COMBINING A LINE SEARCH WITH AN ALTERNATE LIGHT SOURCE WHEN SEARCHING FOR SKELETAL REMAINS

by

Tracy E. Brown
A Research Project
Submitted to the
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of
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Committee:

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George Mason University
Fairfax, VA

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DEDICATION

This is dedicated to my amazingly supportive parents, sister, and brother-in-law.

ACKNOWLEDGEMENTS

I would like to thank the many friends and relatives who have helped make this happen; especially those who came out in less than stellar weather conditions to assist in data collection. Finally, huge thanks go out to Dr. Angi Christensen, my advisor, whose invaluable support and encouragement was key during this process.

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LIST OF ABBREVIATIONS

Alternate Light Source .... ALS
Deoxyribonucleic Acid .... DNA
Light Emitting Diode .... LED
Nanometer .... nm

ABSTRACT

COMBINING A LINE SEARCH WITH AN ALTERNATE LIGHT SOURCE WHEN SEARCHING FOR SKELETAL REMAINS

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George Mason University, 2017

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Searches for human remains in outdoor wooded settings are typically done during the day to allow for the best possible light. As part of the process of decomposition, the skeletal system begins to become disarticulated; this natural process is sometimes altered by scavengers. In all cases, it is important to attempt collection of as many remains as possible. In the cases when remains may be fragmented and/or scavenged, it is important to ensure as many fragments are located and collected as possible. For these scenarios, it would be advantageous to make use of the fluorescent properties of bone. Once the crime scene recovery is complete, to include measurements and mapping of the incomplete skeletal fragments found during the daylight, searchers would find that returning to the scene at night and using an alternate light source (ALS) to locate any final remains is to their benefit. This research involves the comparison of day, night, and combination day/night searches. Upon completion of the data collection, it can be stated

that any search involving the use of an ALS will outperform a search that does not use the ALS. When comparing the night search to the combination day/night search there are minimal differences, it is the comparison of the day search to the combination day/night search that shows significant differences in the number of remains collected. For bone fragments less than 1.5 inches, a greater proportion ($p<0.001$) of bones were located when combining a daytime line search with a nighttime ALS search when compared with a daytime line search alone.

CHAPTER ONE: INTRODUCTION

This paper discusses two research questions. The first question will examine an alternate light source (ALS) and if it can be used to effectively locate skeletal remains in a wooded setting. The second question will go a step further and determine whether the use of an ALS at night, in combination with a line search during the day, will increase the number of bones collected when compared to using either of these methods alone.

The research proposed in this paper will compare the current method used when searching for skeletal remains (daytime line search) with an additional search method (nighttime ALS search) to discover the best route when attempting to piece together a more complete skeleton. There are three search methods this research focused on: line search only (day), ALS search only (night), and a combination search that included both day and night ALS searches. To accurately describe the results of this research topic, it was necessary to test and compare all three methods.

If effective, this research could show law enforcement they must expand current search methods to locate more pieces to complete the skeleton. This has the potential to impact several areas of great importance. Completing the skeleton will allow families to have more of their loved one to bury, identification becomes easier when there are more pieces of the body to work with, and trauma to the bone is more likely to be discovered, allowing a more complete picture of the death event to emerge. With a more complete skeleton, the family of the victim will have more of their loved one to bury; this will assist in receiving some closure. In some cases, it might be hard to identify the remains and having a more complete skeleton could aid in identification. The further a body is allowed to decompose, the usual identification markers such as tattoos, birth marks, and hair color become less obvious. Once completely decomposed it is up to the bones to provide examiners with clues to the identification of the individual. Dirkmaat and Adovasio (1996) state that during the recovery process, the smaller bones of the hands and feet, as well as the teeth, are often missed during the standard, more "rigorous" screening of the soil. While the bones are important to collect as they can indicate any bone trauma, the teeth are used for identification of the individual and should also be vital in collecting.

Haglund (1996b) points out that teeth are one of the main ways people are identified when skeletal remains are involved. If the searchers can locate as many teeth as possible, this will assist in the identification of the body. Search strategies should ensure maximum recovery of all possible remains (Haglund, 1996b). Haglund (1996b) also discusses how easy it is for hands and feet to become disarticulated and, therefore, carried off by scavengers and never recovered. He believes this is because as muscle mass decreases, it becomes easier for canids to move sections of the carcass. The larger scavengers are less likely to feed on the body in situ. Canids and other large mammals will drag parts off where they can consume them without concern of other predators. Haglund (1996a) also believes the landscape surrounding the site of remains will have a significant effect on how far remains are taken by scavengers. Wooded sites will tend to limit the distance when compared to open fields.

During the commission of the crime, many remains are tampered with. Sometimes, perpetrators will attempt to dismember a body in hopes of easy disposal and in doing so they sometimes will cause damage to the bones not evident while still covered in flesh. This is also a countermeasure to obstruct or delay identification. During decomposition, trauma and other evidence surrounding the death may become less obvious. Upon locating more of the bones, investigators ensure any evidence tampering, as well as clues vital to the total picture of death, are taken into consideration during the prosecution of the crime. For cases that do involve bone fragmentation, it is important to recover the maximum number of fragments possible so reconstructions can be completed. As in many cases, the analysis into the manner of death focuses on skeletal trauma (Maples, 1986; Morse, 1983).

The actual method of searching is also important. Due to the many factors that affect whether or not the skeleton is complete, it is important that investigators employ the best search method possible to yield the highest number of remains found based on the terrain of the search area.

CHAPTER TWO: SEARCHES

There are standard search methods that all law enforcement departments rely upon. Search methods are needed to ensure that every part of the scene is thoroughly and systematically searched so nothing is missed. One of the main points to remember about scene searches for medico-legal purposes is that a forensic investigation must ensure the evidence is collected legally and can be used to establish links between suspect, crime, victim, and possible testimony (Dirkmaat & Adovasio, 1996). A full picture of the scene with as much evidence collected as possible will ensure these points are met.

It should be noted, while members of the law enforcement community (local, state, and federal) have training in conducting searches for evidence, they have little experience in conducting searches for human remains (Dirkmaat & Adovasio, 1996). Most will not have the training necessary to be able to identify whether an item found is skeletal versus non-skeletal or human versus non-human in origin. It has been recommended that searches have a forensic anthropologist on hand to assist in these and other matters (Dirkmaat & Adovasio, 1996).

Search Methods

Search methods are a vital part of crime scene investigations. The specific methods used vary depending on the size and location of the crime. When conducting a search in an enclosed location such as a home, a spiral, grid, or point-to-point search is best. When conducting a search in an outdoor location, such as a wooded setting, a line or grid method is the best to use.

Vanlaerhoven and Hughes (2008) compared various methods when searching for scavenged and scattered remains, and even indicate during their studies that not all parts were found. According to their study, they found that they could not conclusively say which method applied worked best; the outcome of each method depended on manpower available and the type of scavengers involved. Vanlaerhoven and Hughes (2008) did point out, however, that the simplest and most important aspect of a forensic investigation is the recovery of remains.

Outdoor locations provide searchers with many obstacles. Immovable objects such as trees, fences, or bodies of water become a problem. While a zone search is possible, it requires a lot of detail in preparing the scene for the search. A zone search involves dividing the area to be searched into multiple quadrants. Each quadrant becomes its own mini crime scene. A line search, also known as a lane or strip search, is flexible when it comes to set up. Currently, remains that are scattered on the surface (i.e. not buried) are recovered using a screening technique in conjunction with proper search methods to ensure buried remains are also recovered (Dirkmaat & Adovasio, 1996).

Line Search

The line search involves more than one person standing arms width apart at one end of the search area. Fields of vision should overlap so as not to miss any items of importance. The individuals then walk together across the scene to the other side of the predetermined boundary, taking care when brushing aside debris covering the ground.

When they feel they have found something that might be of importance they should mark the item with a flag. Law enforcement will then follow up with each flag, judge if it is relevant, and if so, process the find as evidence. The line search can be modified to use with fewer people.

For most large outdoor searches, the law enforcement community might have to rely upon volunteers from the local community. In the best-case scenario, law enforcement will be able to recruit extra personnel and volunteers so that the line of searchers extends the entire length of one side of the search perimeter, requiring only one pass. The volunteer searchers should never pick up or handle the item of evidence unless they have been trained and told to do so. The volunteers must be provided with instructions on how to conduct a search and what to do when they believe an item of relevance has been located.

Alternate Light Source

An ALS is typically used in forensic cases with fingerprints, trace evidence, or biological evidence. While trace evidence might fluoresce when just a light is shone on it, both fingerprints and biological evidence that cannot be seen with the naked eye require a chemical reagent be applied to the area so the ALS will illuminate the fingerprint or biological stain. Fingerprints will also require cyanoacrylate fuming prior to the application of the chemical agent. Due to the natural composition of bones and teeth, no chemical reagent or cyanoacrylate fuming is needed for them to fluoresce under the ALS.

An ALS will assist in the search for remains due to the composition of bones and teeth that cause them to fluoresce at certain wavelengths. The collagen component of bone is the compound that contributes most to a bone's fluorescence (Bachman & Ellis, 1965). Bachman and Ellis (1965) also describe the composition of bone as a matrix of the mineral apatite and the protein collagen.

Little research has been done as to whether bone will still fluoresce after being burned. If the bone has been significantly burned it will not fluoresce, however parts of a larger piece of bone that are less burned or that have been shielded from the fire will show some fluorescence. The organic components of the bone continue their exothermic reaction even after death. When bone is exposed to heat and becomes charred it will eventually calcine and lose all organic content and moisture. Since collagen is the organic compound that contributes to the fluorescence of bone, when this thermal reaction occurs and the bone loses its organic content, the bone will no longer fluoresce.

Using the ALS method requires the same set up as the line search noted previously, with the alteration that the individuals are searching at night and using the ALS with colored glasses instead of the naked eye. Combining a line search and the ALS search requires the individuals to participate in the day line search and return later (preferably that same night), covering the same area, in the same manner, this time with the ALS. At the very least, this ensures the search area is looked at twice in a systematic manner.

In their 1998 study, Craig and Vezaro discuss the positive implications for using an ALS. Craig and Vezaro (1998) used an ALS and conducted two experiments to try to distinguish bones and teeth from rocks of similar size and shape. They first compared the bones and rocks in a lab setting and then applied it to a known grave. The results in this study showed a strong fluorescence from the bones and teeth that made them easily distinguishable from the rocks. Several of the rocks included in the experiment even had an inherent fluorescence to attempt make it harder to distinguish the rocks from the bones. They state the fluorescence of the bones and teeth can lead to a positive victim identification and corroboration of other evidence that could lead to a successful prosecution. During their experiment, Craig and Vezaro (1998) also discussed several case studies in which an area known to have bone fragments was subjected to the ALS in order to locate fragments. During one such case, several skull fragments were missing from a victim at a “dump site”. The ALS was used in the victim’s car and several bone fragments were found. These bones were later identified as non-human bones the victim had been feeding to his dog (Craig & Vezaro, 1998).

The ALS has also been used in underwater research when attempting to distinguish bones and teeth from other materials found in underwater crime scenes. Christensen et al. (2014) discusses a more efficient practice involving the use of an ALS underwater. The researchers wanted to see if skeletal remains would fluoresce while underwater, thereby being distinguishable from the surrounding debris. Christensen et al. (2014) discovered it would be useful to include an ALS in underwater recovery methods as bone and teeth still visibly fluoresced. Divers are generally not trained to make the distinction between skeletal remains and surrounding marine material. By giving divers the ALS this will eliminate the need to bring everything to the surface for someone else to assess.

One concern for law enforcement is the relevance of this technique to cold cases. Remains that date back roughly fifty years can still have significance in unsolved crimes. Not only do bones fluoresce, Swaraldahab and Christensen (2016) discovered bone will fluoresce up to two hundred years (depending on taphonomy) postmortem. The study compared bones from recent, semi-recent, historic, and ancient collections. If remains are located and are still fluorescing, it is possible they are from a more recent time period as opposed to an ancient time period (and therefore not relevant in the medico-legal context).

Taphonomic Changes

In order to understand the relationship between searching for skeletonized remains and fluorescence, it is important to understand what happens to a skeleton postmortem. Taphonomy refers to the postmortem state of human remains. Taphonomic changes can occur for a variety of reasons to include weather, scavenger activity, soil conditions, and surrounding vegetation.

After death, the body begins to decompose and the organic material starts to break down. There are two chemical processes that occur immediately following death. Autolysis is the destruction of the body's cells by their own enzymes. Putrefaction is when the bacteria in the digestive system causes the deterioration of the body's tissues. As the soft tissues break down, the skeletal system becomes more exposed, and the chance of scattering of remains increases.

Remains may be scattered in a variety of manners. According to Haglund et al. (1989), the primary contributor to the scattering of remains are animals. As the body decomposes, various animals become attracted to it due to the odor given off by decomposition. Animals see the decomposing body as a source of food. Humans are also responsible for scattering remains, either by (accidental or purposeful) dismemberment or disarticulation (Dirkmaat & Adovasio, 1996). Another contributing factor to scattering remains is location. When remains are deposited, for example, at the top of an incline, as they decompose and become disarticulated, the bones can roll to the bottom of the incline. When searching for remains, it is important to take location and the surrounding terrain into account. Disarticulation can expose remains to other types of damage and thus reduce the remains into smaller parts that become disturbed more easily (Haglund, 1996a).

CHAPTER THREE: MATERIALS AND METHODS

Forty-eight domestic pig (*Sus scrofa*) bones and teeth, all measuring ≤ 1.5 inches in length, were labeled in pencil with the letters A-AV (Figure 1). The bones had been previously cleaned using warm water maceration. Since an initial search of the area should lead to the recovery of larger, more obvious bones, the bones chosen in this case were small and typical of the teeth, hand, and foot bones that might be missed during the initial scene search. Each of forty-eight orange pin flags were also labeled with the letters A-AV.

Figure 1: Remains A-AV

The Forensic Science Research and Excavation Dig Site on the campus of George Mason University was chosen because of its semi-controlled environment and the central location to the participants (Figure 2). The perimeter of the area was measured and the labeled orange pin flags were placed at random throughout the designated search area. The baseline was marked off one hundred three inches west from one corner and a twenty-five-foot measuring tape was placed in the north to south direction. Using baseline measuring technique, a second twenty-five-foot measuring tape was placed perpendicular to the first (baseline) until it reached the first orange pin flag. The baseline technique involves the use of a measuring tape placed through the middle of the scene, beginning at a fixed point (in this case the fence) and all measurements are taken at an angle perpendicular to this line (Table 1). This measurement was noted and the process was repeated for each of the forty-eight flags (Table 2). Once all the flag locations had been measured, a map was created for ease of collecting results (Figure 3). Prior to each search, the bones were placed and the flags were removed from the scene.

Figure 2: Search scene on 11/06/2016

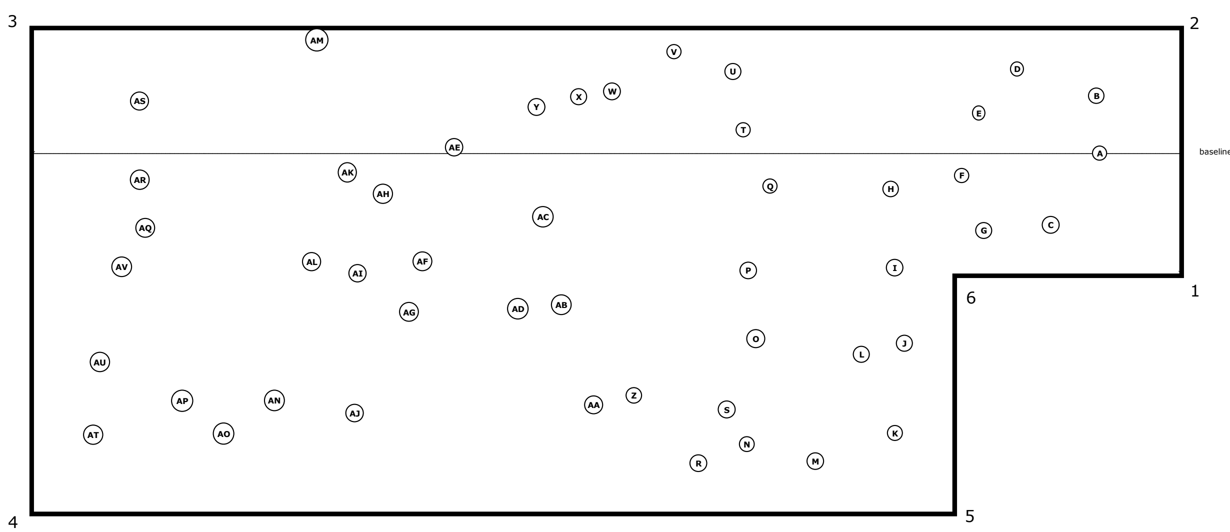

Figure 3: Map of remains

Table 1: Overall measurements of search scene (in feet and inches)

Side	***Length***
side 1 – side 2	16’ 0.5”
side 2 – side 3	69’ 9”
side 3 – side 4	37’ 4”
side 4 – side 5	61’ 6.5”
side 5 – side 6	17’ 1”
side 6 – side 1	16’ 3”
side 1 - baseline	8’ 7”

Table 2: Location of each remain (in feet and inches)

Bone	**Distance from side1/side2**	**Distance from baseline**
A	5’ 7”	3”
B	5’ 8”	-4’ 2”
C	9’ 3”	5’ 1.5”
D	11’ 6”	-5’ 10”
E	14’ 4”	-2’ 10”
F	15’ 7.5”	1’ 6”
G	14’ 1”	5’ 7.5”
H	20’ 8”	2’ 8.5”
I	20’ 4”	8’ 3”
J	19’ 7”	13’ 8.5”
K	20’ 4”	20’ 0.5”
L	22’ 9”	14’ 6”
M	26’ 1”	22’ 1”
N	30’ 11”	20’ 11.5”
O	30’ 3”	13’ 3.5”
P	28’ 9”	8’ 5”
Q	29’ 3.5”	2’ 4”
R	34’ 4”	22’ 2.5”
S	32’ 5”	18’ 4”

T	31’ 2”	-1’ 8.5”
U	32’	-5’ 10”
V	36’ 2.5”	-7’ 5”
W	40’ 8”	-4’ 4.5”
X	43’	-4’ 1”
Y	46’	-3’ 4.5”
Z	39’ 1”	17’ 6”
AA	42’	18’ 3”
AB	44’ 1”	11’ 0.5”
AC	45’ 7”	4’ 7”
AD	47’ 4”	11’ 3”
AE	52’ 4.5”	-2”
AF	54’ 3”	7’ 10”
AG	55’ 1”	11’ 6”
AH	57’ 1”	2’ 9.5”
AI	58’ 10”	8’ 7”
AJ	59’ 1”	18’ 6.5”
AK	59’ 8.5”	1’ 3”
AL	62’ 2”	7’ 9.5”
AM	62’	8’ 3”
AN	64’ 10”	17’ 7”
AO	68’ 6”	20’ 1”
AP	71’ 5”	17’ 8”
AQ	74’ 1”	5’ 4”
AR	74’ 5.5”	1’ 10.5”
AS	74’ 6”	3’ 8”
AT	77’ 9”	20’ 1”
AU	77’ 4”	15’ 0.5”
AV	75’ 9”	8’ 2.5”

Search teams consisted of volunteers who agreed to participate in one of the three search methods. None of the searchers were trained law enforcement personnel or forensic specialists. Inexperienced searchers were chosen due to their availability and to standardize search parameters. Not enough experienced searchers were available and mixing the experience level may have skewed the results. There were thirteen teams made up of two individuals each. Teams were recorded alphanumerically, so names were not associated with the results, beginning with 1A1B and finishing with 15A15B, where the number corresponds to which round of the search they were performing and the letter indicates the team member.

Teams 1A1B through 4A4B performed the day only search, teams 6A6B through 9A9B performed the night only search, and teams 11A11B through 15A15B performed the combination search. Since the latter teams had to return to conduct their night search, their day search rounds ranged from 11-15 and their night search rounds ranged from 16-20 so as not to confuse which search was being performed. The teams that performed the combination search (e.g. returning at night after their day search) were only looking to find the remains they did not locate in the original day search. They did not have to look again for the remains they had found previously. To achieve this, the pin flags indicating the remains they had previously found were left in place and the bones removed, ensuring only the bones not recovered were available to locate. Prior to the first team that conducted a night search, round 6 – team 6A6B, they were given the orange and yellow glasses and shown what remains looked like under each wavelength to determine which yielded the brightest fluorescence and best visibility (Figure 4 / Figure 5). It was for this reason the 450nm wavelength was used.

Figure 4: Bones under orange glasses

Figure 5: Bones under yellow glasses

For this research, the line search was chosen because of the many obstacles impeding the path of searchers. It is also the simplest method and easiest to understand and follow for searchers not familiar with forensic procedures.

Upon the arrival of each team of two, they were led into the search area and handed a copy of the Search Directions (Appendix 1). The teams were shown a small bag of additional *Sus scrofa* bone and tooth fragments as reference. The perimeter of the search area was discussed and any questions were answered. As the teams began, a timer was started and the date, time, and weather conditions were noted.

As the teams found items believed to be of interest, the item was confirmed by the letter indicated on it to be part of this experiment and was then circled in marking pen (light blue for day searches and dark blue for night searches) on the map designated for that team. The bone was replaced with the corresponding orange pin flag. Once the team reached the end of the search area, the timer was stopped, duration noted, and the located remains were tallied. For the purposes of this research, a time limit was not imposed. Duration of the search was noted to observe possible practical applications of conducting a search in the manner proposed.

In the case of searching at night, there was little variation in the directions and search procedure. Prior to the start of each night search, the teams were each given a pair of orange lens or yellow lens glasses, along with the ALS. The ALS in this case was a Rofin Poli*Light-Flare® Plus*. The light is a hand-held rechargeable flashlight with interchangeable LED heads in varying wavelengths. The colored glasses are required as eye protection from the 450nm wavelength of light emitted by the ALS; at this wavelength, there is potential for retinal damage. The color on the glasses also blocks out incident light, allowing the wearer to more clearly see the fluorescence.

Documentation occurred on individual maps for each search team as well as in spreadsheet format; both showing which bone (by letter) was found each time. Graphs were used to show overall trends and data. Since the weather and dates were recorded for each search, it was noted how weather may have had an impact on the searches. The remains were originally placed in November, prior to the first team beginning their day search. Leaf coverage was average and typical for the area. It had been a mild fall at that point and the leaves had not completely fallen from the trees.

A statistical analysis was conducted on the results of each team using the program Minitab®. The test of two proportions compared the number of bones found with the number of possible bones the searchers could find. This tested the proportions using Fisher's Exact; a significance test used when the numbers and the sample sizes are small. Another statistical analysis conducted were t-tests in Microsoft Excel to determine if the mean (average number of remains found) in the sets of data were significantly different.

CHAPTER FOUR: RESULTS

No time limit was imposed on the search teams; however, duration of search was noted. The shortest time was thirty-four minutes and the longest time was two hours and seventeen minutes. On average, the day only teams searched for one hour twenty-six minutes and the night only teams searched for fifty-seven minutes. The combination teams, when combining their day and night searches, searched for an average of two hours fifty-six minutes when breaking it down to each search, they searched for one hour twenty-eight minutes.

Summary statistics for the number of bones found by each group are shown in Table 3. The standard error is a measure of statistical accuracy. The smaller the spread, the more accurate the data set is said to be. The standard deviation measures how spread out the numbers are from the mean. Mean, median, and mode calculations give the average, middle number, and number that appears most often, respectively.

Table 3: Summary statistics of each search type

Day		*Night*		*Day & Night*	
Mean	19	Mean	33	Mean	37.4
Standard Error	2.677063067	Standard Error	2.121320344	Standard Error	2.204540769
Median	18.5	Median	34.5	Median	38
Mode	#N/A	Mode	36	Mode	#N/A
Standard Deviation	5.354126135	Standard Deviation	4.242640687	Standard Deviation	4.929503018
Sample Variance	28.66666667	Sample Variance	18	Sample Variance	24.3
Kurtosis	1.5	Kurtosis	1.5	Kurtosis	-1.727887009
Skewness	0.547284932	Skewness	-1.414213562	Skewness	-0.274654354
Range	13	Range	9	Range	12
Minimum	13	Minimum	27	Minimum	31
Maximum	26	Maximum	36	Maximum	43
Sum	76	Sum	132	Sum	187
Count	4	Count	4	Count	5

The day line search only teams (1A1B – 4A4B) found an average of 19 remains, the night ALS search only teams (6A6B – 9A9B) found an average of 33 remains, and the day/night combination search teams found an average of 37.4 remains. Figure 6 shows the average number of bones found by each search type, Figure 7 and Figure 8 show the total number of remains found by each group.

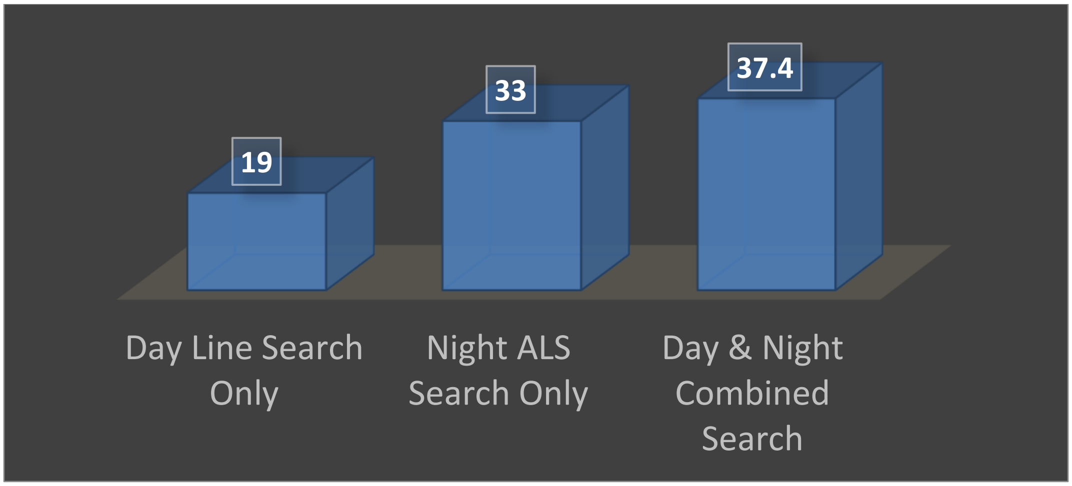

Figure 6: Average number of bones found by search type

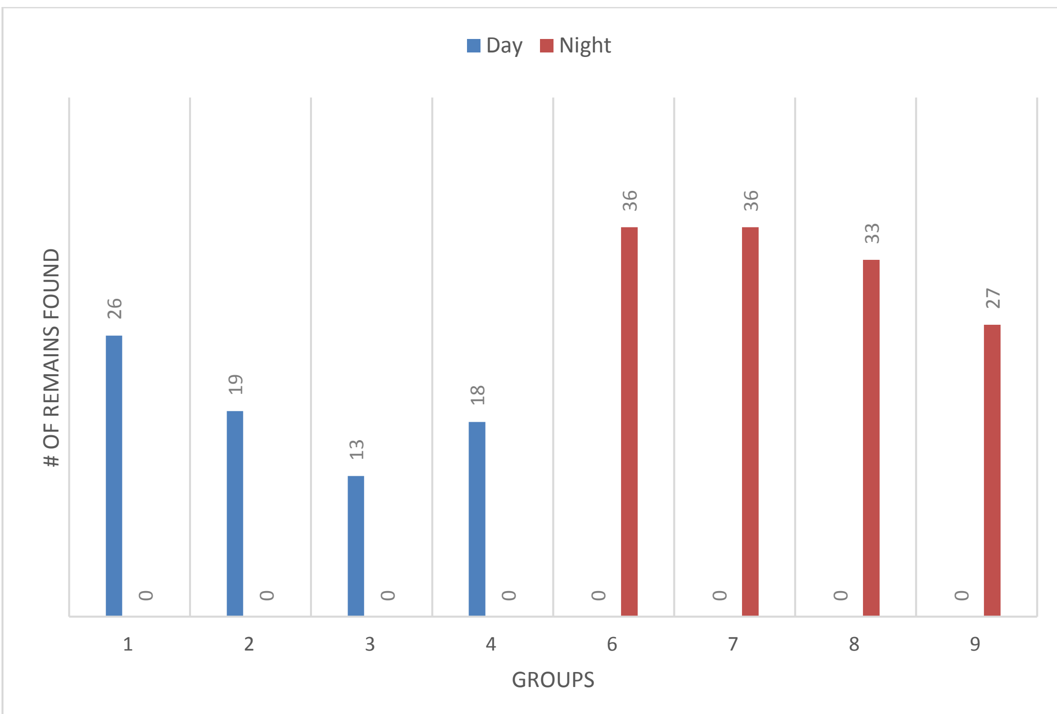

Figure 7: Number of remains found when using one method

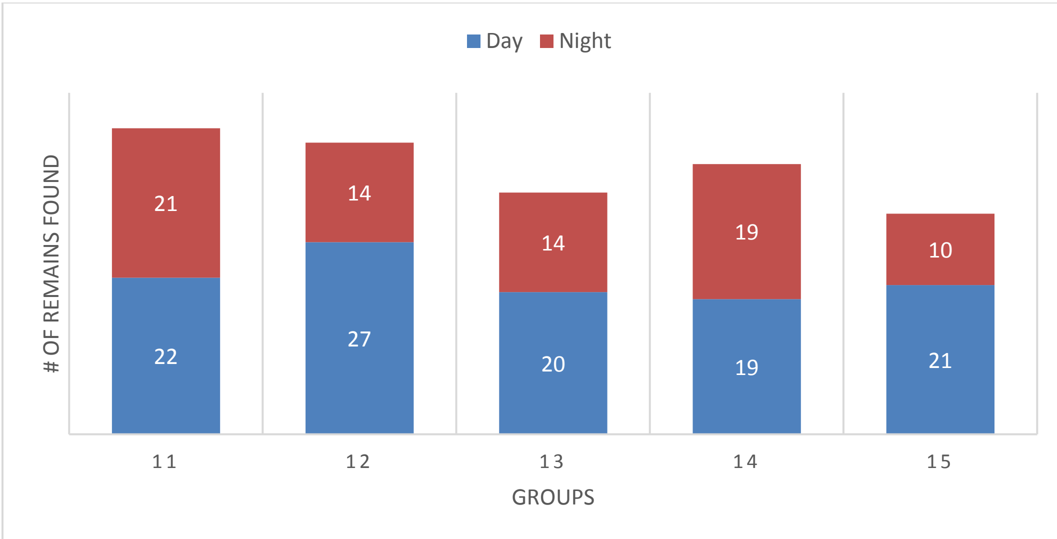

Figure 8: Number of remains found when combining methods

Data Analysis

A test of proportions was conducted using the program Minitab® to compare the total proportions of bones found by each group. The proportion was calculated using the total number of bones found by all searches in the group divided by the total number of bones the searchers could find. The day group found about 40% of possible bones, the night group found 68% of possible bones, and the combination group found 78% of possible bones (Table 4). Differences were significant between all groups. The day versus night search shows $p < 0.0001$ as does the day versus day/night combination search. The calculation comparing the night versus day/night combination shows $p < 0.05$ (Table 5).

Table 4: Proportion of total bones found by search group

Search Group	***Proportion of Total Bones Found***
Day Only	0.395833
Night Only	0.687500
Combination Day/Night	0.779167

Table 5: P-value proportion by search group

Search Group Comparison	***P-value***
Day vs. Night	< 0.001
Night vs. Combination	< 0.05
Day vs. Combination	< 0.001

The t-tests conducted in Microsoft Excel were looking at averages for the total number of bones found instead of proportions of the total. When looking at the total number of bones found as averages and conducting the t-test, the p-values for day search versus night search and day search versus combination search show the p-value = <0.01 and the p-value = 0.201 for the night search versus the combination search. Since the p-value is not < 0.05, based on the averages this is not statistically significant (Table 6). The overall differences in averages between the day searches and the night searches as well as the day searches and the combination searches are very different while the difference between the night searches and the combination searches are less different.

Table 6: T-test of averages by search group

Search Group Comparison	***P-value***
Day vs. Night	< 0.05
Night vs. Combination	> 0.05
Day vs. Combination	< 0.05

CHAPTER FIVE: DISCUSSION

There was some variation in which remains were found by the groups with some found every time and a few not found at all. There were seven remains found during every search and eight found during almost every search. The assumption being because the area where they were ended up with little to no leaf coverage and they were essentially sitting out in the open. There were fourteen items found least number of times and three not found at all. Assuming this is because there was significant leaf coverage that ended up in that section of the search area, the search teams were not able to find these remains as frequently. Figure 9 shows the location of these remains. The items circled in green indicate the remains found most often, the items circled in purple indicate the remains that were found least often, and the items circled in red indicate the remains that were not found at all during the searches. As time passed and more leaves fell, December brought some very windy days. The increase in wind caused the leaves to move south towards the center of the research area. It was noted that once all the leaves had fallen, searches were more difficult and it was less likely the remains in the center of the search site were located.

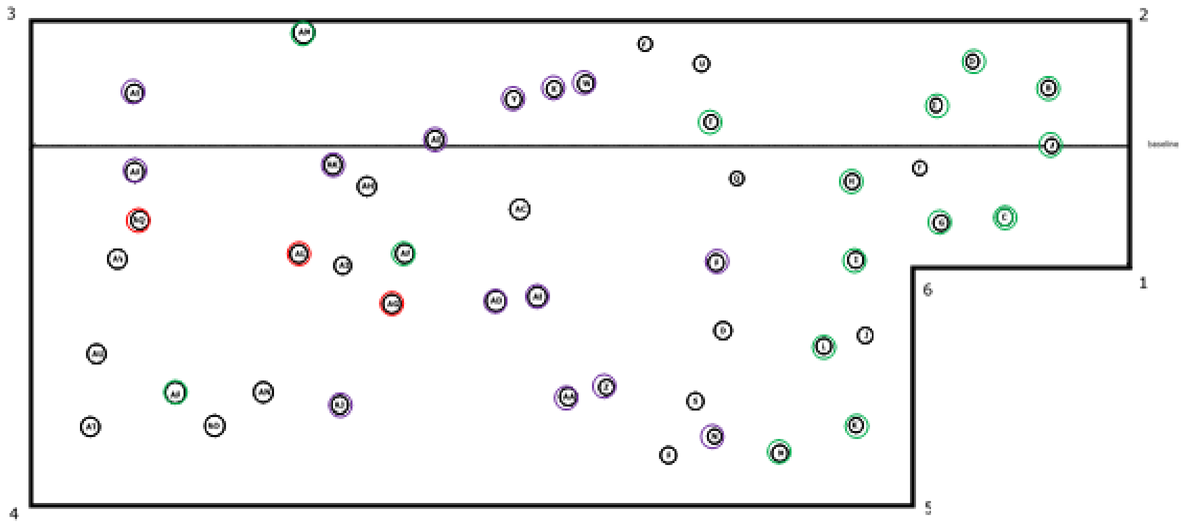

Figure 9: Frequency of finds

There was variation noted in the direction of travel for the search teams. Six teams chose to work in a west-to-east direction while the other seven teams chose to work south-to-north. Four teams used long tree branches to move debris instead of using their feet or hands. Another observation noted for three of the teams conducting the combination day and night searches was the realization that it was helpful to scan the surface area ahead of them before they moved anything out of the way to look under the leaves. Some remains were missed when the teams immediately started clearing things out of the way. One of the night search teams discovered that during their search if one partner walked backwards using two sticks to clear everything while the other partner walked forward shining the ALS, this was a very efficient way of locating remains.

Figure 10 depicts nine bones scattered among rocks and leaves in the daylight. Although there are nine bones in the picture, the bones are harder to distinguish from surrounding leaves and other debris unless the searcher is standing over them (Figure 11).

Figure 10: Nine bones in daylight

Figure 11: Four bones in daylight

Each night group noticed there was a certain type of leaf, stick, or moss that fluoresced in a similar manner to the bones and teeth. This caused a pause and double check prior to moving on with the search. Surprisingly, there was little confusion between "glowing" rocks and fluorescing teeth and bones. Originally it was thought this would be a problem as many of the rocks at the research site were white to the naked eye. The night groups also noted that, with the use of only one ALS, there were two "methods" of approach that made the search easier and go smoothly. Holding the light and stick (if used) in the same hand while searching, essentially making it one piece of equipment, was a lot easier than trying to maneuver both the stick and the ALS. This practice was seemingly made necessary because of the limited number of searchers in each team, as well as only having one ALS.

A night search poses many hazards one may not come across on a search during the day. In a wooded area, similar to the one for this research, there are hazards that include but are not limited to: uneven terrain, fallen trees, thorn bushes, loose tree branches, vines, and rocks. These hazards could all be out in the open (and, therefore, visible during a day search) or hidden under layers of leaves, as was the situation with this research.

A precaution to take when conducting a search at night, in a possibly hazardous wooded area similar to this one, would include having a "spotter." The spotter would walk off to the side of the searchers with a standard flashlight keeping an eye out for items that could become hazardous and pointing them out as necessary. A spotter was used successfully for the night searches during this experiment. It should be noted and was verified, it is not possible to see the fluorescing remains if the flashlight beam crosses the path of the ALS beam. If the spotter or one of the searchers has a regular flashlight, it should be pointed away from the direct area being searched.

Limitations

As with all research, there were noted limitations to this research project. For this research, a small wooded area was used with inexperienced searchers. Ericsson and Lehman (1996) discovered that experienced searchers are better at adapting to the environment they are searching in than inexperienced searchers. Experienced searchers may draw on past experience in order to have a "list" of places likely to conceal items of evidence (Baber & Butler, 2012). Inexperienced searchers were chosen for the research because of their availability and so as not to skew any results by mixing experienced search groups with inexperienced search groups. The belief is with more experienced searchers, more remains might have been found; they may have alternate debris clearing techniques that have proven successful in the past.

With the exception of team 15A15B, the teams that participated in the combination method of searching, did not come back the same day after completing their day search. This resulted in changes to the terrain between searches; the biggest change being leaf coverage. While this was not ideal for research purposes, it does create a more true-to-life scenario.

When closing in on the two-hour mark for some groups, the ALS would flash on and off a few times, then remain on. Since the ALS is portable, a definite limitation is battery life. This could be avoided by having multiple batteries on hand and switching out the light as needed.

Law enforcement departments are typically on a tight budget. While it would only be a one-time cost, the ALS may not be affordably priced for some smaller departments. At the time of this writing, a top-of-the-line kit, complete with eight rechargeable flashlights and LED heads, a case that doubles as a charger, and the appropriate eyewear, can run upwards of $14,987 (Arrowhead Forensics, 2017). The more basic kit, with three rechargeable flashlight packs and LED heads, still comes in at $5,782 (Arrowhead Forensics, 2017). A single rechargeable flashlight and LED head can range in cost from $1,859 - $2,052, depending on the wavelength of the LED (Arrowhead Forensics, 2017). It would be advantageous if departments are able to afford more than one ALS at a time as it was discovered during the course of this research that two searchers would have a hard time looking for remains with only one light and the small beam it produces. For this research, one ALS and two searchers proved a challenge in the dark, as they had to work well as a team to ensure the searcher not holding the ALS was not just looking at a darkened search area. Despite this struggle, the teams were still able to locate almost 80% of the remains.

During this research, the remains were collected as each group found them to ensure scavengers or people did not make off with them between searches. Prior to each new team, the remains were placed in their positions again. This process made sense for the semi-uncontrolled environment in this research. This did ensure that most of the remains were closer to the surface and, therefore, more visible than the ones that were not found by the team before them. The remains that were not located by the previous team were left in situ and were further buried under the leaves and debris as each team moved through.

When conducting an experiment, sample size is always something to consider. This research was conducted with four to five teams of two in each method, a relatively small sample size. Instead of creating a full line of searchers along one side of the search area, as is the case with a traditional line search, the small sample size required teams to weave back and forth through the scene. An experiment conducted with more groups (possibly of varying sizes) to test each method would allow for a better picture of whether this theory is statistically significant on a much bigger scale.

The ALS is not a "one-situation-fits-all"; it requires the bones and teeth to be very close to the surface, as the ALS cannot penetrate debris or soil. Bones and teeth that have been subjected to weather conditions may not fluoresce as much as remains that have not been subjected to weather. This is also the case for bones that have been compressed in the soil (e.g. from being walked on) and end up covered. The fluorescence in these situations will not be as visible.

A final limitation involving ALS is that it can only detect the *fluorescence* of bone and teeth. Human remains are not the only ones that will fluoresce; remains from any animal will also fluoresce. When using this method in real world applications, it is still necessary to conduct confirmatory tests to discover whether the remains are human or non-human.

Future Directions

More research should be conducted to include various factors not addressed in this research. Varying terrain, weather conditions, or location may yield different results than in this research. Another point of interest would be to see the effectiveness of the ALS on remains that had not been previously processed (intact remains compared to disarticulated, processed remains). A more controlled environment would allow the test remains to be left out after each search without fear of tampering. In future research, it might be necessary to compare experienced searchers, members of the forensic community, or law enforcement to members of the general public in order to identify any issues with searchers and their knowledge or experience. This study focused on a line search. Future studies would benefit from applying the use of an ALS to other relevant search methods.

More research should also be conducted into the general scope of crime scene searches. Time pressure related to searching a scene can have an impact on the actual search (Smith et al., 2008). There might be cases where this influences the overall search and the results drawn from it.

CHAPTER SIX: CONCLUSION

This research demonstrated that combining a line search during the day with an ALS search at night will significantly increase the number of bones and teeth found in an outdoor wooded area. This research also demonstrated that combining these methods as indicated will ensure law enforcement has the best idea of what occurred during the incident. It also demonstrated using an ALS in a wooded setting is possible when searching for remains. When searching for trace evidence, biological fluid evidence, or fingerprints, it is sometimes necessary to use a chemical reagent for fluorescence to occur. This is not the case with bones and teeth, eliminating the need for the extra step when searching for skeletal remains. While not currently common practice, Dirkmaat & Adovasio (1996), stated in their research that there are benefits to returning to the scene after recovery to search for and collect additional evidence.

When skeletal remains are discovered and the scene is marked off, it is common practice to take advantage of the daylight. During a night scene, flood lights are brought in and the searchers always return the next morning to finish searching. To ensure the highest number of remains are collected, it is best for the searches to be conducted during the day, then repeated at night using an ALS. This combination of searching should be brought into standard practice for law enforcement agencies. Combining search methods yielded an average of eighteen more remains than when only searching during the day.

78% of remains were recovered when combining search methods while only 40% of remains were recovered using the current standard of a daytime only search.

APPENDIX

Appendix 3: Search Directions

Research hypothesis: Using an Alternate Light Source to perform a line search when trying to locate skeletal remains will increase the number of bones collected when compared to using these methods alone.

The most common search method for an outdoor crime scene/recovery of remains is the line search.

- Form a line at one end of the search area, standing arm's length apart
- Be sure the line of vision overlaps so as not to miss any evidence
- Walk forward at a slow pace, paying attention to the small area surrounding you
- Gently brush aside leaves and debris as necessary but take care not to disturb any possible remains
- When you find something that might be of relevance, let the researcher know
    - Do not remove the item of evidence
- When you reach the opposite end of the search area from where you started, begin the back-and-forth pattern
    - Repeat until the end of the search area

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