EXAMINATION OF THE DURATION OF IMMERSION IN WATER AND EXTENT OF PRUNING OBSERVED ON FINGERTIPS

by

Sheena M. Ross

A Research Project
Submitted to the
Forensic Science Forensic Research Committee
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Master of Science
Forensic Science

Primary Research Advisor
Andrea Zaferes
Medicolegal Death Investigator, Consultant, Instructor
Dutchess County Medical Examiner Office
Forensic Aquatic Consulting & Training, LLC
Lifeguard Systems

Secondary Research Advisor
Shelly Herold
Forensic Science Consultant Program Manager
Office of Special Investigations

GMU Graduate Research Coordinator
Dr. Joseph A. DiZinno
Associate Professor
GMU Forensic Science Program

Spring Semester 2022
George Mason University
Fairfax, VA

ACKNOWLEDGMENTS

I would like to thank my family and colleagues for their support, and the volunteers who dedicated many hours of their time to make this research possible. Thank you to my advisors, Inv Andrea Zaferes, Special Agent Shelly Herold, and Special Agent Elizabeth Richards, Ph.D., for their guidance, feedback, reassurances, and mentorship in developing this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND/OR SYMBOLS

Degrees Fahrenheit .... °F
Degrees Celsius .... °C
Digital Single Lens Reflex .... DSLR
Null Hypothesis .... H_0
Millimeters .... mm
Microns/Micrometer .... μm
Percent .... %
Potential of Hydrogen .... pH

Abstract

EXAMINATION OF THE DURATION OF IMMERSION IN WATER AND EXTENT OF PRUNING OBSERVED ON FINGERTIPS

Sheena M. Ross

George Mason University, 2022

Graduate Research Coordinator: Dr. Joseph A. DiZinno

In the realm of forensic science, fingers are normally thought of as evidence for identification; however, it is imperative that the forensic science community understands other valuable evidence that fingers can provide in aquatic medicolegal death investigations and criminal nonfatal investigations. This research project examined the development of fingertip pruning during 120 minutes of immersion in warm tap water that was allowed to cool, instead of being held constant. Additionally, this research examined the dissipation of fingertip pruning for 60 minutes after removal from the water. This research utilized ImageJ, an image analysis software, to provide two measures of quantitative results: the amount of swelling of individual friction ridges at each time interval and the percentage of the overall fingertip surface area with visible pruning. The findings of this study indicated that friction ridges increased in width as the duration of immersion increased, with some variation. Additionally, the percentage of surface area covered by pruning had a strong correlation between duration of immersion in water and duration of time removed from water. Lastly, the changes in the fingertip condition occurred quickly, within 20 minutes, and even after two hours of water immersion, the most obvious presence of pruning dissipated within 30 minutes; this supported that fingertip pruning should be treated as transient evidence in aquatic criminal investigations.

INTRODUCTION

The forensic science community and crime scene investigation rely on the accumulation of circumstantial evidence and facts to support a hypothesis of what occurred during the commission of a crime. Finding and analyzing evidence often requires deductive reasoning but this skill can be neglected and overlooked during investigations. For example, fingers and fingerprints are normally thought of as qualitative evidence used for identification. However, it is imperative that the forensic science field utilizes deductive reasoning and discerns what other valuable evidence that fingers can provide in aquatic investigations. This research addresses the importance of evidence findings in aquatic investigations, specifically the phenomenon of skin wrinkling after immersion in water.

Research Questions

This research answered the following: 1) the correlation between duration of immersion in water and the development of pruning, 2) the correlation between duration of immersion of removal from water and the dissipation of pruning, and 3) the applicability of pruning as transient evidence. Previous research into pruning skin used both macroscopic and microscopic assessments of changes to the skin after immersion in water. This research was designed to benefit crime scene investigation and therefore, a digital camera was used. A Digital Single-Lens Reflex (DSLR) camera provides more detail than the macroscopic assessments and less detail than the microscopic assessments; therefore, this research also answered if a DSLR camera provided enough detail for reliable quantitative data.

Goal and Objective

The primary objective of this research was to mimic the factors of residential aquatic death scenes that involved a bathtub. This was the most beneficial design during the planning process, given time and equipment constraints. Essentially, this research serves as a baseline study for future research. The goal of this research was twofold: 1) to conduct an experiment that could be as controlled as possible, and 2) to provide a solid foundation of data that future research could use to address complex scenes involving more human and environmental factors.

Importance of Research

Currently, there are no national standards for aquatic medicolegal death investigation response. Basic textbook recommendations do not specify more details other than documenting the body's condition (Armstrong & Erksine, 2018). That said, skin pruning has been a factor in criminal investigations, such as *People v. Szatanek*, 169 A.D.3d 1448, 92 N.Y.S.3d 516 (N.Y. App. Div. 2019). In these cases, those conducting the investigative and litigation processes would have benefited greatly by having appropriate knowledge and training on the importance of skin pruning evidence. This research can apply across various situations, including negligent, accidental, suicidal, or homicidal scenes. The findings may not determine what occurred independently; however, the findings can serve as supporting circumstantial evidence much like most of the evidence collected during investigations. The results of this research will have a direct impact on crime scene response and documentation by supporting the necessity of treating finger pruning as transient evidence that must be documented immediately.

Background

History

Friction ridge impressions utilized as a means for identification date back to approximately 221 B.C. in ancient China during the Qin Dynasty (Barnes, 2011). The use of friction ridges as a mode of identification is well documented in China, Japan, and India, all of which predate European 'discovery' (Barnes, 2011). Then, in the late 17th century, Europeans began to study fingerprints and Sir Francis Galton was commonly credited as the first to scientifically show how fingerprints could be used for identification purposes (Barnes, 2011). Given the extensive history and research into friction ridge impressions and identification, there has been little scientific thought given to what other evidence fingers and friction ridges can provide to a criminal investigation.

Aquatic Deaths

Drowning is considered a public health threat, resulting in 372,000 deaths worldwide (WHO, 2014). In the U.S., drowning is the tenth most common type of death due to injury. In 2016, there were 4,628 fatal drownings in the U.S. (CDC, 2017). It may be presumed that water-related deaths are accidental drownings; however, other possibilities must be considered during the investigation of these types of deaths, as drowning as a cause of death is a diagnosis based on the exclusion of other potential causes (Armstrong & Erksine, 2018). Water investigations can be complicated in that they are commonly labeled as accidental drownings, which harms the ability to recognize and document indicators of foul play (Armstrong & Erksine, 2018). The cause of death of a body found in or near water should not be immediately presumed as drowning. The death could be accidental, suicidal, homicidal, or drowning caused by underlying health condition (Armstrong & Erksine, 2018). Suicidal and homicidal drownings are less common, yet significant. The number of U.S. suicides by drowning ranged from one to nine percent of suicides, depending on geographic location and access to bodies of water (Wirthwein et al., 2001; Byard et al., 2001). There were fewer drownings attributed to homicide (Modell et al., 1999). Nevertheless, water is an important variable in any investigation where the body is partially or fully immersed in water or when witnesses report they removed the body from water, to include non-fatal neglect investigations. Proper assessment of the body, to include the extent of pruning skin, will provide investigations evidence to support or refute witness statements, and to better determine approximately how long a body may have been in water.

Postmortem Submersion Interval

Most forensic studies related to bodies in water assess the Postmortem Submersion Interval (PMSI), the period between entry into water and recovery of the body. The purpose of those studies was to determine the ability to accurately predict how long a body was in the water. PMSI assessment was based on an aquatic decomposition scoring list separated into three parts: face aquatic decomposition score (FADS), torso decomposition score (TADS), and limb aquatic decomposition score (LADS) (Heaton et al., 2010; van Daalen et al., 2017). Studies also estimated the PMSI based on insect activity (Wallace et al., 2008) and bacteria (Dickson et al., 2011; Benbow et al., 2015). Although PMSI was relevant to this study in that it was used to assess bodies in water, the research findings were limited as most of the bodies were typically further along in decomposition. Once a body displayed advanced decomposition such as marbling, bloating, sloughing, or skin slippage, skin pruning was no longer relevant. The LADS listed nine levels of descriptive stages; this research project findings were limited to stages one (*no visible changes*) and two (*mild wrinkling of skin on hands and/or feet. Possible goose pimpling*). Any further along into body decomposition, wrinkling was not as relevant since there were other clear indicators of decomposition suggesting a longer time interval.

Experimental Design

This was a quantitative research project that was designed as a causal comparative study. This research was accomplished by conducting an experiment on five adult subjects who immersed their right hands in water. The researcher then assessed the relationship between duration of water immersion and the development of skin pruning. Additionally, this research assessed the relationship between duration of time after removal from water immersion and the dissipation of skin pruning. Overall photos were obtained prior to water immersion and during the drying phase. Close up photos were obtained throughout the experiment, during both the immersion and drying phase. Subjects were required to have a minimum of 48 hours between sessions and were also asked to ensure that no swimming, soaking in a bathtub, or other extended water immersion activity occurred within 48 hours of each session.

The close-up images were analyzed in image analysis software to provide the findings. Part one of the analysis measured the width of one friction ridge across the 60-image series for each subject. The identified friction ridges were not required to be in the same general area for each subject. The basis for identifying a ridge was based solely on the best quality image and focus for analysis. Part two of the analysis assessed the percentage of surface area affected by pruning across the 60-image series. This was accomplished by using a grid overlay composed of $1mm^2$ squares. A square was classified as affected by pruning if 100% of the square showed indication of pruning, no matter how slight. The hypothesis was duration of immersion in water affected ridge width and overall surface area pruning. Therefore, the null hypothesis was duration of immersion affected neither ridge width nor surface area pruning. Linear regression was performed to calculate correlation and significance for each portion.

LITERATURE REVIEW

For the purpose of this research and paper, the terms ‘pruning’ and ‘wrinkling’ were used interchangeably for what was previously referred to as “washerwoman’s hands” in historical research.

Reh (1984), a German forensic pathologist, conducted research on the development of “washerwoman’s hands.” Reh used cadavers that were deceased between one and ten hours prior to the experiment, without any desiccation lines on the fingers. Researchers immersed the hands in water ranging from 10-18°C (approximately 50-64.4°F). The duration of the experiments did not exceed 300 minutes. Initial formation of washerwoman's skin at the fingertips was observed at 20-30 minutes and the entire finger was affected by this phenomenon after 50-60 minutes. Reh noted some outliers that took longer to display total coverage, which were attributed to an abnormal callous or fat strip underneath the skin. All findings were macroscopically analyzed without optical aids. Reh concluded that washerwoman's skin depended on water temperature and disappeared slowly in open air. Reh asserted the need for further investigation to determine the duration of immersion in water that would result in irreversible evidence of skin wrinkling. Reh's research provided a general basis for this research project, with water temperature and rate of dissipation as important factors for further study and verification.

Weber (1978) documented microscopic results of water immersion for 120 minutes. Microscopic images were analyzed using a 1μm scale; a singular pore on a friction ridge served as a measurement point. The findings indicated a positive correlation between the duration in water and the percentage increase in ridge width, with first evidence of swelling occurring at five minutes. Additionally, the study showed that deceased bodies resulted in similar quantitative results in the swelling changes in the skin ridge width compared to living subjects. Sixty minutes after removal in a 20°C (68°F) room, the wrinkles completely dissipated on living subjects.

Weber (1984) published the first results on the qualitative and quantitative time-related changes regarding washerwoman's hands. This research examined 50 fingertips on 35 corpses, both male and female, between one to four hours postmortem. The hands were immersed in a constant 37°C (98.6°F) city tap water for 24 hours; immersion was interrupted at set intervals, with the interruption lasting between 30-60 seconds. Quantitative results determined no significant difference in friction ridge width between the left and right hands, between the sexes, or between ages. Importantly, the age range of bodies studied was 18-92 years old. Ridges appeared to influence each other during aqueous swelling. Qualitative results identified six time-related stages. Weber's research provided a more structured and systematic framework compared to Reh's design and offered more details on possible variables. Weber's methods were utilized to develop this research methodology; however, details were modified to remain beneficial to the framework of crime scene investigation, for example, using a DSLR camera instead of a microscope. Additionally, this research fell within stages 1-3 as defined in Weber's research: Stage 1, normal state – zero minutes, Stage 2, Wetting – ten minutes, and Stage 3, Swelling – up to four hours in water.

Scientific studies related to PMSI have been conducted. The conditions and variables of those PMSI studies were relevant to this research project, despite their original purpose was related to taphonomy. In 1967 and 1969, Reh published a table for the estimation of the time interval of immersion (Madea & Doerentz, 2010-11). His findings found a high correlation between water temperature and progression of decomposition. Additionally, a 2010 U.K. study also attempted to create a tool to estimate PMSI. The U.K. study demonstrated that decomposition was strongly related to time and temperature and that decomposition did not differ significantly among aquatic environments (Heaton, Lagden, Moffatt, & Simmons, 2010). The aquatic environments in Heaton et al. were various freshwater locations throughout the U.K. and did not involve any saltwater variables. The results of these studies were valuable in that they show correlation of water temperature to decomposition and that varying fresh water sources may not greatly impact body changes. Reh 1967, 1969; Reh et al. 1977; Weber 1978, 1982 also supported that speed and intensity of wrinkling depend on water temperature and duration of immersion in water. These findings were applicable to the development of pruning.

METHODS AND MATERIALS

Materials

1. 7-Gallon MDX Tote
2. Metric Ruler, metal
3. Foam Backing
4. Nikon D700
5. Nikon D5600
6. Tripod
7. Ring Light
8. Speed Flash
9. Digital Ambient Thermometer
10. Digital Probe Thermometer, liquid
11. Water Test Strips
12. Refractometer
13. ImageJ Software

Methods

Pilot Test

Prior to beginning the experiment with subjects, the student researcher conducted a pilot test to determine appropriate materials and methods. First, the cooling rate of water in a bathtub was compared to the cooling rate of a MDX container over approximately two hours. The cooling rate differed by 3.1%. The assumption was that the cooling rates were similar enough to consider the container an acceptable substitution for a bathtub during the study.

Secondly, the student researcher conducted a self-test to anecdotally assess the first onset and development of pruning over 120 minutes. The intervals selected were similar to the intervals used in Weber 1978 and Weber 1984. The decision to end immersion at 120 minutes was for practical reasons considering the test subjects were living and discomfort needed to be limited. Additionally, Weber utilized the same immersion time in the 1978 study for his living subjects and was able to make conclusive findings related to pruning skin without needing a longer interval.

Preparation Protocol

This study involved five living, female subjects who each participated in five repetitions of the study. Subject B, however, was only able to accomplish three of the five repetitions. The 7-gal container was disinfected before each use and then rinsed with water to remove any chemical remnants. The container was filled with Virginia or Maryland tap water to an approximate six-inch depth, which equated to approximately four gallons. Varify Drinking Water Test Strips were used to measure pH values, with an acceptable range between 6.5-7. A refractometer was calibrated and utilized to ensure the water salinity was <0.05%. A Thomas Scientific© solar thermometer ideal for measuring liquid temperatures was used to measure the water temperature. The thermometer was calibrated to standards provided by the National Institute of Standards and Technology (NIST), which remained current until June 2023. The probe was submerged in the water to an approximate thee-inch depth to ensure the starting temperature was 95°F. Additionally, a Thomas Scientific© Thermometer and Humidity Monitor was used to monitor the ambient environment. The thermometer was calibrated to

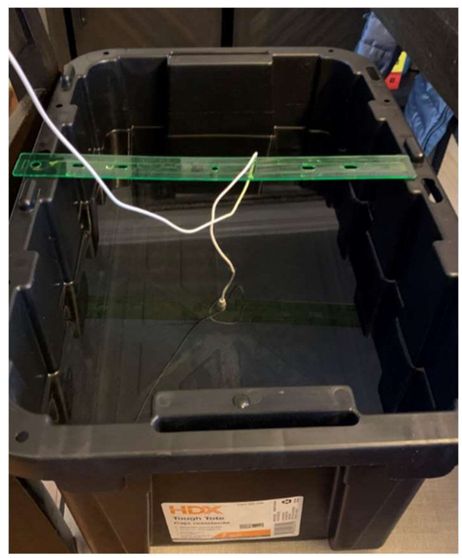

Figure 1 Container set up with probe thermometer.

standards provided by the NIST, which remained current until August 2023. An acceptable range of ambient temperature was 69-74°F. This range was selected to best replicate average home temperatures, with a limited 5°F temperature range for a more controlled testing environment. Throughout this research, humidity ranged from 25-35%, with one repetition at 50% humidity. Humidity was not a controlled variable.

Subject Set Up Protocol

The student researcher directed subjects to wash their hands with soap, using lukewarm water for at least 20 seconds for the purpose of removing any barriers and contaminants on the skin that could impact results. Subjects then lightly pat-dried their hands using a towel or paper towel. This same methodology for drying was used throughout the session to prevent any disruption or changes to the pruning skin. Once dry, overall photographs were taken of the right hand alone and then right and left hands side by side for comparison. The overall images were obtained using a Nikon D5600 DSLR camera. Then a close-up image was obtained of the right hand's middle fingertip, utilizing a Nikon D700 DSLR camera attached to an inverted tripod. The subjects were directed to center their finger in a 1" drawn square on the foam backdrop. The purpose was to better control the positioning of the finger, which would facilitate image analysis. A ring light was placed around the camera lens to provide even lighting, preventing any lighting issues from a speed flash during macrophotography.

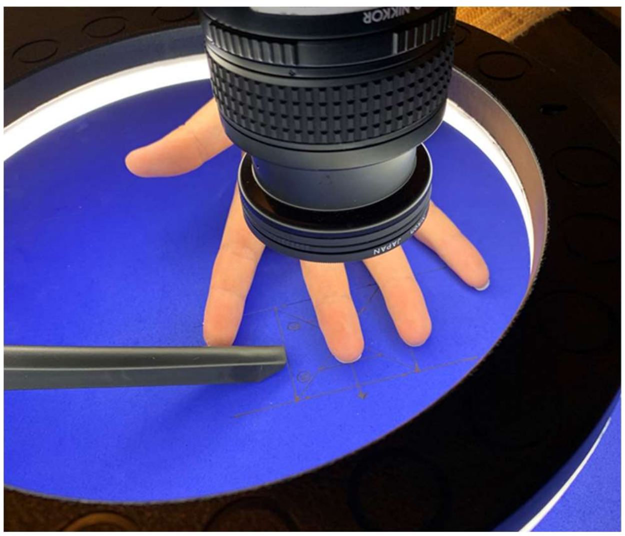

Figure 2 Close-up photo set up.

Immersion Phase

The subject sat in one location and once the water reached 95°F as indicated by the probe thermometer, they immersed their right hand in the water, ensuring the entire hand at least up to the wrist remained submerged under the water. The immersion was interrupted at 10, 20, 30, 45, 60, 90, and 120 minutes. The subject then pat dried their hand and centered their right, middle finger under the camera lens as previously described. At least two images, one with scale and one without scale were obtained at each interval. At removal, the researcher stopped the immersion timer and began a separate timer to ensure each interruption lasted ≤60 seconds. A timer was restarted for the next immersion time interval. This was done so the total duration of immersion in water was exactly 120 minutes. Only close-up images were obtained during the 10-90 minutes intervals; close-up and overall images were obtained at 120 minutes. The final water temperature was also measured at 120 minutes to monitor variation between subjects and repetitions.

Figure 3 Subject D session set up.

Drying Phase

The skin pruning dissipation was monitored for 60 minutes post immersion at 15-minute intervals. An uninterrupted timer was started immediately at the end of the 120-minute immersion. At 15, 30, 45, and 60 minutes both close-up and overall images were obtained. During the drying phase, the subjects remained in place and did not use their right hand until the 60 minutes was over.

ANALYSIS AND INTERPRETATION

A total of 276 images were quantitatively analyzed in two parts. First, the width of one friction ridge was measured at each time interval for both the immersion and drying phase. Second, the overall percentage area of the fingertip affected by pruning was measured. For the purposes of this study, pruning was defined as a change in the surface shape of the fingertip skin. An increase in friction ridge width did not automatically equate to pruning. ImageJ, an image processing tool developed by the National Institute of Health (NIH) was utilized to analyze the images. ImageJ had the capability to calculate area and pixel value statistics of user-defined selections and measured distances (NIH, 2022). In this study, the researcher set the scale manually for each repetition as a certain number of pixels per mm. The number of pixels varied between each subject and session but were determined by using the images with scale, see figure 4. Due to a DSLR camera being utilized, as opposed to a microscope, which was used in Weber's previous studies, the scale was unable to be set per µm in a reliable manner.

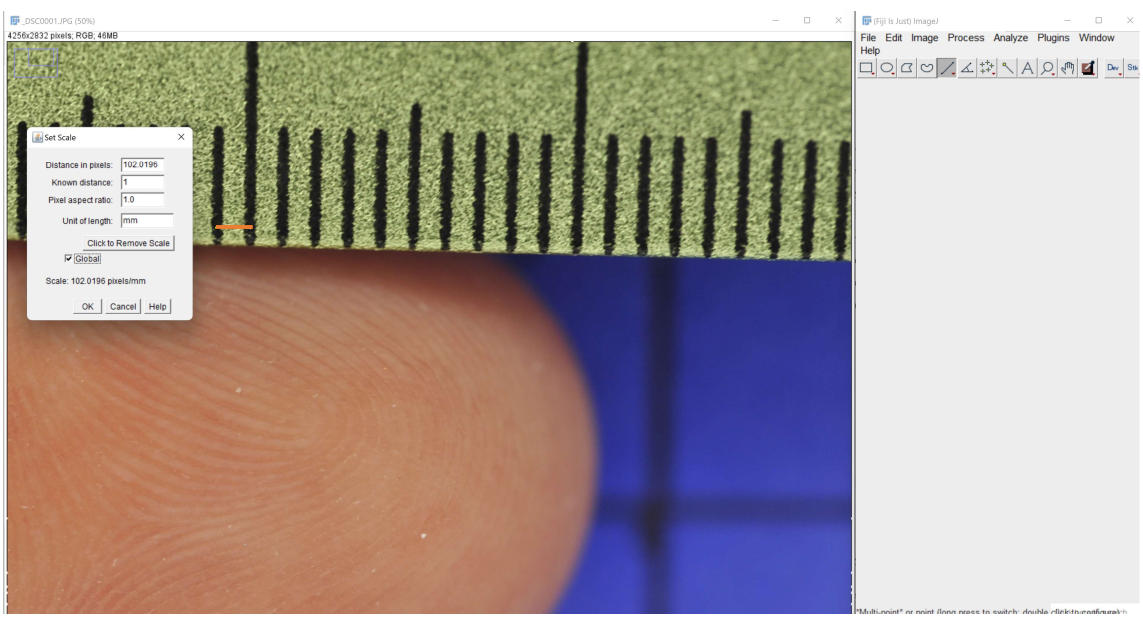

Figure 4 Manual scale in ImageJ.

Subject A

Subject A completed all sessions within two weeks, allowing at least 48 hours in between each session. The ending water temperature varied 0.7°F over the five sessions. Ambient temperature varied by 3.1°F over the five sessions. Both variables remained within acceptable range determined by the research design. Humidity ranged by 9%. Table 1 shows each session data information related to water and ambient variables.

Table 1. Subject A Session Variable Data.

	DATE	pH	Salinity	Water °F (Start)	Water °F (End)	Ambient °F (High)	Ambient °F (Low)	Humidity (Avg)
SESSION 1	4-Feb	6.5	0	95	84.2	72.5	71.3	32%
SESSION 2	7-Feb	6.5	0	95	84.2	74	71.3	23%
SESSION 3	10-Feb	6.5	0	95	83.6	74	71.5	24%
SESSION 4	13-Feb	6.5	0	95	84.2	72.5	70.9	25%
SESSION 5	16-Feb	6.5	0	95	84.3	73.6	72.5	23%

Friction Ridge Width

Subject A's friction ridge widths proved difficult to analyze accurately and reliably with a DSLR camera. Specifically, focusing on the selected friction ridge was not acceptable for multiple time intervals. This was due to the behavior of Subject A's skin, likely due to her having dry skin or attributed to expected biological variance between people. The swelling and pruning that occurred was irregular and crenulated in appearance, see figure 5, as opposed to a smoother and wavy surface appearance as crime scene investigators or pathologists may expect. As such, measurements were not obtained in images where the student researcher was unable to confidently identify the proper area of the selected

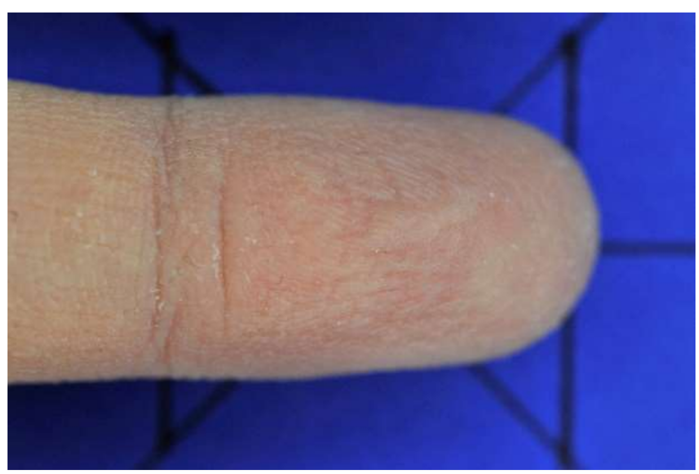

Figure 5 Subject A, showing crenulated appearance during pruning.

friction ridge or images where the edges of the friction ridge could not be confidently identified. This resulted in removing session five from this portion of analysis and portions of sessions two, three, and four. Enough data remained for analysis and interpretation despite this limitation. Figure 6 shows a positive correlation between ridge width and duration in water and figure 7 shows a negative correlation between ridge width and duration after being removed from water. Although variation in measurement is apparent, each repetition indicated a positive correlation during the immersion phase and a negative correlation during the dry phase.

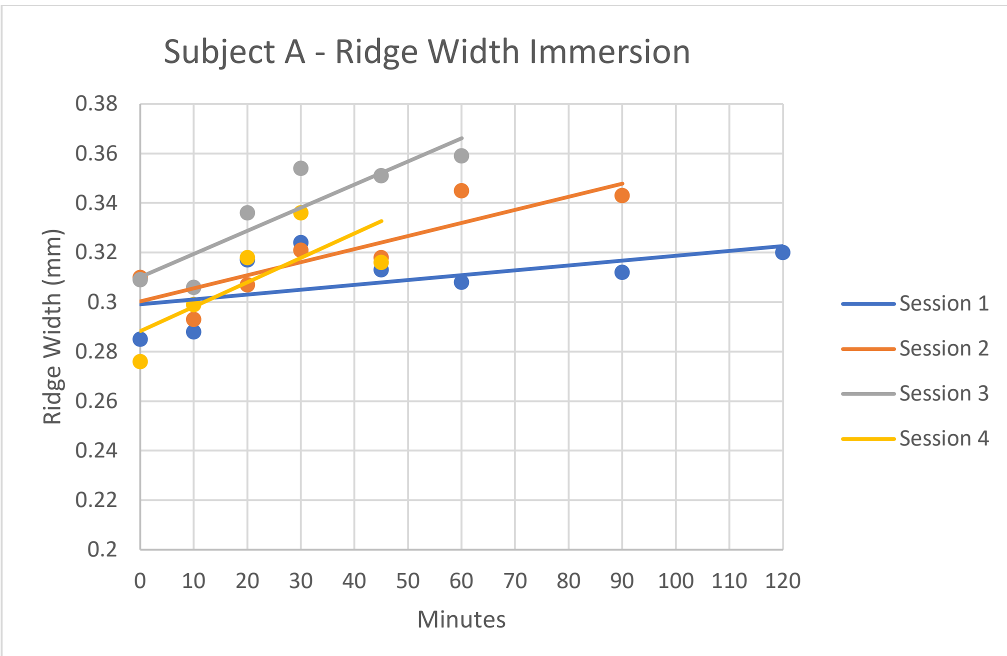

Figure 6. Scatterplot showing correlation between duration of immersion in water and ridge width.

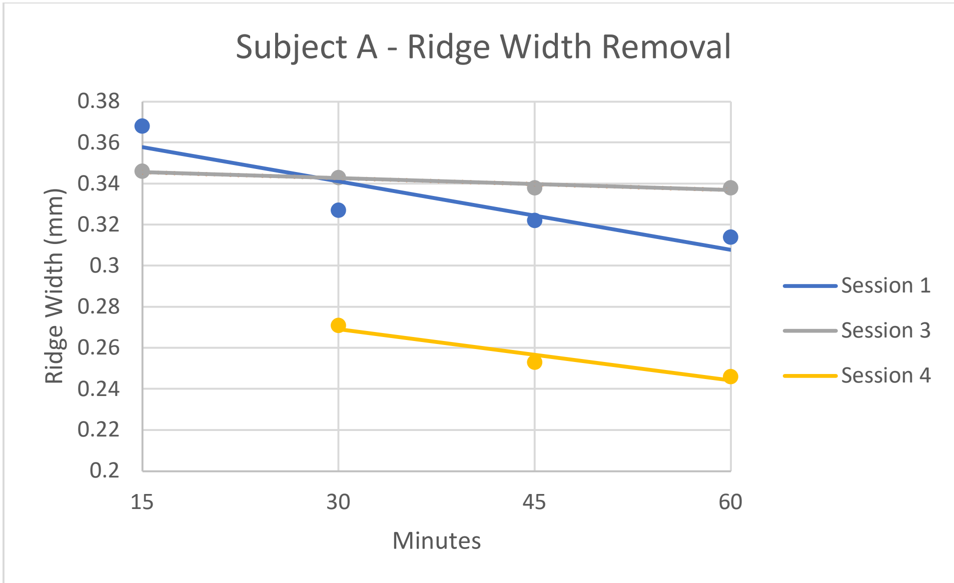

Figure 7. Scatterplot showing correlation between duration of time since removal and ridge width.

During Subject A's immersion phase, the Pearson correlation, or multiple R value, showed a range of .563 - .895. This meant there was a moderate to high correlation between ridge width and duration of immersion in water. The R^2 values in session one and session four were the lowest, .317 and .581 respectively. This means that up to 31.7% and 58.1% of variability in ridge size was explained by duration of immersion in water. That said, session two and session three resulted in R^2 values of .758 and .801, respectively, which indicated a much stronger correlation. Accordingly, the P-value of sessions two and three were <0.05; therefore, the null hypothesis was rejected, and the relationship between the duration of water immersion and ridge width was determined to be statistically significant. However, the opposite was true for sessions one and four, with P-values >0.05. Tables 2-3 display the statistics and data sets. The variation could be attributed to a small sample size since statistical significance is more so dependent on a large sample size rather than correlation. For the practical purposes of crime scene response, a correlation was still relevant.

Table 2. Subject A, Immersion Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4
Mean	0.308375	0.319571	0.335833	0.309
Median	0.3125	0.318	0.3435	0.316
Standard Deviation	0.014392	0.018955	0.023267	0.022627
Sample Variance	0.000207	0.000359	0.000541	0.000512
Skewness	-0.96209	0.263038	-0.57055	-0.58199
Range	0.039	0.052	0.053	0.06
Minimum	0.285	0.293	0.306	0.276
Maximum	0.324	0.345	0.359	0.336
Count	8	7	6	5

Table 3. Subject A, Immersion Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4
Multiple R	0.563293372	0.870995	0.895042	0.762328
R Square	0.317299423	0.758632	0.8011	0.581145
Standard Error	0.012844133	0.010201	0.011602	0.01691
t Stat	1.669917943	3.964243	4.013805	2.040191
P-value	0.145973841	0.010697	0.015946	0.134022
H_0	Fail to reject	Reject	Reject	Fail to Reject

During Subject A's drying phase, the Pearson correlation showed a range of .894-.969. This meant that there was a strong to very strong correlation between ridge width and duration of time removed from water. The R^2 values indicated that 80-93.9% of variability in ridge size could be explained by duration of time since removed from water. However, the P-values were all >0.05; the deviation from the null hypothesis was not statistically significant, and the null hypothesis was not rejected, despite a strong to very strong correlation. During this phase, only four measurements were obtained, which could have caused a poor statistical result. Again, for the practical purposes of crime scene response, this correlation is still relevant. Tables 4-5 display the statistics and data sets.

Table 4. Subject A, Drying Phase (Ridge Width) Descriptive Statistical Data.

	Session1	Session 3	Session 4
Mean	0.33275	0.34125	0.256667
Standard Error	0.012051	0.001974	0.007446
Median	0.3245	0.3405	0.253
Standard Deviation	0.024102	0.003948	0.012897
Sample Variance	0.000581	1.56E-05	0.000166
Skewness	1.703457	0.475483	1.175956
Range	0.054	0.008	0.025
Minimum	0.314	0.338	0.246
Maximum	0.368	0.346	0.271
Count	4	4	3

Table 5. Subject A, Drying Phase (Ridge Width) Correlation and Linear Regression.

	Session 1	Session 3	Session 4
Multiple R	0.894507	0.948401	0.969216
R Square	0.800143	0.899465	0.939379
Standard Error	0.013197	0.001533	0.004491
t Stat	-2.8297	-4.23008	-3.93648
P-value	0.105493	0.051599	0.158373
H_0	Fail to Reject	Fail to Reject	Fail to reject

Surface Area Pruning

Determining the surface area for pruning was slightly more subjective; therefore, the following parameters were followed to maintain a structured and reliable method. First, a grid composed of approximately 1mm^2 squares was overlaid on each fingertip image in ImageJ. Each 1mm^2 square was colored in if it was 100% affected by pruning at its earliest onset. Pruning required the shape and/or texture of the fingertip surface to change, no matter how slight, see figure 8.

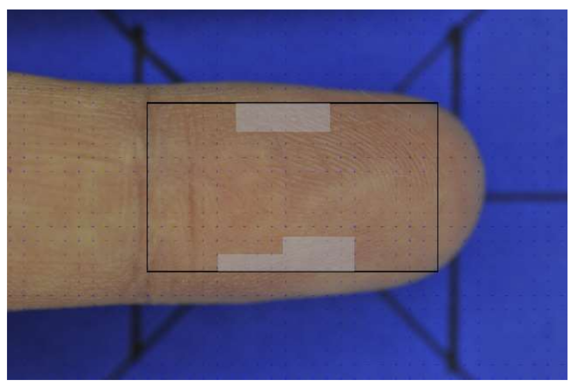

Figure 8. Grid and grey shaded area showing surface area pruning method.

Figure 9 shows a positive correlation between duration of immersion in water and percentage of area affected by pruning. Figure 10 shows a negative correlation between duration of time removed from water and percentage of area affected by pruning.

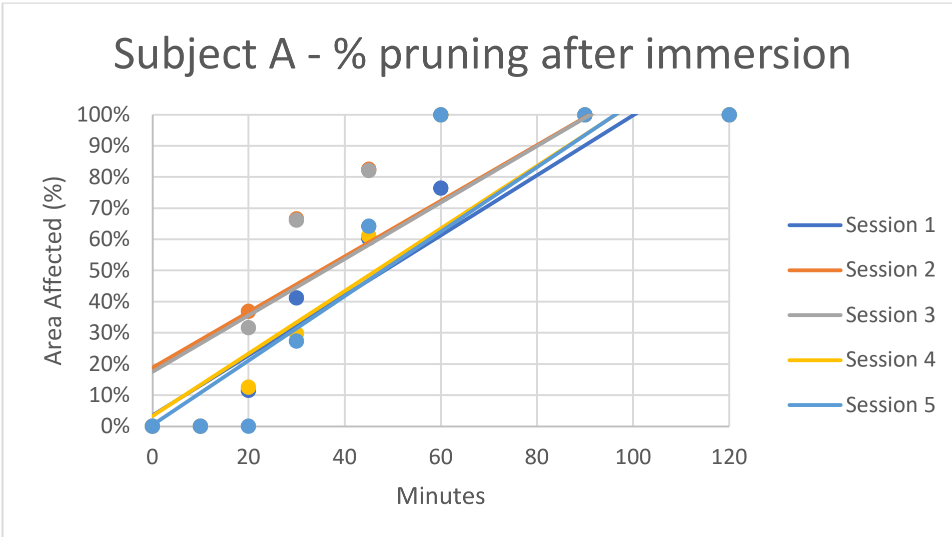

Figure 9. Scatterplot showing correlation between duration of immersion in water and pruning.

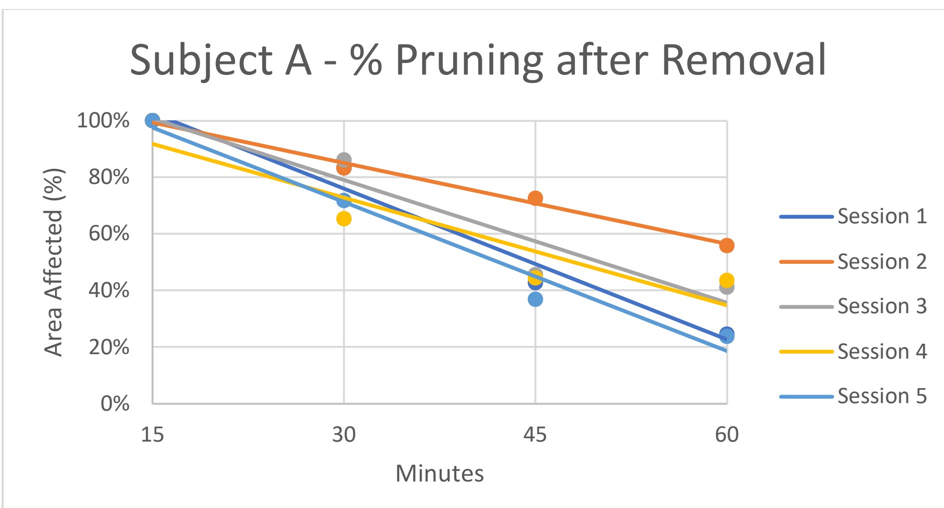

Figure 10. Scatterplot showing correlation between duration of time since removal and pruning.

There was a greater consistency of results when assessing the percentage of the surface area affected by pruning than the measuring of ridge widths. The Pearson correlation ranged from 0.853 - 0.947 throughout the five sessions, indicating a strong to very strong correlation. The R^2 values indicated 72.8%-89.8% of the area affected by pruning was explained by the duration immersed in water. The P-values for all five sessions were <0.05, meaning the null hypothesis was rejected and the alternate hypothesis was accepted. The statistical data for the immersion phase are shown in table 6 and table 7.

Table 6. Subject A, Immersion Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.4869	0.6075	0.6	0.5043	0.489375
Standard Error	0.1485	0.1528	0.1543	0.1605	0.167481
Median	0.5075	0.7455	0.7415	0.454	0.4575
Standard Deviation	0.4201	0.4323	0.4363	0.4541	0.473707
Sample Variance	0.1765	0.1868	0.1904	0.2062	0.224399
Skewness	0.0273	-0.637	-0.577	0.0962	0.073906
Range	1	1	1	1	1
Minimum	0	0	0	0	0
Maximum	1	1	1	1	1
Count	8	8	8	8	8

Table 7. Subject A, Immersion Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.947553	0.853374	0.85704	0.912579	0.902001
R Square	0.897857	0.728247	0.734517	0.8328	0.813606
Standard Error	0.145023	0.243387	0.24284	0.200546	0.220902
t Stat	7.262324	4.009848	4.074352	5.466737	5.117605
P-value	0.000347	0.00704	0.006544	0.001563	0.002183
H_0	Reject	Reject	Reject	Reject	Reject

The Pearson correlation for Subject A area coverage drying phase ranged from 0.928-0.996 indicating very strong correlation across the five sessions. The R^2 indicated that 86.3-99.3% of the variation of area coverage percentage was explained by duration of time since removal. Session four was the only session in which the P-value was >0.05; therefore, the null hypothesis was not rejected. Session four data may not have resulted in a statistically significant result; however, the strength of the positive correlation is still relevant for the purposes of this study. The remaining four sessions all resulted in P-values <0.05. Tables 8-9 display the statistical data for the drying phase of area coverage.

Table 8. Subject A, Drying Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.62675	0.7795	0.68225	0.6335	0.58125
Standard Error	0.17472	0.092631	0.146384	0.13218	0.172463
Median	0.6305	0.7795	0.6585	0.549	0.5435
Standard Deviation	0.349441	0.185261	0.292769	0.26436	0.344926
Sample Variance	0.122109	0.034322	0.085714	0.069886	0.118974
Skewness	-0.03555	-1.9E-15	0.171985	1.253177	0.422087
Range	0.754	0.441	0.588	0.564	0.762
Minimum	0.246	0.559	0.412	0.436	0.238
Maximum	1	1	1	1	1
Count	4	4	4	4	4

Table 9. Subject A, Drying Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.985312	0.996498	0.956443	0.928835	0.986231
R Square	0.970839	0.993007	0.914783	0.862735	0.972651
Standard Error	0.073083	0.018974	0.104673	0.119956	0.069862
t Stat	-8.16001	-16.8527	-4.63353	-3.54547	-8.43378
P-value	0.014688	0.003502	0.043557	0.071165	0.013769
H_0	Reject	Reject	Reject	Fail to Reject	Reject

Subject B

Subject B completed three of the five sessions within two weeks, allowing at least 48 hours in between each session. Although Subject B was unable to complete all sessions due to medical issues, all measurements were successfully obtained. The ending water temperature varied 0.7°F over the three sessions. Ambient temperature varied by 2°F over the three sessions. Both variables remained within acceptable range determined by the research design. Humidity ranged by 3%. Table 10 shows each session data information related to water and ambient variables.

Table 10. Subject B Session Variable Data.

	DATE	pH	Salinity	Water °F (Start)	Water °F (End)	Ambient °F (High)	Ambient °F (Low)	Humidity (Avg)
Session1	19-Jan	6.5	0	95	83.3	71.5	71.8	26%
Session 2	22-Jan	6.5	0	95	83.8	71.8	70.4	23%
Session 3	29-Jan	6.5	0	95	84	72	70	23%

Friction Ridge Width

Consistent with Subject A, Subject B's immersion and removal data indicated a positive and negative correlation, respectively, as shown in figures 11-12. Although correlation was visually evident in the scatter plots, the statistical assessment varied in strength.

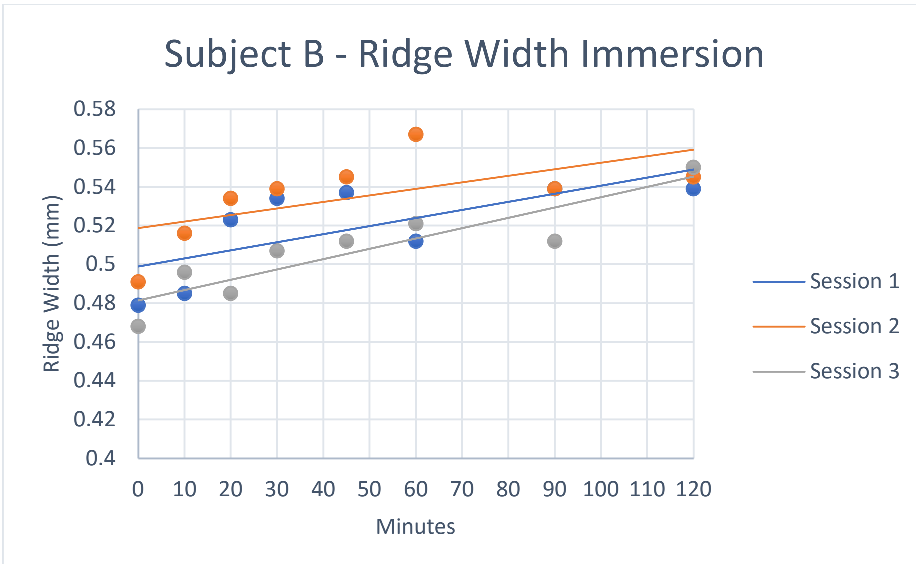

Figure 11. Scatterplot showing correlation between duration of immersion in water and ridge width.

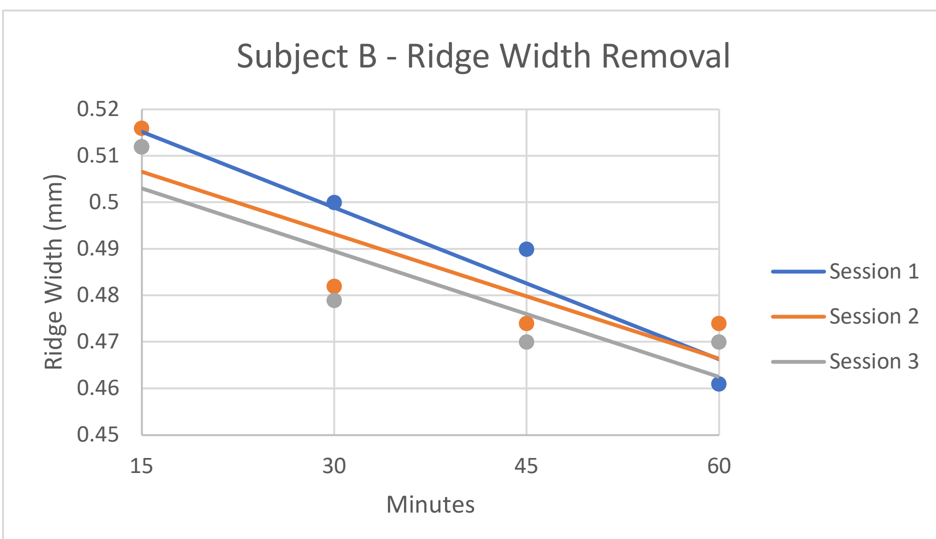

Figure 12. Scatterplot showing correlation between duration of time since removal and ridge width.

The Pearson correlation varied from 0.681-0.895, indicating a moderate to strong correlation. The R^2 value for session one and two indicated that only 38.2% - 49.6% of the variation in ridge widths could be explained by duration of immersion in water. However, session three indicated 80.3% of the variation was explained by duration of immersion in water. As expected, the P-values for session one and two were >0.05, so the null hypothesis was not rejected. The P-value for session three was <0.05, so in this replication with Subject B experiment, the null hypothesis was rejected. The lower values could be a result of limited data or a result of measurement error, which is expected in manual measurements. Nevertheless, the findings remain relevant as each replication with Subject B still shows a correlation between the friction ridge size and duration of water immersion. Tables 11-12 display the statistical data for the immersion phase related to ridge widths.

Table 11. Subject B, Immersion Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	Session 2	Session 3
Mean	0.5185	0.5345	0.506375
Standard Error	0.00863	0.007964	0.0086787
Median	0.5285	0.539	0.5095
Standard Deviation	0.0244	0.022526	0.024547
Sample Variance	0.0006	0.000507	0.0006026
Skewness	-0.9455	-0.86351	0.2461426
Range	0.06	0.076	0.082
Minimum	0.479	0.491	0.468
Maximum	0.539	0.567	0.55
Count	8	8	8

Table 12. Subject B, Immersion Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3
Multiple R	0.703958	0.618261	0.895861
R Square	0.495557	0.382247	0.802566
Standard Error	0.018719	0.019124	0.011781
t Stat	2.42782	1.926815	4.938616
P-value	0.051314	0.102295	0.002608
H_0	Fail to Reject	Fail to Reject	Reject

Additionally, Subject B showed variable statistical significance with regards to friction ridge width during the drying phase, despite correlation. The correlation coefficients ranged from 0.873 - 0.966, which indicated strong to very strong correlation. The R^2 values ranged from 0.746 - 0.933. However, the P-values for session two and three were >0.05; therefore, the null hypothesis was not rejected. This occurrence can be explained because the data range was minute in session two and three because the ridge measurement was the same at 45 and 60 minutes after being removed from water. The drying phase only had four data points, as such two identical consecutive measurements limited the capability of statistical analysis. The drying phase statistical data is displayed in tables 13-14.

Table 13. Subject B, Drying Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	Session 2	Session 3
Mean	0.49075	0.4865	0.48275
Standard Error	0.01089	0.010012	0.0099781
Median	0.495	0.478	0.4745
Standard Deviation	0.02178	0.020025	0.0199562
Sample Variance	0.00047	0.000401	0.0003983
Skewness	-1.0292	1.799498	1.7470462
Range	0.051	0.042	0.042
Minimum	0.461	0.474	0.47
Maximum	0.512	0.516	0.512
Count	4	4	4

Table 14. Subject B, Drying Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3
Multiple R	0.966292	0.863887	0.873334
R Square	0.93372	0.746301	0.762712
Standard Error	0.006867	0.012353	0.011906
t Stat	-5.30801	-2.42556	-2.53546
P-value	0.033708	0.136113	0.126666
H_0	reject	fail to reject	fail to reject

Surface Area Pruning

Figure 13 shows a positive correlation between duration of water immersion and percentage of area affected by pruning. Figure 14 shows a negative correlation between duration of time removed from water and percentage of area affected by pruning.

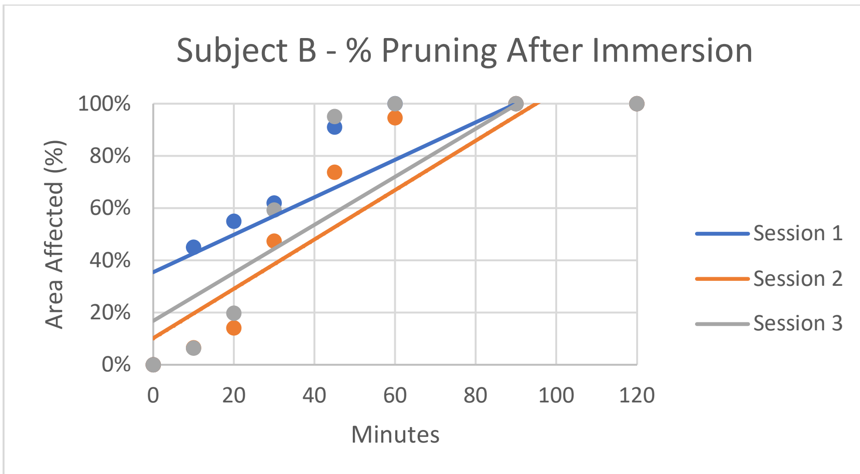

Figure 13. Scatterplot showing correlation between duration of immersion in water and pruning.

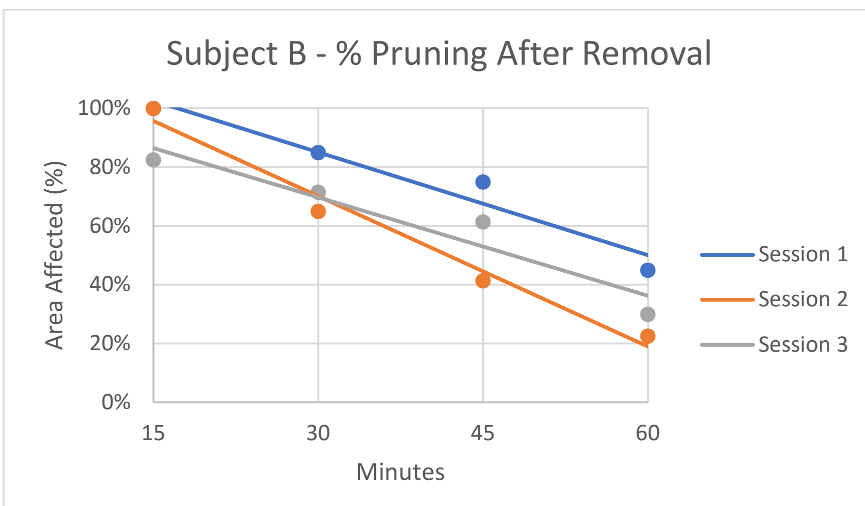

Figure 14. Scatterplot showing correlation between duration of time removed from water and pruning.

There was a great consistency of results when assessing the percentage of the surface area affected by pruning than measuring the ridge widths. The Pearson correlation ranged from 0.830 - 0.905 throughout the three sessions, indicating a moderate to high correlation. The R^2 values indicated 68.9% - 81.9% of the area affected by pruning could be explained by duration of immersion in water. The P-values for all sessions were <0.05, meaning the null hypothesis was rejected and the alternate hypothesis was accepted. The statistical data for the immersion phase are shown in table 15 and table 16.

Table 15. Subject B, Immersion Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**
Mean	0.69125	0.54525	0.600375
Standard Error	0.12641	0.152804	0.1589048
Median	0.765	0.605	0.7715
Standard Deviation	0.35755	0.432194	0.4494508
Sample Variance	0.12784	0.186791	0.202006
Skewness	-1.0366	-0.18831	-0.425155
Range	1	1	1
Minimum	0	0	0
Maximum	1	1	1
Count	8	8	8

Table 16. Subject A, Immersion Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	**Session 2**	**Session 3**
Multiple R	0.830107	0.905046	0.846199
R Square	0.689078	0.819107	0.716053
Standard Error	0.215345	0.198546	0.258687
t Stat	3.646562	5.212375	3.889824
P-value	0.01075	0.001991	0.008078
H_0	Reject	Reject t	Reject

The Pearson correlation for Subject B's area coverage drying phase ranged from 0.957-0.990 indicating very strong correlation across the sessions. The R^2 value indicated that 91.5% - 98% of the variation of area coverage percentage could be explained by duration of time since removal. Tables 17-18 display the statistical data for the drying phase of area coverage. In the case of Subject B, assessing the fingertip surface area resulted in more useful and practical data due to the small range of measurements of Subject B's friction ridges.

Table 17. Subject B, Drying Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	Session 2	Session 3
Mean	0.7625	0.5725	0.61325
Standard Error	0.11614	0.16682	0.1128771
Median	0.8	0.532	0.6645
Standard Deviation	0.23229	0.33364	0.2257541
Sample Variance	0.05396	0.111316	0.0509649
Skewness	-0.8751	0.592549	-1.177626
Range	0.55	0.774	0.524
Minimum	0.45	0.226	0.3
Maximum	1	1	0.824
Count	4	4	4

Table 18. Subject B, Drying Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3
Multiple R	0.972598	0.989798	0.95672
R Square	0.945946	0.979701	0.915312
Standard Error	0.066144	0.058219	0.080462
t Stat	-5.91608	-9.82481	-4.64932
P-value	0.027402	0.010202	0.04328
H_0	Reject	Reject	Reject

Subject C

Subject C completed five sessions within three weeks, allowing at least 48 hours in between each session. The ending water temperature varied 1.1°F over the five sessions. Ambient temperature varied by 3.3°F over the five sessions. Both variables remained within acceptable range determined by the research design. Humidity ranged by 2%. Table 19 shows each session's data information related to water and ambient variables.

Table 19. Subject C Session Variable Data.

	DATE	pH	Salinity	Water °F (Start)	Water °F (End)	Ambient °F (High)	Ambient °F (Low)	Humidity (Avg)
SESSION 1	19-Jan	6.5	0	95	83.6	71.8	70.9	25%
SESSION 2	22-Jan	6.5	0	95	82.5	72	70.7	23%
SESSION 3	26-Jan	6.5	0	95	83.6	72.2	70.9	22%
SESSION 4	29-Jan	6.5	0	95	82.7	72.2	70.7	22%
SESSION 5	9-Feb	6.5	0	95	83.6	74	71.8	24%

Friction Ridge Width

Figure 15 shows a positive correlation between ridge width and duration of immersion in water and figure 16 shows a negative correlation between ridge width and duration of time removed from water. Although variation in measurement is apparent, each repetition indicated a positive correlation during the immersion phase and a negative correlation during the dry phase.

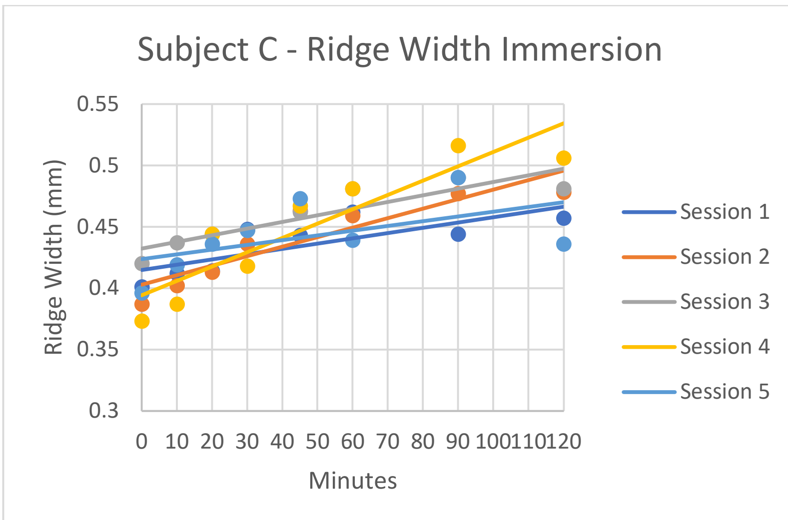

Figure 15. *Scatterplot showing correlation between duration of immersion in water and ridge width.*

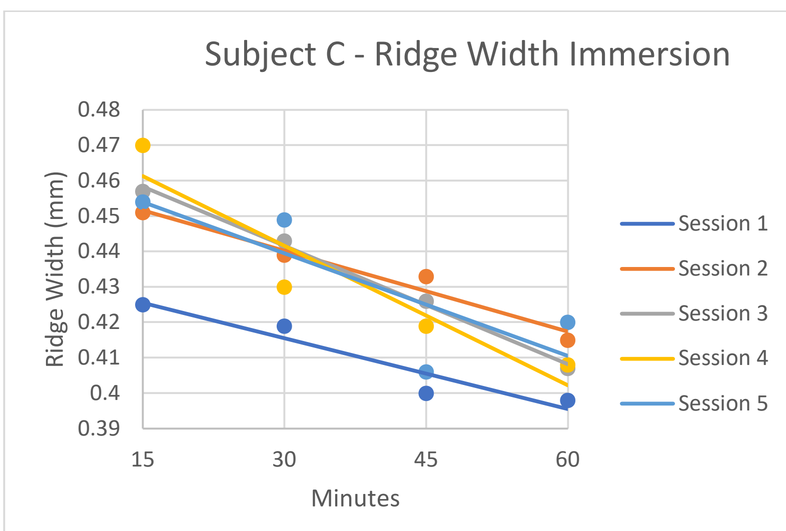

Figure 16. *Scatterplot showing correlation between duration of time since removal and ridge width.*

During Subject C's immersion phase, the Pearson correlation showed a range of 0.544 - 0.909, indicating a moderate to very high correlation between ridge width and duration of immersion in water. The R^2 value of session 5 was the lowest, indicating that only 29.6% of variability in ridge size was explained by duration of time in water. Whereas the remaining sessions resulted in R^2 values between .601 and .827, indicating that 60.1% - 82.7% of variability in ridge size was explained by duration of time in water. Accordingly, the P-value of sessions one through four were <0.05; therefore, the null hypothesis was rejected, and the relationship between water immersion and ridge width was determined to be statistically significant. However, the opposite was true for session 5, with a P-values >0.05. Tables 20-21 display the immersion phase statistical data.

Table 20. Subject C, Immersion Phase (Ridge Width) Descriptive Statistical Data.

	Session1	Session2	Session3	Session4	Session5
Mean	0.435	0.439	0.458	0.449	0.442
Standard Error	0.008	0.012	0.009	0.019	0.01
Median	0.444	0.448	0.455	0.456	0.438
Standard Deviation	0.023	0.035	0.025	0.053	0.029
Sample Variance	5E-04	0.001	6E-04	0.003	9E-04
Skewness	-0.45	-0.36	-0.1	-0.23	0.231
Range	0.061	0.091	0.07	0.143	0.094
Minimum	0.401	0.387	0.42	0.373	0.396
Maximum	0.462	0.478	0.49	0.516	0.49
Count	8	8	8	8	8

Table 21. Subject C, Immersion Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.775515	0.908339	0.903275	0.909499	0.544366
R Square	0.601424	0.82508	0.815905	0.827188	0.296334
Standard Error	0.015577	0.015924	0.011486	0.023815	0.026562
t Stat	3.008919	5.319899	5.15673	5.359088	1.589582
P-value	0.023734	0.001795	0.002101	0.00173	0.163031
H_0	Reject	Reject	Reject	Reject	Fail to Reject

During Subject C's drying phase, the Pearson correlation ranged between 0.812 - 0.997. This meant that there was a very strong correlation between ridge width and duration of time removed from water. The R^2 values indicated that 66% - 99.5% of variability in ridge size could be explained by duration of time since removed from water. Similar to Subject A, the strong correlation still resulted in P-values >0.05. Specifically, the null hypothesis was not rejected in session four and five. Session one and two had P-values <0.05. Again, for the practical purposes of crime scene response, a strong correlation is still relevant despite P-values. Tables 22-23 display the drying phase statistics and data sets.

Table 22. Subject C, Drying Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Mean	0.411	0.435	0.433	0.432	0.432
Standard Error	0.007	0.008	0.011	0.014	0.012
Median	0.41	0.436	0.435	0.425	0.435
Standard Deviation	0.014	0.015	0.022	0.027	0.023
Sample Variance	2E-04	2E-04	5E-04	7E-04	5E-04
Skewness	0.149	-0.56	-0.27	1.366	-0.27
Range	0.027	0.036	0.05	0.062	0.048
Minimum	0.398	0.415	0.407	0.408	0.406
Maximum	0.425	0.451	0.457	0.47	0.454
Count	4	4	4	4	4

Table 23. Subject C, Drying Phase (Ridge Width) Correlation and Linear Regression.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Multiple R	0.954331	0.981156	0.997749	0.940712	0.812417
R Square	0.910747	0.962667	0.995502	0.884939	0.660022
Standard Error	0.00495	0.00355	0.001775	0.011232	0.016454
t Stat	-4.51754	-7.18132	-21.04	-3.922	-1.97047
P-value	0.045669	0.018844	0.002251	0.059288	0.187583
H_0	Reject	Reject	Reject	Fail to Reject	Fail to Reject

Surface Area Pruning

Figure 17 shows a positive correlation between duration of immersion in water and percentage of area affected by pruning. Figure 18 shows a negative correlation between duration of time removed from water and percentage of area affected by pruning.

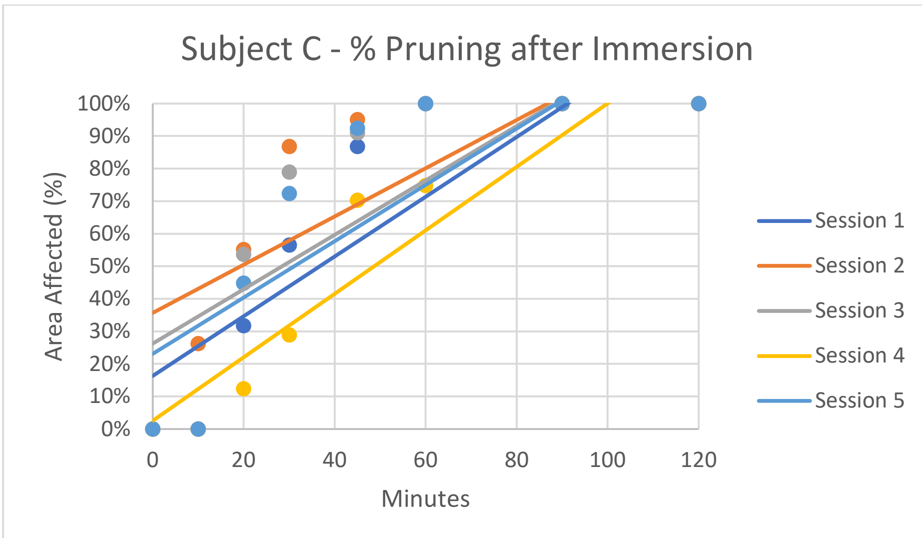

Figure 17. Scatterplot showing correlation between duration of immersion in water and pruning.

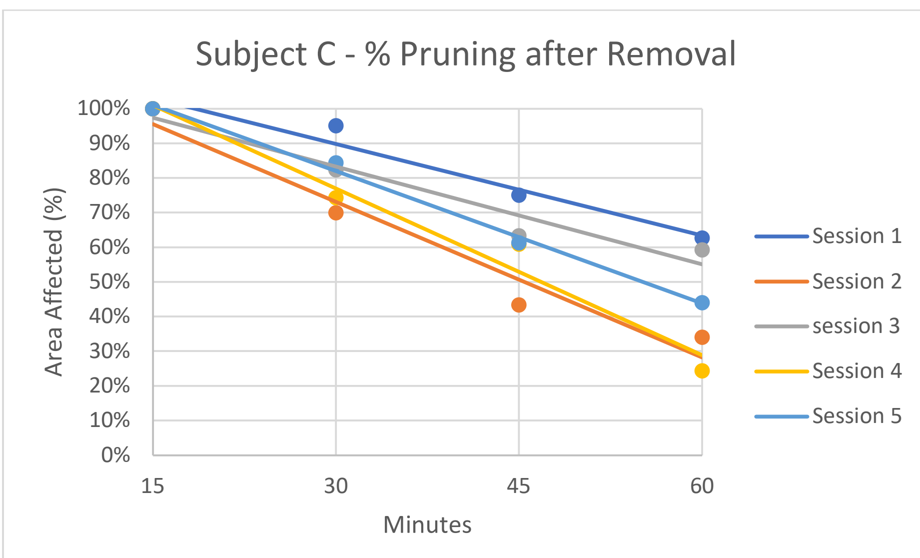

Figure 18. Scatterplot showing correlation between duration of time since removal and pruning.

There was greater consistency of results with assessing the percentage of surface area affected by pruning than by measuring ridge widths. The Pearson correlation ranged from 0.784 -

0.940 throughout the five sessions, indicating a strong to very strong correlation. The R^2 values indicated 61.5% - 88.4% of the area affected by pruning was explained by the duration of immersion in water. The P-values for all five sessions were <0.05, meaning the null hypothesis was rejected and the alternate hypothesis was accepted. The statistical data for the immersion phase are shown in table 24 and table 25.

Table 24. Subject C, Immersion Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Mean	0.594	0.704	0.655	0.483	0.637
Standard Error	0.155	0.138	0.153	0.152	0.154
Median	0.717	0.91	0.85	0.496	0.824
Standard Deviation	0.44	0.39	0.433	0.429	0.436
Sample Variance	0.193	0.152	0.187	0.184	0.19
Skewness	-0.49	-1.1	-0.98	0.065	-0.82
Range	1	1	1	1	1
Minimum	0	0	0	0	0
Maximum	1	1	1	1	1
Count	8	8	8	8	8

Table 25. Subject C, Immersion Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Multiple R	0.862847	0.784313	0.798113	0.940107	0.8194
R Square	0.744505	0.615148	0.636985	0.8838	0.671417
Standard Error	0.240014	0.261382	0.281746	0.157833	0.270135
t Stat	4.181367	3.096836	3.244725	6.755384	3.501459
P-value	0.005805	0.021202	0.017582	0.000513	0.012804
H_0	Reject	Reject	Reject	Reject	Reject

The Pearson correlation for Subject C area coverage drying phase ranged from 0.977-0.997, indicating very strong correlation across the five sessions. The R^2 indicated that 94.4% - 99.5% of the variation of area coverage percentage could be explained by duration of time since removal. The five sessions all resulted in P-values <0.05 and therefore, the null hypothesis was rejected. Tables 26-27 display the statistical data for the drying phase of area coverage.

Table 26. Subject C, Drying Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.832	0.619	0.763	0.65	0.725
Standard Error	0.087	0.148	0.094	0.158	0.123
Median	0.851	0.567	0.729	0.677	0.729
Standard Deviation	0.174	0.296	0.187	0.315	0.247
Sample Variance	0.03	0.088	0.035	0.099	0.061
Skewness	-0.35	0.724	0.664	-0.49	-0.07
Range	0.373	0.659	0.407	0.756	0.559
Minimum	0.627	0.341	0.593	0.244	0.441
Maximum	1	1	1	1	1
Count	4	4	4	4	4

Table 27. Subject C, Drying Phase (Area Coverage) Correlation and Linear Regression.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.977865	0.977566	0.971691	0.984276	0.997368
R Square	0.95622	0.955635	0.944184	0.968799	0.994744
Standard Error	0.044625	0.076414	0.054243	0.068157	0.021929
t Stat	-6.60931	-6.56356	-5.81654	-7.88037	-19.4552
P-value	0.022135	0.022434	0.028309	0.015724	0.002632
H_0	Reject	Reject	Reject	Reject	Reject

Subject D

Subject D completed all sessions within five weeks, allowing at least 48 hours in between each session. The ending water temperature varied by 3.6°F over the five sessions. Ambient temperature varied by 3.1°F over the five sessions. Both variables remained within acceptable range determined by the research design. Humidity ranged by 28%; however, if session four data was removed due to being an outlier, then humidity only ranged by 3%. Table 28 shows each session data information related to water and ambient variables.

Table 28. Subject D Session Variable Data.

	DATE	pH	Salinity	Water °F (Start)	Water °F (End)	Ambient °F (High)	Ambient °F (Low)	Humidity (Avg)
SESSION 1	25-Jan	6.5	0	95	84.9	72.2	71.5	24%
SESSION 2	28-Jan	7	0	95	82.5	70.9	70.9	22%
SESSION 3	15-Feb	6.5	0	95	84.9	74	73.6	22%
SESSION 4	23-Feb	6.5	0	95	86.1	74	74	50%
SESSION 5	1-Mar	6.5	0	95	85.1	74	73	25%

Friction Ridge Width

Figure 19 showed a positive correlation between ridge width and duration of immersion in water and figure 20 showed a negative correlation between ridge width and duration of time removed from water. Although variation in measurement was apparent, each repetition indicated a positive correlation during the immersion phase and a negative correlation during the dry phase.

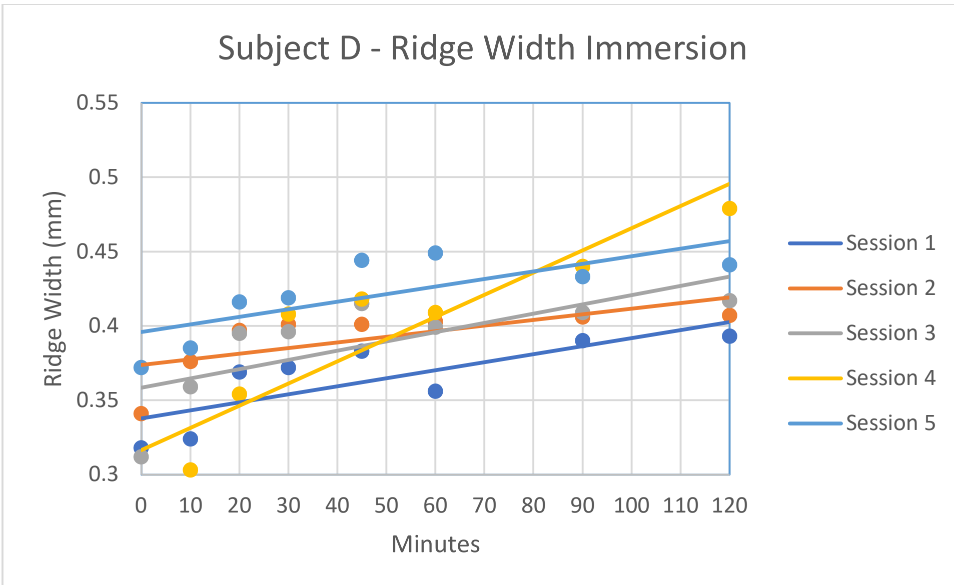

Figure 19. Scatterplot showing correlation between duration of immersion in water and ridge width.

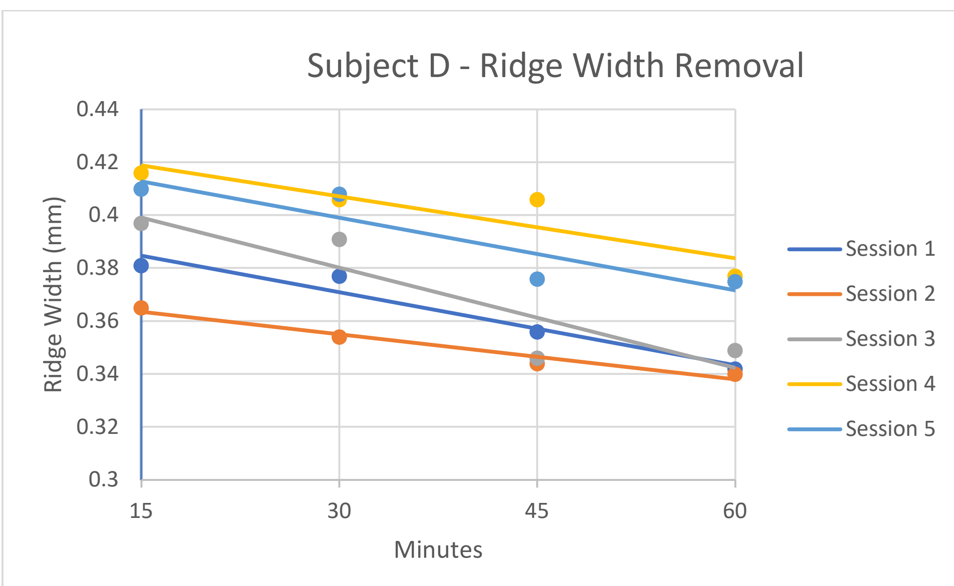

Figure 20. Scatterplot showing correlation between duration of time since removal and ridge width.

During Subject D's immersion phase, the Pearson correlation showed a range of 0.691 - 0.905. This meant there was a moderate to very high correlation between ridge width and duration of immersion in water. The R^2 values ranged from 0.478 - 0.819. The P-value of session two was >0.05; therefore, the null hypothesis was not rejected. In the remaining four sessions, the P-values were <0.05 and the relationship between duration of water immersion and ridge width was determined to be statistically significant. Tables 29-30 display the statistics and data sets for the immersion phase related to ridge widths. There was still a positive correlation in session two; however, the small differences between measurements when compared to the other sessions could have contributed to not resulting in statistical significance.

Table 29. Subject D, Immersion Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Mean	0.363	0.392	0.388	0.387	0.42
Standard Error	0.01	0.008	0.013	0.024	0.01
Median	0.371	0.401	0.398	0.409	0.426
Standard Deviation	0.029	0.023	0.036	0.068	0.028
Sample Variance	8E-04	5E-04	0.001	0.005	8E-04
Skewness	-0.79	-2.01	-1.7	-0.48	-0.86
Range	0.075	0.066	0.105	0.198	0.077
Minimum	0.318	0.341	0.312	0.281	0.372
Maximum	0.393	0.407	0.417	0.479	0.449
Count	8	8	8	8	8

Table 30. Subject D, Immersion Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Multiple R	0.780416	0.691142	0.721996	0.904968	0.747206
R Square	0.60905	0.477678	0.521279	0.818967	0.558317
Standard Error	0.019341	0.017664	0.02659	0.031333	0.020254
t Stat	3.057322	2.342468	2.556049	5.209901	2.75398
P-value	0.022301	0.057649	0.043138	0.001996	0.033117
H_0	Reject	Fail to Reject	Reject	Reject	Reject

During Subject D's drying phase, the Pearson correlation showed a range of 0.897 - 0.982. This meant there was a very strong correlation between ridge width and duration of time removed from water. The R^2 values indicated that 80.5% - 96.4% of variability in ridge size was explained by duration of time since removed from water. However, the P-values for session three, four, and five were all >0.05; the deviation from the null hypothesis was not statistically significant, and the null hypothesis was not rejected, despite a very strong correlation. This was a similar result to Subject A; only four measurements were obtained, and the measurements did not decrease with each time interval. In one time interval in each session, the ridge width remained the same which could have caused a poor statistical result. Since the smallest unit of measurement used was a millimeter, there remains a strong likelihood that the ridges did decrease in size on the micrometer level; however, this detail was unattainable with the DSLR camera. Tables 31-32 display the statistics and data sets for the drying phase pertaining to ridge widths.

Table 31. Subject D, Drying Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Mean	0.364	0.351	0.371	0.401	0.392
Standard Error	0.009	0.006	0.013	0.008	0.01
Median	0.367	0.349	0.37	0.406	0.392
Standard Deviation	0.018	0.011	0.027	0.017	0.019
Sample Variance	3E-04	1E-04	7E-04	3E-04	4E-04
Skewness	-0.44	0.658	0.032	-1.51	0.007
Range	0.039	0.025	0.051	0.039	0.035
Minimum	0.342	0.34	0.346	0.377	0.375
Maximum	0.381	0.365	0.397	0.416	0.41
Count	4	4	4	4	4

Table 32. Subject D, Drying Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Multiple R	0.972893	0.981823	0.904161	0.896953	0.913435
R Square	0.946521	0.963976	0.817508	0.804525	0.834363
Standard Error	0.005187	0.002598	0.014119	0.009119	0.009651
t Stat	-5.9496	-7.31564	-2.99322	-2.86906	-3.17405
P-value	0.027107	0.018177	0.095839	0.103047	0.086565
H_0	Reject	Reject	Fail to Reject	Fail to Reject	Fail to Reject

Surface Area Pruning

Figure 21 showed a positive correlation between duration of immersion in water and percentage of area affected by pruning. Figure 22 showed a negative correlation between duration of time removed from water and percentage of area affected by pruning.

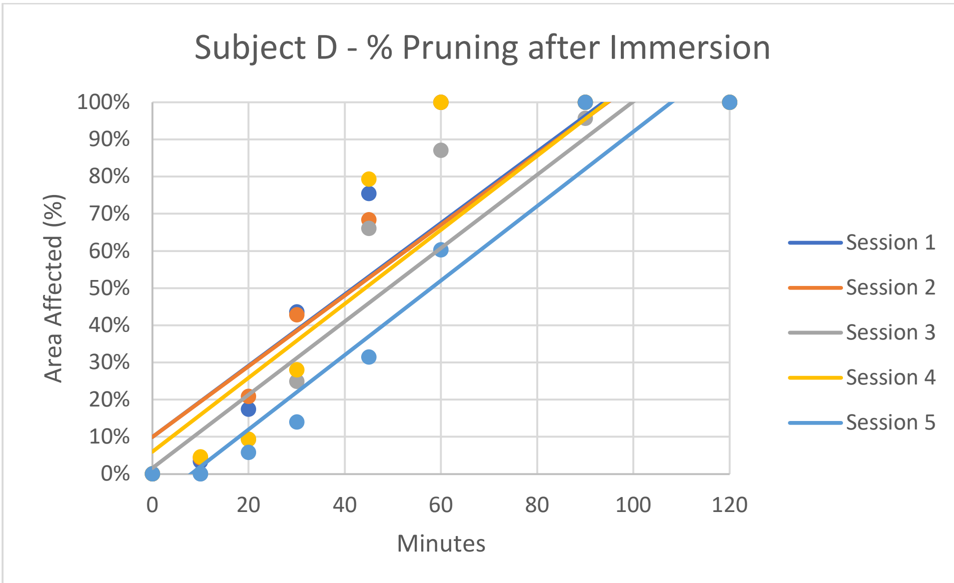

Figure 21. Scatterplot showing correlation between duration of immersion in water and pruning.

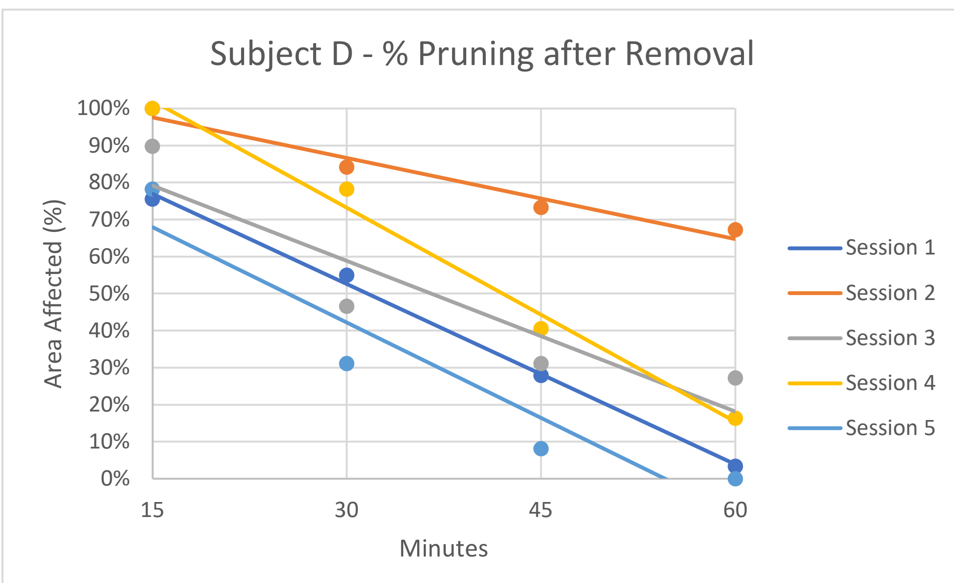

Figure 22. Scatterplot showing correlation between duration of time since removal and pruning.

The surface area percentage resulted in a Pearson correlation range of 0.889 - 0.971 throughout the five sessions, indicating a very strong correlation. The R^2 values indicated 79% - 94.2% of the area affected by pruning could be explained by the duration of immersion in water. The P-values for all five sessions were <0.05, meaning the null hypothesis was rejected and the alternate hypothesis was accepted. The statistical data for the immersion phase are shown in table 33 and table 34.

Table 33. Subject D, Immersion Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Mean	0.55	0.546	0.479	0.527	0.39
Standard Error	0.157	0.153	0.155	0.164	0.151
Median	0.596	0.556	0.455	0.537	0.228
Standard Deviation	0.443	0.434	0.439	0.463	0.426
Sample Variance	0.196	0.188	0.192	0.214	0.182
Skewness	-0.17	-0.1	0.063	-0.03	0.723
Range	1	1	1	1	1
Minimum	0	0	0	0	0
Maximum	1	1	1	1	1
Count	8	8	8	8	8

Table 34. Subject D, Immersion Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Multiple R	0.895467	0.906525	0.929128	0.888583	0.97058
R Square	0.80186	0.821788	0.863278	0.789581	0.942025
Standard Error	0.212907	0.197707	0.175229	0.229388	0.110868
t Stat	4.927645	5.260015	6.155057	4.744942	9.873866
P-value	0.002636	0.001901	0.000843	0.003175	6.23E-05
H_0	Reject	Reject	Reject	Reject	Reject

The Pearson correlation for Subject D's area coverage drying phase ranged from 0.916 - 0.999 indicating very strong correlation across the five sessions. The R^2 values indicated that 83.8% - 99.7% of the variation of area coverage percentage could be explained by time since removal. Despite the strength of the correlation, sessions three and five had P-values that were >0.05; therefore, the null hypothesis was not rejected. As stated under the previous subject analysis, the strength of the positive correlation remains relevant for the purposes of this study and practical application. Tables xx-xx display the statistical data for the drying phase of area coverage.

Table 35. Subject D, Drying Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.405	0.812	0.487	0.588	0.294
Standard Error	0.157	0.072	0.143	0.187	0.176
Median	0.415	0.788	0.389	0.594	0.196
Standard Deviation	0.315	0.144	0.287	0.375	0.351
Sample Variance	0.099	0.021	0.082	0.14	0.123
Skewness	-0.14	0.78	1.534	-0.06	1.256
Range	0.721	0.328	0.626	0.837	0.782
Minimum	0.034	0.672	0.272	0.163	0
Maximum	0.755	1	0.898	1	0.782
Count	4	4	4	4	4

Table 36. Subject D, Drying Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.998613	0.980873	0.915501	0.994688	0.946653
R Square	0.997229	0.962111	0.838141	0.989405	0.896152
Standard Error	0.020288	0.034295	0.141259	0.047254	0.138651
t Stat	-26.8267	-7.12646	-3.21815	-13.6662	-4.1544
P-value	0.001387	0.019127	0.084499	0.005312	0.053347
H_0	Reject	Reject	Fail to Reject	Reject	Fail to Reject

Subject E

Subject E completed all sessions within three weeks, allowing at least 48 hours in between each session. The ending water temperature varied 1.4°F over the five sessions. Ambient temperature varied by 3.6°F over the five sessions. Both variables remained within acceptable range determined by the research design. Humidity ranged by 4%. Table 37 shows each session data information related to water and ambient variables.

Table 37. Subject E Session Variable Data.

	DATE	pH	Salinity	Water °F (Start)	Water °F (End)	Ambient °F (High)	Ambient °F (Low)	Humidity (Avg)
SESSION 1	25-Jan	6.5	0	95	84.2	71.8	71.5	24%
SESSION 2	28-Jan	7	0	95	82.8	70.9	70.4	22%
SESSION 3	2-Feb	6.5	0	95	84.2	72	70.7	24%
SESSION 4	8-Feb	6.5	0	95	84.2	74	72.2	26%
SESSION 5	15-Feb	6.5	0	95	84	74	71.6	22%

Friction Ridge Width

Figure 23 showed a positive correlation between ridge width and duration of immersion in water and figure 24 showed a negative correlation between ridge width and duration of time removed from water. Although variation in measurement is apparent, each repetition indicated a positive correlation during the immersion phase and a negative correlation during the dry phase.

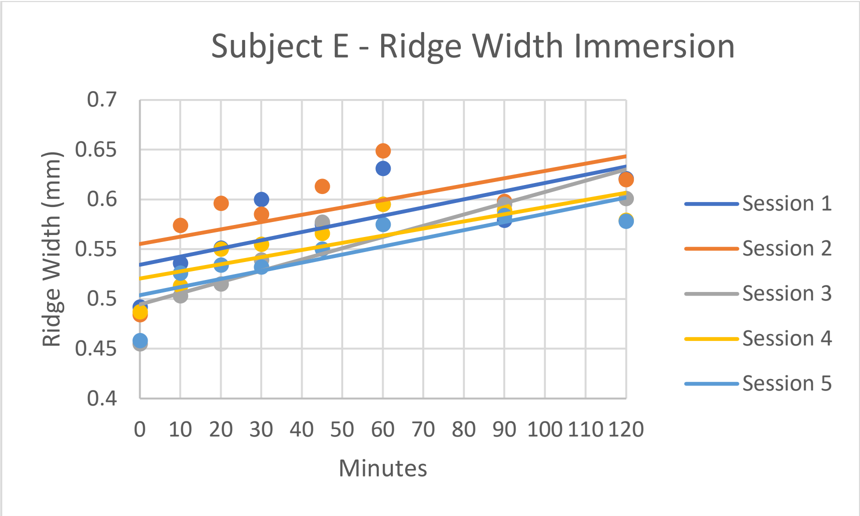

Figure 23. Scatterplot showing correlation between duration of immersion in water and ridge width.

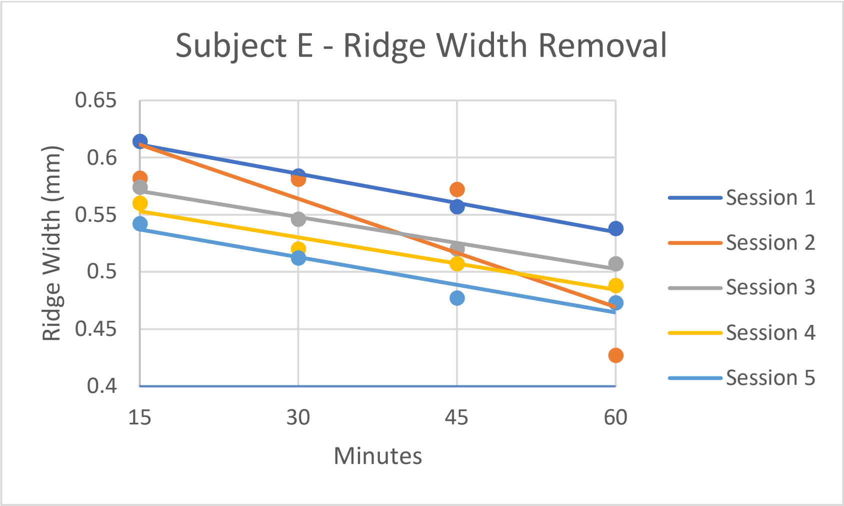

Figure 24. Scatterplot showing correlation between duration of time since removal and ridge width.

During Subject E's immersion phase, the Pearson correlation, or multiple R value, showed a range of 0.623 - 0877. This showed a moderate to high correlation between ridge width and duration of immersion in water. The R^2 value in session two was the lowest at 0.388 and the corresponding P-value was >0.05, so the null hypothesis was not rejected. However, in the remaining sessions, the R^2 values ranged from 0.544 - 0.769 and the P-values were <0.05, resulting in rejecting the null hypothesis. Tables 38-39 display the statistics and data sets for the immersion phase related to ridge widths.

Table 38. Subject E, Immersion Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.363	0.392	0.388	0.387	0.42
Standard Error	0.01	0.008	0.013	0.024	0.01
Median	0.371	0.401	0.398	0.409	0.426
Mode	#N/A	0.401	#N/A	#N/A	#N/A
Standard Deviation	0.029	0.023	0.036	0.068	0.028
Sample Variance	8E-04	5E-04	0.001	0.005	8E-04
Skewness	-0.79	-2.01	-1.7	-0.48	-0.86
Range	0.075	0.066	0.105	0.198	0.077
Minimum	0.318	0.341	0.312	0.281	0.372
Maximum	0.393	0.407	0.417	0.479	0.449
Count	8	8	8	8	8

Table 39. Subject E, Immersion Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.737474	0.622843	0.876787	0.791973	0.827027
R Square	0.543867	0.387933	0.768756	0.627221	0.683974
Standard Error	0.033601	0.04106	0.027701	0.024753	0.024813
t Stat	2.674709	1.950091	4.466161	3.177316	3.603582
P-value	0.036795	0.099046	0.004255	0.019141	0.011318
H_0	Reject	Fail to Reject	Reject	Reject	Reject

During Subject E's drying phase, the Pearson correlation showed a range of 0.807 - 0.995. All sessions displayed a very strong correlation between ridge width and duration of time removed from water. The R^2 values indicated that 65.2% - 99% of the variability in ridge size could explained by duration of time since removed from water. All P-values, except session two, were <0.05; the deviation from the null hypothesis was statistically significant, and the null hypothesis was rejected. Session 2 measurements for 15 and 30 minutes removed from water were the same, which could have contributed to not having obtained statistical significance, despite having a multiple R value of 0.807. Tables 40-41 display the statistics and data sets for the drying phase related to ridge widths.

Table 40. Subject E, Drying Phase (Ridge Width) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.573	0.541	0.537	0.519	0.501
Standard Error	0.017	0.038	0.015	0.015	0.016
Median	0.571	0.577	0.533	0.514	0.495
Standard Deviation	0.033	0.076	0.03	0.03	0.032
Sample Variance	0.001	0.006	9E-04	9E-04	0.001
Skewness	0.383	-1.98	0.548	0.93	0.672
Range	0.076	0.155	0.067	0.072	0.069
Minimum	0.538	0.427	0.507	0.488	0.473
Maximum	0.614	0.582	0.574	0.56	0.542
Count	4	4	4	4	4

Table 41. Subject E, Drying Phase (Ridge Width) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.995191	0.807295	0.988125	0.969999	0.96232
R Square	0.990404	0.651726	0.97639	0.940899	0.926059
Standard Error	0.003969	0.054787	0.005581	0.009075	0.010812
t Stat	-14.3676	-1.93458	-9.09456	-5.64272	-5.00487
P-value	0.004809	0.192705	0.011875	0.030001	0.03768
H_0	Reject	Fail to Reject	Reject	Reject	Reject

Surface Area Pruning

Figure 25 shows a positive correlation between duration of immersion in water and percentage of area affected by pruning. Figure 26 shows a negative correlation between duration of time removed from water and percentage of area affected by pruning.

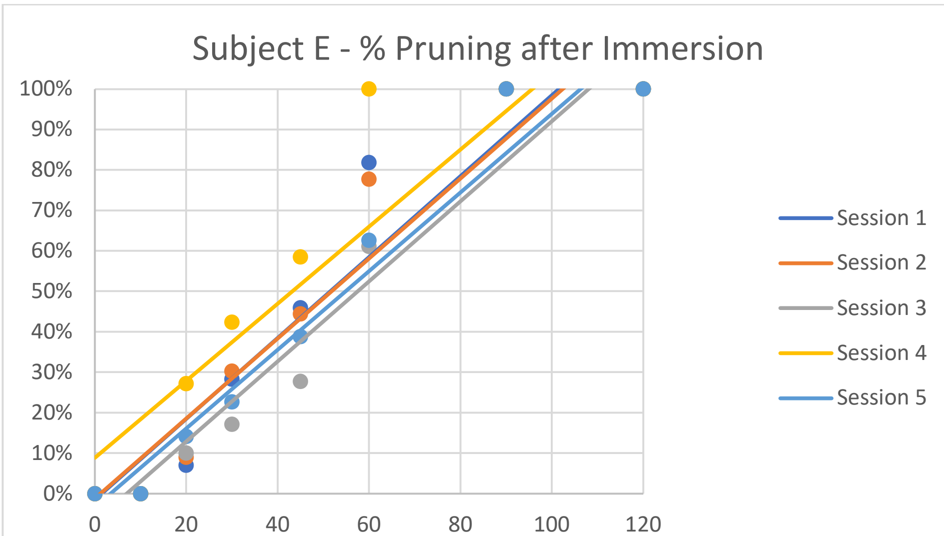

Figure 25. Scatterplot showing correlation between duration of immersion in water and pruning.

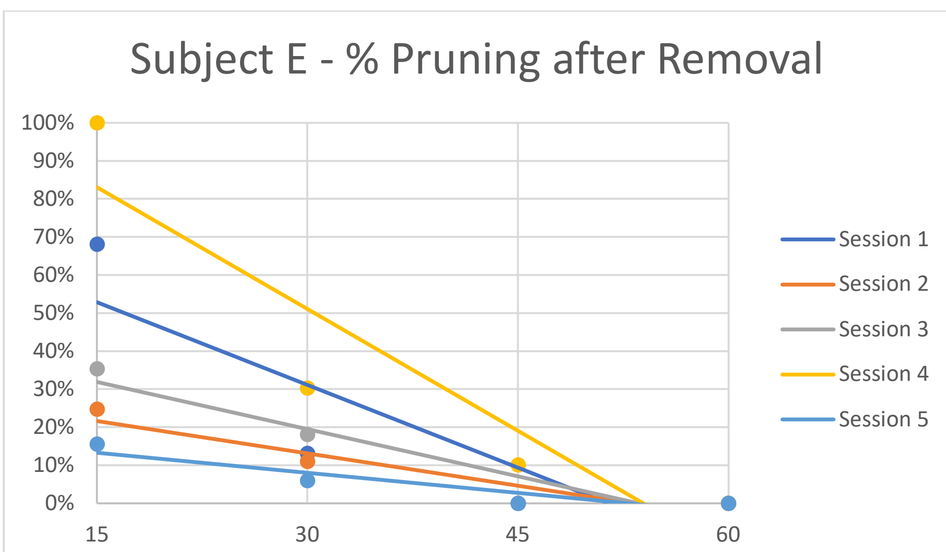

Figure 26. Scatterplot showing correlation between duration of time since removal and pruning.

There was greater consistency of results with assessing the surface area percentage affected by pruning than by measuring the ridge widths. The Pearson correlation ranged from 0.911 - 0.976 throughout the five sessions, indicating very strong correlations. The R^2 values indicated 83% - 95.3% of the area affected by pruning could be explained by the duration of immersion in water. The P-values for all five sessions were <0.05, meaning the null hypothesis was rejected and the alternate hypothesis was accepted. The statistical data for the immersion phase are shown in table 42 and table 43.

Table 42. Subject E, Immersion Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Mean	0.454	0.452	0.395	0.535	0.423
Standard Error	0.153	0.15	0.149	0.153	0.145
Median	0.371	0.374	0.224	0.505	0.308
Standard Deviation	0.434	0.426	0.421	0.432	0.411
Sample Variance	0.188	0.181	0.177	0.186	0.169
Skewness	0.294	0.319	0.743	-0.06	0.581
Range	1	1	1	1	1
Minimum	0	0	0	0	0
Maximum	1	1	1	1	1
Count	8	8	8	8	8

Table 43. Subject E, Immersion Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Multiple R	0.952186	0.959351	0.970203	0.911467	0.976299
R Square	0.906659	0.920355	0.941294	0.830772	0.95316
Standard Error	0.143175	0.129744	0.110233	0.19186	0.096145
t Stat	7.634152	8.326737	9.808371	5.42725	11.0497
P-value	0.000264	0.000163	6.47E-05	0.001622	3.27E-05
H_0	Reject	Reject	Reject	Reject	Reject

The Pearson correlation values for Subject E's area coverage drying phase ranged from 0.865 - 0.945 indicating very strong correlations across the five sessions. The R^2 values indicated that 74.8% - 89.3% of the variation of area coverage percentage was explained by duration of time since removal. Interestingly, Subject E was the only subject in which all sessions resulted in P-values >0.05 and the null hypothesis was not rejected. This data may be explained by the fact that, with each session, Subject E experienced 100% dissipation of all pruning by 40 to 60 minutes after removal from water. This repeat occurrence limited the data that could be used by statistical analysis but did not negate the strong correlation as indicated by the scatterplots and the Pearson correlation values. Tables xx-xx display the statistical data for the drying phase of area coverage.

Table 44. Subject E, Drying Phase (Area Coverage) Descriptive Statistical Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean	0.203	0.089	0.134	0.351	0.054
Standard Error	0.162	0.059	0.085	0.225	0.037
Median	0.066	0.055	0.091	0.202	0.03
Standard Deviation	0.325	0.117	0.169	0.451	0.074
Sample Variance	0.105	0.014	0.029	0.203	0.005
Skewness	1.796	1.039	0.813	1.562	1.246
Range	0.681	0.247	0.353	1	0.156
Minimum	0	0	0	0	0
Maximum	0.681	0.247	0.353	1	0.156
Count	4	4	4	4	4

Table 45. Subject E, Drying Phase (Area Coverage) Correlation and Linear Regression Data.

	Session 1	Session 2	Session 3	Session 4	Session 5
Multiple R	0.864653	0.936957	0.945046	0.917327	0.925547
R Square	0.747625	0.877889	0.893112	0.841489	0.856637
Standard Error	0.199715	0.050183	0.067827	0.219734	0.034153
t Stat	-2.43407	-3.7919	-4.08794	-3.25844	-3.45697
P-value	0.135347	0.063043	0.054954	0.082673	0.074453
H_0	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

RESEARCH RESULTS AND DISCUSSION

This research found that the ridge widths enlarged as duration of immersion in water increased, with variance. The ridge widths at 120 minutes were larger than the ridge widths at zero minutes; however, the largest measurements occurred between 30-120min of immersion. This variation could be attributed to measurement error and equipment limitations. Specifically, the scale was set manually in the image analysis software and a DSLR camera is unable to provide measurements to the micron, which is a more precise unit of measurement when dealing with friction ridges. However, this variation also generally supported Weber (1984) in that the friction ridges enlarged and compressed. As the finger swelled and pruning developed, it was not uniform, and some skin sank into valleys whereas other skin raised into hills. It was logical, then, to find that friction ridges enlarged and compressed. Within 15 minutes of removal from water, the friction ridges across all subjects started to reduce in size. It also appeared that ridge width had a stronger correlation to duration of time during the drying phase.

This research also found that in three percent of the repetitions, pruning presented in as early as 10 minutes. At 20 minutes, 95.7% of the repetitions indicated pruning and 100% of the repetitions showed pruning by 30 minutes. Pruning affected 100% of the surface area by 60 minutes. These findings support Reh's findings (1984) that pruning developed between 20-30 minutes, with full onset between 50-60 minutes. Although, this study started with 95°F water, it was allowed to cool. This could be why the findings resulted in similar findings to Reh's study that utilized cool water. Within 30 minutes removed from water, 5% - 94% of pruning dissipated. At 60 minutes removed from water, 33% - 100% of the pruning dissipated. The limitation in this study was that the subjects were living. Weber (1978) found that 100% of the living subjects presented full dissipation by 60 minutes of drying, while the ambient temperature was 68°F; additionally, Reh (1984), noted pruning was still present at 60 minutes of drying in the deceased subjects. This research disclosed that 74% of the repetitions showed evidence of pruning remaining at 60 minutes. If Subject E was removed due to the fact that Subject E was the only one who experienced 100% dissipation each session, then 94% of the remaining repetitions showed evidence of pruning at 60 minutes. This finding contradicts Weber's findings, but it can be attributed to biological variation or different ambient environments, such as humidity or air flow. Although evidence of water immersion was still visible at 60 minutes from removal after 120 minute immersion, the intensity at which the pruning presented was diminished and would likely have continued to diminish until full dissipation given more time. The intensity of pruning and dissipating characteristic is vital information for the purposes of crime scene investigation and timely evidence collection.

There were limitations with regression and analyzing the statistical significance of the data due to the smaller sample sizes. Understanding that calculating the P-value was dependent on the sample size rather than degree of correlation, it was necessary to determine which value was most important and significant in the practical application of this research. Since this research aimed to support crime scene response, the correlations and R^2 values were significant enough to find that the assessment of pruning and wrinkling skin on fingertips cannot be ignored during aquatic death scenes. The strength of circumstantial evidence relies on the accumulation of such evidence to support the facts of the investigation; the correlation between duration of immersion in water and duration of time removed from water was significantly relevant enough to ensure that this evidence be documented appropriately during aquatic scenes.

CONCLUSION

This research displayed that the extent of pruning on fingertips could be utilized to roughly estimate duration of immersion if other variables are known, such as water characteristics, water temperature, and ambient temperature. Most importantly, this research supported that pruning dissipates after removal from water, with full dissipation occurring as soon as 45 minutes after removal from water. As such, finger pruning is vital, transient evidence in an aquatic scene and needs to be documented immediately. Medicolegal death investigators commonly take more than one hour to arrive on scene. By waiting for their arrival to document this evidence on the body, it may be lost and can hinder the investigation. A close-up image of the fingertip in addition to over photographs of the hand was most helpful in analyzing and assessing the extent of pruning.

Future Research

Future research is necessary to build upon this study with increased data sets and developed methodologies to limit human error. Future areas of research include studying feet wrinkling or the impacts of full body versus partial immersion. Variable water composition and temperature are also areas worth studying since there is conflict with the composition of water or other liquid as a significant factor. Weber (1984) challenged Schleyer-Pommenich's claim that the mineral concentrations of sea saltwater did not influence the formation of pruning and opined that this assertion needed to be verified. Subject factors such as race, ethnic origin, age, vocation, medical history (e.g., eczema, diabetes, seizure medicine, etc.) and hydration levels are all important areas of study. Weber (1978) found no significant difference between age; however, this was the only study that specifically disclosed an age range and needs to be verified. Additionally, environmental factors are important, such as comparing indoor to outdoor scenes or an arid to humid environment.

REFERENCES

Armstrong, E., & Erksine, K. (2018, March). Investigation of Drowning Deaths: A Practical Review. *Academic Forensic Pathology, 8*(1), 8-43. doi:10.23907/2018.002

Barnes, J. (2011). History. In S. a. Scientific Working Group on Friction Ridge Analysis, *Fingerprint Sourcebook* (pp. 7-13). Washington, DC: National Institute of Justice.

Byard, R., Houldsworth, G., James, R., & Gilbert, J. (2001, June). Characteristic features of suicidal drowning - A 20 year study. *American Journal of Forensic Medical Pathology, 22*(2), 134-8. doi:11394746.10.1097/00000433-200106000-00005

Centers for Disease Control and Prevention (CDC). (2017, December 1). *Unitentional drowning deaths in the United States, 1999-2010*. Retrieved from https://www.cdc.gov/nchs/data/databriefs/db149.htm

Heaton, V., Lagden, A., Moffatt, C., & Simmons, T. (2010). Predicting the Postmortem Submersion Interval for Human Remains Recovered from U.K. Waterway. *Journal of Forensic Sciences, 55*(2), 302-307. doi:https://doi.org/10.1111/j.1556-4029.2009.01291.x

Katz, M., & Ramot, Y. (2015). Aquagenic wrinkling of the palms. *Canadian Medical Association Journal (CMAJ), 187*(18), E515. doi:https://doi.org/10.1503/cmaj.150074

Madea, B., & Doerentz, E. (2010-11). Commentary On: Heaton V, Lagden A, Moffatt C, Simmons T. Predicting the Postmortem Submersion Interval for Human Remains Recovered from U.K. Waterways. J Forensic Sci 2010;55(2):302-7. *Journal of Forensic Sciences, 55*(6), 1666-1667. doi:https://doi.org/10.1111/j.1556-4029.2010.01517.x

Modell, J., Bellefluer, M., & David, J. (1999). Drowning without aspiration: is this an appropriate diagnosis? *Journal of Forensic Science, 44*(6), 1119-23. doi:PMID: 1058235310.1520/jfs14580j

NIH. (2022, January 11). *ImageJ Release Notes*. Retrieved from ImageJ: https://imagej.nih.gov/ij/notes.html

People v. Szatanek, 169 A.D.3d 1448, 92 N.Y.S.3d 516 (N.Y. App. Div. 2019).

Reh, H. (1967). Anhaltspunkte f'tir die Bestimmung der Wasserzeit. *Dtsch Z Ges Gerichtl Med, 59*, 235-245.

Reh, H. (1984). On the Early Postmortai Course of "Washerwoman's Skin" at the Fingertips (translated). *Rechtsmedizin, 92*, 183-188.

Reh, H. (n.d.). Diagnostik des Ertrinkungstodes und Bestimmung der Wasserzeit. *Triltsch Dtisseldorf*, 141.

Reh, H. H. (1977). Die Sch~itzung der Todeszeit bei Wasserleichen. *Z Rechtsmed, 79*, 261-266.

Weber, W. (1978). Zur Waschhautbildung der Fingerbeeren. *Z Rechtsmed, 81*, 63-66.

Weber, W. (1982). Fltissigkeitspenetration durch Leistenhaut. *Z Rechtsmed, 88*, 195-193.

Weber, W., & Laufkötter, R. (1984). Stage Classification of Washerwoman's Hands at Experimental Time Intervals (translated to English). *Rechtsmedizin, 92*, pp. 277-290.

Wirthwein, D., Barnard, J., & Prahlow, J. (2002, Jan). Suicide by drowning: a 20 year review. *Journal of Forensic Science, 47*(1), 131-6. doi:12064640.10.1520/jfs15213j

World Health Organization (WHO). (2014, November 17). *Global report on drowning: preventing a leading killer* . Retrieved from https://www.who.int/publications/i/item/global-report-on-drowning-preventing-a-leading-killer