



Sexual homicide and the forensic process: The decision-making process of collecting and analyzing traces and its implication for crime solving



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ABSTRACT

The focus of the current study is to examine the collection and analysis of traces that are related to crime scene behaviors in sexual homicide cases as well as the factors influencing the solving of these crimes. Using 230 sexual homicide cases from the SHIELD database, we computed two neural network models based on the multi-layer perceptron algorithm. First, we determined whether certain crime scene characteristics predicted the collection and analysis of traces (dependent variable for Model 1). Not surprisingly, the results indicate that trace collection and analysis were more likely to occur in sexual homicide cases with crime scene behaviors exhibiting the highest risk for trace transfer (e.g. close interactions with the victim) as well as the best conditions for trace persistence (e.g. body is found indoors). Situational and physical aspects of the crime scene are thus taken into account when deciding on the collection and analysis of traces. Second, we examined the situations in which the collection and analysis of traces contributes to crime solving (dependent variable for Model 2). The results suggest that the collection and analysis of traces does not necessarily predict the resolution of the case. Specifically, the analyses show that the collection and analysis of traces is useful for crime solving when: (1) the offenders' behaviors increase the opportunities for leaving traces at the crime scene, and (2) when the environmental and temporal aspects are favorable to the collection of traces. The impact of trace collection and analysis on case resolution is thus depending on the context of the case. Furthermore, the subsequent steps, such as the result of the trace analysis, the introduction into a database, the obtention of a result from this comparison, etc. might also affect case resolution, and thus interfere in the link between trace collection and analysis and case resolution.

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1. Introduction

The crime scene is the starting point of any traditional criminal investigation [26,28,36,65]. The crime scene and the traces left are especially crucial in cases of sexual homicide as both are necessary to identify them as such. As suggested by the Federal Bureau of Investigation (FBI) [53], for a homicide to be considered as sexual, it has to present at least one of the following characteristics at the crime scene: victim's attire or lack of attire, exposure of the sexual parts of the victim's body, sexual positioning of the victim's body,

insertion of foreign objects into the victim's body cavities, evidence of sexual intercourse, and evidence of substitute sexual activity, interest, or sadistic fantasy.

Important pitfalls impede the investigation of sexual homicide. For instance, sexual homicide presents a low base rate – between 1% and 4% of all homicides [6] – which makes gaining valuable and reliable knowledge about these crimes and offenders challenging. More specifically, accumulating knowledge that can inform effective investigative practices has been problematic, as many investigators cannot rely upon investigative experience to approach these crimes. In addition, while the behavioral elements of sexual homicide crimes differ from other types of violent crime, they are still an inherently heterogeneous group. Each case may vary in terms of the modus operandi and ritualistic behavior exhibited, causing each case to appear unique. The differential characteristics as well as the possible presence of psychopathology, which may be identified through a

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careful study of the crime scene, may appear atypical for the detective involved in such a case for the first time. Due to these various investigative challenges, traces are critical to the criminal investigation and its outcome. The focus of the current study is to examine the collection and analysis of traces that are related to crime scene behaviors in sexual homicide cases as well as the factors influencing the solving of these crimes.

2. Crime scene investigation and the use of traces

The use of traces in a criminal investigation follows a three-step decision process [12,31]: (1) the decision to attend a scene, (2) the decision to search for and collect traces, and (3) the triaging of traces for forensic analysis. The gradational flow of this process limits the impact traces can have on the course of investigation, as well as on the resolution of the case. For example, traces left at a crime scene that is not attended by the police and therefore not investigated, cannot be used in the later stages of the judicial process.

Once the police have decided to attend a crime scene and proceed to the investigation stage, the criminal investigation faces the issue of to 'find'. As suggested by Kind (1994) [43], to 'find' is to search for traces in the context of crime scene investigation. Fundamentally, to 'find' includes a chance component. However, the investigation is active in its nature, and its outcome depends on what one is looking for. At best, the search for traces results in their detection, which implies the crucial capability of recognizing traces as such. While this is easily conceivable for visible traces (e.g., fingerprints, shoe marks), biological traces – especially contact traces – are often not visible at the crime scene. This is why the concept of trace detection needs to be understood in a wider sense. Specifically, adopting the hypothetical-deductive reasoning process allows for the "imagination" of possible traces at specific locations according to the case scenario or the presence of other traces [40]. The crime scene investigator must thus "imagine" or infer which traces may have been exchanged during the criminal event, which ones may remain, and which ones could be relevant to the case at hand and provide answers to the investigative questions [30].

To find the most relevant traces at a crime scene, the search for traces must be systematic and based on cognitive and observational skills. A broad understanding of the criminal and immediate environments as well as the range and properties of traces is also required [30,29,52,54]. The factors influencing the search for traces can be separated into three categories [27,34]: (1) human (i.e., the knowledge), (2) structural (i.e., the organization, strategy, resources), and (3) contextual (i.e., the type of encountered situations). Moreover, finding traces may also be influenced by the behavior of offenders, such as their ability to limit the traces they leave and their forensic awareness [37].

Once traces have been identified and recognized as such, a decision regarding their collection is made. Material considerations, as well as cognitive aspects, need to be taken into account in this decision. The material aspect refers to components such as the quality of the trace and the availability of technological resources. The cognitive aspect includes a retrospective dimension (i.e., the knowledge of traces, their properties, and their collection techniques) as well as a "prospective orientation of the scene examiner to a set of likely investigative and evidential trajectories to which these artefacts may become decisive – or at least relevant" ([62], p.763).

In parallel with these studies on the decision-making process underlying the search and the collection of traces, researchers worked for a better understanding of the true contribution of forensic science to security and justice. Rather than focusing on the factors influencing the early steps of the investigation process, end-to-end studies [55,14,47,15,48,35,46] consider the processing of traces through the entirety of the judicial process. This method allows for trace evidence to be used at different steps. Metrics include

the timeliness and number of crime scene investigations, analysis submissions, and reports. For burglary cases, Bruenisholz et al. [15] determined that between 2011 and 2015, 10–40% of cases resulted in the collection and submission of traces for analysis. Furthermore, the authors found that traces were increasingly used in 2015 compared to 2011, with more traces submitted and analyzed yearly, thus positively impacting the arrest rate. Mapes et al. [46] determined that biological traces were collected and analyzed in roughly 60% of serious crime cases but only in 6% of other high-volume crimes (e.g., burglaries, theft, vandalism, etc.). For homicide, it was found that in 97% of cases, physical traces were collected, and in 88% of cases, these traces were submitted for analysis [3].

Interestingly, research has suggested that the collection and analysis of these traces does not guarantee a proportional influence on the outcome of the investigation. For instance, Brodeur [13] found that traces played a role in the identification of the suspect in only 1% of homicide cases. Ten years later, Mapes et al. [46] have shown that a suspect was identified through a hit in the DNA database in only 1% of high-volume crimes and in merely 3% of serious crimes. Similarly, the presence of traces was not predictive of any of the judicial stages (i.e., arrest, charging, conviction) in homicide cases [3]. However, using the same dataset but a different modeling approach, Peterson et al. [49] were able to determine a link between the presence of traces and the arrest of a suspect.

While the importance of the early steps of the crime scene investigation has been recognized [38,45,64], little empirical research has been conducted on the identification of factors involved in the search, detection, and collection of traces at the crime scene of sexual homicide cases [31] as well as their impact on the outcome of the case. Thus, the aim of this study is twofold: (1) to determine the factors influencing trace collection and analysis from offenders' crime scene behaviors, and (2) to study the impact trace collection and analysis has on the resolution of the sexual homicide cases.

3. Methodology

3.1. Data and sample

Data used in this study come from the Sexual Homicide International Database (SHIeID). This database provides information on 762 solved (i.e., cases in which police investigators identified and charged a suspect) and unsolved (i.e., where an offender has not been identified by investigators) cases of extrafamilial (i.e., stranger or acquaintance relationships) sexual homicides that occurred in France and Canada between 1948 and 2018. Data was collected in Canada and France with the same tool created to reference information on victims, offenders, and the crime-commission process with a total of 126 variables (see [18]). Data included in the database comes from various sources of information (e.g., investigative reports, offender interview reports, autopsy reports provided by pathologists, psychological reports provided by a team of forensic psychologists, and reports provided by forensic experts) and were compiled by crime analyst experts in violent crimes who used the same standardized grid of data collection in both Canada and France. Sexual homicide cases were identified using the FBI definition from Ressler et al. [53] which states that for a homicide to be considered as sexual, it has to present at least one of the following characteristics at the crime scene: victim's attire or lack of attire; exposure of the sexual parts of the victim's body; sexual positioning of the victim's body; insertion of foreign objects into the victim's body cavities; evidence of sexual intercourse; evidence of substitute sexual activity, interest, or sadistic fantasy. As the FBI definition has been criticized for potentially presenting false positives (see [7,19,41,59]), all cases included in SHIeID present at least two criteria of the sexual homicide definition. This methodological decision was made to

avoid the inclusion of cases that were only characterized by the victim being found without or lack of attire.

For the current study, we made several choices to select a sample of 230 sexual homicide cases (see Fig. 1). First, we decided to include only cases that occurred in Canada in order to avoid differences in practices for collecting forensic samples between the two countries. Second, we included only cases that occurred after 1990 to ensure that DNA sampling was practiced by forensic services in Canada.¹ We tested the association between the continuous temporal distribution of the collection and analysis of traces. Results showed no significant difference over time ($\beta = -0.002$; $p = 0.951$).

3.2. Measures

3.2.1. Dependent variables

In this study, we computed two different models to predict two dependent variables. The first dichotomous dependent variable identified whether traces were collected and analyzed (0 = no traces were collected and analyzed; 1 = traces were collected and analyzed). The traces collected and analyzed included the following: hair, saliva, blood, semen, and fingerprints. This dependent variable was included as an independent variable in the second model computed in this study. The second dichotomous dependent variable identified the status of the cases at the time of the data collection (0 = unsolved, 1 = solved).²

3.2.2. Independent variables

The selection of independent variables was guided by previous studies focusing on crime scene behaviors predicting the collection and analysis of traces [54], as well as research examining crime scene behaviors in sexual homicide cases [6,2,5]. We selected a total of 12 variables (i.e., 11 dichotomous, and 1 continuous) describing crime scene characteristics observable at both solved and unsolved cases. This information comes from reports provided by coroners, investigators, and forensic experts which included the following: (1) evidence of sexual penetration (i.e., there is evidence that the offender perpetrated vaginal and/or anal penetration of the victim), (2) victim's body was burned, (3) victim sustained gunshot, (4) victim's body was dismembered (i.e., the entire removal, by any means, of a large section of the body of a living or dead person, specifically, the head, arms, hands, torso, pelvic area, legs, or feet, see [60], p. 83), (5) victim was beaten, (6) victim was stabbed/cut, (7) victim was strangled/asphyxiated, (8) evidence of overkill (i.e., infliction of more injury than is necessary to kill a person, see [53]), (9) evidence that the crime scene was cleared/modified (e.g., offender removed or destroyed forensic evidence, offender set fire to scene, offender cleaned the scene, see [20]), (10) evidence that the victim's body was moved from the crime location to another, (11) number of days before body recovery (i.e., measured by subtracting the date the victim was last seen alive from the date the body was recovered), and (12) body recovery location was outdoors (i.e., in contrast to an indoor location).

3.3. Analytical strategy

We computed two neural network models based on the multi-layer perceptron algorithm. Model 1 predicted the trace collection in sexual homicide cases, whereas Model 2 predicted crime solving results. Neural network models are mostly used in data mining and computational science. One of the main objectives of neural network

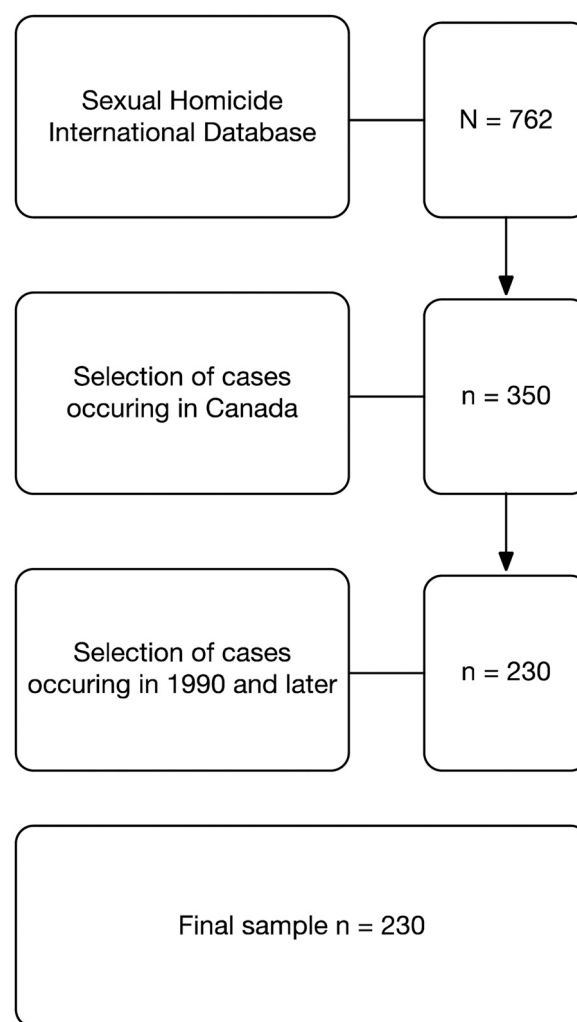


Fig. 1. Sampling procedures.

analysis is to identify complex patterns and relationships between several inputs that cannot be identified by the human brain [10]. This technique is used in a large number of scientific disciplines (e.g., medicine, neuroscience, computer sciences, etc.) and is proving to be particularly promising in the field of social and human sciences given the complexity of predicting human behavior [44]. In comparison with other classical methods of prediction such as logistic regression or classification and regression trees, neural networks present several advantages. Logistic regressions are known to be robust however, this method ignores the possibility that different variables predict the same outcome for different subgroups of individuals (see [58]). Classification and regression trees provide a better representation of the different possibilities of predicting the same outcome for different groups but they are limited in terms of stability and present a risk of overfitting [25,32]. Neural network models avoid the weaknesses of conventional methods. They are particularly effective when the primary goal is outcome prediction and important interactions, or when complex non-linearity exist within the data [44,61]. The multi-layer perceptron neural network algorithm is the most commonly used network architecture consisting of inputs (i.e., independent variables), hidden layers (i.e., nodes) and output layers (i.e., dependent variable). These different layers are connected, and the force of the association is identified through the synaptic weights (i.e., the closer to zero, the weaker the relationship; the farther from zero, the stronger is the relationship). In order to test the quality of the predictive model, the multi-layer

¹ The first forensic use of DNA was in England in 1984. In Canada, it was first used in a criminal context in 1989 in the "Spandex Rapist" case [51].

² Cases committed between later than 2011 were not included to allow sufficient time to consider a case as unsolved (7 years window).

perceptron neural network algorithm consists of training and testing processes [50]. The percentage of correct predictions, as well as the area under the curve (AUC) value from the receiver operating characteristics (ROC) analysis, allowed assessment of the model quality [44].

The neural network analysis was calculated with the Statistical Package for the Social Sciences (SPSS) 27.0 software package. In Model 1, the input layer consisted of the crime scene variables, and the output layer contained two units of the two categories of the dependent variable (no collection of traces = 0; collection of traces = 1). To create the neural network model, 73.47% of cases ($n = 169$) were randomly sampled, while 26.53% of the cases ($n = 61$) were used to test the model. In Model 2, the input layer consisted of the crime scene variables as well as the collection of traces, and the output layer contained two units of the two categories (case is unsolved = 0; case is solved = 1) of the dependent variable.

4. Results

4.1. Descriptive analysis

Table 1 shows the descriptive statistics of variables used in this study. Traces were collected and analyzed in approximately half of the cases (46.09%) and 75.22% of the cases included in our sample were solved by the police. As to violence observed in these cases, almost half involved evidence of sexual penetration (48.26%) and beatings (46.96%). Victims were strangled/asphyxiated in 45.65% of the cases, and evidence of overkill was identified in 41.30% of the cases. Victims were stabbed/cut in 25.22% of the cases, and their bodies were dismembered in 6.09% of the cases. Finally, victims' bodies were burned in 5.65% of the cases and gunshot was sustained in 5.22% of the cases. As to the use of forensic awareness strategies by the offender, the victim's body was moved from the crime location to another location in 36.96% of the cases, while 29.57% of offenders used strategies to clean/modify the crime scene.

Table 2

Model 1: Neural network analysis of factors predicting the collection and analysis of forensic traces ($N = 230$).

		Hidden Layer					Output Layer	
		Node 1	Node 2	Node 3	Node 4	Node 5	No collection and analysis of forensic evidence	Collection and analysis of forensic evidence
Input Layer	(Constant)	-0.13	0.45	0.43	-0.37	0.25		
	Violence observed							
	Evidence of sexual penetration	-0.31	0.73	-0.33	0.02	0.49		
	Victim was beaten	0.57	0.61	0.12	-0.36	0.84		
	Victim was strangled/asphyxiated	-1.10	1.14	-1.17	0.11	-0.66		
	Victim was overkilled	-0.11	0.88	-1.12	-0.11	0.64		
	Victim was stabbed/cut	-1.00	0.33	0.33	-1.44	-0.52		
	Victims body was dismembered	-0.89	-0.03	-0.86	-0.44	0.84		
	Victim's body was burned	-0.16	1.17	-0.20	-0.60	-0.02		
	Victim sustained gunshot	-0.27	-0.37	-0.71	0.77	-0.25		
	Forensic awareness strategies							
	The victim's body was moved from the crime location to another	-0.64	0.47	0.28	-0.42	-0.31		
	Crime scene was cleared/modified	-0.62	0.16	-0.47	0.37	-0.27		
	Crime parameters							
	Number of days before body recovery (continuous)	0.56	-0.37	0.44	-0.20	-0.01		
	Body recovery location was an indoor environment	-0.24	0.29	0.73	0.45	-0.01		
Hidden Layer	(Constant)						0.26	-0.81
	Node 1						0.95	-1.07
	Node 2						-1.03	1.51
	Node 3						1.36	-0.67
	Node 4						-1.01	1.26
	Node 5						-0.50	1.06
Classification								
% of correct classification (training sample)		81.30%						
% of correct classification (testing sample)		82.10%						
AUC		0.81						

Table 1

Descriptive analysis of the sample ($N = 230$).

	n =	%
Dependent variables		
Collection and analysis of forensic traces	106	46.09
Crime solved	173	75.22
Violence observed		
Evidence of sexual penetration	111	48.26
Victim was beaten	108	46.96
Victim was strangled/asphyxiated	105	45.65
Victim was overkilled	95	41.30
Victim was stabbed/cut	58	25.22
Victims body was dismembered	14	6.09
Victim's body was burned	13	5.65
Victim sustained gunshot	12	5.22
Forensic awareness strategies		
The victim's body was moved from the crime location to another	85	36.96
Crime scene was cleared/modified	68	29.57
Crime parameters		
Average Number of days before body recovery (continuous)	58 ^a [SD= 190.07, 0–1370 ^b]	
Body recovery location was an indoor environment	101	43.91

^a Corresponds to the mean.

^b Corresponds to the range.

4.2. Multi-layer perceptron neural network: Model 1

Table 2 presents findings of the neural network analysis predicting the collection and analysis of traces. Results showed that the model presented a good level of prediction with an Area Under the Curve (AUC) of 0.81 (see Appendix 1). The model correctly classified approximately 81.3% of the training sample and 82.1% of the testing sample. This model was based on five nodes (i.e., hidden layers) which includes three nodes to predict the collection and analysis of forensic evidence and two nodes to predict the absence of trace

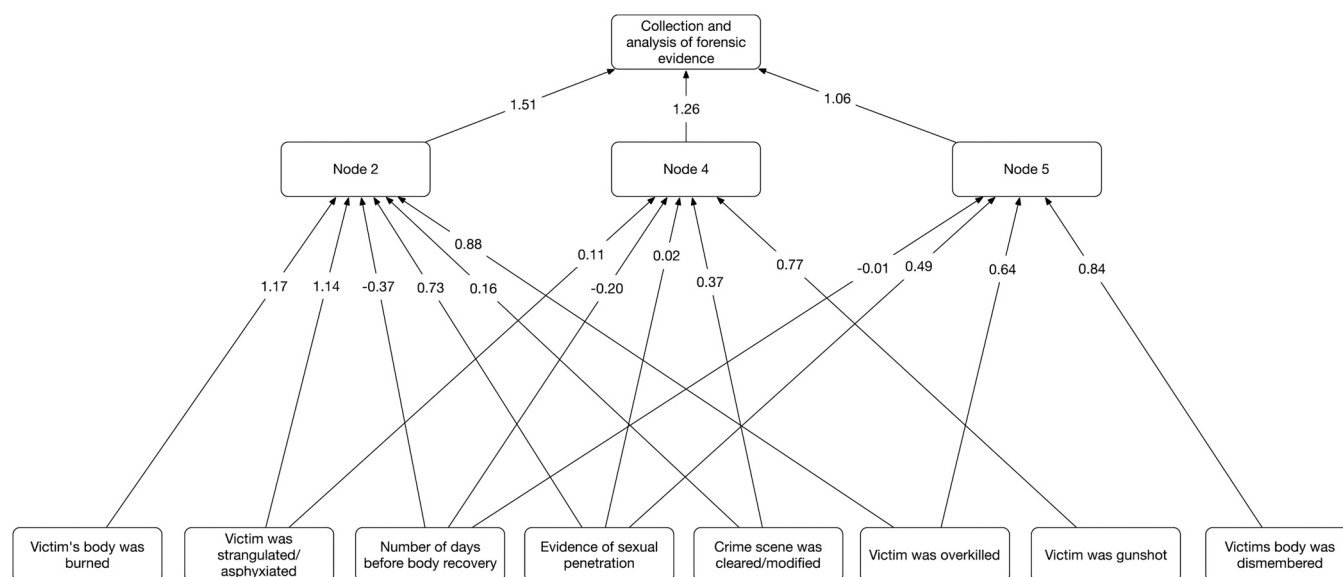


Fig. 2. Model 1: neural network of best factors predicting the collection and analysis of forensic evidence (N = 230).

collection and analysis. Specifically, nodes 2, 4, and 5 predicted the collection of traces while nodes 2 and 4 predicted the absence of trace collection and analysis. Fig. 2 summarizes the best factors of the model predicting the collection and analysis of traces according to the variable normalized importance indicators. Node 2 showed that cases with evidence of sexual penetration (0.73), where the victim was beaten (0.61), strangled/asphyxiated (1.14), stabbed/cut (0.33), burned (1.17), where there was evidence of overkill (0.88) were more likely to have traces collected and analyzed. Moreover, cases in which the victim's body was moved from the crime location to another (0.47), where body recovery location was indoor (0.29), where offenders used strategies to clean/modify the crime scene (0.16), and for which the number of days before body recovery was low (−0.37) were more likely to have traces collected and analyzed. Node 4 showed that cases with evidence of sexual penetration (0.02), where victims were strangled/asphyxiated (0.11), victim sustained gunshot (0.77), where strategies were used by offenders to clean/modify the crime scene (0.37), where body recovery location was indoor (0.45), with a low number of days before body recovery (−0.20) were more likely to have traces collected. Node 5 showed that cases with evidence of sexual penetration (0.49), overkill (0.64), dismemberment (0.84), and for which the number of days before body recovery was low (−0.01) were more likely to have traces collected and analyzed.

Table 3 summarizes and classifies the normalized importance of each variable predicting the collection and analysis of traces. The variables with the greatest predictive weight, in descending order, were evidence of sexual penetration, number of days before body recovery, crime scene was cleaned/modified, evidence of overkill, victims' body was dismembered, victim's body was burned, victim was strangled/asphyxiated, body recovery location was outdoor. The following variables were not significant in predicting the collection and analysis of forensic evidence: victim was beaten, victim was stabbed/cut, victim sustained gunshot, the victim's body was moved from the crime location to another location.

4.3. Multi-layer perceptron neural network: Model 2

Table 4 presents findings of the neural network analysis predicting the crime-solving outcome. Results showed a high level of prediction for the model, with an Area Under the Curve (AUC) of 0.85 (see Appendix 2). The model correctly classified approximately

Table 3

Model 1: Best factors classification of factors predicting the collection and analysis of forensic traces (N = 230).

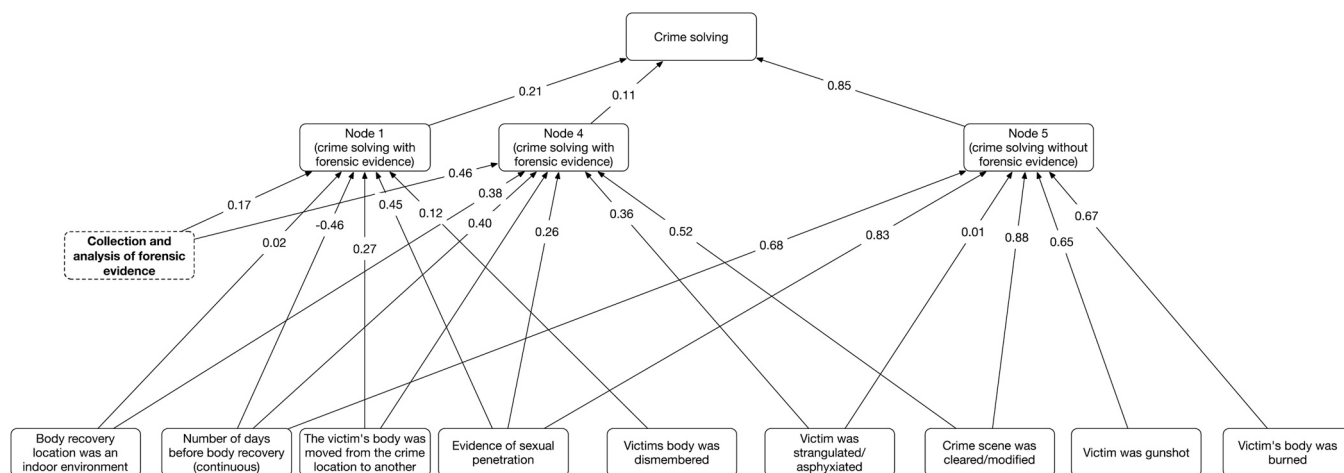
Ordered factors	Importance	Normalized Importance
Evidence of sexual penetration	0.14	100.00%
Number of days before body recovery	0.09	82.40%
Crime scene was cleared/modified	0.08	72.90%
Victim was overkilled	0.08	70.20%
Victims body was dismembered	0.06	64.90%
Victim's body was burned	0.07	52.50%
Victim was strangled/asphyxiated	0.07	51.00%
Body recovery location was an indoor environment	0.07	50.10%
Victim was beaten	0.05	36.90%
Victim was stabbed/cut	0.04	26.90%
Victim sustained gunshot	0.03	18.40%
The victim's body was moved from the crime location to another	0.03	17.10%

83.3% of the training sample and 83.9% of the testing sample. This model was based on six nodes (i.e., hidden layers) including three nodes to predict the crime solving and three other nodes to predict the absence of case solving. Fig. 3 summarizes the results of the model predicting the crime solving of sexual homicide cases. Node 1 showed that cases with evidence of sexual penetration (0.45), where victims were beaten (0.27), dismembered (0.12), and moved to another location than the crime location (0.27) were more likely to be solved. Moreover, cases with a low number of days before body recovery (−0.46), where the body recovery location was indoor (0.02), and for which traces were collected and analyzed (0.17), were more likely to be solved. Node 4 showed that cases with evidence of sexual penetration (0.26), where victims were strangled/asphyxiated (0.36), where victims' bodies were moved to a different location than the crime location (0.22), and when offenders cleaned/modified the crime scene (0.52) were more likely to be solved. Moreover, cases with a low number of days before body recovery (−0.07), where the body recovery location was indoor (0.38), and for which forensic evidence were collected and analyzed (0.46), were more likely to be solved. Finally, Node 5 showed that cases with evidence of sexual penetration (0.83), where victims were beaten (0.14), strangled/asphyxiated (0.01), stabbed/cut (0.33), burned (0.67), with evidence of

Table 4

Model 2: Neural network analysis of factors predicting the crime solving of sexual homicide cases (N = 230).

		Hidden Layer						Output Layer	
		Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Unsolved cases	Solved cases
Input Layer	(Constant)	-0.15	-0.53	0.35	0.53	0.67	0.00		
	Violence observed								
	Evidence of sexual penetration	0.45	0.09	-0.62	0.26	0.83	-0.40		
	Victim was beaten	0.27	0.23	0.53	-0.05	0.14	0.06		
	Victim was strangled/asphyxiated	-0.35	-0.45	-0.73	0.36	0.01	0.21		
	Victim was overkilled	-0.12	-0.20	0.15	-0.16	0.38	-0.65		
	Victim was stabbed/cut	-0.36	-0.45	0.11	-0.12	0.33	0.37		
	Victims body was dismembered	0.12	-0.21	-0.51	-0.13	-0.05	-0.24		
	Victim's body was burned	-0.46	-0.47	0.23	-0.57	0.67	0.04		
	Victim sustained gunshot	-0.13	-0.26	-0.83	-0.05	0.65	-0.35		
	Forensic awareness strategies								
	The victim's body was moved from the crime location to another	0.27	-0.34	0.40	0.22	-0.17	-0.40		
	Crime scene was cleared/modified	-0.33	0.23	-0.56	0.52	0.88	0.13		
	Crime parameters								
	Number of days before body recovery	-0.46	-0.14	-0.08	-0.07	0.68	0.45		
	Body recovery location was an indoor environment	0.02	0.12	-0.76	0.38	-0.72	0.11		
	Collection and analysis of forensic traces	0.17	-0.06	0.35	0.46	-0.14	-0.31		
Hidden Layer	(Constant)							-0.17	0.52
	Node 1							-0.15	0.21
	Node 2							-0.23	-0.30
	Node 3							0.78	-0.90
	Node 4							-0.35	0.11
	Node 5							-1.08	0.85
	Node 6							0.32	-0.46
Classification									
% of correct classification (training sample)		87.40%							
% of correct classification (testing sample)		83.10%							
AUC		0.87							

**Fig. 3.** Model 2: neural network of best factors predicting the crime solving of sexual homicide cases (N = 230).

overkill (0.38), and who sustained gunshot (0.65), were more likely to be solved. Moreover, cases with a higher number of days before body recovery (0.68) were more likely to be solved.

Table 5 summarizes and classifies the normalized importance of each variable predicting crime solving. The variables with the greatest predictive weight, in descending order, were evidence of sexual penetration, body recovery location was indoors, crime scene was cleared/modified, number of days before body recovery, victim was gunshot, victim's body was burned, collection and analysis of traces, and victim was strangled/asphyxiated. The following variables were not significant in predicting the crime solving: victim's

body was dismembered, the victim's body was moved to a different location from the crime location, victim was beaten, evidence of overkill, and victim was stabbed/cut.

5. Discussion

Over the past years, a handful of studies have focused on the factors influencing the collection and analysis of traces in the criminal justice process (e.g., [11,52,54]). Moreover, an increased attention has been dedicated to the study of the impact traces have on the outcome of the case. Yet, results have been scarce and

Table 5

Model 2: Best factors classification of factors predicting the crime solving of sexual homicide cases (N = 230).

Ordered factors	Importance	Normalized Importance
Evidence of sexual penetration	0.14	100.00%
Body recovery location was an indoor environment	0.12	89.10%
Crime scene was cleared/modified	0.11	77.50%
Number of days before body recovery	0.10	74.30%
Victim was gunshot	0.10	72.40%
Victim's body was burned	0.08	59.00%
Collection of biological samples	0.08	57.66%
Victim was strangled/asphyxiated	0.07	54.20%
Victims body was dismembered	0.06	44.40%
The victim's body was moved from the crime location to another	0.06	40.40%
Victim was beaten	0.05	36.20%
Victim was overkilled	0.04	32.30%

conflicting, leaving us with a limited understanding of the decision making behind the collection and analysis of traces as well as how much these traces really matter in the criminal justice process.

This study aims to contribute to these important questions by examining the process of trace collection and analysis in sexual homicide cases. Specifically, the first step was to determine which crime scene behaviors were more likely to lead to the collection and analysis of traces. The second step was to identify criminal situations in which the collection and analysis of traces led to the solving of the crime. In order to answer these questions, 230 sexual homicide cases that occurred in Canada were examined. Neural network models were computed instead of logistic regression models in order to capture the different combinations of factors that predicted the same outcome (i.e., collection and analysis of traces and crime solving).

5.1. Sexual homicide crime scene behaviors to predict the collection and analysis of traces

In the descriptive part of the study, we found that the percentage of sexual homicide cases for which traces are collected and analyzed (46%) is lower than previous studies of serious crimes. For instance, Mapes et al. [46] reported that biological traces were analyzed in 57% of serious crimes. In addition, Baskin and Sommers [3] found higher rates among homicide cases, in which 97% of cases had traces collected and 81% of cases had traces analyzed. Although several reasons may explain the infrequent use of traces (e.g., lack of communication and knowledge; [16,56]), our findings highlight two factors that appear determinant in the decision to collect and analyze traces in sexual homicide cases. First, as shown in previous studies [3,4,63], the use of forensic science appears to depend on the seriousness of the offense. Thus, our findings show that the variables with the highest predictive power for collection and analysis of traces are related to the greater level of cruelty in sexual homicide, such as evidence of overkill, and the dismemberment or burning of the victims' body. These crime scene behaviors lead to a higher likelihood that the offender may leave traces behind. Such high-intensity crime scene behaviors consequently influence the finding, the collection, and the analysis of traces. These results suggest that the greater probabilities of trace transfer during such high-intensity criminal activity may influence the finding, the collection and the analysis of traces. Second, the other factor that may influence the decision to collect and analyze traces is the consideration of the

physical and situational components of the crime scene. Our findings showed that when the victim's body was recovered sooner and recovered indoors, traces were more likely to be collected and analyzed. These two variables relate to the consideration of the persistence of traces in particular circumstances, that is, the property of substances and materials to persist over time on certain surfaces in sufficient quantity and quality for analytical purposes. In other words, when conditions seem favorable to trace persistence (e.g., the body is recovered indoors and within a few days), more traces could be available for crime scene investigators to collect and analyze. Finally, another possible explanation for the lack of trace evidence is related to the date of the cases in the study's sample. In older cases, biological traces may not have been routinely collected. In addition, a case-specific context might involve questioning the utility of collecting traces, such as when the suspect is already at the scene.

5.2. The collection and analysis of traces is not always associated with crime solving

One of the central questions related to the study of the usefulness of forensic science is whether or not the use of traces leads to the solving of crimes. This question is often the object of myths that is associated with the crime scene investigation (CSI) effect (e.g., [22,23,24]), which gives a prominent and oversimplified role to the collection of traces in the investigative process and the identification of suspects. In the current study, our findings indicate a resolution rate of 75%, which is higher than in previous studies. For instance, Baskin and Sommers [3] reported an arrest and conviction rate of 50% and 34% respectively in homicide cases, while the homicide clearance rate for Canada in 2020 is situated around 64% [57]. It is possible that the higher homicide clearance rate observed in our study is due to the sexual nature of these homicides. First, the presence of sexual activities multiplies the victim-offender interactions, which in turn increases the likelihood of leaving traces according to the Locard's exchange principle [33]. Second, individuals involved in sexual homicide present a different criminal career than those involved in non-sexual homicides [17,9]. Accordingly, the presence of previous convictions for individuals involved in sexual homicide could result in their inclusion in existing forensic databases (e.g., DNA databases such as CODIS), which would facilitate their identification in case of trace collection and analysis. Both factors would presuppose an impact of forensic science on case resolution. Finally, since sexual homicide is a particularly serious crime, with some of our cases involving great level of violence and cruelty, law enforcement agencies may have deployed greater resources to solve those crime compared to more "typical" homicide.

Our findings also show that the collection and analysis of traces is associated with the crime-solving outcome for certain combinations of homicide crime scene behaviors. Specifically, three combinations of factors predict the crime-solving outcome (nodes 1, 4, 5), while three others are associated with the non-solving crimes (nodes 2, 3, 6). Among the combination of factors predicting the crime-solving, we observe that the collection and analysis of traces is positively associated with crime solving in two combinations (nodes 1, 4). However, our results also show that in some cases, the analysis and collection of traces is not positively associated with crime solving (i.e., node 5) nor is it positively associated with the non-solving of crimes (i.e., node 2). These results reflect the debate surrounding the role and utility of trace collection and analysis for crime solving. While our results show a nuanced picture of the contribution of forensic science to crime solving, they do not suggest that the collection and analysis is counterproductive to the

investigation. Rather, they reiterate the complexity of the contribution of material traces to an investigation process, which draws on various other sources of information (e.g. testimony, confession) thus reinforcing the idea that traces are not the silver bullet as often portrayed by the CSI effect. Solving sexual homicide cases is a multifactorial phenomenon [2,5] partially based on the skills of investigators (James and Beauregard, 2018)[37] or even sometimes luck [39]. More research are thus still needed to better evaluate the overall contribution of forensic science to sexual homicide investigation.

The identification of certain crime scene behaviors in sexual homicides that are associated with the collection and analysis of traces and the resolution of the crime suggests two possible explanations for such relationship. The first is the amount of traces to be exploited. Our results indicate that the presence of sexual penetration, the use of forensic awareness strategies, and the presence of strangulation/asphyxiation during the crime better predict crime solving through trace collection and analysis. These results are congruent with theoretical principles (e.g. Locard's principle) and previous empirical studies suggesting that certain behaviors (i.e., leaving semen at the scene, attempting to destroy the scene, close interactions with the victim) lead to an increase in the amount of traces that can be collected and compared with existing databases [8,20,21,2,5]. Second, we observe that when the body is recovered indoors and shortly after the murder, it is more likely that traces were collected and analyzed as well as the case being solved. The elapsed time between the commission of the crime and body discovery exposes the crime scene to weather and environmental elements. In turn, the quality of available traces may become degraded, harder to find and appreciate, or even destroyed (Martin et al., 2019). Accordingly, and as highlighted in our study, traces collected promptly in a protected environment (e.g., indoors) seem to be more easily exploited and useful to the investigation.

6. Conclusion

To the best of our knowledge, the current study is the first to investigate the process of collecting and analyzing traces in sexual homicide cases and its relationship to the resolution of these crimes. First, we determined whether certain crime scene characteristics predicted the collection and analysis of traces. Not surprisingly, the results indicate that trace collection and analysis were more likely to occur in sexual homicide cases with crime scene behaviors exhibiting the highest risk for trace transfer (e.g. close interactions with the victim) as well as the best conditions for trace persistence (e.g. body is found indoors). Second, we examined the situations in which the collection and analysis of traces contributes to crime solving. The results suggest that the collection and analysis of traces does not necessarily predict the resolution of the case. Specifically, the analyses show that the collection and analysis of traces is useful for crime solving when: (1) the offenders' behaviors increase the opportunities for leaving traces at the crime scene, and (2) when the environmental and temporal aspects are favorable to the collection of traces.

There are several limitations to this study. First, the sample consist of only cases from Canada – excluding cases from the

provinces of Quebec and Ontario. We cannot exclude that investigative and forensic practices may vary between provinces as law enforcement agencies operate differently across Canada. Therefore, our results may not be representative of the treatment of sexual homicide cases at the provincial level. Similarly, since investigative and forensic practices vary greatly across different countries, *de facto* generalizations cannot be achieved internationally. Second, the details regarding the type of traces collected and used were not available for analysis. Such data would have contributed additional information to the study by providing explanations as to why certain behaviors that are theoretically riskier for trace transfer (e.g. victim was stabbed/cut, the victim's body was moved to another location) seem to only be weak predictors of the collection and analysis of traces. Third, although the study focused on the collection and analysis of traces, it was not possible to include the results of the trace analyses (e.g., DNA match). It is possible that some traces have been analyzed in a case, such as a DNA sample, but did not lead to a positive result or to a match in any databases. Finally, a multivariate approach was conducted with a limited sample size. While the use of artificial neural network models is quite appropriate with small sample sizes [66,42], other studies have suggested that the 'factor 10' rule-of-thumb that was adopted in this study could be insufficient and that a 'factor 50' rule of thumb was preferable [1]. Despite these analytical limitations, we believe that the results should be understood in terms of trends (i.e., positive or negative) rather than the exact values of the statistical weight of each factor.

The study presents several implications for the investigation of sexual homicide and the crime scene investigation in unusual cases. The results highlight the importance of knowledge on the transfer and persistence mechanisms across the range of traces potentially left by the offender at the crime scene. It calls for an in-depth knowledge about traces for crime scene investigators so that they can infer on which traces may have been exchanged during the criminal event and which ones may still remain to maximize detection [31,30]. Despite sexual homicide cases posing various challenges to investigators due to their low base rate, the current findings may help identify crime scene behaviors that could lead to a collection and analysis of traces that would subsequently result in the resolution of the case. It could therefore assist investigators who have little experience with this type of crime to make efficient decisions.

Future studies should attempt to replicate our findings with data from other countries to confirm the generalizability of our results or to specify a new model. Moreover, a more in-depth analysis considering the different types of traces collected should be undertaken to provide a better understanding of trace collection and analysis as well as to better inform crime scene investigation practices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

See Figs. A1 and A2.

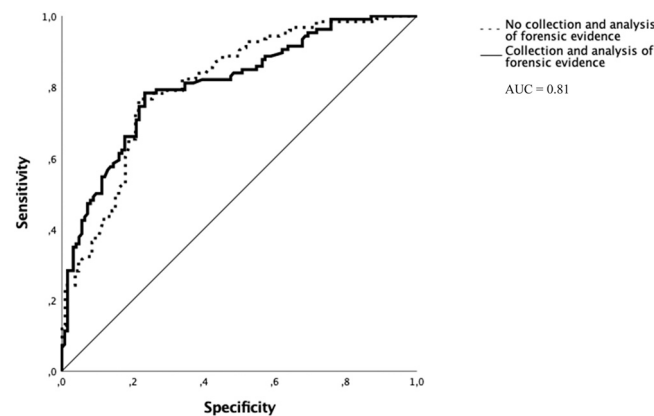


Fig. A1. ROC curve analysis of model 1.

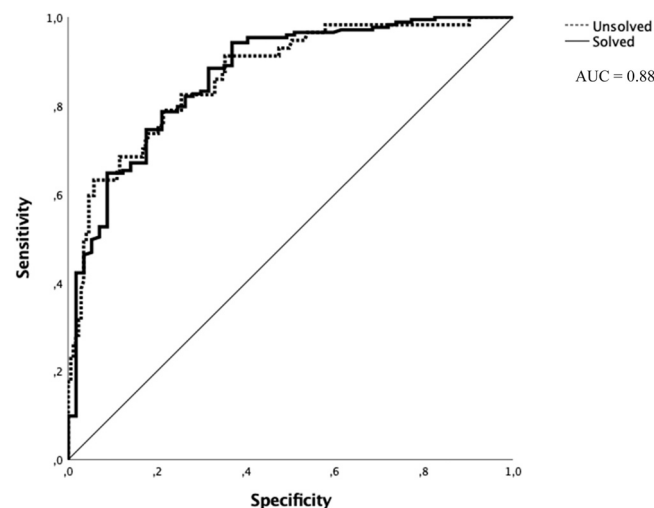


Fig. A2. ROC curve analysis of model 2.

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