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A statistical study of the time intervals between serial homicides

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ABSTRACT

The “cooling-off period”, or inter-murder interval, has been used to differentiate between serial, spree, and mass murderers for decades. The present research examines the utility of this concept by studying the distribution of 2837 inter-murder intervals for 1012 American serial homicide offenders using data from the Consolidated Serial Homicide Offender Database. The distribution is smooth, following a power law in the region of 10–10,000 days. The power law is cut off in the region when inter-murder intervals become comparable with the length of human life. Otherwise there is no characteristic scale in the distribution. The decades long inter-murder intervals are not anomalies, but rare events described by the power-law distribution and therefore should not be looked upon with suspicion. This study found there to be no characteristic spree or serial homicide offender interval, only a monotonous smooth distribution lacking any features. This suggests that there is only a quantitative difference between serial and spree killers which represent merely different aspects of the same phenomenon.

The repetitive, yet occasional, nature of serial homicide was first acknowledged in the 1970s by those that referred to these crimes as “sequence killings”. Much has been surmised about the components of the serial murder definition since those early days (Yaksic, 2019a) but there is still no universal agreement as to what constitutes serial murder (Petee & Jarvis, 2000). The existing definition is fraught with pitfalls (Adjorlolo & Chan, 2014; Egger, 1984; McNamara & Morton, 2004; Yaksic, 2018) as various subtypes of offenders are included in research cohorts, such as organized crime members (Dietz, 1986), murderous health care workers, parents who kill their children, professional assassins and persons who kill spouses or lovers (Keeney and Heide, 1994), terrorists, outlaws, pirates, gang members, genocidal perpetrators (Lester and White (2012), witness elimination killers, robbery homicides (Osborne & Salfati, 2015), drug dealers, and doctors who prescribe an abundance of pain killers that lead to many deaths. Yaksic (2019b) argues that spree killers and serial homicide offenders (SHOs) are no longer dissimilar enough to warrant separate classification as they have converged into one cohort. DeLisi and Scherer (2006) recommend including the aforementioned categories in the serial murder definition to allow for a fuller array of SHOs and to avoid the semantic issues that hamper potential understanding of this topic.

The current serial murder definition endorsed by the Federal Bureau of Investigation (National Center for the Analysis of Violent Crime, 2008) identifies a SHO as someone that commits two or more murders, in separate instances, over a span of time. Although the quest to attain balance between broad and narrow definitions is still ongoing (Farrell, Keppel, & Titterington, 2011), consensus often relies upon the “cooling-off period”, an all-encompassing term used to denote a supposed “return to normalcy” during inter-murder intervals. The “cooling-off period” is theoretically used to separate SHOs from other murderers who kill in response to situational factors, convenience, survival and conflict resolution and not as a significant feature of their lifestyle (Yaksic, 2018). Of the few endeavors to look critically at the “cooling-off period”, Osborne and Salfati (2015) argue that these intervals are crucial in defining serial homicide. Others (Douglas, Burgess, Burgess, & Ressler, 2013; Shanafelt & Pino, 2014; Yaksic, 2015; 2019b) interpret this descriptor as a timeworn concept held over from a time when little was understood about SHOs given that serial murderers often think about killing during periods of down time and do not fully disengage from the process of killing. The debate surrounding this aspect of the serial murder definition is ongoing and the concept warrants further study.

Literature Review

Although there is a multitude of scholarly literature on SHOs, there is not much that quantitatively studies the time intervals between murders. Researchers state that these interruptions in an SHO's killing activity “range from days to weeks or months” (Geberth, 2006: p. 476) and argue that a SHO's series must be comprised of such time breaks or compute the mean and median of these intervals (Osborne & Salfati, 2015). While experts disagree on a standard “cooling-off” length, these

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lapses between homicides typically span some portion of the time between the conclusion of the SHO's previous homicide to the beginning of the subsequent murder. These interruptions have traditionally contained an emotional component, thought to be psychologically beneficial to the offender. Although it is assumed that they return to "their usual way of life" in the interim (Douglas et al., 2013), researchers have little understanding of the behaviors that SHOs engage in during these intervals between homicides because it is impossible to discern the degree to which SHOs remain entrenched in their "killing lifestyle" (Yaksic, 2015). They may dedicate effort and time to planning future crimes or ruminating about past ones, and hiding other activities through surreptitious behaviors or impression management. Lange (1999), for instance, introduced the idea that circumstances in the life of the offender influence the length of these intervals but specifically how this occurs remains unknown. SHOs also have the capacity to be distracted by other opportunities and those with longer timespans may be committing other crimes (Osborne & Salfati, 2015). Given the short period between the intervals of some SHOs, it is possible that they may never truly "cool off".

These findings lend support to the viewpoints of Shanafelt and Pino (2014) and Yaksic (2019a) that there is little importance to the serial/spree distinction when it comes to understanding these crimes. Other researchers are insistent that there is meaning in inter-murder intervals. While Schlesinger, Ramirez, Tusa, Jarvis, and Erdberg (2017) identified a sizeable subgroup of SHOs that committed homicides in rapid-sequence fashion, the majority of SHOs killed with longer than a 14-day period between homicides. Edelstein (2020) found that periods between SHO's murders are longer in the beginning of a series and get subsequently shorter, (meaning that the "cooling-off period" has a latent function in that it initially facilitates future homicides), but the unexplored concept of escalation[1] was relied on to explain the decay in this function. Another plausible explanation for what is occurring during inter-murder intervals, however, is that SHOs are learning how best to select their victims, what methods work for them situationally, and overcoming fear (Yaksic et al., 2019b). Learning is an active process, one that grows easier with trials and additional effort, the benefits of which would be unseen to those assuming that SHOs "return to normal" during the breaks between homicides. Serial homicide series are also subject to the ebbs and flows of variability experienced during any dynamic process, such as boredom, stasis, and the need to fulfill other obligations.

1. Purpose

The present research aims to examine the meaningfulness of the "cooling-off period" and the further necessity of relying on these intervals to differentiate between categories of murderers by building on Simkin and Roychowdhury (2014). In that study, the statistics of inter-murder intervals for three SHOs was investigated and a probability distribution of those interludes was found. Most of the temporal breaks were of the order of few days, while some intervals were months and very few were years long.[2] Those intervals also followed a power-law distribution (Simkin & Roychowdhury, 2011). We hypothesize that the inter-murder interval probability distribution follows a power law. A stochastic neural net model was proposed to explain the observed power law distribution of inter-murder intervals. The present study aims to replicate the Simkin and Roychowdhury (2014) analysis on a larger cohort of SHOs.

2. Methods

2.1. Analytical strategy

While some compute basic statistics such as the mean and median of these intervals (Osborne & Salfati, 2015), we investigate the whole probability distribution function. The present study utilizes the Consolidated Serial Homicide Offender Database (CSHOD) (Aamodt et al., 2020) and repeats the previous statistical analysis using this much larger dataset of 2837 inter-murder intervals for 1012 SHOs between the years 1901 and 2014. This large-scale effort supports the conclusions and modeling of Simkin and Roychowdhury (2014). The CSHOD, a trusted source in the field of SHO research and the result of the combined efforts of several law enforcement officials, mental health practitioners, pracademics, professors, and students, was mined for all records that met our inclusion criteria, the development of which required extensive research. We adopted the method provided by Osborne and Salfati (2015)[3] and included more cases by using a simpler, "more inclusive" interpretation of the current FBI definition, the "unlawful killing of two or more victims by the same offender(s), in separate events" (National Center for the Analysis of Violent Crime (NCAVC), 2008).

The database did not contain the exact date for every murder. Often only the month or even only the year was available. We selected those solitary killers for which we had the exact dates for each of their murders. Even if a killer committed a single murder on an uncertain date and many murders on certain dates he or she was excluded at this stage. While Osborne and Salfati (2015) state that archival data may serve as an appropriate data source for studying serial homicide time intervals, erroneous records are commonplace since data on serial homicide offenses is amassed primarily from secondary sources. Several records contained misspellings that led to the duplication of records or erroneous dates that would have led to their deletion. Misspellings and erroneous dates were corrected before analysis began. If a killer committed a single murder with an accomplice and many murders on his or her own he or she was excluded. We did not set a minimum or maximum timeframe within which the offender must have accomplished their goals since, as Osborne and Salfati (2015) point out, time intervals may fluctuate or exhibit a degree of stability. Although many authors do utilize the "cooling-off period" as part of their exclusion criteria, offenders were not required to have engaged in this temporal element to be included in the study.

3. Procedure

Time sequence data was collected and organized based on the date of offense rather than the date the victim's remains were located since Osborne and Salfati (2015) argue that offense start date will result in more accurate calculations of serial homicide time intervals rather than using the date the body was found. The database does not contain exact times of murders, only the date. For this reason, we could not study the inter-murder intervals of less than a day. For a date to be specific, it must have been logged as the standard mm/dd/yyyy in the database. Any records listing only yyyy or mm/yyyy data were removed. If a SHO had at least one record with an uncertain date all of his/her records were removed from the sample. Some of the SHOs committed all their murders on the same date (though in separate events). Such SHOs were

[1] Escalation refers to a theoretical state where the offender acclimates to the level of gratification received from a previous homicide and requires ever increasing levels of stimulation, thus homicides need to occur at an increasing frequency to sustain themselves.

[2] Very few intervals were years long partly due to a recent decline in prolific SHOs (Yaksic et al., 2019a) and a rise in potential SHOs (Yaksic, Harrison, Konikoff, Allely, De Silva, Smith-Inglis, Matykiewicz, Giannangelo, Daniels & Sarteschi, 2019).

[3] Their method echoes Brantley and Kosky's (2005) belief that the Federal Bureau of Investigation (FBI) favors broadness in that they are careful to omit any reference to motivation, behavior or psychological characteristics in their definition.

excluded at this stage for they do not give us known inter-murder intervals. However, if the SHO committed only some of the murders on a single date(s) he or she was included in the analysis. We just merged all murders committed on a single date(s) into single event(s) labeled by the date(s).

As this was a study of time interval data alone, Osborne and Salfati's (2015) methodology, where motivations of offenses were not evaluated, was followed. Pinpointing an offender's exact motive can be impossible given the multitude of influences they are known to operate under (Beasley, 2004). Pino (2005) reminds researchers to consider that the offender's social situation coupled with surrounding economic and political pressures, time and geography and community characteristics may make them more likely to act in a certain manner. The victim's actions could influence the offender's behavior (Bateman & Salfati, 2007) or the offender's perception that the victim lied, cheated, insulted, or hurried them may be at play in their decision to act (Quinet, 2011). There is little empirical evidence about SHO's motivations and they must be inferred from observable behavior (Kraemer, Lord, & Heilbrun, 2004). Given this research, it seems unreasonable to include motivation as part of this study's inclusion criteria.

4. Sample

At the end, we were left with 1012 SHOs who committed murders on at least two different dates. There was a total of 2837 inter-murder intervals for those SHOs. To account for the point of view that SHOs claiming “merely” two lives differ fundamentally from other subtypes (Yaksic, 2018), we purged the SHOs with only two killing dates from our sample and studied 587 SHOs with at least three killing dates and their 2412 inter-murder intervals. Finally, we selected 34 prolific SHOs, with at least 10 killing dates, and analyzed their 607 inter-murder intervals. Each of these operations was completed using Microsoft Excel and Access.

5. Results

We will start with the distribution of SHOs regarding the number of killing dates. To represent the data, the so-called logarithmic binning was used which is customary in studying data that follow a power-law distribution (Simkin & Roychowdhury, 2011). To the first bin (Table 1) go the SHOs with two kill dates. To the second, those with more than two but less than or equal to four. To the third, those with more than four but less than or equal to eight. And so on. The upper boundary of each subsequent bin increases twice. The size of each subsequent bin also increases twice. However, on the logarithmic scale (Fig. 1) the bin boundaries are equally spaced. Such binning is necessary because if conventional binning were used the vast majority of bins on the upper end of the distribution will be empty. The frequency distribution was computed by dividing the number of SHOs in the bin by the size of the bin and dividing the result by the total number of SHOs. The observed frequency distribution was used as an estimate of the probability distribution.

As one can see from Fig. 1 we can well approximate the probability distribution by a power law (here n is the number of killing dates):

$$p(n) = C \times n^{-\gamma}.$$

Table 1
Distribution of 1012 killers by the number of kill dates

Number of kill dates	Number of killers	Probability
2	425	0.41996
3–4	371	0.1833
5–8	171	0.042243
9–16	31	0.003829
17–32	10	0.000618
33–64	4	0.000124

$C \approx 4$ and $\gamma \approx 2.5$.

The number of killing dates coincides with the total number of killings in the case when the SHO always killed only one person on a single day. Since it is almost always the case the distribution of the SHOs regarding the victim count will be almost identical to the above. For these 1012 SHOs, there were 2837 inter-murder intervals. The longest interval is 16,963 days which is over 46 years. Table 2 shows the distribution of their length. It uses the same logarithmic binning as Table 1. Only the upper boundary is shown.

We plotted the data of Table 2 in Fig. 2. There is a good power-law fit for the range of inter-murder intervals between 10 and 10,000 days, given by Eq.(1) (this time n is the length of intervals in days) with $C \approx 0.4$ and $\gamma \approx 1.16$. There is a drop off at high intervals, where they become comparable with the length of human life (10,000 days is 27 years). This is apparently the only characteristic scale in the problem.

There is a controversy of what constitutes a SHO with regard to the minimum killing events with some researchers demanding at least three events (Fox & Levin, 2014). The SHOs with at least 3 killing dates were selected to comply with this practice. There were 587 of those with the total of 2412 inter-murder intervals. The longest interval is 11,804 days or over 32 years. Table 3 shows their distribution. The data of Table 3 were plotted in Fig. 3. Again, there is a good power-law fit for the range between 10 and 10,000 days. This time with slightly different parameters $C \approx 0.6$ and $\gamma \approx 1.23$.

We also selected the prolific SHOs, those with at least 10 kill dates. There were 34 of those and 607 inter-murder intervals. The longest is 5673 days or over 15.5 years. The distribution is in Table 4. The data of Table 4 were plotted in Fig. 4. Once more there is a good power-law fit for the range between 10 and 10,000 days, again with different parameters $C \approx 1.7$ and $\gamma \approx 1.46$.

The 1.46 power law exponent obtained for the SHOs with at least 10 killing dates is only slightly below the theoretical value of 1.5 produced by the stochastic neural net model of a SHO (Simkin & Roychowdhury, 2014). We obtained the 1.46 exponent by least-square fitting the binned data starting with the 16-day bin. If instead we fit the data starting with the 32-day bin we get $\gamma \approx 1.54$ which is slightly above the theoretical value. A maximum likelihood estimate for the intervals of 9 or more days (since the 16-day bin contains all intervals between 9 and 16 this is a match to the least-square fit starting with the 16-day bin) gives $\gamma \approx 1.48$. A maximum likelihood estimate for the intervals of 17 or more days (this is a match to the least-square fit starting with the 32-day bin) gives $\gamma \approx 1.56$. Both maximum likelihood estimates are very close to the corresponding least-square estimates and to the theoretical value.

The power law exponent does match the theoretical one for the prolific SHOs with at least 10 killing dates. However, when we decrease the threshold to at least 2 killing dates the power law exponent, γ, drops to 1.16. To understand what is going on, the distribution of inter-murder intervals for 425 SHOs with exactly two killing dates is shown in Fig. 5.

Using manual inspection, we arranged the SHOs into two groups (see Table 5). Distribution A which includes 239 SHOs is approximately a power law with exponent 1.5. Distribution B which includes 186 SHOs is approximately exponential, with $\frac{1}{5000}$ murder probability on any given day. Distributions A and B are plotted in Fig. 6. This partitioning can potentially be done in an automated manner using a mixture model and Maximum Likelihood estimation techniques: Each SHO's intervals are drawn either from a power law distribution with an unknown exponent or an exponential distribution with an unknown mean. Both the exponent and the mean can be estimated, as well as the most likely assignment of each SHO's intervals to one of the distributions, by maximizing the likelihood of the data.

To test whether or not an escalation effect exists, we compared the first and the last inter-murder intervals for 587 SHOs who had at least two intervals and committed three or more homicides. In 204 cases, the

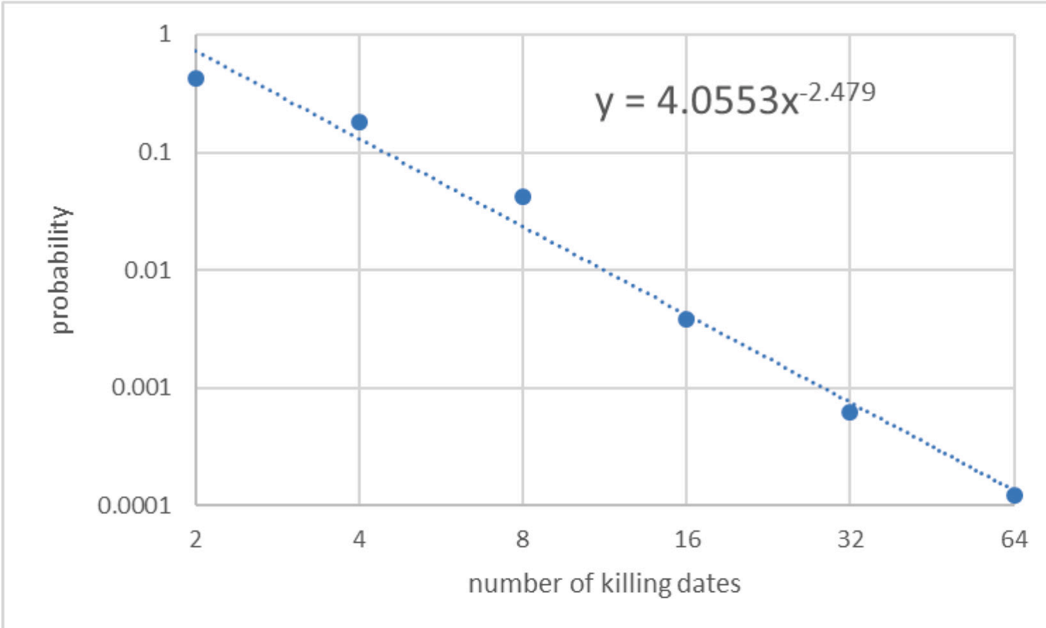

Fig. 1. The distribution of 1012 killers by the number of killing dates.

Table 2
Distribution of length of 2837 inter-murder intervals for 1012 serial killers

Interval length (in days)	Number of intervals	Probability
1	111	0.039126
2	67	0.023616
4	127	0.022383
8	170	0.014981
16	275	0.012117
32	321	0.007072
64	290	0.003194
128	284	0.001564
256	286	0.000788
512	264	0.000364
1024	196	0.000135
2048	192	6.61E-05
4096	140	2.41E-05
8192	94	8.09E-06
16,384	19	8.18E-07
32,768	1	2.15E-08

last interval was longer than the first. In 14 cases, they were equal. In 369 cases, the last interval was shorter. In 63% of cases, the last interval was longer. Since the standard error is only 2%, the escalation effect is confirmed to exist. We observed that the mean length of the first interval (840 days) is only 1.8 times longer than that of the last interval (469 days). Compared to the range of the intervals (which is from 1 to over 10,000 days), the acceleration effect is only a small perturbation. Because one may argue that the sample is dominated by the consecutive intervals for the SHOs with just three homicides, we repeated the analysis for 34 SHOs with at least 10 killing dates. For 13 of those, the last interval was longer than the first. For one SHO they were equal. For 20, the last interval was longer than the first. In summary, the last interval is longer than the first in 59% of the cases. The standard error is 8% so this result is consistent with the previous sample.

The results of Schlesinger et al.'s (2017) investigation of inter-murder intervals can be explained by the ordinary law of chances rather than by intrinsic differences between different categories of killers. Out of 2837 inter-murder intervals in our database, 76.6% are of 14 days or more. This means that if we select m intervals at random the probability that all of them will be 14 days or more is 0.766^m and the probability that all of them will be less than 14 days is 0.234^m. Using the distribution of the 1012 killers in our database by the numbers of murders we can compute the expected percentage of killers with all intervals of 14 days or more: $\boldsymbol{x = \frac{1}{1012} \sum N(n) 0.766^{n-1}}$. Here $N(n)$ is the number of killers with n murders. The computation gives $x = 56.9\%$ which is remarkably close to the 56.8% figure of Schlesinger et al. (2017). For the expected percentage of SHOs with all intervals less than 14 days a similar calculation gives 15.7%. This is a bit larger than the 13.6% figure of Schlesinger et al. (2017), but only six criminals fit that categorization. This difference is well within the sampling error.

6. Discussion

The present study sought to examine the utility of the concept of the "cooling-off period", also known as inter-murder intervals between serial homicides. Few studies have dedicated effort to discerning the meaning behind these temporal breaks between homicides. The present research compliments those few previous studies by expanding on the theoretical basis for the existence of such intervals. We found that the probability distribution of time intervals between murders is a smooth, monotonously decreasing function of interval length. The major deviation of the data from the theoretical model is the flattening of the distribution at small inter-murder intervals. Simkin and Roychowdhury (2014) argued that the model predicts how often SHOs will want to kill. However, SHOs may not have an opportunity to commit a homicide without undue risk of being apprehended. The most accomplished SHOs are very cautious and do not act on every presented opportunity. Krivich and Ol'gin (1993) describe how the SHO in Simkin and Roychowdhury (2014) would often go for a hunt and return unsuccessful. This makes short inter-murder intervals less frequent than what the theory would predict.

Some researchers might classify extremely large intervals as anomalies but they are instead rare events governed by the same probability distribution which also describes shorter inter-murder intervals. Resultantly, one should not look upon the long inter-murder intervals with suspicion. This cautionary guidance is particularly pertinent to the case of SHO Lonnie Franklin Jr., given the moniker of "Grim Sleeper" due to a gap of 13 years (1989–2002) over which no recorded murder could be attributed to him. This gap was viewed as more of a forensic failure rather than a natural outcome with the popular sentiment being that he must have murdered several victims

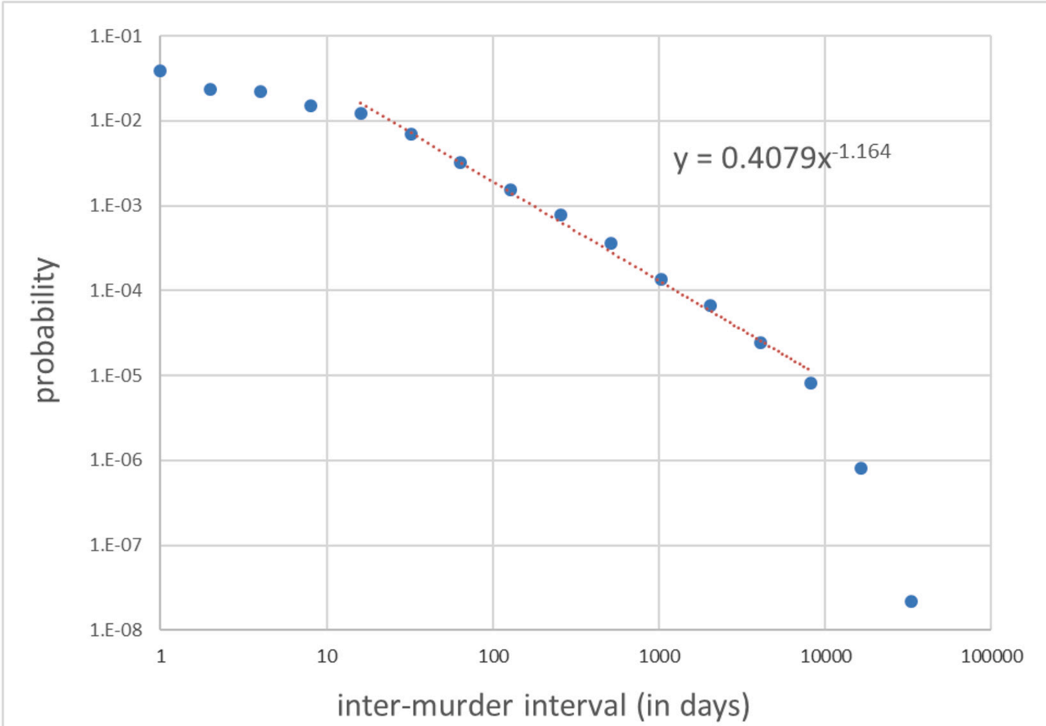

Fig. 2. Distribution of length of 2837 inter-murder intervals for 1012 serial killers. The circles represent serial killers; the line is a power-law fit.

Table 3
Distribution of length of 2412 inter-murder intervals for 587 serial killers who had at least 3 killing dates

Interval length	Number of intervals	Probability
1	92	0.038143
2	59	0.024461
4	114	0.023632
8	148	0.01534
16	245	0.012697
32	292	0.007566
64	260	0.003369
128	256	0.001658
256	252	0.000816
512	233	0.000377
1024	172	0.000139
2048	143	5.79E-05
4096	88	1.78E-05
8192	51	5.16E-06
16,384	7	3.54E-07

during this so-called dormant period (Zupello, 2016). Our study shows that such a long gap is statistically consistent and (barring further evidence) is not anomalous. The Appendix addresses the possibility that one or more murders were missed during Franklin's career and dormant period and the careers of SHOs like him.

A possible explanation for the discrepancy of a power-law fit in the region 10–10,000 days with an even smaller exponent~1 is that a large fraction of the SHOs with a small number of murders are not like the majority of the SHOs who plan a murder when their desire to kill crosses a threshold, as posited in (Simkin & Roychowdhury, 2014). For such SHOs the theory predicted that the desire to kill becomes irresistible with intervals that follow a power law distribution. The other SHOs may be driven by other reasons. As a result, the inter-murder interval distribution may also be different. The simplest model is the Poisson process where every day there is a fixed small probability to commit a murder. This leads to an exponential distribution of inter-murder intervals. We assume that the SHOs with exactly two kill dates are drawn from a mixture of SHOs with a power-law distribution of inter-murder intervals, and those with exponential inter-murder distributions.

Other researchers have reached unexplainable conclusions when exploring time intervals as they relate to serial homicide. To our knowledge, the only previous mathematical study of the time patterns of serial killers is that by Lange (1999). After analyzing the time series of eleven SHOs, Lange (1999) discovered that not only is serial murder not the result of some underlying chaotic process but that three basic patterns - Attracting, Repelling and Pulsing - could be seen in the cyclic behavior of SHOs. Lange (1999) used a polynomial map to express the (n + 1)th inter-murder interval through nth and (n-1)th intervals. Afterward he used regression to find the coefficients of the polynomial that will maximize the correlation coefficient between the actual time series of inter-murder intervals and the time series obtained using the polynomial map. Unfortunately, Lange (1999) could not discern a satisfactory reason for this but hypothesized that the (real or imagined) presence or absence of police surveillance, personality differences, marriage, the influence of a partner, or geographic factors could influence a SHO's pattern. There may be some validity to this theory as Osborne and Salfati (2015) found that socially involved offenders engage in serial murder less frequently due to social bonds or other commitments that make their life too busy, stating that the data imply that longer time intervals may be associated with SHOs who are actively involved in their communities. Longer intervals may also be the result of failed ruses or cons that require the SHO to approach multiple people over time.

The current research is an important step in addressing the confusion surrounding the “cooling-off period.” For instance, Edelstein (2020) recently stated that the preprint of the present research “found that the time intervals between murders were smooth with no profound peaks of shorter or longer intervals. This contradicted an earlier study that claimed that as killers escalate their lethal behavior, the interval between the murders gets shorter.” This statement mischaracterizes the

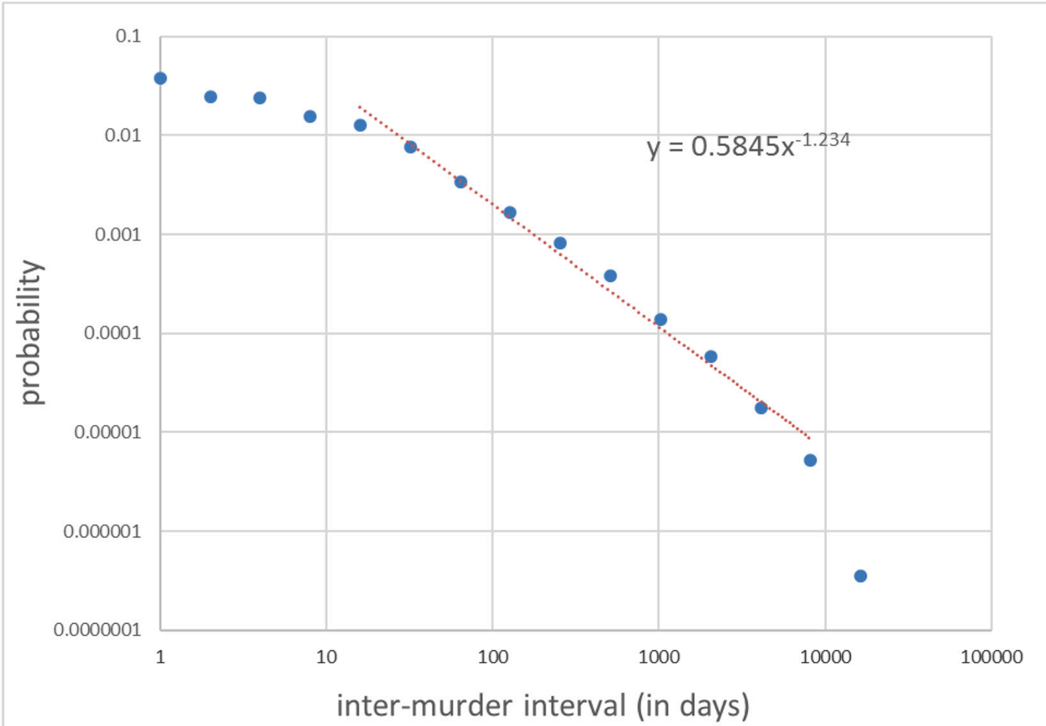

Fig. 3. Distribution of length of 2412 inter-murder intervals for 587 serial killers who had at least 3 killing dates. The circles represent serial killers; the line is a power-law fit.

Table 4
Distribution of length of 607 inter-murder intervals for 34 serial killers who had at least 10 killing dates

Interval length	Number of intervals	Probability
1	21	0.034596
2	14	0.023064
4	30	0.024712
8	53	0.021829
16	74	0.015239
32	97	0.009988
64	93	0.004788
128	72	0.001853
256	57	0.000734
512	38	0.000245
1024	29	9.33E-05
2048	14	2.25E-05
4096	10	8.04E-06
8192	5	2.01E-06

preprint in that we did not study the differences between the inter-murder intervals for each SHO based on their place in the sequence but rather studied the probability density function of all intervals for all SHOs lumped together. This function is smooth with no peaks.

Determining the most appropriate manner in which to wrangle with the concept of the spree killer raised some interesting issues. Although an in-depth study of such behaviors - and the differentiation between spree and SHOs – found that these cohorts are similar[4] (Yaksic, 2019b) some researchers continue to distinguish a spree killer as a separate category from a SHO (Safarik & Ramsland, 2020). Spree murder has historically been defined as the killing of three or more people within a 30-day period and serial murder as the killing of three or more people over a period of more than 30 days, with a significant "cooling-off period" between the killings (Holmes & Holmes, 2010). A problem with such a definition becomes evident when the murder pattern of any accomplished SHO is reviewed. Fig. 7 shows the cumulative number of murders as a function of time for Charles Cullen. There are clear spree-like periods when the cumulative number grows steeply and periods with large intervals between murders. For example, Cullen killed on 5/31/96, 6/9/96, and 6/24/96 which would make him a spree killer according to the Holmes and Holmes (2010) definition. From 7/10/96 until 6/22/01 five people were murdered with the minimum inter-murder interval of over 200 days. This would make him a SHO according to the Holmes and Holmes (2010) definition. Information on what activities the offender engaged in during the break in time sequence was not captured for this study as that is outside the scope of our stated purpose.

Schlesinger et al. (2017) investigated inter-murder intervals for 44 SHOs and found that six offenders (13.6%) had intervals less than 14 days. They classed these killers as "rapid-sequence homicide offenders" (RSHOs), formerly spree killers, but this data can be explained by an ordinary law of chances rather than by RSHOs being intrinsically different from the rest of the SHOs. To illustrate this point let us consider a study where instead of 44 different killers we will take 44 different coins and toss each of them a few times. Some of the coins will produce all heads, some – all tails, and some – a mixture of heads and tails. One may be tempted to classify some of the coins as head-coins and tail-coins. This, however, would be wrong since one can obtain the same result with a single coin tossed 44 times.

For our purposes, labels given to SHOs by the news media or other public comments were scrutinized since the length of time between offenses of individuals thought to be SHOs did sometimes mirror that of individuals thought to be spree killers. The media often uses the terms SHO and spree killer interchangeably, as Skrapec (2001) illustrates with the case of Andrew Cunanan. More recently, this discrepancy was demonstrated in the instances of Gary Lee Sampson and Christopher Dorner where news outlets referred to each killer with both the spree and serial denomination. Recent research has demonstrated that SHOs

[4] In that spree and serial killers often kill their victims using a singular method, have limited mobility, kill a similar number of victims both known and unknown to them and are both supremely motivated by domestic anger

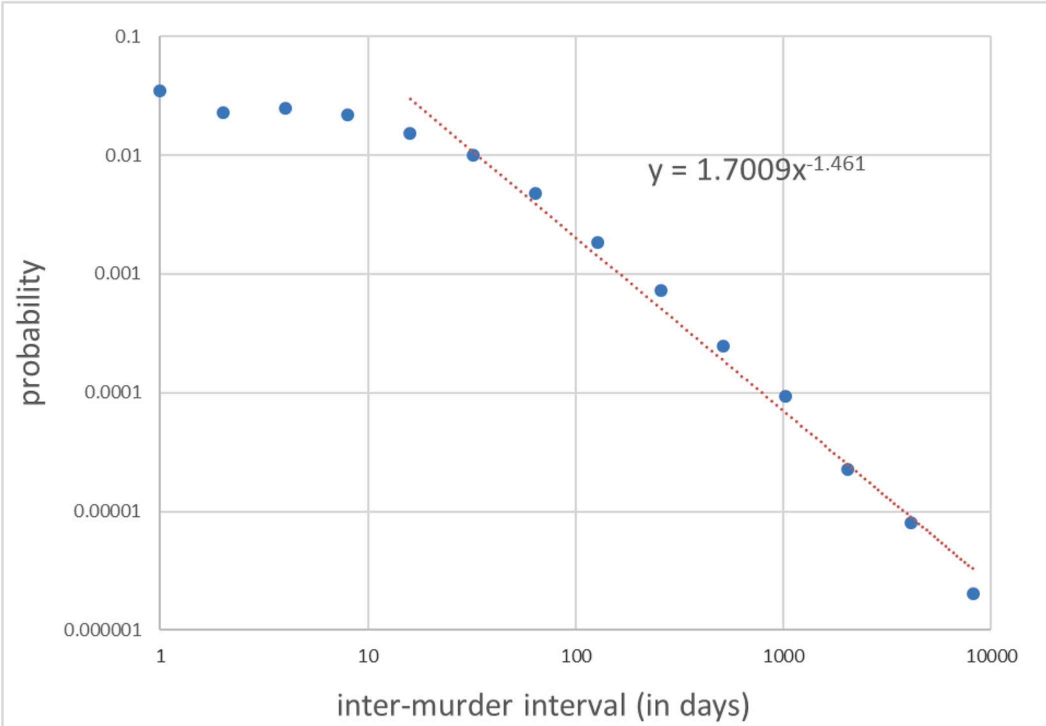

Fig. 4. Distribution of length of 607 inter-murder intervals for 34 serial killers who had at least 10 killing dates.
The circles represent serial killers; the line is a power-law fit.

are given the luxury of time to wind down between offenses, not because of superior knowledge of forensic techniques, talent or skill, but due to a multitude of variables beyond their control including the degree of witness involvement, varying levels of police pressure and even luck (Yaksic et al., 2020a; Yaksic, Allely, Taylor, et al., 2019b). If given the freedom to escape, it is inevitable that the spree offender would stop killing before continuing where he left off after a period of time had passed. Vice versa, it is entirely possible that a SHO can exhibit spree-like, "run and gun" behaviors by the end of their series due to unplanned circumstances that arise (Yaksic, 2015, 2019b, 2020b).

For these reasons, Osborne and Salfati (2015) argue that the clinical interpretation and psychological aspect of the "cooling-off" concept should be discarded and re-conceptualized into time intervals. The "cooling-off period" presented another aspect of difficulty to this study as it has been a critical aspect of the SHO definition since its inception and used to differentiate it from other forms of multiple murder (NCAVC, 2008), such as spree killings. Use of this component in this manner has presented operational challenges that hamper the usability

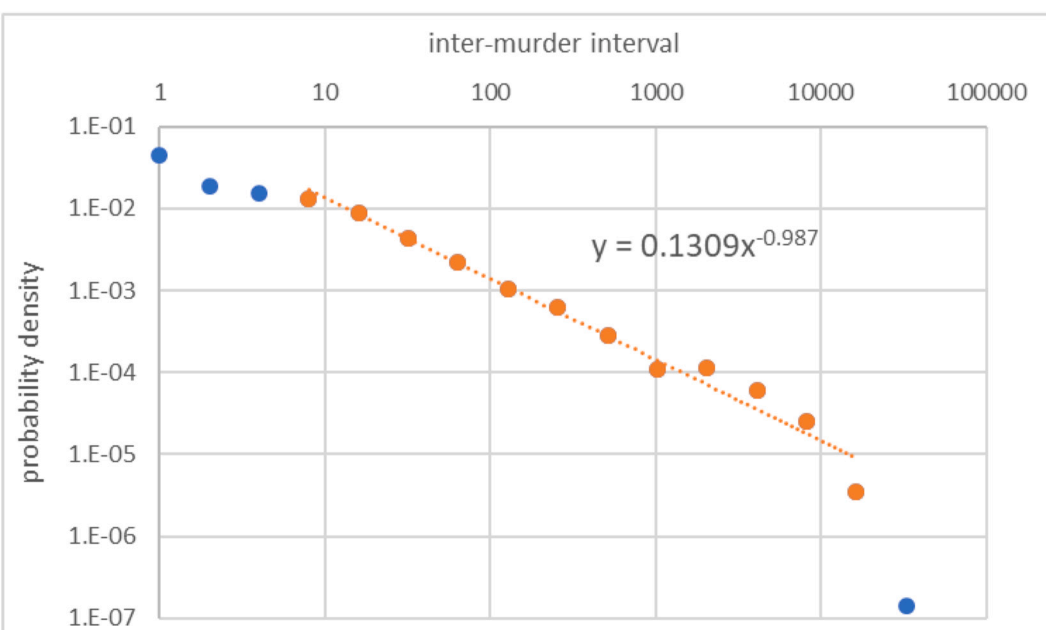

Fig. 5. Distribution of length of 425 inter-murder intervals for 425 serial killers who had exactly 2 killing dates.
The circles represent serial killers; the line is a least-square power-law fit.

Table 5
Distribution of length of 425 inter-murder intervals for 425 serial killers who had exactly 2 killing dates

Upper boundary of intervals (in days)	Number of intervals	Probability density	Distribution A		Distribution B	
			Number of intervals	Probability density	Number of intervals	Probability density
1	19	4.47E-02	19	7.95E-02		
2	8	1.88E-02	8	3.35E-02		
4	13	1.53E-02	13	2.72E-02		
8	22	1.29E-02	22	2.30E-02		
16	30	8.82E-03	30	1.57E-02		
32	29	4.26E-03	28	7.32E-03	1	3.36E-04
64	30	2.21E-03	28	3.66E-03	2	3.36E-04
128	28	1.03E-03	24	1.57E-03	4	3.36E-04
256	34	6.25E-04	26	8.50E-04	8	3.36E-04
512	31	2.85E-04	19	3.11E-04	12	2.52E-04
1024	24	1.10E-04	6	4.90E-05	18	1.89E-04
2048	49	1.13E-04	11	4.49E-05	38	2.00E-04
4096	52	5.97E-05	4	8.17E-06	48	1.26E-04
8192	43	2.47E-05	1	1.02E-06	42	5.51E-05
16,384	12	3.45E-06			12	7.88E-06
32,768	1	1.44E-07			1	3.28E-07

The distribution in two parts: Distribution A, which is approximately a power law with exponent 1.5, and Distribution B which is approximately exponential.

of the SHO definition for both law enforcement and researchers (Adjorlolo & Chan, 2014). Although Dowden (2005) urges researchers to explore spree killers in greater detail to determine whether they should be considered separately or should be subsumed under the category of serial murderer, the FBI dissolved the spree killer classification during their Serial Murder Symposium (NCAVC, 2008). Perhaps echoing the FBI's stance, Douglas et al. (2013) characterizes the “cooling-off period” as a historical artifact. The results presented here support the viewpoint of Osborne and Salfati (2015) and Yaksic (2019b) that spree homicide may not be distinguishable from serial homicide. The work of the present authors substantiates the FBI's call for the elimination of the concept of spree murder and inclusion of those cases under the broader classification of serial murder (Hickey, 2015), closing the debate around whether we should continue to differentiate between spree and SHOs (Adjorlolo & Chan, 2014).

7. Limitations

This inquiry is not without a host of limitations. Similar to Osborne and Salfati (2015), missed offenses, such as those not yet linked to the killer could not be accounted for. It would have been of great importance to calculate the time lapses in minutes and hours but that data was not available. We were not able to parse out those SHOs for whom murder is a sensationalistic episode imbedded within a larger criminal career (DeLisi & Scherer, 2006) from SHOs who tend to fantasize and plan the crime and pursue and ultimately kill their victims without the interpersonal conflict and emotional provocation (Brantley & Kosky, 2005). We also could not examine, as DeLisi and Scherer (2006) had, whether or not the SHOs in our study should be considered conventional criminals who happened to commit more than one homicide, mainly because our data was not that granular.

We agree with Harbort and Mokros (2001) that SHOs are not just

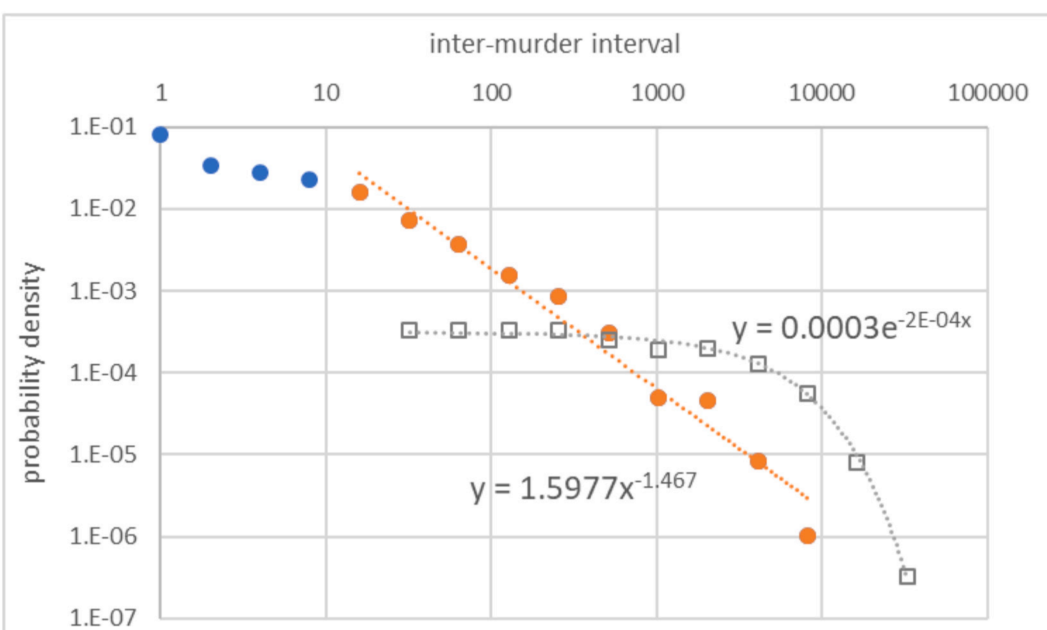

Fig. 6. Decomposition of the distribution shown in Fig. 5.
Distribution A, which includes 239 killers, is shown by solid circles.
Distribution B, which includes 186 killers, is shown by empty squares.
The lines are least-square fits.

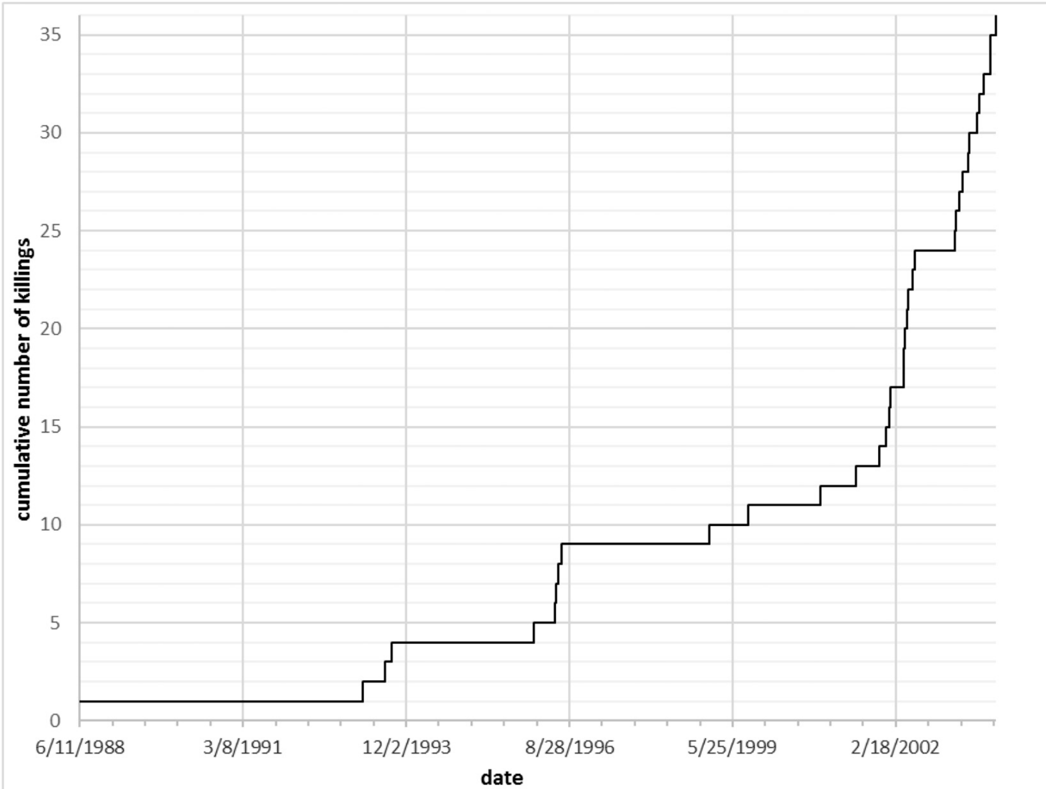

Fig. 7. Cumulative number of killings committed by Charles Cullen.
The major marks on the horizontal axis are separated by 1000 days and the minor ones by 200 days.

homicide offenders who happen to be more prolific. Although not a necessary requirement for inclusion, we are confident that the grand majority of SHOs in our dataset are true predators who commit unprovoked violence and relish in causing the death of another, yearning to repeat this process. As Hickey (2015) states, real SHOs are people who make it their life's work. While our adoption of a wide view of serial murder allows us to avoid the possibility of under-inclusion of SHO cases, we may have over-included as our definition may be contrary to that used by law enforcement agencies (Adjorlolo & Chan, 2014).

Our mixture of all types of SHOs may hamper serious attempts at generalization as comparisons of dissimilar populations can result in misleading or erroneous outcomes (Beasley, 2004). As Skrapec (2001) states, studies that collapse together a broad array of cases compromise the meaningfulness of the data probably because the interaction of the individual with specific elements of his external world should be examined to understand the transformation and progression of their nature, a process beyond the scope of this study. Although Simkin and Roychowdhury's (2014) findings were based on three SHOs from different countries, this database only captures US based SHOs and we therefore do not know if our findings are generalizable to SHOs in other parts of the world.

We relied on data from solved serial homicides which introduced the potential for a self-selection bias where SHOs from unsolved series could maintain characteristics that are different from SHOs that were apprehended. Future research should test whether or not apprehended SHOs have shorter inter-murder intervals at the end of their series compared to those of unsolved serial homicide series. Research of this nature might find that SHOs were more likely to be apprehended because they grew more impatient over time.

8. Conclusion

We were alarmed to learn that few SHO studies employ statistical analyses, relying instead on visible data (Dowden, 2005; Yaksic, 2015). The scarcity of systematic studies ensures the unreliability of existing information (Arndt et al., 2004) leading much of what is represented about serial offending to be based on misinformation or myth (Jenkins, 1994; Walters, Drisnale, Patrick, & Hickey, 2015). Kraemer et al. (2004) urges researchers to advance beyond case studies and conclusions unsupported by empirical evidence, noting that empirically based analyses are both possible and needed to improve the current state of research on SHOs which is lacking (Culhane, Hilstad, Freng, & Gray, 2011). Experts should adopt the practice of looking at statistically analyzed data (Safarik & Ramsland, 2012) because, as Beasley (2004) notes, relying on the individual narratives provided in case studies leads to excessive attention to the bizarre at the expense of more mundane but also more common features. Future studies should analyze every offense within a series (Osborne & Salfati, 2015) as the absence of such granular data prevented our efforts to study potential SHOs (Yaksic et al., 2019c) and their failure to act perfectly on their subsequent intentions to kill a third victim (Adjorlolo & Chan, 2014), attempted homicides interrupted by their early apprehension.

We were still able to study a large portion of all known SHOs. Given new theoretical opinions on the lack of a distinction between serial and spree killers, all offenders that were formerly designated as spree killers were classed as SHOs and included in the CSHOD used in our study. Figs. 2-4 do not show any characteristic spree killer or SHO interval but a monotonous smooth distribution lacking any features. This suggests that there is only a quantitative difference between spree killers and SHOs which represent merely different aspects of the same phenomenon.

This exercise demonstrates not only the utility of the CSHOD but the advantages related to developing a multidisciplinary team of researchers, each with varying backgrounds and expertise (Yaksic, 2017), an underutilized but oft successful approach. The present research contributes to science with the finding that only a quantitative difference between SHOs and spree killers exists and was made possible by combining the resources and know-how of mathematicians with a subject matter expert. We encourage others to plan and execute projects employing the multidisciplinary research team approach as the results can be worthwhile and surprising.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrimjus.2020.101751.

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