mugshot after arrest on April 24, 2018.

Background

Joseph James DeAngelo was born on November 8, 1945 in Bath, New York. He enlisted in the United States Navy in 1964 and completed 22-months of active service in Vietnam. DeAngelo graduated from the Roseville police academy in 1968, beginning his law enforcement career as a burglary unit officer. He began his criminal career with a combined 120 burglaries in Visalia, CA over a 22-month period. After being transferred to the Auburn police department DeAngelo was first arrested in 1979 for shoplifting and was released from the police force. DeAngelo's employment in the 1980's is unknown; however, from 1990 to his 2017 retirement he worked as a truck mechanic for the Save Mart Supermarkets in Roseville, CA. On April 24th, 2018, the Sacramento County Sheriff's office arrested DeAngelo for eight-counts of first-degree murder. He plead guilty to 13 counts of first-degree murder with special circumstances on June 29, 2020. Joseph DeAngelo was sentenced to twelve consecutive life sentences plus eight years (*Sacramento County Superior Court Statement of Probable Cause,* 2018).

Results

After his arrest, DeAngelo plead guilty to 13 murders spanning over an eleven-year period. He committed his first murder on September 11th, 1975 and did not commit another for 875 days. The longest interval between crimes was 1742 days which occurred before his final murder. The average elapsed time was 555.4 days with a standard deviation of 607.5 days. The thirteen murders occurred in eight separate events. For dates on which double murders occurred no interval between the killings was inputted (there were no 0-day intervals).

Table 1: DeAngelo's murders between Sept. 11, 1975 and May 4, 1986. The average elapsed time between murders was 555.42 days (SD = 607.5 days).

Cumulative Victims	Location	Date of Murder	Days Elapsed
1	Visalia. CA	9/11/1975	
3	Sacramento, CA	2/2/1978	875
5	Goleta, CA	12/30/1979	696
7	Ventura, CA	3/13/1980	74
9	Dana Point, CA	8/19/1980	159
10	Irvine, CA	2/6/1981	171
12	Goleta, CA	7/27/1981	171
13	Irvine, CA	5/4/1986	1742

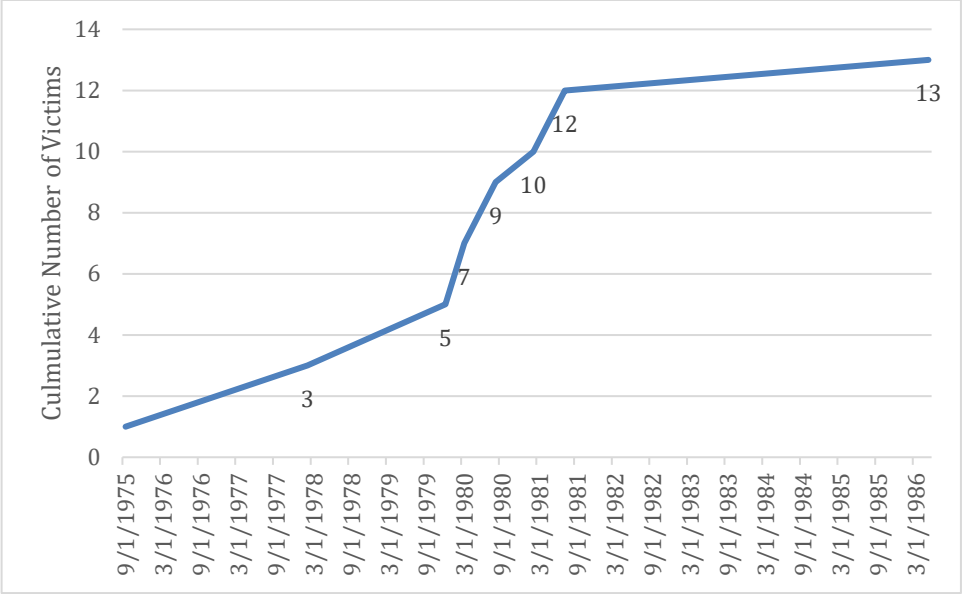

Figure 1: Distribution of DeAngelo's murders over time. The shortest time elapsed between crimes was 74 days, while the longest was 1742 days.

Applying a Grubb's test to the data set identified the murder on May 4th, 1986 as an outlier. Removing this point from the set decreases the average interval between crimes to 357.7 day with a standard deviation of 338.2 days.

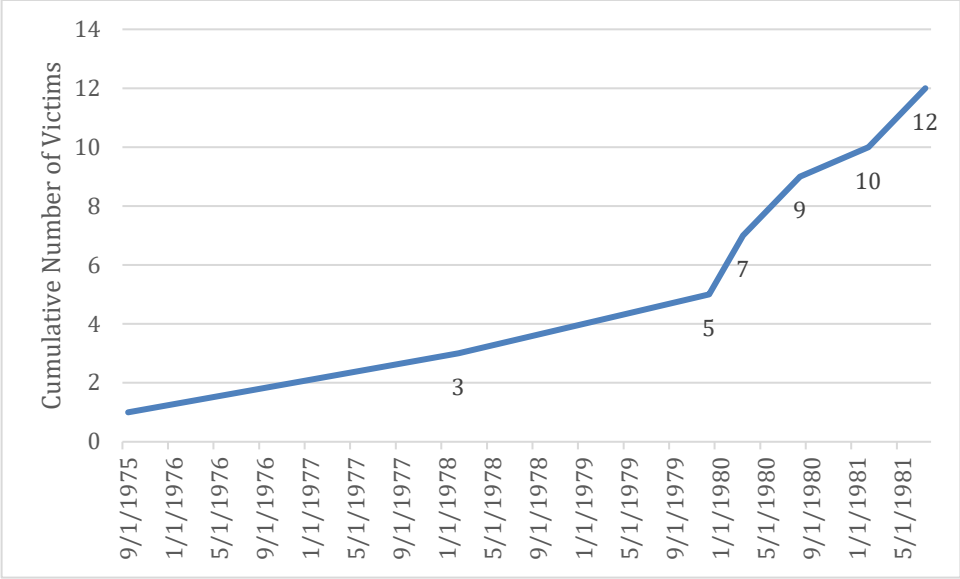

Figure 2: Distribution of DeAngelo's murders without the 1986 outlier. Average time between crimes was 357.7 days (SD = 338.2). The longest elapsed time between crimes was 875 days.

There is an additional factor that must be considered in determining the average cooling off period between DeAngelo's crimes: his perpetration of sexual assaults in the intervals between murders. Assuming such assault function similarly to murders in satisfying an urge, these crimes can be added to the set of murders. For the sake of this study, only assaults that occurred within the same six-year period as the standardized set of murders are considered. Compiling data sets shows an average cooling off period of 38.3 days (*SD* = 55.5 days). The longest interval between crimes was 281 days, while the shortest was 20.5 hours.

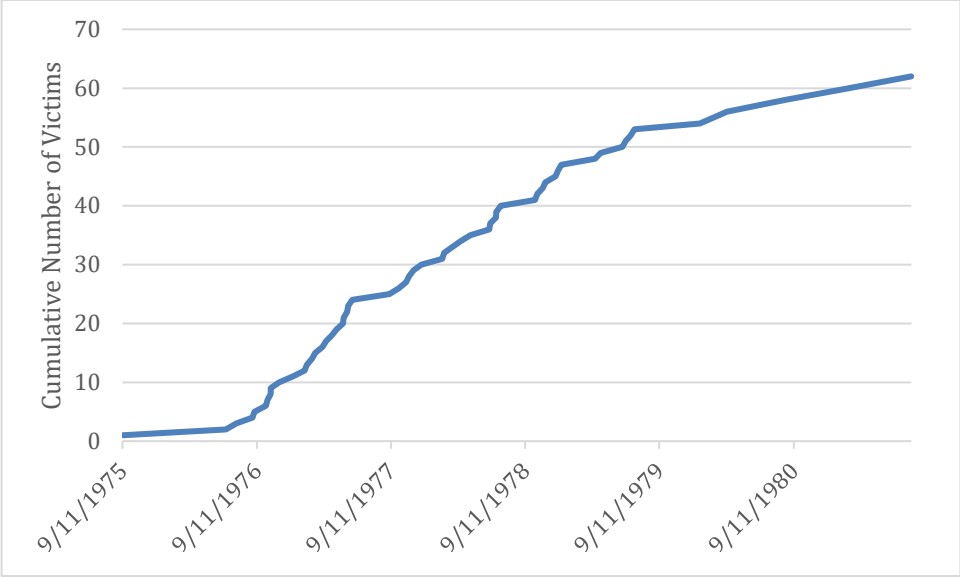

Figure 3: Distribution of DeAngelo's murders and sexual assaults without the 1986 outlier. Average time between crimes was 38.3 days (SD = 55.5). The shortest elapsed time was 20.5 hours, while the longest elapsed time was 281 days.

Joseph DeAngelo was able to maintain a prolonged criminal career because of his police training and mobility. He was able to avoid being apprehended by applying countermeasures that made it nearly impossible to trace him. DeAngelo wore gloves and a mask during his attacks, and rarely left any forensic evidence (ex. DNA, fingerprints, etc.) at the crime scenes (Murphy & Arango, 2020). Additionally, his career caused him to move between jurisdictions, providing an additional cover for his crime. Both factors presumably played a large role in the durations of his cooling-off periods. Unlike many offenders, DeAngelo did not exhibit any drastic decrease of intervals between murders near the end of his criminal career, often called an "unravelling." (Piercy, 2019). Instead DeAngelo's cooling-off periods grew towards the end. His final nine crimes, all of which were murder, had an average interval 143.75 days. Compared to the 38.3 day average intervals between assaults, these data point towards an additional qualifier that determines the length of the cooling-off periods.

Based on the data, DeAngelo required nearly four times as long to recover from a murder as he did an assault. Murders can thus potentially be defined as a more taxing behavior, requiring a longer refractory period.

Case Study II: *Jeffrey Lionel Dahmer (aka Milwaukee Cannibal)*

Image 3: Dahmer's mugshot after arrest on July 22, 1991

Background

Jeffrey Lionel Dahmer was born on May 21st, 1960 in Milwaukee, Wisconsin. According to family and friends Dahmer exhibited a peculiar fascination with dead animals throughout his childhood. He would routinely dismember carcasses and store the remains in large glass jars in a backyard shed. Dahmer's fascination with dead animals stayed within him through high school. Classmates have mentioned to investigators that Dahmer would often invite his friends over to witness him dismembering animals.

Dahmer's first attempt at attacking someone occurred when he was just 16-years old. According to Dahmer, he had recently come to terms with his identity as a homosexual man and fantasized about strangling a local jogger who he found attractive. One day he hid in the bushes along the runner's route; however, the runner did not go out on that particular day. In an attempt to suppress his urges, Dahmer began excessively drinking in his senior year of high school. In one instance, a teacher caught him surrounded by numerous empty beer cans in a school parking lot only a few weeks before graduation. When the teacher threatened to report him, Dahmer explained the

matter away by saying he was experiencing problems at home. He would go on to graduate high school in May of 1978. Dahmer would commit his first murder just three weeks later.

Dahmer would commit 17 murders up until his arrest on July 22, 1991. Dahmer was deemed legally sane and was put on trial in January of 1992, even though he was diagnosed with numerous mental disorders including borderline and schizotypal personality disorders. He was ultimately sentenced to 16 life sentences and served time at the Columbia Correctional Institution in Wisconsin. On November 28, 1994, Dahmer was bludgeoned to death by another inmate during their work assignment (FBI FOIPA File 7-MW-26057).

Results

Dahmer was confirmed to have killed 17 people between 1978 and 1991. These murders all occurred during different events as Dahmer's *modus operandi* (M.O.) involved him only ever assaulting on person at a time. Dahmer's average cooling-off period between murders was 300 days, with a standard deviation of 833 days. The longest interval between murders occurred after his first murder on June 6th, 1978. It would be 3388 days, or 9.2 years, before he would commit his second murder.

Table 2: Dahmer's murders between June 7, 1978 and July 19, 1991. The average elapsed time between murders was 299.44 days (SD = 833.06).

Cumulative Victims	Location	Date of Murder	Days Elapsed
1	Bath, OH	6/6/1978	
2	Milwaukee, WI	9/15/1987	3388
3	West Allis, WI	1/16/1988	123
4	West Allis, WI	3/24/1988	68
5	West Allis, WI	3/25/1989	366
6	Milwaukee, WI	5/20/1990	421
7	Milwaukee, WI	6/14/1990	25
8	Milwaukee, WI	9/3/1990	81

9	Milwaukee, WI	9/24/1990	21
10	Milwaukee, WI	2/18/1991	147
11	Milwaukee, WI	4/7/1991	48
12	Milwaukee, WI	5/24/1991	47
13	Milwaukee, WI	5/27/1991	3
14	Milwaukee, WI	6/30/1991	34
15	Milwaukee, WI	7/5/1991	5
16	Milwaukee, WI	7/12/1991	7
17	Milwaukee, WI	7/19/1991	7

The interval between Dahmer's first and second murder is considered an outlier based upon the results of a Grubb's test. There are circumstances in Dahmer's life that may explain why this cooling-off period was outside of his typical range. Six weeks after Dahmer committed his first murder, when it would have been likely for him to commit another murder, he was forced to move back into his father's home. This scenario likely compromised Dahmer's ability to commit a murder since his M.O. involved spending time with the corpse at his home post-mortem. After Dahmer dropped out of college his father persuaded him to enlist in the Army in January 1979. He remained in the Army until he was honorably discharged in March 1981. Dahmer returned home to his father in September of that year, until eventually being sent to live with his grandmother in Ohio. Part of Dahmer's M.O. was to preserve body parts of his victims, an act that presumably requires Dahmer to have his own space. Staying at his grandmother's house was not conducive for murder since Dahmer was unable to follow his M.O.

When the outlier between the first two murders is removed, Dahmer's average cooling-off period drops considerably from 300 to 47 days (SD = 46 days). Without the outlier, the longest interval between crimes was 147 days which occurred between his ninth and tenth murder.

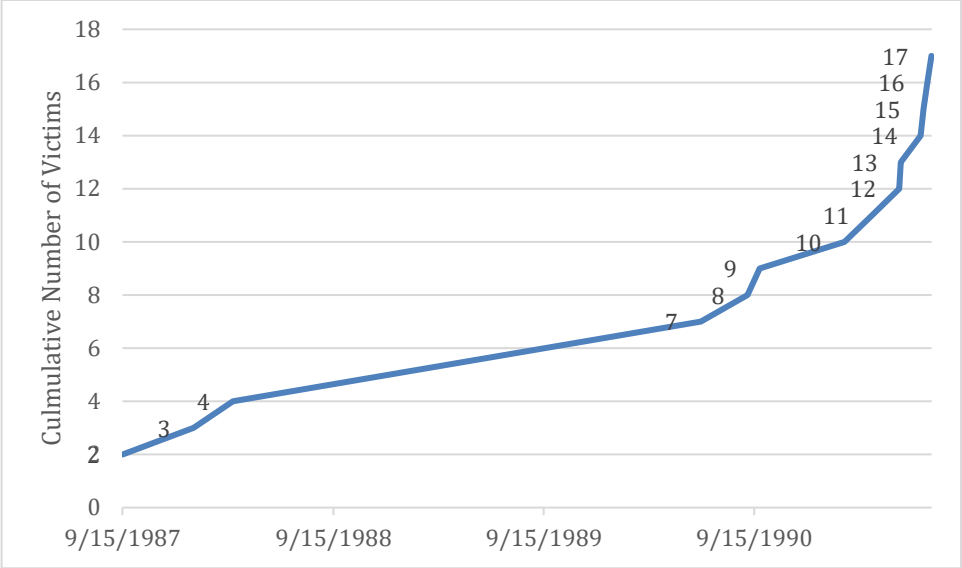

Figure 4: Distribution of Dahmer's murders without 1978 outlier. Average time between crimes was 47.38 days (SD = 46.18). The shortest elapsed time between crimes was 3 days, while the longest was 147 days.

***Case Study III**: John Wayne Gacy (aka Killer Clown)*

Image 4: Gacy's mugshot after arrest on December 22, 1978.

Background

John Wayne Gacy was born in Chicago, Illinois on March 17, 1942. Throughout his childhood, Gacy endured an abusive father. In 1962, Gacy moved to Las Vegas after an altercation with his father. He found work as a mortuary attendant and stayed in Nevada for three months. Gacy returned to Illinois in 1963 and began attending Northwestern Business College, even though he flunked out of high school. He graduated with an associate's degree that same year and began work at the Nunn-Bush Shoe Company.

In 1964 Gacy joined the local United States Junior Chamber, or Jaycees, and he got engaged to Marlynn Myers. They later married in September. Gacy and his wife eventually moved to Waterloo, Iowa to manage Myers' father's KFC restaurants. Gacy again joined the local Jaycees in 1967; however, he was subsequently arrested after sexual assaulting the son of another Jaycee member. On November 7, 1968, Gacy plead guilty to one count of sodomy relating to his attack. He was granted parole with probation in June of 1970. Due to the conditions of his parole Gacy relocated back to Chicago to live with his mother. In 1975 Gacy joined the Jolly Joker clown club, where he created his character Pogo the clown. That same year Gacy began murdering young men and boys. He became known as the killer clown.

Gacy was eventually arrested on December 21, 1978 as the police were investigating the disappearance of a teenager. Twenty-six bodies were exhumed from Gacy's basement. He was ultimately convicted on 33 counts of murder and was sentenced to death by legal injection. Gacy served time at the Menard Correctional Center until his execution on May 10, 1994 (*The People of the State of Illinois, 1984)*.

Results

Gacy is thought to have committed more than 33 murders; however, law enforcement have only been able to confirm 27 victims between January 3, 1972 and December 11, 1978. The average elapsed time between crimes was 97 days (*SD* = 250.9), with the longest and shortest intervals being 1295 and 0 days, respectively.

Table 3: Gacy's murders between Jan. 3, 1972 and Dec. 11, 1978. The average elapsed time between murders was 97.46 days (SD = 250.96).

Cumulative Victims	Location	Date of Murder	Days Elapsed
1	Chicago, IL	1/3/1972	
2	Chicago, IL	7/21/1975	1295

3	Chicago, IL	4/6/1976	260
4	Chicago, IL	5/14/1976	38
5	Chicago, IL	5/14/1976	0
6	Chicago, IL	6/3/1976	20
7	Chicago, IL	6/13/1976	10
8	Chicago, IL	8/5/1976	53
9	Chicago, IL	8/6/1976	1
10	Chicago, IL	10/25/1976	80
11	Chicago, IL	10/25/1976	0
12	Chicago, IL	10/26/1976	1
13	Chicago, IL	12/12/1976	47
14	Chicago, IL	1/20/1977	39
15	Chicago, IL	3/15/1977	54
16	Chicago, IL	7/6/1977	113
17	Chicago, IL	9/15/1977	71
18	Chicago, IL	9/25/1977	10
19	Chicago, IL	10/17/1977	22
20	Chicago, IL	11/10/1977	24
21	Chicago, IL	11/18/1977	8
22	Chicago, IL	12/9/1977	21
23	Chicago, IL	2/16/1978	69
24	Chicago, IL	6/30/1978	134
25	Chicago, IL	11/4/1978	127
26	Chicago, IL	11/24/1978	20
27	Chicago, IL	12/11/1978	17

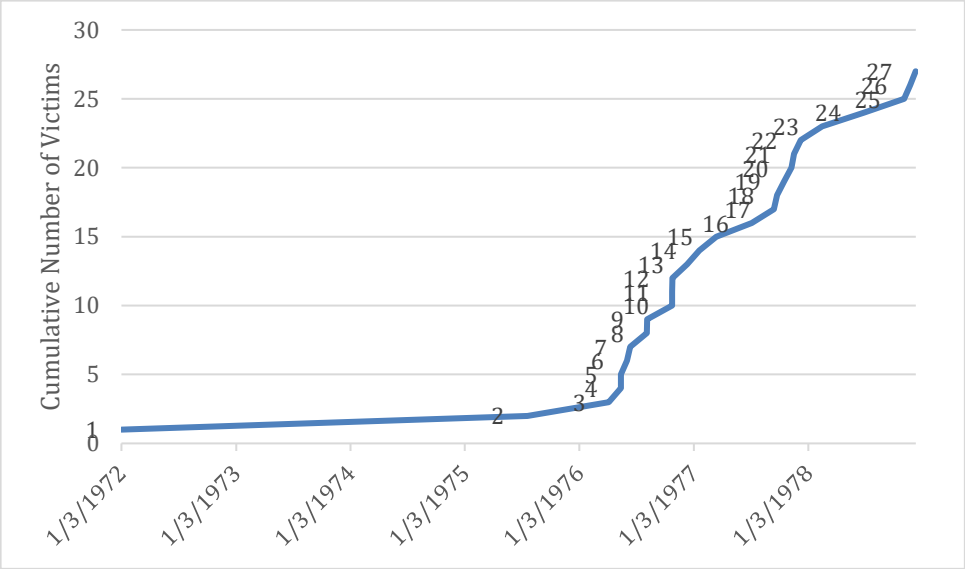

Figure 5: Distribution of Gacy's murders over time. The shortest time elapsed between crimes was 0 days, while the longest was 1295 days.

There are two outliers in the overall set of murders. The first is the interval between the first and second murder (1295 days), and the second between the second and third interval (260 days). Removing these points from the set drastically change the observed trends. Gacy's average cooling-off period essentially halves, decreasing from 97 days to 41 days (*SD* = 40.0 days). The longest observed interval is 134 days.

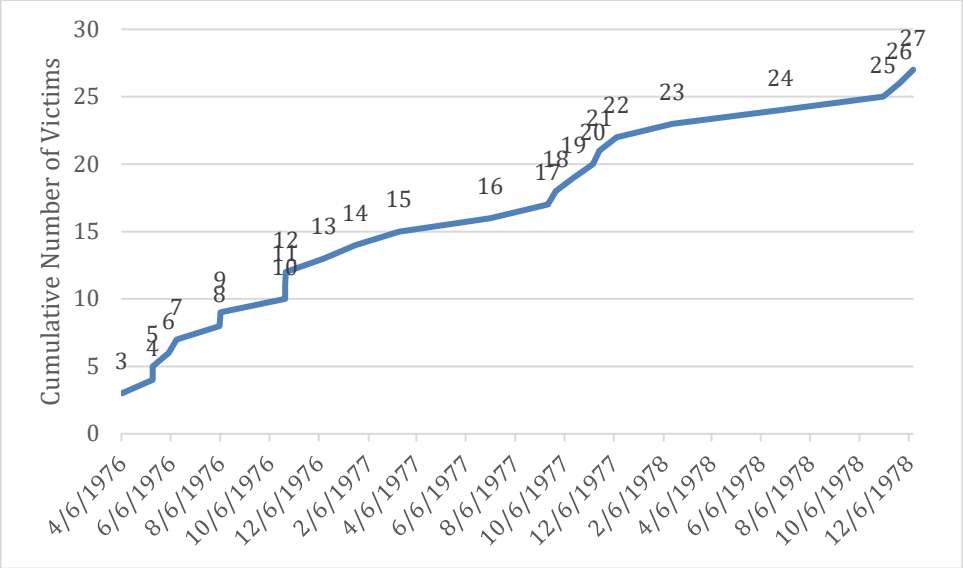

Figure 6: Distribution of Gacy's murders without 1972 and 1975 outliers. Average time between crimes was 40.79 days (SD = 40.04). The shortest elapsed time between crimes was 0 days, while the longest was 134 days.

Case Study IV: *Theodore "Ted" Robert Bundy*

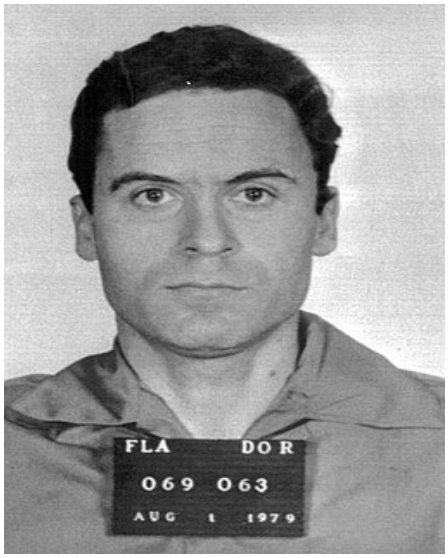

Image 5: Bundy's mugshot after conviction on August 1st, 1979.

Background

Theodore Robert Bundy, birthname Theodore Cowell, was born on November 24, 1946 in Burlington Vermont. The identity of Bundy's father has never been confirmed, and Bundy spent most of his childhood being raised by his grandparents to avoid the social stigma of being born out of wedlock. Bundy graduated from high school in 1965 and went on to attend the University of Puget Sound for a year before eventually transferring to the University of Washington to study Chinese. He dropped out in 1968 and travelled throughout the United States until he returned to the

university in 1970 to complete a degree in psychology. After graduating in 1972, Bundy worked on Governor Daniel J. Evans' successful reelection campaign. In 1973 he began attending law school at the University of Puget Sound (UPS) Law School. By early 1974 Bundy had begun routinely missing classes at UPS, and by April 1974 he had fully withdrawn from the program as reports of women missing throughout the Pacific Northwest began to circulate.

Bundy committed his first confirmed murder on February 1, 1974 though there is speculation that there may have been previous victims. He murdered women at the rate of about one victim per month through mid-1974. To evade police Bundy moved to Utah in August of 1974 and continued pursuing a law degree at the University of Utah Law School. Women began disappearing in the surrounding area shortly thereafter. Until his first arrest on August 16, 1974 Bundy continued to commit murders throughout Utah, Colorado, and Idaho. In June of 1975 Bundy was sentenced to 15-years in Utah State Prison. After being extradited to Aspen, Colorado in early 1977, Bundy escaped on June 7th during a court hearing. He was caught by police six days later on June 13th. He escaped again on December 30th and was able to remain at large until February 15th, 1978. On February 10th, 1980, Bundy was sentenced to death by electrocution. Bundy was executed on January 24th, 1989 at the age of 42 at the Florida State Prison (*State of Florida v. Theodore Robert Bundy, 1985)*.

Results

In the decade between his final arrest and execution, Bundy confessed to thirty murders of which only 20 have been confirmed by law enforcement. According to police, Bundy committed the twenty murders between February 1, 1974 and February 9,

1978. The average elapsed time between murders was 77 days (*SD* = 208 days), with the longest interval being 932 days. The twenty murders were committed as 19 separate events, with the only overlap occurring during his second to last attack.

Table 4: Bundy's murders between Feb. 1, 1974 and Feb. 9, 1978. The average elapsed time between murders was 77.32 days (SD = 208.15).

Cumulative Victims	Location	Date of Murder	Days Elapsed
1	Seattle, WA	2/1/1974	
2	Olympia, WA	3/12/1974	39
3	Ellensberg, WA	4/17/1974	36
4	Corvallis, OR	5/6/1974	19
5	Burien, WA	6/1/1974	26
6	Seattle, WA	6/11/1974	10
7	Lake Sam., WA	7/14/1974	33
8	Lake Sam., WA	7/14/1974	0
9	Holladay, UT	10/2/1974	80
10	Midvale, UT	10/18/1974	16
11	Lehi, UT	10/31/1974	13
12	Bountiful, UT	11/8/1974	8
13	Aspen, CO	1/12/1975	65
14	Vail, CO	3/15/1975	62
15	Grand Junc., CO	4/6/1975	22
16	Pocatello, ID	5/6/1975	30
17	Provo, UT	6/28/1975	53
19	Tallahassee, FL	1/15/1978	932
20	Lake City, FL	2/9/1978	25

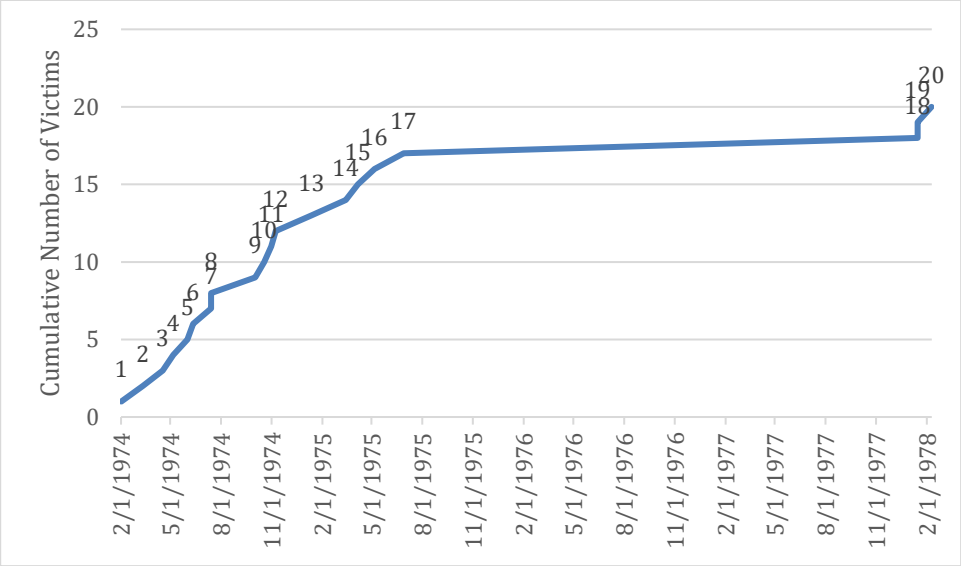

Figure 7: Distribution of Bundy's murders over time. The shortest time elapsed between crimes was 0 days, while the longest was 932 days.

Figure 1 has a clear outlier between the 17th murder on June 28, 1975 and the 18th murder on January 1, 1978, an interval of 932 days. Applying a Grubbs' test confirms this point to be an outlier; however, when contextualized within the progression of Bundy's career, there is an obvious explanation for this uncharacteristically long cooling-off period. As previous mentioned, Bundy was initially arrested on August 16th, 1975 and remained in custody until his escapes in 1977. The final three murders occurred during his second escape.

Considering the circumstances during those 932 days that made it nearly impossible for Bundy to commit additional murders, it is worth separating his career into two parts and analyzing the trends separately. Letting the first part of his career be all the confirmed murders before his initial arrest, trends change drastically from those observed in his entire career. The average number of days between crimes is halved, decreasing from 77 days to only 32 days (SD = 22.8 days). Bundy's longest cooling-off period was 80 days, occurring between his 8th and 9th murder. This coincides with his

move from Washington to Utah. The shortest interval was 0 days, which is attributed to him abducting two unrelated victims at Lake Sammamish State Park on July 14th, 1974.

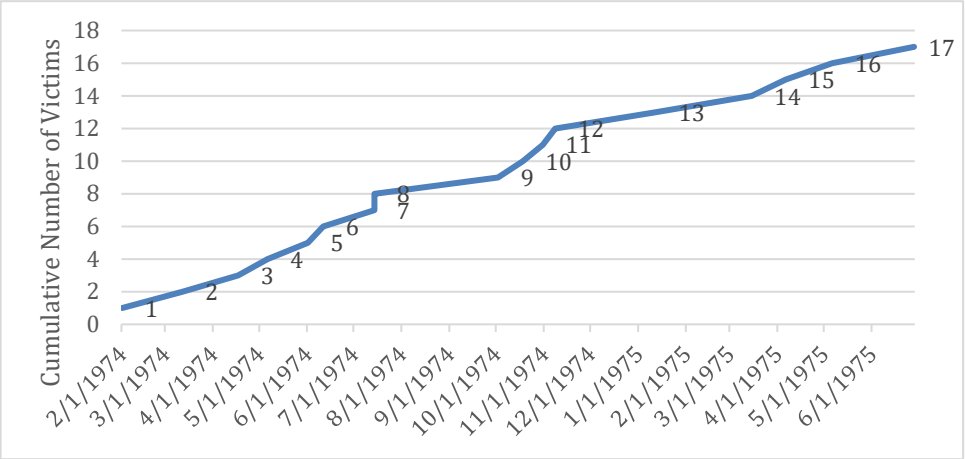

Figure 8: Distribution of Bundy's murders before 1975 arrest. Average time between crimes was 32 days (SD = 22.8). The shortest elapsed time was 0 days, while the longest was 80 days.

In the second part of his career, Bundy committed only three murders over two separate events. Both occurred within his second escape. He committed his 18th and 19th murders during his attack on the Chi Omega sorority at Florida State University on January 15, 1978. In total Bundy attack and bludgeoned five women at the sorority of which three survived. Bundy committed his final murder 25 days later on February 9th, 1978. This was the last murder he is confirmed to have committed before his final arrest on February 15th, 1978. Though this sample is small, it falls within the same trends observed in his career prior to his first arrest. The 25 days between crimes fall within one standard deviation (22.8) of the mean days elapsed between crimes (32).

Throughout his criminal career, Ted Bundy maintained a remarkably consistent pattern regarding the length of his cooling-off periods between crimes. During his escape, Bundy underwent a cooling-off period that aligned with the recovery patterns observed prior to his original arrest. Even with the increased pressure of law

enforcement attempting to apprehend him, Bundy was seemingly in no rush to commit more murders before he completed his recovery cycle. This could be an indication of a biological mechanism causing him to be unable to respond to stimuli until completing his cooling-off period, in much the same way as neurons are unable to fire until completing their refractory period.

Case Study V: *Richard Leyva Muñoz Ramírez (aka The Night Stalker)*

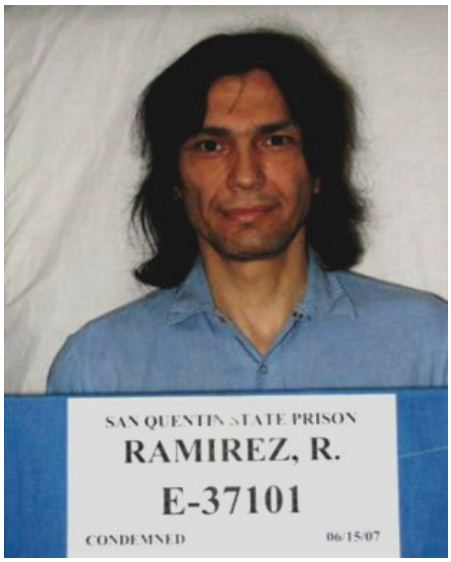

Image 6: Ramirez in 2007.

Background

Born on February 29, 1960, Richard Leyva Muñoz Ramírez was the youngest of five children. Ramírez was incredibly close to his eldest cousin Mike growing up; however, at only 12-years old Ramírez witnessed Mike murder his wife over a domestic argument. After the incident, family members reported Ramírez becoming withdrawn and eventually turned to using the hallucinogenic drug LSD. He worked at a local Holiday Inn until his termination following an attempted assault on a female patron. Ramírez dropped out of high school in the ninth grade and eventually moved to California, where he soon became known as the Night Stalker.

It is speculated that Ramírez's first victim might have been murdered on April 10, 1984; however, evidence suggests the presence of a second person at the murder who may have been the true perpetrator. The earliest confirmed murder happened on June 28, 1984 in Glassell Park, a neighborhood in northern Los Angeles. Ramírez

committed 13 murders over the course of the next year until he was apprehended on August 31, 1985. He was eventually convicted on 13 counts of murder, 5 counts of attempted murder, 11 counts of sexual assault and 14 counts of burglary. Ramírez was sentenced to 19 consecutive life sentences at San Quentin State Prison, where he remained until his death due to B-cell lymphoma on June 7, 2013 (*The People of California v. Richard Ramírez,* 1990).

Results

Ramírez committed 13 confirmed between June 28, 1984 and August 18, 1985. These murders took place over 11 separate events. The average time elapsed between the murders was 42 days (*SD* = 79.4 days), with the longest time being 262 days. The shortest cooling-off period was 0 days.

Table 5: Ramierez's murders between Jun. 28, 1984 and Aug. 18, 1985. The average elapsed time between murders was 41.6 days (SD = 79.44).

Cumulative Victims	Location	Date of Murder	Days Elapsed
1	Glassell Pk, CA	6/28/1984	
2	Rosemead, CA	3/17/1985	262
3	Rosemead, CA	3/17/1985	0
5	Whittier, CA	3/27/1985	10
6	Monterey. CA	5/14/1985	48
7	Arcadia, CA	7/2/1985	49
8	Monterey, CA	7/7/1985	5
10	Glendale, CA	7/20/1985	13
11	Sun Valley, CA	7/20/1985	0
12	Diamond, CA	8/8/1985	19
13	San Fran., CA	8/18/1985	10

It is apparent from Table 5 that the interval between the first and the second murder is an outlier within the set. This can be confirmed by applying a Grubb's test. Removing this point from the set decreases Ramírez's average cooling-off period to only 17 days (*SD* = 18.79). The longest interval between his crimes occurred in the interim of his sixth and seventh murder, lasting 49 days.

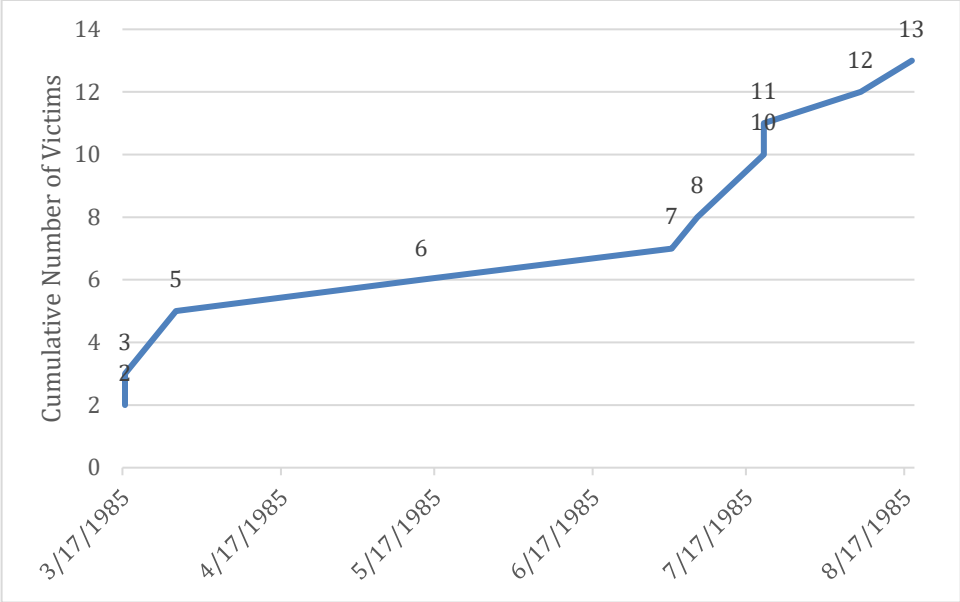

Figure 9: Distribution of Ramírez's murders without 1984 outlier. Average time between crimes was 17.11 days (SD = 18.79). The shortest elapsed time between crimes was 0 days, while the longest was 49 days.

Case Study VI: *Edmund Emil Kemper III (aka Co-ed Killer)*

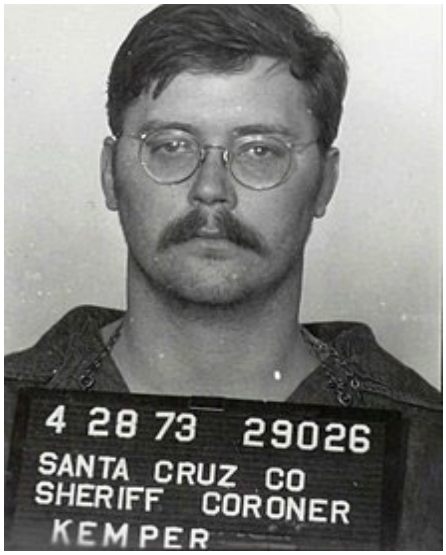

Image 7: Kemper's mugshot in 1973.

Background

Edmund Emil Kemper III was born on December 18, 1948 in Burbank, California. From an early age Kemper exhibiting antisocial tendencies and was often considered an outcast, although his staggering height made him stand out amongst his peers. In adolescence Kemper began showing increased cruelty to animals, often murdering house pets for showing more affection towards his siblings. Kemper's behavior become more erratic after his parents separated in 1957. Kemper was left to live with his mother with whom he had a dysfunctional and often tumultuous relationship. At 14, Kemper ran away from his

mother's house to live with his father in Van Nuys, California; however, upon arrival Kemper learned that his father had remarried. Kemper stayed only a few days with his father until he was sent to live with his grandparents in North Fork, California.

On August 27, 1964 Kemper murdered both his grandparents after getting into a heated argument with his grandmother. He was only 15 years old at the time. At the insistence of his mother, Kemper remained at the crime scene and waited for police to arrive. He was taken into custody that same day. Court psychiatrists diagnosed Kemper with paranoid schizophrenia and concluded that he did not understand the magnitude of his crimes. Kemper was sent to Atascadero State Hospital, a correctional facility primarily focused on the rehabilitation of mentally ill convicts. Kemper was considered a model prisoner and psychiatrists at the facility began to question his original diagnosis. They noted that he exhibited no signs of hallucinations, bizarre thoughts, or other indications of mental illness. Atascadero staff routinely noted Kemper's above averaging intellect. Against the recommendations of the psychiatric staff, Kemper was released on December 18, 1969.

After his release Kemper applied to work as a police officer in Santa Cruz, California, although he was ultimately denied the job. He maintained close relationships with police officers and eventually found work in the California Department of Transportation. Kemper began picking up hitchhikers in early 1972 and eventually started murdering them. He would go on to murder eight people over the course of a year. His final murder occurred on April 20, 1973. Kemper made a surprise visit to his mother's house and proceeded to bludgeon her with a hammer. He then invited her best friend over and strangled her in an attempt to create a cover story that the two were on

vacation together. Kemper fled the scene; however, he eventually turned himself in to the authorities in Colorado on April 24, 1973. He was convicted on eight counts of murder and sentenced to eight concurrent life sentences. Kemper is currently serving out his time at the California Medical Facility in Vacaville, California (State of California Board of Parole Hearings, 2017).

Results

Between murders, Kemper showed an average cooling-off period of 631.8 days (*SD* = 1217.2 days). He committed a total of ten murders over six separate events between August 27, 1964 and April 21, 1973. The longest interval between crimes occurred after his first murder. It took Kemper 2,808 days to commit another murder.

Table 6: Kemper's murders between Aug. 27, 1964 and Apr. 21, 1973. The average elapsed time between murders was 631.8 days (SD = 1217.2).

Cumulative Victims	Location	Date of Murder	Days Elapsed
2	North Folk, CA	8/27/1964	
4	Alameda, CA	5/5/1972	2808
5	San Fran., CA	9/14/1972	132
6	Aptos, CA	1/8/1973	116
8	Santa Cruz, CA	2/5/1973	28
10	Aptos, CA	4/21/1973	75

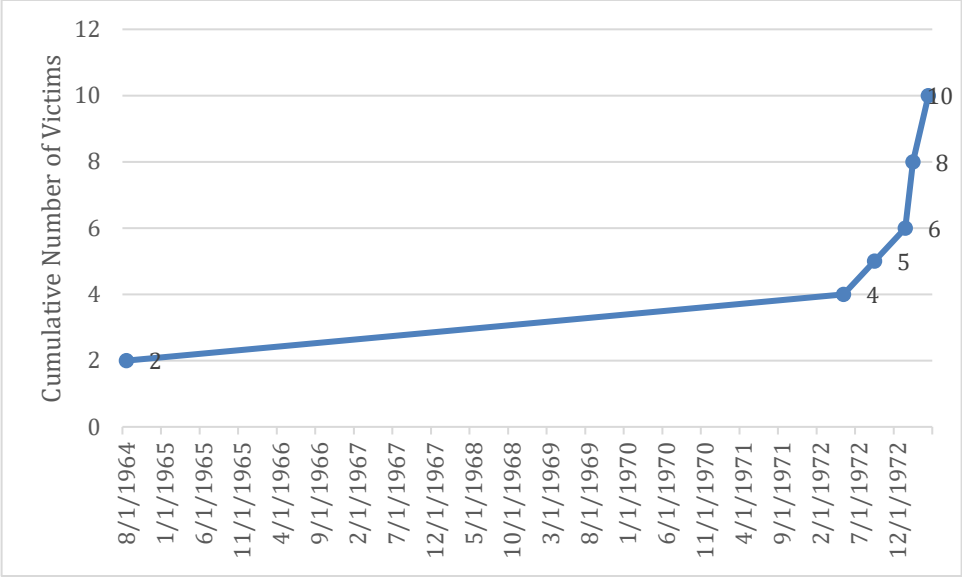

Figure 10: Distribution of Kemper's murders over time. The longest interval between crimes was 2,808 days, while the shortest was 75 days.

The average time between his crimes significantly decreases once the first two murders are removed from the set as outliers. Kemper's first incarceration corresponded to the interval of time between his first set of murders and his second set of murders. Without this outlier, Kemper's average cooling-off period decreases from 631.8 days to 87.75 days (*SD* = 46.5 days). The longest interval between crimes was 132 days and the shortest was 28 days.

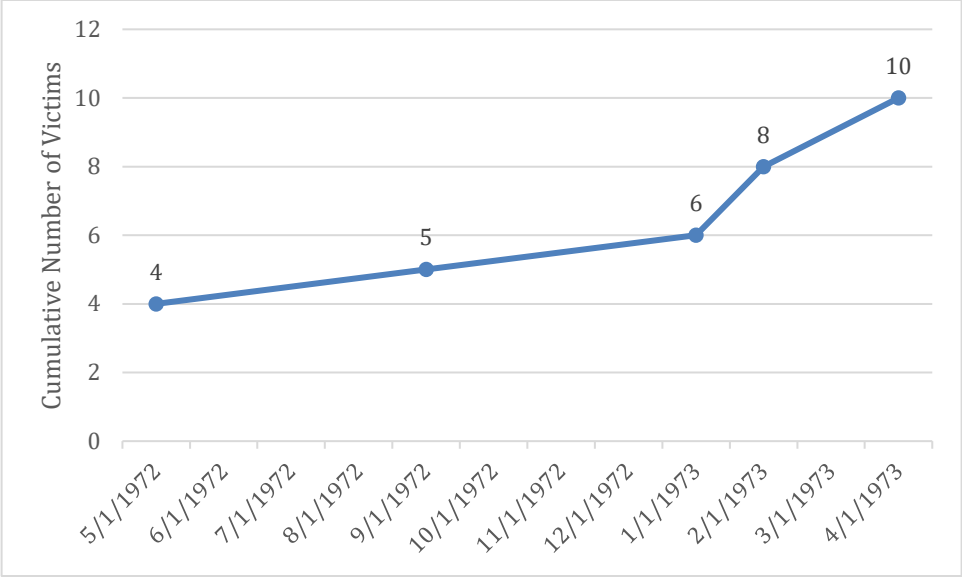

Figure 11: Distribution of Kemper's murders without 1964 outlier. Average time elapsed between crimes was 87.75 days (SD = 46.5). The longest interval was 132 days, while the shortest was 28 days.

Kemper committed the majority of his murders within a year. The duration of his cooling-off periods noticeably declined towards the end of his career with his shortest interval of just 28 days occurring between his sixth and seventh cumulative murder. Interestingly, his second shortest cooling-off period (75 days) occurred between two double murder events.

Case Study VII: *Dennis Lynn Rader (aka BTK Killer*)

Image 8: Rader's mugshot after arrest on February 25, 2005.

Background

Dennis Lynn Rader was born on March 9, 1945 in Pittsburg, Kansas. Radar primarily grew up in Wichita and exhibited signs of sexual sadism and zoo-sadism from a young age. After graduating high school, Radar attended Kansas Wesleyan University for only a year. He ultimately dropped out and joined the United States Air Force, serving from 1966 to 1970. Radar returned to Wichita after his discharge and earned a B.S. in Administrating of Justice from Wichita State University in 1979.

Radar committed his first murder on January 15, 1974, killing four members of the Otero family. That same year Radar began work as an ADT technician. He was tasked with installing home security systems throughout the great Wichita area. Demand for such security increased drastically as reports of a serial killer, called the BTK killer, circulated. Radar gave himself the nickname BTK Killer, an abbreviation of bind, torture, kill, in a letter to the Wichita Sun. Radar would go on to kill 10 people between 1974 and 1991. He was eventually arrested on February 25, 2005 and ultimately convicted of ten counts of first-degree murder. Radar is currently serving out his sentence at the El Dorado Correctional Facility in Butler County, Kansas (Sedgwick County District Court Transcript of Pleas of Guilty, 2005).

Results

Radar committed ten murders across seven different events between January 15, 1974 and January 12, 1991. His average cooling-off period was 1034.3 days (*SD* = 984.2). The longest interval between crimes occurred after his 7th murder, where it took him 2,697 days or 7.3 years to commit his next murder. Radar's shortest cooling-off period was 79 days, which occurred between his first set of murders and his next murder. There were no identifiable outliers during Radar's criminal career.

Table 7: Rader's murders between Jan. 15, 1974 and Jan. 12, 1991. The average elapsed time between murders was 1034.3 days (SD = 984.2 days).

Cumulative Victims	Location	Date of Murder	Days Elapsed
4	Wichita, KS	1/15/1974	
5	Wichita, KS	4/4/1974	79
6	Wichita, KS	3/17/1977	1078
7	Wichita, KS	12/8/1977	266
8	Wichita, KS	4/27/1985	2697
9	Wichita, KS	9/16/1986	507
10	Park City, KS	1/12/1991	1579

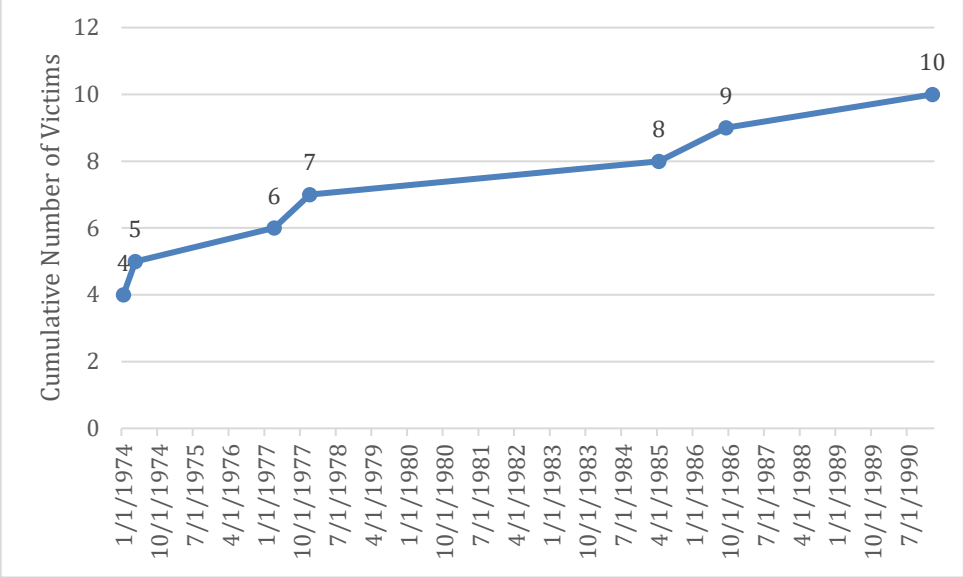

Figure 12: Distribution of Rader's murders over time. The longest elapsed time was 2697 days, while the shortest was 79 days.

Radar's ten murders spanned over nearly two decades. The duration of his cooling-off periods is noticeably larger than the other case studies. There does not seem to be any regularity in the duration of Radar's cooling-off period, as evidenced by the

large standard deviation. It is worth noting that the shortest interval between crimes throughout his entire career happened after he committed a quadruple murder, an action than presumably requires a massive energetic expenditure. It was expected that instances of multiple murders would require longer cooling-off periods.

Case Study VIII: *David Richard Berkowitz (aka Son of Sam)*

Image 9: Berkowitz's mugshot after arrest on August 11, 1977.

Background

Richard David Falco was born on June 1, 1953 to Elizabeth Broder and Joseph Klineman in Brooklyn, New York. According to Broder, Richard was given the last name Falco after Klineman threatened to leave Broder if she gave their son his last name. Richard was given the surname Falco after his mother's ex-husband Tony Falco (Abrahamsen, 1985). A few days later Broder put Falco up for adoption. She is believed to have done this in response to Klineman threating to leave her if she kept the child. Falco was adopted by Pearl and Nathan Berkowitz, who rearranged the child's first two names and gave him their surname. David Richard Berkowitz was the couple's only child.

Berkowitz exhibited behavioral issues from an early age and routinely was disciplined for offenses ranging from petty larceny to minor arson. After his adoptive mother died when he was just 14, Berkowitz's behavior worsened, but no legal intervention ever occurred. He graduated from Christopher Columbus High School in 1971 and immediately joined the army at only 17. Berkowitz served honorably until his

discharge in June of 1974. He eventually tracked down his birth mother and was reportedly disturbed after hearing about the circumstances of his adoption. In 1976 Berkowitz started work as a driver for the Co-Op City Taxi company. He would bounce around jobs until his arrest in 1977.

On December 24, 1975 Berkowitz attacked two women in Co-Op city with a hunting knife. Although Berkowitz managed to stab both women multiple times, the two women survived. After this botched attack Berkowitz began using a handgun as his murder weapon. His first successful murder happened on July 29, 1976 when he shot two women in the Bronx. Both women sustained gunshot wounds, however, only one woman's injuries proved fatal. Berkowitz would go on to kill five more people before his arrest on August 10, 1977. He confessed to the shootings the following day and was sentenced to 6 concurrent life sentences. Berkowitz is currently serving out his sentence at the Shawangunk Correctional Facility in Ulster County, New York (*The People of New York v. David Berkowitz, 1978)*.

Results

Over the course of his criminal career, Berkowitz committed six murders across 5 different events. The average elapsed time between his crimes was 91.75 days (*SD* = 69.9 days). Berkowitz's longest cooling-off period was 185 days, which occurred between his first and second murder. The shortest time between murders happened after his third murder. It took him only 39 days to commit an additional two murders in the same event.

Table 8: Berkowitz's murders between Jul. 29, 1976 and Jul. 31, 1977. The average elapsed time between murders was 91.75 days (SD = 69.9).

Cumulative Victims	Location	Date of Murder	Days Elapsed

1	Bronx. NY	7/29/1976	
2	Queens, NY	1/30/1977	185
3	NYC, NY	3/8/1977	37
5	Bronx, NY	4/16/1977	39
6	Brooklyn, NY	7/31/1977	106

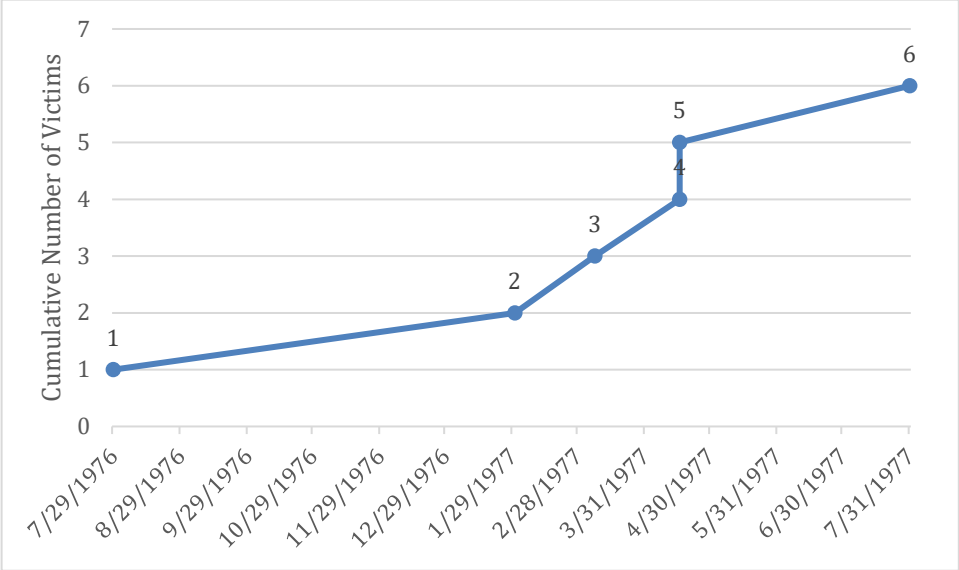

Figure 13: Distribution of Berkowitz's murders over time. The longest elapsed time was 185 days, while the shortest was 37 days.

Berkowitz has the lowest cumulative number of victims of the case studies, with a victim count of 6 people. Over the course of a year Berkowitz murdered six individuals; five of those murders occurred within only seven months.

Case Study IX: *Randall Woodfield (aka I-5 Killer, I-5 Bandit)*

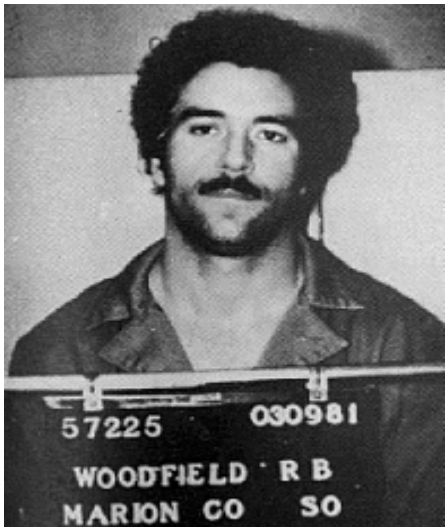

Image 10: Woodfield's mugshot on March 9th, 1981.

Background

Randall Woodfield was born on December 26, 1950 in Salem, Oregon. Woodfield was raised in Otter Rock and was considered popular amongst his peers. A star football player, Woodfield graduated from Newport High School and went on to play at the collegiate level for Portland State University in 1970. Woodfield was arrested several times while at PSU, for offenses ranging from vandalism to public indecency. He eventually dropped out mid-way through his junior year and was selected by the Green Bay Packers in the 1974 NFL Draft.

Woodfield was a member of the Packer's practice squad until he was cut during the 1974 season. He played for a semi-professional team in Manitowoc, Wisconsin until he returned to Portland in late 1974. In 1975 Woodfield was arrested after several women were assaulted and robbed. He confessed to the attacks in exchange for a reduced sentence. Although initially sentenced to ten years in prison, Woodfield was freed on parole after only four years.

On October 9, 1980, Woodfield murdered a former classmate from high school who he had maintained contact with during his time in prison. Over the next year, Woodfield would commit six more murders across cities along the I-5 in the Pacific Northwest. Woodfield was arrested on March 7, 1981 after being identified in a line-up

by a witness. Although prosecutors had collected enough evidence to convict him of all the murders, Woodfield was only officially charged with murdering his fourth victim. He was convicted and sentenced to life in prison plus 90 years. Woodfield is currently serving out his sentence at Oregon State Penitentiary in Salem, Oregon (*State of Oregon v. Randall Brent Woodfield, 1982)*.

Results

Although it is speculated that Woodfield more that forty-four murders, only seven have been confirmed by law enforcement. These seven murders happened between October 9, 1980 and February 15, 1981 across five different events. Woodfield's cooling-off periods were on average 32.25 days (*SD* = 21.17 days). The longest cooling-off period of his career happened between his third and fourth murder. It lasted 52 days. The shortest was only 12 days, between his sixth and seventh murder.

Table 9: Woodfield's murders between Oct. 9, 1980 and Feb. 15, 1981. The average elapsed time between murders was 32.25 days (SD. = 21.17).

Cumulative Victims	Victim's Initials	Date of Murder	Days Elapsed
1	Portland, OR	10/9/1980	
3	Portland, OR	11/27/1980	49
4	Keizer, OR	1/18/1981	52
6	Shasta, CA	2/3/1981	16
7	Beaverton, OR	2/15/1981	12

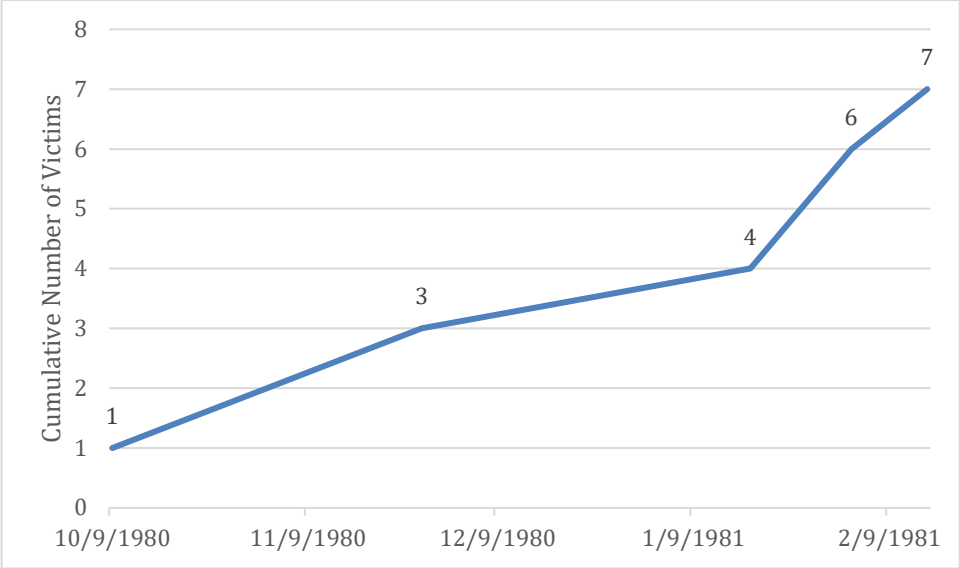

Figure 14: Distribution of Woodfield's murders over time. The longest elapsed time was 52 days, while the shortest was 12 days.

Based only the seven murders than have been confirmed by law enforcement, Woodfield exhibited brief cooling-off periods in comparison to other case studies. Interestingly his shortest cooling-off period (12-days) occurred after he committed a double homicide. As more murders become linked to Woodfield, the length of his average cooling-off period will likely change.

Case Study X: *Gary Leon Ridgway (aka Green River Killer)*

Image 11: Ridgway's mugshot after arrest on November 30, 2001.

Background

Gary Leon Ridgway was born on February 18, 1949 in Salt Lake City, Utah. Throughout his childhood Ridgway observed numerous violent arguments between his parents and on occasion was the target of abuse. Ridgway struggled academically and was held back a year in high school. He managed to graduate from Tyee High School in 1969 and joined the United States Navy. During his time in the Navy, Ridgway began soliciting sex workers although his religious ideologies were against such proclivities. After being discharged in 1971 Ridgway began proselytizing door-to-door and continued to regularly solicit sex workers.

Ridgway began attacking woman in 1982. Most of Ridgway's victims were thought to be either runaways or sex workers as he predominantly picked them up along the State Route 99. Ridgway was dubbed the "Green River Killer" due to him using the river as his primary disposal site for his victims' bodies. Police suspected that Ridgway was the Green River Killer as early as 1983; however, they did not have enough evidence to definitively link him to the murders. Ridgway passed a polygraph test in 1984 and police collected a DNA sample from him in 1987. This sample was stored until 2001 when the swab was used for DNA profiling. The sample linked Ridgway to

his fourth, fifth, sixth and twenty-fifth murder and served as the evidentiary backing for his arrest warrant. Ridgway was arrested on November 30, 2001.

Two years later, on November 5, 2003, Ridgway plead guilty to 48 counts of aggravated first-degree murder. In exchange for pleading guilty Ridgway managed to avoid the death penalty. He was sentenced to 48 life sentences without the possibility of parole and is currently serving his sentence at Washington State Penitentiary in Walla Walla, Washington (*State of Washington v. Gary Leon Ridgway, 2003)*.

Results

Of the forty-eight murders to which he plead guilty, Ridgway has been forensically linked to forty-five of them by law enforcement. Between those forty-five murders, Ridgway had an average cooling-off period of 63.57 days (*SD* = 215.53). His longest elapsed time between murders was 1122 days or just over three years. It took him three years to commit his final verifiable murder. The shortest cooling-off period taken by Ridgway was 0 days.

Table 10: Ridgway's murders between Jul. 8, 1982 and Mar. 5, 1990. The average elapsed time between murders was 63.57 days (SD = 215.53).

Cumulative Victims	Location	Date of Murder	Days Elapsed
1	Des Moines, WA	7/8/1982	
2	Des Moines, WA	7/17/1982	9
3	Kent, WA	7/25/1982	8
4	Kent, WA	8/1/1982	7
5	Kent, WA	8/11/1982	10
6	Kent, WA	8/12/1982	1
7	Auburn, WA	8/29/1982	17
8	Des Moines, WA	9/15/1982	17
9	Fed. Way, WA	9/20/1982	5
10	Seattle, WA	9/26/1982	6
11	Portland, OR	10/8/1982	12
12	Renton, WA	10/9/1982	1
13	Portland, OR	10/20/1982	11
14	Renton, WA	12/3/1982	44

15	Seattle, WA	12/24/1982	21
16	Pierce Cou., WA	12/24/1982	0
17	Auburn, WA	3/3/1983	69
18	Auburn, WA	3/8/1983	5
19	Auburn, WA	4/10/1983	33
20	Des Moines, WA	4/14/1983	4
21	Auburn, WA	4/17/1983	3
22	Fed. Way, WA	4/17/1983	0
23	Auburn, WA	4/30/1983	13
24	Maple Val., WA	5/3/1983	3
25	Enumclaw, WA	5/22/1983	19
26	Renton, WA	5/23/1983	1
27	Maple Val., WA	5/31/1983	8
28	Auburn, WA	5/31/1983	0
29	Des Moines, WA	6/8/1983	8
30	Des Moines, WA	7/18/1983	40
31	North Bend, WA	7/25/1983	7
32	North Bend, WA	8/18/1983	24
33	Enumclaw, WA	9/5/1983	18
34	Des Moines, WA	9/12/1983	7
35	North Bend, WA	9/28/1983	16
36	Enumclaw, WA	10/11/1983	13
37	Enumclaw, WA	10/26/1983	15
38	North Bend, WA	10/30/1983	4
39	North Bend, WA	11/1/1983	2
40	North Bend, WA	12/23/1983	52
41	Seattle, WA	2/6/1984	45
42	Auburn, WA	3/21/1984	44
43	Seattle, WA	10/17/1986	940
44	Seattle, WA	2/7/1987	113
45	Seattle, WA	3/5/1990	1122

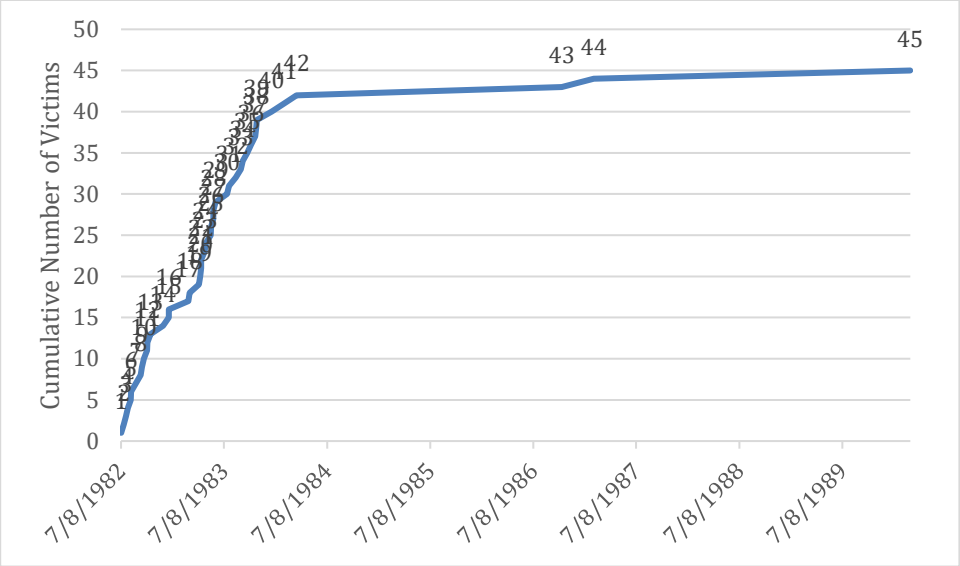

Figure 15: Distribution of Ridgway's murders over time. The longest elapsed time was 1122 days, while the shortest was 0 days.

A Grubb's test identifies five outliers across Ridgway's career. The first outlier is the 69-day cooling-off period between his sixteenth murder on December 24, 1982 and seventeenth murder on March 3, 1983. The next is the 52-day cooling-off period between his thirty-nineth murder on November 1, 1983 and fortieth murder on December 23, 1983. The final three outliers represent the last three cooling-off periods of his career. The elapsed time was 940, 113, and 1122 days, respectively. Removing these outliers from the set significantly decreases the average elapsed time between murders from 63.37 days to 12.85 days (SD 12.75).

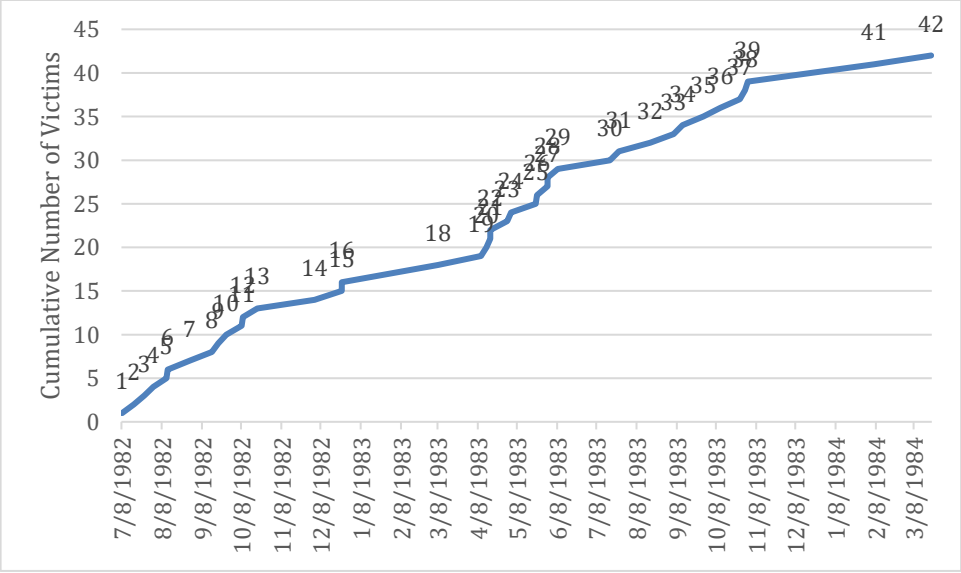

Figure 16: Distribution of Ridgway's murders without five outliers. Average time elapsed between crimes was 12.85 days (SD = 12.75). The longest interval was 45 days, while the shortest was 0 days.

Ridgway had the most cumulative murders during his career as well as the shortest average duration for cooling-off periods across the case studies.

Discussion

To date, the trends previously observed throughout different serial killers' cooling-off periods are that longer intervals decrease the probability of another murder, inconsistent intervals are most likely due to external circumstances outside of the killer's control, and most serial killers' cooling-off periods are on average longer than fourteen days (Edelstein, 2020). The conducted case studies either confirmed or contradicted these claims, with the results summarized in Table 11. Relative Standard Deviations (RSD) were calculated to compare the size of each case's standard deviations to its mean. Larger values denote more variability within the data.

Table 11: Summary of the average length of cooling-off periods in the ten case studies.
* denotes statistics computed once outliers were removed.

Murderer	Victims	Mean (days)	SD (days)	RSD	Mean* (days)	SD* (days)	RSD*
J. DeAngelo	13	555.42	607.5	109.37	357.7	338.2	94.55
J. Dahmer	17	299.44	833.06	278.21	47.38	46.18	97.47
J. Gacy	27	97.46	250.96	257.50	40.79	40.04	98.16
T. Bundy	20	77.32	208.15	269.21	32	22.8	71.25
R. Ramírez	13	41.6	79.44	190.96	17.11	18.79	109.82
E. Kemper	10	631.8	1217.2	192.66	87.75	46.5	52.99
D. Rader	10	1034.3	984.2	95.16	1034.3	984.2	95.16
D. Berkowitz	6	91.75	69.9	76.19	91.75	69.9	76.19
R. Woodfield	7	32.25	21.17	65.64	32.25	21.17	65.64
G. Ridgway	45	63.57	215.53	339.04	12.85	12.75	99.22

The first apparent contradiction between the case studies and the accepted criteria is that longer cooling-off periods do not necessarily deplete the probability of a subsequent murder. Of the ten cases, eight murderers' longest interval between crimes occurred after their first murder or in the middle of their careers. A possible explanation

for this contradiction is behavioral escalation (Edelstein, 2020; Holmes, 1998). It is thought that a killer's first murder is often the most satisfying in terms of mitigating urges and fantasies; however, the killer becomes increasing dissatisfied once subsequent murders prove to be unfulfilling. This leads to decreased cooling-off periods and in some cases a switch in M.O. to more cruel tactics (Edelstein, 2020).

Only two murderers' longest cooling-off periods occurred after their second to last murder, aligning them with the accepted trends. Joseph DeAngelo waited 1742 days before committing his final murder, and Gary Ridgway waited 1122 days. Interestingly, these two men were the only two of the case studies to seemingly stop murdering under their own terms as opposed to the others who were apprehended shortly after their last crimes. It took law enforcement nearly eleven years to arrest Ridgway, and a staggering thirty-two years to arrest DeAngelo. According to the second accepted trend regarding cooling-off periods, these two instances of inconsistent intervals likely point to there being external circumstances that may have hindered the killer's ability to murder. For DeAngelo and Ridgway it is unclear as to what these circumstances were; however, due to oddity of how abruptly they ended their criminal careers it would be worth looking into in subsequent research. Both men have confessed to more crimes then they were charged with, so it is likely that some murders happened between their last confirmed killings and arrest dates.

Seven of the ten cases contained outliers, and in many cases, circumstances could be determined that impacted the killer's ability to find their next victim. As with Kemper and Bundy, previous incarcerations presumably inhibited their ability to continue their careers on their natural timeline. Understanding the killer's life

circumstances around the time of the murders, especially focusing on where they should be within their cooling-off period, provides more context as to how their criminal career was able to unfold. When outliers were present, it proved important to look into the circumstances surrounding the murder in order to yield more accurate averages for each killer's cooling-off period. In some cases, the murderer's cooling-off period nearly halved once the outliers were removed from the data set.

The results of this research were most strongly aligned with the third observed trend that most serial killers exhibit an average cooling-off period of at least 14 days, and in most cases exceeding 30 days. The only case that contradicted this trend is an interesting outlier, considering the cumulative number of victims was more than twice that of the second most successful murderer. Gary Ridgway murdered 45 people over the course of eight years, and exhibited an average cooling-off period of 12.85 days once outliers were removed. With a standard deviation of just 12.75 days, Ridgway arguably exhibited the most consistent pattern of the duration of cooling-off periods across the cases. However, once RSDs are considered it appears that Kemper's cooling-off periods were more consistent.

The standard deviations across the case studies varied widely as seen in Figure 20.

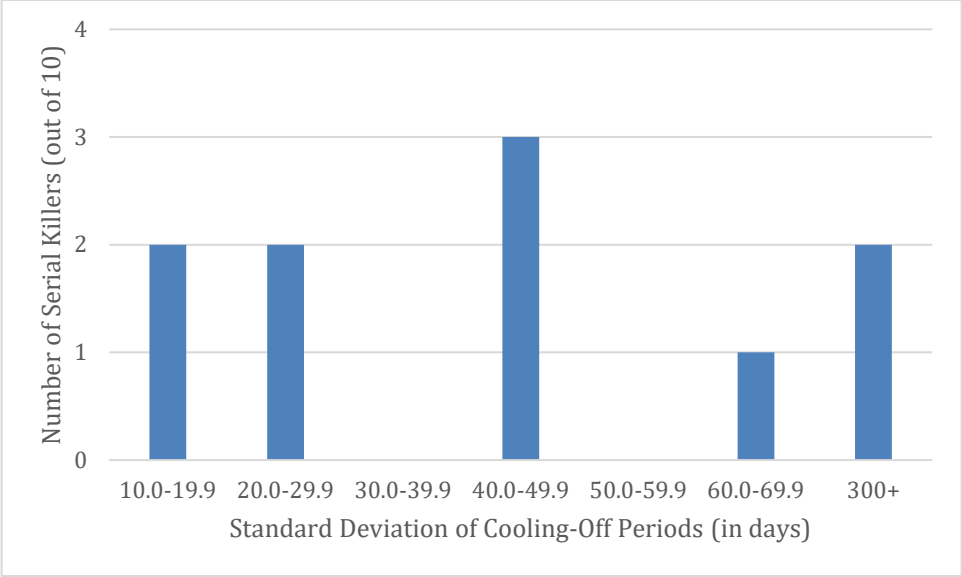

Figure 17: Distribution of SD of cooling-off periods.

Gary Ridgway and Richard Ramírez had the smallest standard deviations at 12.75 and 18.79 days, respectively. Furthermore, they exhibited the two shortest average cooling-off periods. Ramírez averaged 17.11 days while Ridgway averaged only 12.85 days. Lower standard deviations indicate that there is less variability in the length of these killers' cooling-off periods, implying that these two exhibited the most consistency in terms of the interval of time between crimes. It is important to note, however, that cooling-off periods cannot be negative in length so the size of the standard deviation may be misleading. Calculating the relative standard deviation (RSD), which indicates how big the standard deviation is with respect to the mean, shows that Ridgway and Ramírez have the two highest RSD values, indicating that some of the seeming consistency in the duration of their cooling-off periods may be due to the fact that their average cooling-off periods were the two shortest.

In addition to testing the previously observed trends of serial killers, the purpose of this study was to propose an underlying biological basis for why serial killers have

cooling-off periods. Identifying both the function and cause of cooling-off periods would allow for a more complete understanding of why serial killers act in the manner that they do. Without access to real time scans of the neural activity while killers are active, any proposed mechanism behind the cooling-off periods is purely speculative. This thesis is no exception.

A potential alternative to use in lieu of brain scans are rigorously studied biological phenomena that mirror that same sort rising and falling actions observed with serial killers. One such mechanism that is aligned particularly well with the fluctuations of activity in serial killers is the propagation of action potentials in neurons. Simkin and Roychowdhury (2014) hypothesized that large, simultaneous firing of neurons cause a serial killer to commit murder. Furthermore, they proposed that in a similar manner to neurons, serial killers have to undergo a recovery period before they are able to commit subsequent murders. Comparing the manner in which a neuron polarizes itself to its resting potential to the cooling-off period of serial killers could explain the biological cause behind cooling-off periods. It may imply a similarity in function such that the killers require a resting state in order to return to a state where they are able to be stimulated enough to murder.

Once a neuron propagates an action potential it enters its refractory period. During this time is it either impossible or highly improbable that another stimulus will cause the membrane potential to exceed its threshold potential. There is some variability in the duration of refractory periods; however, generally it takes between one to three milliseconds. It is important to note that the timescale of neural refractory periods are considerably smaller than cooling-off periods, however, there are some indications that

a similarities can still be made between the two. Considering the infrequency of murderers committing two discrete killings within a short interval, it is likely that only incredibly strong stimuli can prompt the killer to perpetrate again while they are in their cooling-off period. Of the 168 murders across the ten case studies, a cooling-off period of less than a day only occurred 4.2% of the time. Furthermore, serial killers exhibited cooling-off periods lasting only a day 3.0% of the time. Considering the smallness of the sample size no definitive claims can be made; however, the implications of these findings warrant additional research. If shortened cooling-off periods are found to be significantly inconsistent across serial killers' then there is merit to believing that a killer is highly unlikely to kill while in their cooling-off period. In short, a cooling-off period may have similar functionality to the refractory period of neurons.

What separates serial killers from mass murders or spree killers is the temporal separation of their crimes. Serial killers commit their crimes in discrete events and then return to normal life. Cooling-off periods are universally present across serial killers, so understanding their function and importance is imperative to furthering the understanding of serial killers.

Methodological Limitations

Due to the nature of this research, there are many limitations that must be considered when presenting the findings. The first apparent constraint of this study is the sample size. Ideally this same research would be replicated across a larger sample to produce more valid and reliable findings. The next obvious limitation is the potential for missed offenses perpetrated by the serial killers. This study only included offenses that were dually confirmed by law enforcement and the murderers, inherently leaving out

murders that may occurred but lack confirmation from both sides. Such murders would have some effect on the findings of this study considering its focus on the duration of time between crimes. In cases where missed offenses are present, the inclusion of such data points would likely change the mean duration of a killer's cooling-off period.

Another methodological limitation of the study is the active exclusion of offenses that were not murder. Serial killer's M.O.s often included auxiliary crimes that may alter the perceived satisfaction from the offense, subsequently altering the duration of or need for a cooling-off period. Furthermore, instances of multi-person homicides were weighted the same as single victim killings. Considering the discrepancy in necessary planning and energy expending during the crime, multi-victim offenses likely require longer cooling-off periods.

Environmental circumstances likely play a role in the duration of killer's cooling-off periods. As noted in the case studies, events like incarcerations can skew the calculated mean cooling-off periods as they impede upon the killer's ability to commit another murder. This makes it difficult to determine whether cooling-off periods are preferentially determined by a biology or environmental circumstances.

Conclusion

The results of this study showed that the three observed trends from previous research on the cooling-off periods of serial killers are not universal. Furthermore, due to the uniqueness and variability of cooling-off periods, it is hard to establish general patterns regarding the duration of cooling-off periods. In terms of relating cooling-off periods to neural refractory periods, the rarity of short cooling-off periods indicates that within the data there may exist some connection besides a purely analogical approach; however, without subsequent research with robust empirical data the relationship remains speculative.

The implications of understanding the function and biological processes behind cooling-off periods are enormous. If the behavior is proven to be linked to some neurological process, then researchers will have a greater understanding of what separates serial killers from other violent offenders on a biological level. This will close the gap to understanding what causes someone to become a serial killer. Furthermore, establishing trends in cooling-off periods could help law enforcement create more accurate profiles when they are pursuing serial murders, including forecasting when the killers are most likely to commit their next murder.

A furthered understanding of cooling-off periods is imperative to answering the remaining questions regarding behaviors of serial killers; however, existing research is limited by the available technology and understanding of the biological differences of serial killers. As brain scans become more accurate and their interpretations more precise, there is potential for behaviors like cooling-off periods to be definitively linked to neural activity. As it stands, research into cooling-off periods tends to be neglected in

comparison to other behaviors, however, in recent years there has been a call for further investigation into this phenomenon. It is imperative that future research into serial killers continues to build the collective understanding of cooling-off periods as this behavior is integral to differentiating serial murders from other violent behaviors. Any behavior that elucidates the differences of serial murders to the extent that cooling-off periods do merits deeper consideration and further research, as it may prove to be essential to our understanding of how serial killers come to be.

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