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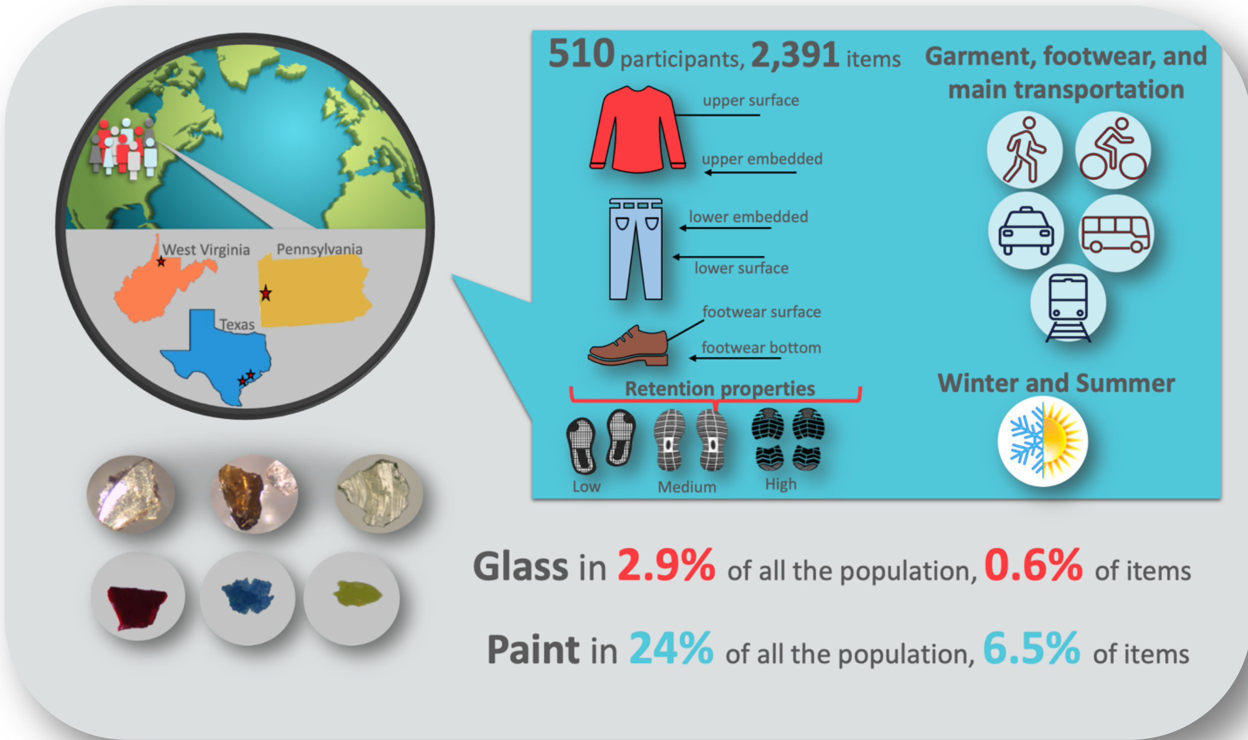
FINAL RESEARCH REPORT

Development of baseline survey of random presence of glass and paint for the interpretation of evidence in the US courts



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I PROJECT SUMMARY

1.1. Abstract

Over the last four decades, significant efforts have been devoted to developing and validating databases, technologies, and consensus-based standards describing the significance of glass and paint as physical evidence, particularly regarding conclusions of source association or exclusion. Still, forensic scientists, academics, and the legal community are starting to have open debates on the use of more overarching interpretation approaches beyond the source level. However, in the absence of local data regarding the prevalence of trace materials on the general public relative to those involved in an alleged event, the application of these models in our courts would remain challenging and hardly compelling.

The paucity of this fundamental information also decreases the efficiency of decisions made while collecting evidence at the crime scene and formulating significant investigative leads. Ground knowledge on how common it is to find glass and paint traces in the general population, their relative incidence by material type (e.g., architectural vs. vehicle), or by location (e.g., shirt vs. footwear) are a few examples of questions that should be substantiated with empirically verifiable data. Consequently, the overall goal of this study is to obtain baseline data on the frequency of occurrence of glass and paint relevant to the U.S. territory to fill out this existing gap.

This project addressed essential factors never evaluated before in a single and systematic study. The study provides data from four different cities in two geographical regions of the United States, including small and metropolitan areas with diverse socioeconomic and demographic conditions. It also evaluates the frequency rates of these traces in different seasons. It considers factors that may influence the retention of glass and paint on apparel, such as modes of transportation and clothing and footwear worn. Finally, a full characterization of features of interest in the recovered traces by appropriate analytical techniques permits the evaluation of the relevance of glass and paint occurrence by major end-uses.

The sampling of glass and paint particles in the four cities allowed recruiting 510 volunteers. A total of 2,391 garments and pairs of footwear were sampled from six locations: the upper and lower surfaces, embedded areas on the top and bottom clothing, the footwear surfaces, and the footwear embedded areas (soles). Some of the significant findings of this study are:

1) Paint traces were more common in the general population than glass.
2) Paint residues were found in 24% of the overall background participants, compared to only 2.9% for glass. These rates varied more substantially by specific cities for paint than glass. For example, depending on the town, 4 to 39% of volunteers had paint, and 0.9 to 7% glass.
3) Considering all the 2,391 clothing and footwear samples, 6.5% of the items bore paint traces, while 0.6% had glass. Again, these numbers vary by city, with more variation observed on the paint frequency (1 to 29% of items had paint, versus 0.2 to 1.4% glass, depending on the city)
4) Glass was mainly recovered from the surfaces and soles of the footwear. In comparison, paint was primarily recovered from the garments' upper and lower surfaces.

5) Most individuals and items inspected contained a single glass or paint fragment, with few exceptions containing multiple fragments. No more than two fragments were observed from a single group
6) The glass and paint traces were predominantly small, with most glass sizes below 1 mm and most paint smaller than 0.5 mm.
7) The parallel occurrence of glass and paint in a single individual was very rare (2 out of 510 individuals), and even more uncommon to find both traces in a single item (none of the garments or footwear contained glass and paint on the same item).
8) Most of the glass recovered from the background populations was classified as a container followed by sheet soda-lime-silicate, with some specialty formulations also encountered in the Houston and Pittsburgh collections.
9) Some end-use classifications of glass were challenging, as they represented unusual formulations of glass, such as portable electronic device screen protectors, high-iron glass fragments, and zinc-phosphate glass. This raised a flag that expanded databases and interpretation protocols may be needed as modern glass may come to the attention of forensic practitioners.
10) Much of the paint recovered from the general population was single-layered architectural or automotive paint with various binders and pigment compositions.
11) A higher occurrence of glass and paint was found in the winter than in summer in a city where the average temperatures dropped in the winter by approximately 40 °F. The study indicates that differences in the clothing worn and the primary modes of transportation during these seasons affect the background of these traces in that background population.
12) The study also indicates that the cities' demographics, socioeconomic circumstances, and urban design affect glass and paint occurrence rates. For instance, college towns with similar populations and infrastructure led to a similar frequency of glass and paint, as well as generally similar clothing-fashion and choices of transportation modes. On the other hand, larger metropolitan areas had substantially different rates of occurrence. Houston presented the largest occurrence of glass and paint. Interestingly, the volunteers reported using a personal vehicle as the primary mode of transportation, with none indicating significant walking. The Pittsburgh participants, who reported walking as the primary mode of transportation around the city area, presented a low occurrence of glass and the lowest occurrence of paint.
13) The factor that was most significantly different across the four cities was the mode of transportation, while the clothing type was relatively similar, except for the winter collection set.

The results of this extensive survey agree with some general observations reported in the literature, specifically the findings described in points 1, and 4 to 6 above. However, the overall rates of occurrence for glass and paint provide relevant contemporary information for the U.S. territory. Our results were relatively comparable with studies conducted in Canada[57] and Australia[51.53] but significantly smaller than some European regions[52,54,55], providing evidence of the relevance of using baseline data that reflect the reality of the population of interest.

The remaining of our findings (points 2, 3, and 8 to 13) provide new information on the occurrence of glass and paint for the U.S. population and identify confounding factors that should be considered when interpreting this type of evidence. Finally, the present study revisited a type of survey that was originally published in the early Seventies and saw the last study of this kind in 2009. The research illustrates how this U.S. survey data can be utilized in the interpretation of trace materials by improving an approach developed by Coulson et al.[54] and re-evaluating the estimation of two parameters typically used for activity level likelihood ratio formula. The probability P to observe a certain number of groups of fragments on garments and the probability S to observe a given number of fragments for a given group were estimated using standard numerical optimization and a zeta distribution. This led to the development of the package *fitPS* (https://cran.r-project.org/web/packages/fitPS/fitPS.pdf) used within the open source statistical software R, which has been made available to the public.

This study is anticipated to provide fundamental data and resources to overcome challenges in the forensic assessment of glass and paint evidence in our criminal justice system, assisting practitioners and the trier of fact in making informed decisions. Moreover, this research provides a knowledge base needed to fully utilize trace evidence to its authentic potential, including activity-related investigative and reconstruction leads, rather than restricting its value to source inferences.

1.2. Problem statement

Forensic glass and paint examinations benefit from an established consensus regarding standard guidelines and the scientific validity of the methods.[1-8] Since glass and paint are mass-produced products; several interagency studies have focused on evaluating the significance of source commonality among questioned and known items. The peer-reviewed literature reports error rates associated with exclusions or associations and the individual and combined discrimination power of the examination techniques, given the variations within and between sources of the materials.[9-43]

However, the real value of glass and paint evidence does not stop at the source attribution but instead requires the incorporation of propositions related to the significance of the evidence given a particular activity context.[44,45] For instance, probabilistic information regarding the transfer of materials during a criminal event versus random or secondary transfer is essential for an overall assessment.[46-48] Moreover, the activity information can be integrated to offer a more encompassing use of trace evidence for reconstruction and intelligence support. With the advent of powerful identification tools such as DNA and fingerprints, the essence of trace evidence has been diminished by the misconception of its sole use as associative evidence. Nonetheless, trace evidence has a unique potential to answer questions that other forensic sub-disciplines cannot, such as what happened and how the evidence was transferred. Re-incorporating trace evidence to its full capacities could have an impactful paradigm shift in the practice of forensic science.

Challenges associated with the interpretation of trace evidence have attracted a great deal of interest over the past few years. Some court systems in European countries, Australia and New Zealand, have adopted the use of likelihood ratios and other approaches that formally quantify the weight of glass and paint evidence under alternative propositions.[44-50] In the United States, however, this has not been a common practice in part because implementing such models in our judicial system requires a body of knowledge currently limited in this field.

Irrespective of the interpretation approach used to evaluate the evidence—Bayesian, Frequentist, or Classical— studies on baseline frequency occurrence are essential in the assessment of the relevance of the evidence. For instance, it is common in cases involving either paint or glass for counsel to ask the forensic expert how likely it is to find either paint or glass on a randomly chosen individual from the population. The reasons for asking this question are two-fold. Firstly, depending on whether the counsel is acting for the prosecution or the defense, the aim is to elicit a statement of relative rarity.

Second, to determine whether the expert can substantiate the statement with scientific research. A further question of interest is whether any of the studies quoted were local or recent. We know, through a comparison of the baseline work reported in the literature, that there are differences due to time, geographic location, and the activities of the individuals surveyed. If these differences have a bearing on the value of the evidence, then it is incumbent on the experts testifying in the case to know how the weight of the evidence is impacted by these differences. Such knowledge can only be acquired by carrying out surveys like the one conducted in this project.

Therefore, the findings of this study are anticipated to provide a body of knowledge that can be applied to different interpretation models. In this study, we will focus on increasing the body of knowledge on background glass and paint in the general populations. Although transfer and persistence are also of interest for the interpretation of evidence, this topic is out of the scope of this project as the existing research is more extensive. Contrariwise, the literature on baseline data is scarce, and the available surveys are from foreign countries where socioeconomic and demographic circumstances do not necessarily reflect the reality of our society.[51-55] Most importantly, there is a lack of congruence among the findings in these studies. Differences in experimental designs regarding recovery methodologies, sampling size, and the targeted populations cause difficulties in making appropriate data-centered inferences.

We hypothesize that the frequency of occurrence of random glass and paint in the U.S. is low, in the sense that it is not expected to recover many glasses and paint residues in individuals not directly exposed to these materials (i.e., professional exposures) by chance. It also varies widely according to the socioeconomic reality of each country, the type of clothing worn by the population, and the general activities they are involved with.

As a result, this research aims to generate baseline information on glass and paint relevant to the United States, using a pilot model of two small towns and two large cities. The strategic partnership of experienced researchers and statisticians was crucial for maintaining consistency among protocols used for the recovery, preservation, analysis, and interpretation of the data. The primary investigators at West Virginia University (WVU) and Sam Houston State University (SHSU), are conveniently located in regions with sites, climates, and demographics that allowed the collection of samples under statistically and experimentally controlled conditions. Additionally, both university campuses are located near metropolitan areas, which provides a valuable comparative element.

The information derived from this project addressed essential factors such as variations in the random occurrence of glass and paint by garment type, by location, and by season. Physical and chemical analysis of the recovered traces permitted their classification into end-user categories (e.g., container vs. sheet glass; automobile vs. architectural paint) to provide additional context for interpreting the data.

The proposed study is a fundamental piece in assessing the significance of trace materials because it places the findings of a source association under a meaningful framework for the trier of fact. It is anticipated that the outcomes of this research will move the forensic discipline forward, not only strengthening expert opinions by incorporating activity inferences but also expanding the value of trace evidence to a more holistic approach involving close collaboration with crime scene personnel and law enforcement in the reconstruction and investigative stages.

1.3. Major Goals and Objectives

This study aims to improve the knowledge base needed to address activity questions through trace evidence by providing relevant data on the random occurrence of glass and paint residues in U.S. populations, to inform not only expert opinions in court but also investigative frameworks. The overall goal of this proposal is to answer the question: "how much glass and paint is recovered by chance on a member of the general population?" Specifically, the study is designed to answer this question within a context that is relevant to U.S. criminal justice.

As a result, it is anticipated that this study will provide a necessary foundation to help trace evidence to move away from a narrow focus on source attribution to a more inclusive use of the trace evidence on case reconstruction, and integration of activity questions in the assessment of its evidential significance. The specific objectives of this research are to:

1) **Objective 1:** Collect data of random presence of glass and paint from four different cities in the US, including two rural and two metropolitan areas that represent a variety of geographies and demographics,

2) **Objective 2:** Evaluate the effect of the type of clothing worn at different seasons (summer and winter) on the occurrence of glass and paint,

3) **Objective 3:** Estimate the frequency rates on garments typically recovered on related investigations such as upper clothing, lower garments, and footwear,

4) **Objective 4:** Evaluate the incidence of glass per location (surface versus pockets/cuffs, sole versus surface shoes), and

5) **Objective 5:** Identify and characterize the primary types of recovered glass and paint and evaluate the variation of the pertinent features considered during regular forensic examinations.

1.4. Research Design, Methods, Data Analysis

1.4.1. Methods of analysis

General sampling protocols and instrumentation

Sampling protocols

The sampling method and collection materials were standardized throughout the study, and the PIs provided cross-training and protocols to the student researchers. Standard operating procedures, instructional videos, and training materials were developed for this study. We completed three training phases to standardize the collection and analysis protocols among the teams: a) review and discussion of literature, b) protocols of sampling and examination, and c) performance assessment via training kits. The SOPs were created and reviewed by both teams for a) labeling, assembly, and storage of sampling kits, b) sampling at site locations, c) examination of samples under the microscope, d) recovering and examining traces, e) peer-review verification protocols, and f) reporting and documenting findings. Also, template forms and videos were created for their use during collection and analysis: a) collection plan and checklists, b) microscopic examination, c) examining glass fragments, and d) examining paint fragments.

Paint and glass residues are often collected at the crime scene and the laboratory by hand-picking (if fragments are large and visible), scraping with a spatula, shacking, tapping, vacuuming, or a combination of them.[36,63] The collection method chosen in this study for clothing and the top-surface shoes is tape lifting. One of the advantages of using a tape pad is its non-intrusive nature, so the volunteers can apply it systematically without invasive body contact. Other benefits of taping are a) the speed of collection and recovery efficiency, b) ease of preservation and storage of the evidence, c) ease of cross-verification by multiple examiners without sample manipulation, and d) prevention of disturbance of the traces and migration between areas in comparison to scraping or shaking.[62,63] Also, the tape lift is secured in a transparent film that conveniently preserves the evidence and facilitates direct observation and labeling of the glass and paints under the microscope. This has proven to be critical for the corroboration of recovered items by a second analyst.

Since taping is not effective on irregular surfaces like soles, the top surface of the footwear was taped first to prevent any migration, and then the soles were searched visually and scraped with tweezers and spatula and recovered on a petri dish. To prevent contamination, butcher paper was placed on the floor where the individual removed their shoes for collection. The researchers conducting the collection wore disposable labcoats and gloves to preserve the integrity of the sampled items.

After surface collection, the pockets and cuffs were turned over and taped separately. Tape lifts were stored in pre-labeled envelopes. Each tape lift and its envelope were labeled with unique identifier codes that indicate the sampling site, date, garment sampling location, sampling type, and a sequential number. None of the samples was traceable to a specific participant since identifiable information was not collected at any time.

Instrumentation

Using oblique, incident, and transmitted light, the search for glass and paint was carried out with Leica EZ4 stereomicroscopes and a Leica LCD KL2500 comparison microscope. Recovered particles were documented photographically using the Leica Application Suite v 3.4.0. or the DP2-BSW software. Stereomicroscopy was also used to check for the hardness of clear fragments using the needle test as well as hackle marks.

Refractive index measurements were made using the GRIM 3 system (Foster and Freeman Ltd) following the ASTM E1967-19 (Standard Test Method for the Automated Determination of Refractive Index of Glass Samples Using the Oil Immersion Method and a Phase Contrast Microscope). The system has a Leica DM 2500 M phase-contrast microscope (with a 589nm d-line filter) and a Mettler Toledo FP82HT hot stage. Software Glass 2.6.135 was used to manage measurements and data. Glass fragments were mounted onto 19 mm x 76 mm Thermo Scientific Menzel- Glaser slides and fixed with 18 mm x 18 mm square cover glasses. Locke Scientific silicone oil type B was used as the mounting medium. Performance checks were carried out using the pK3 or Schott K5 standard.

Glass elemental analysis was conducted by micro-XRF, or SEM-EDS if the fragments were too small for XRF analysis. Fragments were analyzed using a Bruker M4 Tornado micro-X-ray fluorescence spectrometer and were mounted on an XRF film wheel using clear washable glue. Performance checks of the instrument were carried out using NIST 1831, and Zr was used for the calibration. Spectra were collected from each glass fragment for 300 live seconds, with three replicate measurements taken per fragment. The 600 uA current X-ray beam utilized a rhodium X-ray source, operating at 50 kV. Two SDD detectors were used to collect the spectra using 40 keV and 130 kcps. The spot size for the collection was 20 um. A JEOL Model JSM-6490ZB instrument was used to analyze small glasses. Performance checks of the instrument were carried out using NIST 1831, and Cu was used to align the peaks. Spectra were collected from each glass fragment for 1200 live seconds, with a working distance of 18 mm, an accelerating voltage of 20 KeV, and a spot size of 60 μm. Imaging of the fragments was carried out using an accelerating voltage of 2 KeV and a spot size of 40 μm. The working distance was kept around 10 mm and varied slightly to obtain the best focus.

The recovered paint fragments were analyzed on a Perkin Elmer Model Spotlight 200i FTIR (Perkin Elmer, Waltham, MA) to identify the polymers, pigments, and some inorganic fillers in the paint fragments. The paint fragments were placed onto a diamond cell and compressed with even pressure to reduce the thickness of each layer. Analyses were conducted on transmittance or ATR using the microscope mode. Spectral range and resolution were maintained at 4000-500 cm^{-1} and 4 $cm^{-1.}$ Each measurement consisted of 64 scans for transmittance mode and 128 for μATR. Energy and the background were monitored during each run. A polypropylene standard was used for daily performance checks.

Experimental design

For the experimental design, four factors are considered in the study corresponding to the four cities of interest, and for each city the following three levels are evaluated (*u*—upper clothing, *l*—lower clothing, *f*—footwear). For each level, samples will be collected separately from surface (*s*) and from embedded or enclosed areas (*e*).
Two of the cities will represent rural areas while the other two will represent metropolitan areas. In order to account for combinations of levels of each factor, the following model with interactions will be applied:

$$y_{ilk} = \mu + \alpha_i + \beta_l + \gamma_{il} + \varepsilon_{ilk}$$

Where y_{ilk} is the K^{th} replicate measurement of an experimental unit which has received level *i* of city and level *l* of clothing, μ is the mean of all observations, α_i is the effect of city *i*, β_l is the effect of clothing *l*, and γ_{il} is the interaction between city *i* and clothing l, ε_{ilk} is the inherent random variation error remaining after you've subtracted away the effect of population, city, and the interaction of the two. A diagram of the experimental design is shown in the figure 1. As is typical with this type of project, data analysis will involve data exploration, testing and modeling. Raw metadata containing sample identifiers, qualitative descriptors, and quantitative data was processed on Microsoft Excel files, and the curated data was analyzed on an open source database software (R studio).

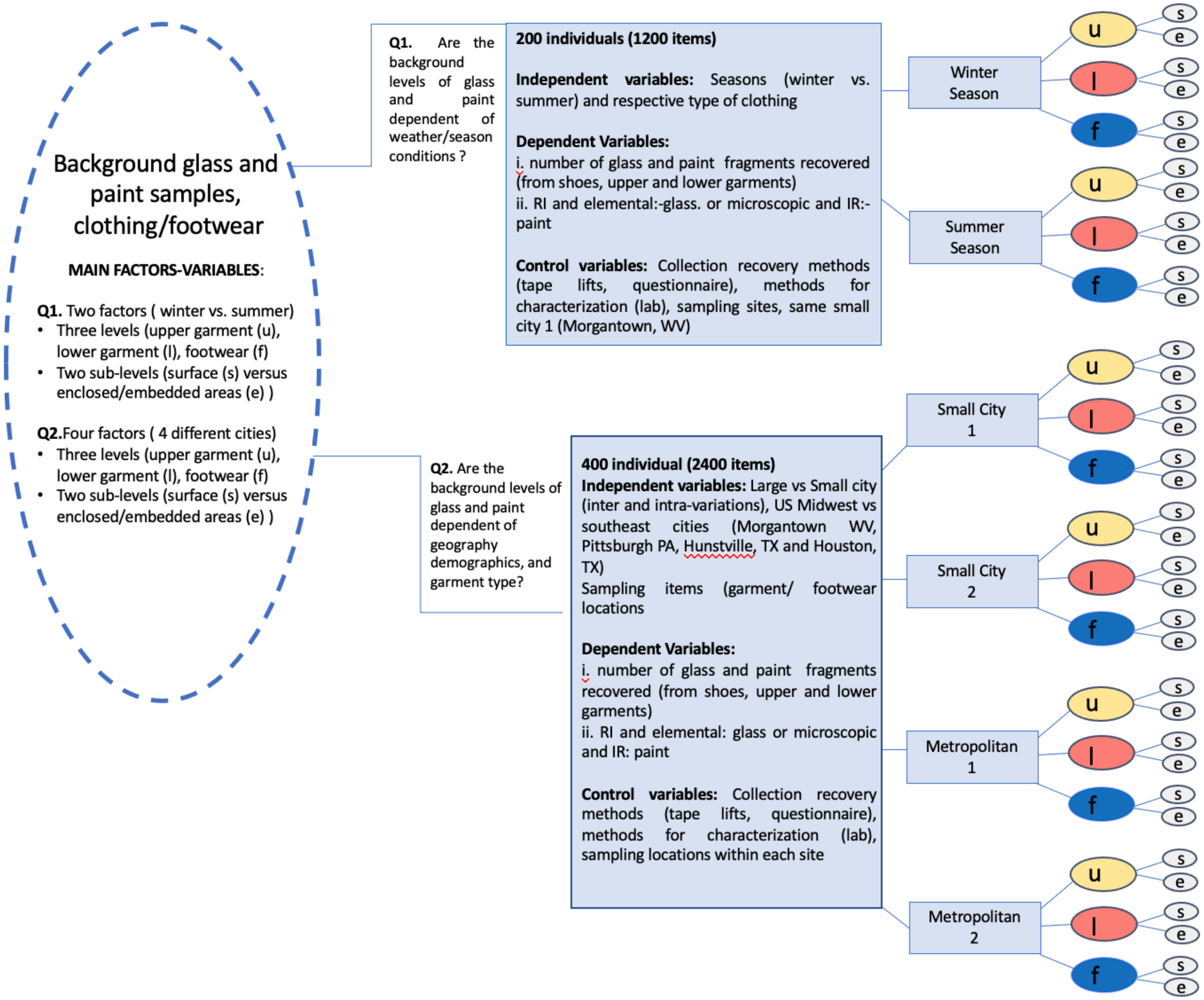

Figure 1. *Summary diagram of the main experimental design. (u—upper clothing, l—lower clothing, f—footwear, s—surface clothing/footwear, e—embedded or enclosed areas, Q: research question). The experiments were designed to collect traces from up to six areas per person.*

Task 1 (Objective 1)—Collect baseline data of glass and paint on convenient sampling populations in the U.S.

Morgantown, WV, and Huntsville, TX, were selected as a model for small cities as they both have a similar population size and represent university towns (WVU and SHSU) that provide a diversity of students representing different cultural and socioeconomic backgrounds. Both universities have an overall diversity ranked above average in the U.S. The population of the two campuses represents a student body from 45 states and small to a mid-size representation of international students from over 40 countries. Both cities have in common sites where people are easy to reach, such as university student centers and shopping centers with similar traffic patterns that will help with the standardization of sample composition. Moreover, both towns are in the proximity of metropolitan areas such as Pittsburgh and Houston, that provide a comparison point regarding the distribution of presence of these traces on the public in larger cities (Table 1).

Shopping centers were initially considered to allow an expansion of demographics. However, due to the COVID situation, malls and shopping centers were unwilling to participate. Instead, we conducted the sampling at university campuses. Volunteers included students, staff, faculty and visitors.

In addition to the chosen similarities, the cities have essential differences. These include the geographical and climate factors that may influence the residents' activities, transportation, and garments. These differences were relevant to establishing the extent to which the findings can be extrapolated to other cities in the U.S.

Participation was voluntary and followed IRB approved protocols. The study will target individuals that self-report not being commonly involved with broken glass or painting activities. A questionnaire was used to record information regarding zip code, age range, modes of transportation commonly employed, type of fabric wore, retention properties of apparel (low, medium, high) and frequency of outdoor activities. No personally identifiable data was collected in the survey. The sampling protocol was not intrusive, and no harmful or stressful effects are expected of the participants that the subject would not usually encounter in everyday life.

It was anticipated that the targeted populations will wear casual apparel commonly worn by an average person and typically received at a crime laboratory from individuals involved in hit and runs, break and entries, assaults and other violent crimes. The items selected for this study are:

a) Upper-body clothing such as shirts, blouses, tank tops, jacket, sweaters, coats, jumpers, and tunics.
b) Lower-body clothing such as skirts, shorts, pants, jeans, and dresses.
c) Footwear such as sneakers, moccasins, dress shoes, flats, sandals, boots, and booties.

Since the persistence of trace materials can vary on enclosed areas of the garments, such as cuffs and pockets, the collection was done separately on the surface areas followed by the less exposed parts of the clothing.[51,54,55,57,59,62] From surface areas, only the external layers were sampled in this study. For instance, if a person is wearing a jacket and a shirt underneath, just the jacket was considered for sampling purposes as the outer layer will represent the most likely item exposed to transfer of paints and glass in a given event. Likewise, footwear sampling was separated into surface areas and soles, as trace materials in the bottoms of a shoe are more likely to transfer and persist.[44,56] Collection sets in four cities were completed, as shown in Table 2.

Table 1. *Demographics, climate and crime index statistics per city.*[a,b,c,d]

CITY	Morgantown, WV	Pittsburgh, PA	Huntsville, TX	Houston, TX
Population	31,073	303,624	40,435	2,304,388
Region division	South Atlantic	Mid Atlantic	West South Central	West South Central
Median resident age	25 years old	33 years old	28 years old	33 years old
Median household income	$38,000	$44,000	$33,000	$47,000
Per capita income	$26,000	$18,000	$13,000	$30,000
Demographics	(W:84%, B:75%, A:5%, H: 3%)	(W:65%, B:22%, A:6%, H: 3%)	(W:50%, B:27%, A:2%, H: 19%)	(W:24%, B:22%, A:7%, H: 44%)
Crime index	200.7	520.1	220.8	520.7
Climate	Humid subtropical and humid continental. Four distinct seasons	Humid subtropical	Humid subtropical	Humid subtropical and humid continental. Four distinct seasons.
Average temperatures Crime index	Summer: hot and humid (74°F) Winter: cool to cold (31°F)	Summer: hot and humid (75°F) Winter: cool to cold (30°F)	Summer: hot and humid (88°F) Winter: mild to cool (67°F)	Summer: hot and humid (84°F) Winter: mild to cool (53°F)

Table Notes:
2021 [a] census and 2021 [b] median U.S crime index 268.4, www.city-data.com,
[c] NOOA, https://www.ncdc.noaa.gov/cdo-web/
[d] Primary race demographics reported as W: white, B: black, A: Asian, H: Hispanic.

Table 2. *Description of the study population and number of items collected*

Target population	Source	Number of samples planned	Collection site / Season	Collection method	Status
1–Small city random presence of traces on individuals' garments and footwear	***Clothing surfaces:*** 1) upper clothing, 2) lower clothing, 3) footwear surfaces. ***Enclosed areas*** - 4) upper clothing cuffs/pockets, 5) lower clothing cuffs/pockets, 6) shoe soles	100 individuals (600 items, one per garment and footwear location)	**-Morgantown,** WV (WVU student center and shopping center such as Walmart) -**Collection in summer May to August**	Taping and scraping (sole shoes)	100% completed (110 individuals, 530 items)
2– Small city random presence of traces on individuals' garments and footwear	Same as 1	100 individuals (same as 1)	**Huntsville, TX** (SHSU student center and shopping center such as Walmart **-Collection in summer June to August**	Taping and scraping (sole shoes)	100% completed (100 individuals, 398 items)
3- Metropolitan city random presence of traces on individuals' garments and footwear	Same as 1	100 individuals (same as 1)	**-Pittsburgh, PA** (shopping center) -Collection in **May to September**	Taping and scraping (sole shoes)	100% completed (100 individuals, 460 items)
4– Metropolitan city random presence of traces on individuals' garments and footwear	Same as 1	100 individuals (same as 1)	-**Houston,** TX (shopping center) -Collection in **May to October**	Taping and scraping (sole shoes)	100% completed (100 individuals, 495items)
5– Small city random presence of traces in summer vs winter seasons	Same as 1	100 individuals (same as 1)	**Morgantown**, WV (**winter, February-March**)	Taping and scraping (sole shoes)	100% completed (10 individuals, 508 items)
Total set	Same as 1	500 individuals (~3000 items)	4 U.S. cities	Taping and scraping (sole shoes)	**510 individuals (2,391 items collected)**

Approximately 14 to 57% of the upper garments and 57 to 78% of the lower garments had some embedded areas, resulting in a smaller number of tape lifts collected on those enclosed locations than on the respective surface areas. The Hunstville collection was particular, as only two of the 200 clothing items had embedded areas (one on the bottom and one on the upper garment); the remaining participants in this set wore clothing without pockets or folds. We also had a few instances where the type of shoe did not allow collection from the surface areas. As a result, from the 510 individuals sampled, a total of 2,391 tape lifts were collected from their apparel (Table 3).

Table 3. *Total number of garments and footwear collected*

Garment Area	Morgantown Winter	Morgantown Summer	Huntsville	Pittsburgh	Houston
Upper surfaces	100	110	100	100	100
Upper embedded	57	21	1	14	20
Lower surfaces	100	110	100	98	100
Lower embedded	57	78	1	57	75
Footwear surfaces	94 pairs	101 pairs	96 pairs	91 pairs	100 pairs
Footwear bottom	100 pairs	110 pairs	100 pairs	100 pairs	100 pairs
Total garment and footwear items	508	530	398	460	495
Participants	100	110	100	100	100

Winter set collected in Morgantown.

A total of 508 garments were collected in Morgantown from 100 individuals during the winter season, including the surfaces and soles of footwear (pairs). All 100 individuals had the upper surface, lower surface, and footwear bottom areas for this winter sampling set. Fifty-seven individuals had upper embedded areas, 60 individuals had the lower embedded areas, and 94 individuals had footwear surface areas.

Summer sets collected in Morgantown, Huntsville, Pittsburgh, and Houston.

SHSU and WVU completed the summer sets in Morgantown (110 individuals) and Huntsville (100 individuals). The collection in Pittsburgh (100 individuals) was done in early September 2021, and the Houston set (100 individuals) was delayed to October 2021. However, the Houston and Pittsburgh the temperatures during collection days were still in the low 80s.

From the Morgantown summer set, the collection from 110 individuals yielded 530 sampled items. A total of 319 garment and 211 footwear areas were collected in this set. Most of these garment areas were considered to have low retention properties, with individuals primarily having thinner and smooth fabrics, while most footwear was identified with higher retention features.

From the Huntsville summer set, 398 garments were collected from 100 individuals; all had upper and lower surface areas, while only one person had clothing with embedded upper and lower surfaces. All shoe soles were sampled (100), while only 96 had surface areas available for taping.

The Pittsburgh summer set yielded 460 sampled garment and footwear areas from the 100 volunteers. Of these areas, 269 garment areas and 191 footwear areas were collected. For this collection, garment and footwear areas were a mix of high and low retention properties. Finally, the Houston set yielded 495 sampled items from 100 participants, 295 garments and 200 pairs of shoes. Most items in the Houston set had medium to high retention, except for the upper garments that were primarily low retention.

Task 2 (Objective 2) — Evaluate the effect of the type of clothing and footwear worn at different seasons (summer and winter) on the occurrence of glass and paint.

The hypothesis in this task is that drastic changes in season (i.e., winter versus summer) influence the incidence of background glass and paint residues. The rationale for the hypothesis is that the weather impacts the indoor and outdoor activities practiced by individuals, the type of footwear and fabrics they wear, the frequency of washing/cleaning of external layers, and the relative surface area of the garments.

Several studies have shown that the transfer and persistence of trace materials are affected by the fabric composition and the footwear anatomy.[56,63] As a result, both the fiber composition and fabric construction of clothing typically worn in winter time is anticipated to retain more traces than those used in summer. Typical outer clothing on winter days includes thermal jackets with synthetic and natural fibers designed to maintain body temperatures, while summer outfits commonly involve lighter garments such as t-shirts, active-wear apparel, and shorts with different fiber polymers and morphologies. Footwear, particularly on snowy days, often encompasses boots and shoes with soles that provide better traction and coarser sole profiles that are anticipated to retain more traces. In addition, factors also expected to play a role in the persistence of background materials are the frequency of outdoor and indoor activities practiced by the individuals in cold and warm weather such as walking, hiking, running, variety of sports leagues, to mention some.

The sample collection for this task was done at one of the control cities evaluated in task one (Morgantown, WV) at the WVU student center and downtown campus during the winter and summer season. All the recovery methods, collection sites, target population, and sampling size, remained constant during the two sampling periods. In addition to the questionnaire filled out by the participants, the examiners conducting the sampling documented weather conditions during the collection day (i.e., average temperature, sunny, rain, snow) and the general observations of fabric and footwear composition worn by the individual, retention properties, and general activity at the time of collection.

The garments and their respective retention type were recorded from each volunteer. Table 4 displays the various garments and their assigned retention categories. Garments considered high retention were sweatshirts, knit fabric, and ripped jeans, whereas plain jeans and khakis were placed under the medium retention type. Items like silk, athletic clothing, and raincoats were considered to have low retention properties. Footwear items that were considered to have high retention properties because their surfaces or soles favor retention include hiking or working boots with high tread. Crocs and athletic shoes with medium grip and sole tread were placed under the medium retention type, and flats, heels, and cowboy boots with flat outsoles were considered low retention. Garments and footwear items sampled in the winter collection were mainly of high retention type, while garments and footwear items from the summer collection were often medium to low retention.

Table 4. *Examples of various garments and their retention characteristics from the summer and winter sets. Many garment types overlapped between the seasons, but some, such as wool, Sherpa, and snow boots, were specific to winter, whereas items like ripped jeans, t-shirts, and Chaco sandals were more prominent in the summer.*

<table>
<tr><th colspan="3">Garments/Retention Category</th><th colspan="3">Footwear/Retention Category</th></tr>
<tr><td>High</td><td>Medium</td><td>Low</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Sweatshirts</td><td>Cotton</td><td>Silk</td><td>Hiking boots</td><td>Crocs</td><td>Flats</td></tr>
<tr><td>Wool</td><td>T-shirts</td><td>Athletic clothing</td><td>Working boots</td><td>Sneakers</td><td>Cowboy boots</td></tr>
<tr><td>Tightly knit fabric</td><td>Plain jeans</td><td>Raincoats</td><td>Snow boots</td><td>Athletic shoes</td><td>High heels</td></tr>
<tr><td>Sherpa</td><td rowspan="2">Khaki shorts</td><td>Puffer jackets</td><td>Rubber soles</td><td colspan="2" rowspan="2">Vans or other "fashion" sneakers with medium to low sole tread</td></tr>
<tr><td>Ripped jeans</td><td rowspan="2">Leggings</td><td>Flip flops (glass only)</td></tr>
<tr><td colspan="2">Flannel shirts</td><td colspan="2">Chaco sandals</td><td></td></tr>
</table>

Task 3 (Objective 1 to 4) — Estimate the frequency rates on upper clothing, lower clothing, and footwear, and thei relative location per garment.

The amount of glass and paint transferred to an individual during a criminal event is known to vary by the relative location to the point of forceful contact (paint) or the breaking point (glass).[36,44,64,65] Likewise, the persistence of trace evidence is influenced by surface versus enclosed/embedded locations (pockets, cuffs, soles). As a result, it is essential in this study to provide baseline information by garment type and location. As described above, this was accomplished by targeting six locations per individual to include items that are representative of typical case samples involved with glass and paint examinations (see table 3, and Figure 1).

Task 4 (Objective 5) — Identify number of groups of traces found by sampling location using characterization of glass type by refractive index and elemental analysis, and paint type by microscopical and infrared analysis.

On each task described above the number and size range of the retrieved traces was documented. According to typical sample size recovered in casework, approximately size ranges were reported. In circumstances where more than one fragment was recovered per inspected item, we gathered analytical data to determine if the particles can be grouped in the same class or if they were transferred from multiple sources. The characterization of glass or paint type provided valuable information about the most common subcategories of traces and the significance of finding fragments unrelated to a particular activity.

For glass, depending on fragment size, the measurements of refractive index and elemental analysis were used to determine if the items originated from a common source or different groups, following standard methods (refractive index ASTM E-1967, and μXRF E-2926-17).[5-7] If recovered glass fragments were smaller than 0.2mm, SEM-EDS was used for elemental composition, which regardless of its inferior sensitivity than the standard methods, it still provides elemental information of major elements that are valuable for classification of glass type.[66]

Likewise, any recovered paint chip was examined using microscopical examination (stereomicroscopy) and micro-FTIR analysis. We followed current standard guides such as ASTM E1601 E2937, E2809, and E2808.[1-4] This allowed recording data of layer structure, color, polymer (i.e., binder type) and pigment composition for the classification of paint type (i.e., architectural vs. automotive).

1.4.1. Data Analysis

Data analysis in this project required using each analytical instrument's software for signal processing, such as background subtraction, smoothing, peak identification, signal integration, and, when applicable, quantitative analysis. All statistical analyses were conducted using Microsoft Excel and R Studio (open source, 1.2.1335).

To illustrate one way of utilizing the survey data in evidence interpretation, a zeta distribution and the R package *fitPS* developed for this study were used to estimate two parameters typically used for activity level likelihood ratio formulas: *P* (probability of observing a given number of groups of fragments on target garments) and *S* (probability of observing a particular number of fragments within a given group).

The calculation of parameters *P* and *S* was carried out using maximum likelihood estimation (MLE) to estimate the shape parameter of a zeta distribution from the observed counts for the number of groups (P) and their size (S). The approach used by Coulson et al. [15] was implemented and improved in this study, which led to the development of the package *fitPS* (https://cran.r-project.org/web/packages/fitPS/fitPS.pdf) used within statistical software R [24]. This package improved on the estimation in that linear interpolation originally used by Coulson et al. [15] was not required, and standard numerical optimization was used instead. The zeta distribution has probability mass function:

$$p(k) = \frac{k^{-s}}{\zeta(s)}$$

Where $\zeta(s)$ is the Reimann zeta function.

1.5. Expected applicability of the research

Trace evidence has the potential not only to provide information related to source attribution but most importantly, it has the ability to determine how and what happened, and who or what was involved in the event. The potential to provide this activity-information is often underestimated, but interestingly it represents one of the main strengths of trace evidence as it could provide valuable information about the significance of the evidence under the specific context of a case, and also better direct investigations.

Knowledge of the background occurrence of trace materials provides critical information to make informed decisions during sampling at the crime scene, case pre-assessment, reconstruction of events and relevance of the evidence.

This proposal gathered, for the first time, data on the background occurrence of glass and paint residues on populations of the United States and evaluated factors that could influence the incidence rates. As a result, the baseline information generated in this study will offer the criminal justice a valuable body of knowledge to integrate trace evidence information for a broader contribution to law enforcement investigative efforts and a more comprehensive assessment of the evidential value in the U.S. courts.

The collection set of 2,391 samples, collected from the clothing and footwear of individuals of the general public and interpretation of the findings serves as the foundation for overarching interpretation methods, as well as future research.

For example, there are a variety of ways in which the information obtained from the background surveys might be applied in the field. The first is simple comparative. That is, how does the information collected for our region/time/population differ from information collected in different regions, or at different times, or for different groups of individuals. The next level of use is for the estimation of probability (density) functions for the quantitative information one might collect from the recovered paint or glass. For example, it is common for a forensic laboratory that deals with glass casework to measure the refractive index (RI) or elemental analysis of the recovered fragments. This information can be used to create an estimate of the probability density functions from where forensic experts estimate the relative rarity of fragments of glass recovered in casework. The final way in which this information may be used is to inform models for computing likelihood ratios at the activity level. In such models, we often require information such as the number of different sources of the questioned material one might expect to find on an individual. For example, we might be interested to know how likely it is that a randomly selected person, not associated with crime, has one or multiple paint fragments of three different layers on their person. This question can be answered with background surveys, and an open-source package was developed to calculate terms used in likelihood ratios and made available to practitioners and other end-users.

Finally, this project provided unique settings and opportunities to enhance STEM training and education to students that will become future forensic scientists; two of the recent graduates joined the forensic science workforce, and the remaining are finalizing their doctorate degrees.

II OUTCOMES

2.1. Activities/accomplishments

Each of the proposed objectives and tasks was satisfactorily completed in this project. The four main tasks contained 59 specific research activities, including the following categories:

1. Sample collection
2. Sample preparation and recovery

3. Examination and identification of the trace materials
4. Data analysis, statistical analysis, and data interpretation
5. Disseminating results in the scientific literature
6. Disseminating findings at scientific meetings
7. Creation and curation of the database

In addition, the project management included six main activities: group meetings to discuss research results, planning meetings to monitor accountability for the main tasks and assignments, advisory meetings with practitioners, data analysis review sessions with statisticians, preparation of progress reports, and submission of manuscripts.

The dissemination of this study's research findings in peer-reviewed journals and scientific forums serves as an indicator of the interest raised within the forensic community. We have disseminated the main results of this research in eight scientific meetings and submitted three publications to peer-review journals, which are in the review process. The research is anticipated to be published in journals of high impact factor and read by a broad forensic audience. Specific results and details of the main milestones are discussed in the following sections.

2.2. Results and findings

2.2.1. Collection and examination of baseline data of glass and paint on sampling populations in the U.S.

This survey studied the baseline occurrence of glass and paint in four different cities, and in one city during different seasons. A total of 510 individuals participated in the study, and when possible, up to six predetermined collection areas were sampled per participant. This generated the collection of 2,391 samples from garments and footwear, which were inspected for the presence of glass and paint following systematic analytical protocols. A total of 179 small paint fragments and 18 glass traces were recovered from all the populations examined. We evaluated the data by several factors; first, we looked at the distribution of samples collected per garment and footwear location in each city (Table 3). With this information, we then evaluated the recovered paint and glass fragments, grouped by location on the apparel item (Table 5). Some general observations can be derived from this data:

1) Paint traces were more prevalent than glass fragments, regardless of the residence city. The number of paint fragments recovered in a single collection set ranged from as low as four and as high as 68, while no collection site produced more than ten glass fragments. A more in-depth discussion of frequency rates per material and city is provided in the following sections.
2) Paint was predominantly recovered from the surfaces of clothing items and rarely recovered from the sole of shoes. In contrast, glass was primarily found on footwear soles. This can be explained by the sharp and hard physical properties of glass that can easily become embedded in the soles, while paint has a softer and smoother surface that can be easily dislodged by friction during activities like walking. On the other hand, the lightweight and flat surface of a paint chip make it more feasible to be retained in the fabrics' weaving and knitting constructions, particularly if they are as small as the ones recovered in this study.

These two general observations are consistent with results reported in previous surveys conducted in other countries, indicating that general trends in the occurrence of glass and paint are applicable. Second, to facilitate the comparison of the occurrence of glass among the sub-groups, we grouped the findings by trace type (glass, paint, or glass & paint) using the following descriptive metrics:

1. Percent of individuals from whom traces were recovered
2. Percent of the garment areas from where traces were recovered
3. Percent of footwear from where traces were recovered
4. Percent of overall sampled items (garments and footwear) from where at least one trace was recovered

Tables 6 and 7 summarize these results for all cities and seasons. Looking first at the glass recovery, the percentage of individuals who bore glass was relatively low, ranging from 0.9 to 7%, depending on the set. When looking at the occurrence of glass by garment or footwear area, less than 0.9% of the garments showed glass, and less than 2.1% of the examined footwear yielded glass. Observing the overall occurrence of glass in garments and footwear, less than 1.4% of the items examined per subgroup had a glass. Moreover, consistent with other studies, all the glass fragments recovered were smaller than 1 mm in size, and most of the glass was found in the footwear.[53,54,67] When combining all the subpopulations (cities and seasons), only 15 out of 510 individuals bore glass (2.9%).

Table 5. *Number of paint and glass collected by apparel item and city.*

Garment Area	Morgantown Winter	Morgantown Summer	Huntsville	Pittsburgh	Houston
PAINT					
us	27	5	17	2	28
ue	6	1	0	0	3
ls	15	10	9	1	8
le	10	1	0	0	4
fs	9	5	1	1	9
fb	1	1	1	0	4
Total	**68**	**23**	**28**	**4**	**56**
Number of Individuals with Paint	**36**	**21**	**24**	**4**	**39**
GLASS					
us	1	0	0	0	0
ue	0	0	0	0	1
ls	1	0	0	0	0
le	1	0	0	1	0
fs	0	1	0	0	1
fb	7	0	1	0	2
Total	**10**	**1**	**1**	**1**	**5**
Number of Individuals with Paint	**7**	**1**	**1**	**1**	**5**

In contrast, paint particulates were more prevalent in the background populations than glass. For instance, 4% to 39% of the individuals bore some paint residues. From the items sampled in each subgroup, 1.1% to 15% of the garments and 0.5% to 6.5% of the footwear held paint fragments. The paint was mainly found on the upper clothing. When looking at garments and footwear items together, paint was recovered on 0.87 to 29% of the items within each set, depending on the city or season. When combining all the subpopulations (cities and seasons), 124 out of 510 individuals bore paint (24%). These paint fragments were smaller than 1 mm, mainly below 200 μm and were predominantly single-layer.

When evaluating the concurrent presence of glass and paint residues on the same individual, the numbers dropped considerably, ranging from 0% to 1%, depending on the subset. Moreover, none of the glass and paint occurred on the same apparel item. Therefore, the findings show that the simultaneous occurrence of glass and paint residues in a single item of an individual is very unlikely.

Finally, in the following sections, we will discuss the observations to answer the main questions of this study:

1) Are the background levels of glass and paint dependent on weather/season conditions?
2) Are the background levels of glass and paint dependent on the geography, demographics, and garment fashion characteristic of each city?

Table 6. *A comparison of the frequency rates of paint and glass traces recovered from the various cities and seasons.*

FREQUENCY RATES	Percent of individuals with traces?	Percent of garment areas with traces?	Percent of pairs of footwear areas with traces?	Total Percentage of garments & footwear areas with traces?	Total fragments recovered in the population
PAINT					**179**
Morgantown Winter PAINT	**36%** (36 out of 100)	**12.3%** (39 out of 314)	**4.1%** (8 out of 194)	**29%** (47 out of 508)	**68**
Morgantown Summer PAINT	**19%** (21 out of 110)	**5.6%** (16 out of 319)	**2.8%** (6 out of 211)	**4.2%** (22 out of 530)	**23**
Huntsville Summer PAINT	**24%** (24 out of 100)	**13%** (26 out of 202)	**1.5%** (2 out of 196)	**6.8%** (27 out of 398)	**28**
Pittsburgh Summer PAINT	**4.0%** (4 out of 100)	**1.1%** (3 out of 269)	**0.5%** (1 out of 191)	**0.87%** (4 out of 460)	**4**
Houston Summer PAINT	**39%** (39 out of 100)	**15%** (43 out of 295)	**6.5%** (13 out of 200)	**11%** (56 out of 495)	**56**
GLASS					**18**
Morgantown Winter GLASS	**7%** (7 out of 100)	**0.9%** (3 out of 314)	**2.1%** (4 out of 194)	**1.4%** (7 out of 508)	**10**
Morgantown Summer GLASS	**0.91%** (1 out of 110)	**0%** (0 out of 319)	**0.47%** (1 out of 211)	**0.19%** (1 out of 530)	**1**
Huntsville Summer GLASS	**1.0%** (1 out of 100)	**0%** (0 out of 202)	**0.51%** (1 out of 196)	**0.25%** (1 out of 398)	**1**
Pittsburgh Summer GLASS	**1.0%** (1 out of 100)	**0.37%** (1 out of 269)	**0%** (0 out of 191)	**0.22%** (1 out of 460)	**1**
Houston Summer GLASS	**5.0%** (5 out of 100)	**0.34%** (1 out of 295)	**2.0%** (4 out of 200)	**1.0%** (5 out of 495)	**5**

Table 7. *A comparison of the frequency rates of concurrent occurrence of both traces (glass and paint) traces from the various cities and seasons, and overall occurrences of glass and paint in the background population.*

FREQUENCY RATES	**Percent of individuals with traces?**	**Percent of garment areas with traces?**	**Percent of pairs of footwear areas with traces?**	**Total Percentage of garments & footwear areas with traces?**
		GLASS AND PAINT		
Morgantown Winter Glass & Paint	**1%** (1 out of 100	**0%** (0 out of 314)	**0%** (0 out of 194)	**0.20%** (1 out of 508)
Morgantown Summer Glass & Paint	**0%** (0 out of 110)	**0%** (0 out of 319)	**0%** (0 out of 211)	**0%** (0 out of 530)
Huntsville Summer Glass & Paint	**0%** (0 out of 100)	**0%** (0 out of 202)	**0%** (0 out of 196)	**0%** (0 out of 398)
Pittsburgh Summer Glass & Paint	**0%** (0 out of 100)	**0%** (0 out of 269)	**0%** (0 out of 191)	**0%** (0 out of 460)
Houston Summer Glass & Paint	**1.0%** (1 out of 100)	**0%** (0 out of 295)	**0%** (0 out of 200)	**0.20%** (1 out of 495)
		OVERALL OCCURRENCE IN ALL FOUR CITIES AND SEASONS		
Overall Percentage of All Cities PAINT (179 fragments)	**24%** (124 out of 510)	**9.1%** (127 out of 1,399)	**3.0%** (30 out of 992)	**6.5%** (156 out of 2,391)
Overall Percentage of All Cities GLASS (18 fragments)	**2.9%** (15 out of 510)	**0.36%** (5 out of 1,399)	**1.0%** (10 out of 992)	**0.6%** (15 out of 2,391)

2.2.2. Effect of season on the occurrence of glass and paint in the general public

The collections were performed in Morgantown WV, a college town representing a small urban U.S. city in the Mid-Atlantic region, to determine the effect of different seasons on the presence of glass and paint. In Morgantown, the temperature ranged from 61 °F to 84 °F in the summer and 21 °F to 44 °F in the winter during the collection dates. The survey collected information about the primary modes of transportation (e.g., personal vehicle, walk, or public transportation), and the type of clothing and footwear worn by participants, including its retention properties (low, medium, or high). Tape lifts and sole scrapings (1,038) were collected from 210 participants and up to six clothing and footwear areas per individual.

Higher occurrences of glass and paint were found in the winter season; this was true whether the frequency rates were estimated by participants or by apparel with traces. For example, the winter collection yielded ten glass fragments and 68 paint particles, whereas the summer collection resulted in one glass fragment and 23 paint particles (Table 6). The percentage of individuals with these traces varied between seasons; 7% of individuals in the winter and 0.9% in the summer had glass, whereas 36% of individuals in the winter and 19% in the summer bore paint. Lastly, when considering the overall garment and footwear areas, 1.4% of the winter set had glass, compared to 0.2% in the summer collection; 9.2% in the winter collection held paint, whereas only 4.2% were found in the summer set. There were no instances where both glass and paint were recovered on the clothing and footwear of the same individual.

The garments and their respective retention type were recorded for each volunteer. Garments considered high retention were items such as sweatshirts, knit fabric, and ripped jeans, whereas plain jeans and khakis were placed under the medium retention type. Items like silk, athletic clothing, and raincoats were considered to have low retention properties. Footwear items that were considered to have high retention properties because their surfaces or soles favor retention include hiking or working boots with high tread. Crocs and athletic shoes with medium grip and sole tread were placed under the medium retention type, and flats, heels, and cowboy boots with flat outsoles were considered low retention. Garments and footwear items sampled in the winter collection were mainly of high retention type, while garments and footwear items from the summer collection were often medium to low retention. Of the 100 volunteers from the winter set, the upper clothing worn in the winter season consisted of 92% sweaters/jackets or coats and 8% short-sleeve T-shirts, whereas the items from 110 volunteers in the summer set consisted of 77% tank tops or T-shirts, and 20% sweaters, cardigans, or jackets. In the summer set, 3% of the garments were also jumpers, dresses, or rompers; only one individual in the winter set wore a jumpsuit. The lower garments in the winter season were primarily 50% leggings and 49% jeans (ripped and plain), while less than 13% of the summer set participants wore leggings, less than 25% wore jeans or slacks, 7% wore sweatpants, and 42% wore athletic shorts, jean shorts, or skirts. As a result, this indicates that the higher occurrence of traces in the winter season can be related to the higher surface areas and retention properties of apparel worn in colder temperatures. The outer layers such as winter coats are also washed less frequently than other upper garments wore in the summer.

Glass Recovery on Winter and Summer Collections

Ten glass fragments were recovered from the winter survey and only one fragment from the summer collection. Figure 2 displays a plot of the Morgantown winter versus the summer glass recovery count. Previous studies recorded glass fragments recovered mainly from footwear and the lower clothing surfaces due to broken glass commonly being in the streets and busy traffic areas[1,2,8]. Accordingly, most of the glass from the winter collection was on the soles of the footwear, with few or none on any other garment area, whereas the summer collection yielded the sole glass fragment on the footwear surface.

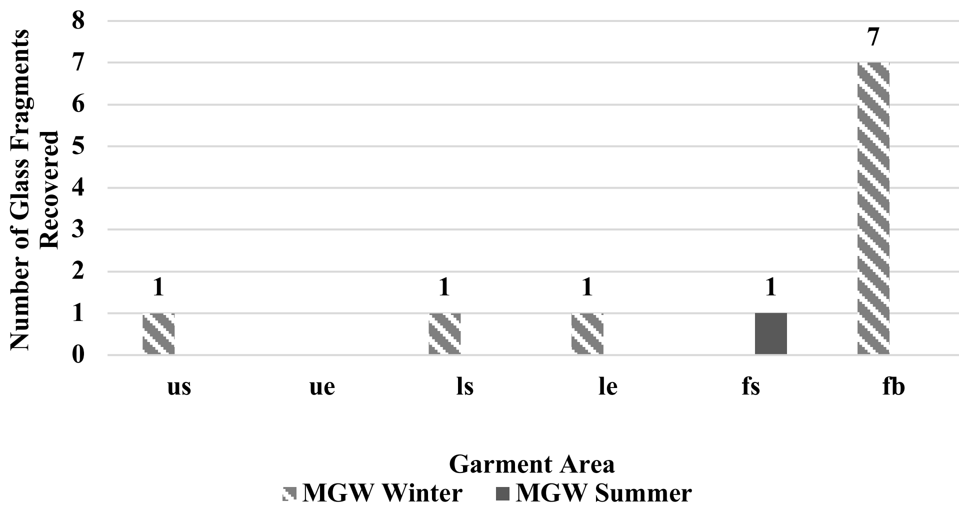

Figure 2. *Glass collection count by season for Morgantown winter and Morgantown summer collections. Most of the glass samples from the winter collection were recovered from the footwear bottom, while the remaining were recovered from the upper surface, the lower surface, and the lower embedded areas. The sole fragment in the Morgantown summer collection was recovered from the footwear surface.*

As previously mentioned, glass fragments were first analyzed via μXRF or SEM-EDS. Figure 3 illustrates a spectrum and data obtained after μXRF analysis of glass sample 029C from the Morgantown winter collection. Using elemental ratios listed in ASTM E2926-17, this sample was determined to be a container glass due to the Ca/Mg ratio above 15 and the Ca/Fe ratio above 30[13,28]. Table 8 displays the classifications of all glass samples for both sets using μXRF. Of the six samples analyzed by μXRF, three were classified as container glass, one as either sheet or container, and two as other types of glass.

The glass fragments analyzed via SEM-EDS had poor sensitivity for Fe that did not allow for the same type of classification as μXRF[29]. Of these five samples, us001, fb002B, and fb016B were classified as glass other than sheet or container, while fb016A was a soda-lime glass that could be either sheet or container glass. Some samples' end-use was considered undetermined or classified as "other", but they were still identified as glass due to their microscopic and optical properties.

After the elemental composition of each glass fragment, refractive index measurements were taken following ASTM E1967-19. The mean and standard deviation were also reported for each fragment and Figure 4 illustrates the comparison of the refractive indices using boxplots. Out of the three items that had two glass fragments, only the fragments on sample fb029 were considered indistinguishable and thus could belong to the same group.

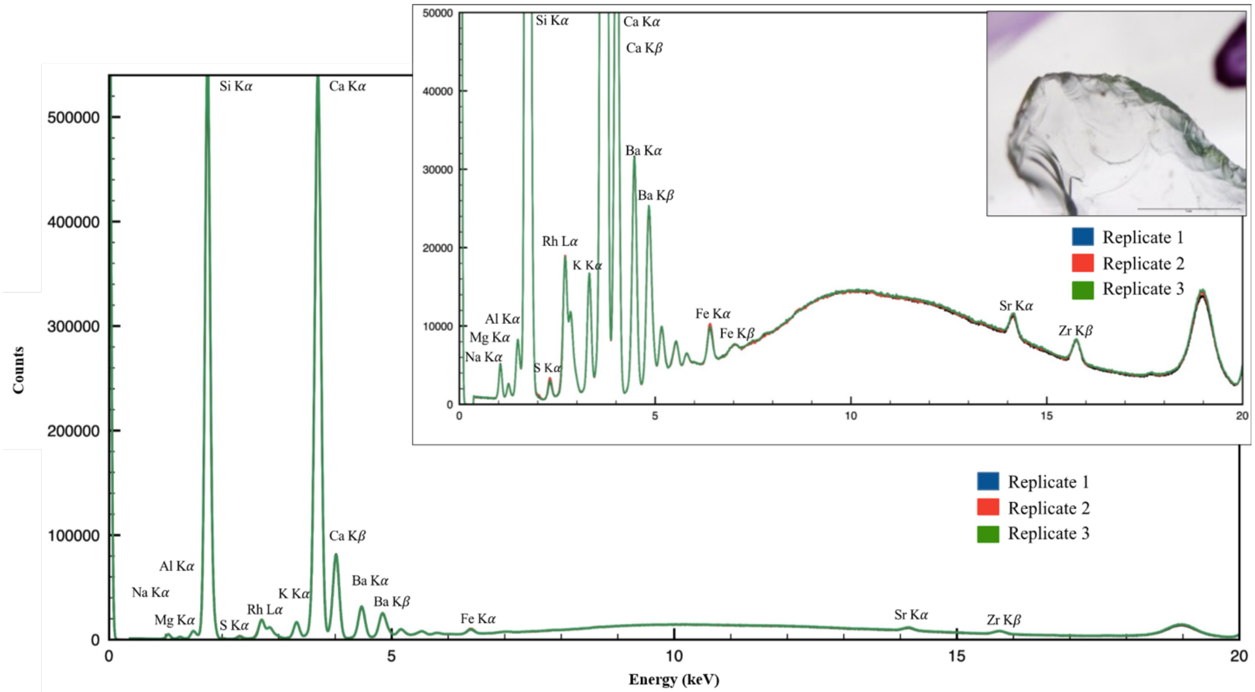

Figure 3. *Example of an μXRF spectrum of glass recovered from individual 029 from the Morgantown winter collection set. This fragment is 1 mm by 2 mm in size and is colorless. Using the relevant peaks, analysts classified this glass as container glass.*

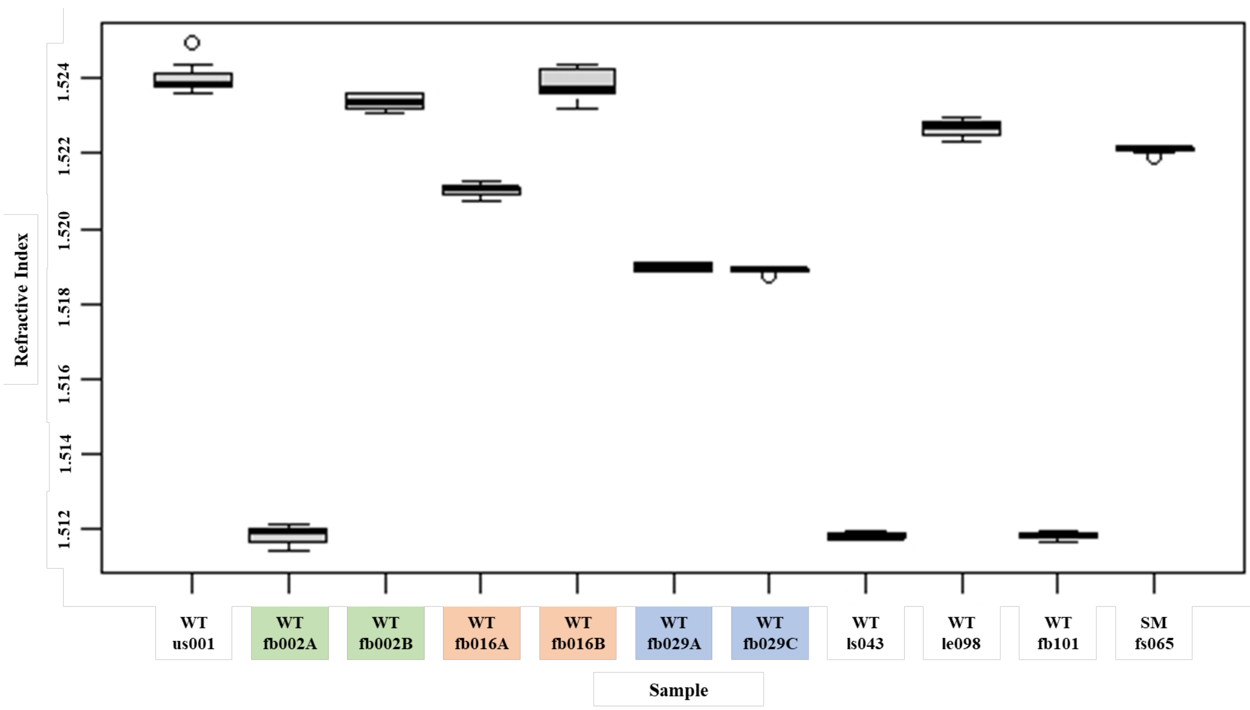

Figure 4. *Boxplots of refractive index measurements for glass collected from the summer and winter sets in Morgantown, WV. Fragments found on the same individual and location are highlighted in the same color to visualize if they could be from different sources*

Table 8. *Glass end-use classifications for Morganton winter and summer collections.*

City/Season	Sample ID	color	Size	RI	Elements	Classification	Comment
Morgantown Winter	MGW-WTus001	colorless	<0.5 mm	1.52389	Na, Al, Si, K, Ti, Cu	undetermined	Elemental analysis was performed via SEM-EDS and no classification was determined due to the absence of a detectable Fe or Mg peak
Morgantown Winter	MGW-WTfb002A	colorless	0.5 mm	1.51182	Na, Al, Si, S	undetermined	Elemental analysis was performed via SEM-EDS and no classification was determined due to the absence of a detectable Fe and Ca peak
Morgantown Winter	MGW-WTfb002B	brown	1 mm	1.52337	Na, Mg, Al, K, Si, S	undetermined	Elemental analysis was performed via SEM-EDS and no classification was determined due to the absence of a detectable Fe or Ca peak
Morgantown Winter	MGW-WTfb016A	colorless	0.25 mm	1.52100	Na, Mg, Al, K, Si, Ca	soda-lime silicate (sheet or container)	Major elements commonly associated with soda-lime
Morgantown Winter	MGW-WTfb016B	colorless	0.75 mm	1.52383	Na, Al, K, Si, Ti, Zn	undetermined	Elemental analysis was performed via SEM-EDS and no classification was determined due to the absence of a detectable Fe and Ca peak
Morgantown Winter	MGW-WTfb029A	colorless	0.5 mm	1.51898	Na, Mg, Al, Si, S, K, Ca, Ba, Fe	Soda-lime-silicate (container)	Ca/Mg and Ca/Fe consistent with soda-lime container glass
Morgantown Winter	MGW-WTfb029C	colorless	2-3 mm	1.51891	Na, Mg, Al, Si, S, K, Ca, Ba, Fe, Sr*, Zr*	Soda-lime-silicate (container)	Ca/Mg and Ca/Fe consistent with soda-lime container glass
Morgantown Winter	MGW-WTls043	colorless	0.3 mm	1.51183	Na, Mg, Al, Si, S, K, Ca, Ti, Fe, As	Soda-lime-silicate (container)	Ca/Mg and Ca/Fe consistent with soda-lime container glass
Morgantown Winter	MGW-WTle098	colorless	0.3 mm	1.52266	Al, Si, S, K, Ca, Fe, Br	Other	Elemental composition no characteristic of soda-lime glass
Morgantown Winter	MGW-WTfb101	colorless	0.25 mm	1.51184	Si, Br, K, Ca, Mn, Fe	Other	Elemental composition no characteristic of soda-lime glass
Morgantown Summer	MGS-fs065	colorless	0.1 mm	1.52209	Na, Mg, Al, Si, S, K, Ca, Ba/Ti, Mn, Fe, Cu, Sr, Zr	soda-lime-silicate (container)	Elemental profile, Ca/Mg and RI suggest soda lime container.

Paint Recovery on Winter and Summer Collections

Of the 68 fragments recovered from the winter set and 23 from the summer set, most were found on the garment's upper and lower surfaces (Figure 5). Various studies have found that paint is commonly recovered from the upper and lower surfaces and less common in embedded areas like pockets and cuffs or footwear. Our findings agree with the general tendencies described in the literature.

As previously discussed for the glass recovery, the results of this study indicate that the type of clothing worn during the summer and winter seasons also influences the number of paint traces. Moreover, Considering the primary transportation reported by the voluteers, in the winter set, 43% informed using personal vehicles, 31% walked to campus, 13% used the local bus and the remainder used some combination of all the forms of transportation that were provided, along with university public transit. In contrast, 70% of summer collection volunteers used personal vehicles, 29% walked to the university, 2% used public transportation, 4% used the PRT, and 4% used a combination of a personal vehicle and walking, the PRT and the local bus, and driving and the local bus. Therefore, another contribution to the differences in the background in the summer and winter seasons may be attributed to transportation and related activities, with higher use of a personal car and less use of public transportation in the summer.

Classification tables 9 and 10 summarize the color, size, and type of paint recovered from each collection. Paint particulates were classified as either architectural, automobile, nail polish, tool, or other based on their microscopic features and the compounds identified by the IR. Figures 6 display an example of classification results for the recovered paint spectra.

The Morgantown summer set yielded 23 paint fragments; only one of the paint fragments had two layers; therefore, the tables and figures will total 24 items, including the 2 layers of the fragment. Of these 23 particulates in the Morgantown summer set, the most common colors were red and blue. Of the 68 fragments of the winter set, three paint fragments had two layers; therefore, the tables will indicate 71 items. The winter collection yielded a more comprehensive range of colors than the Morgantown summer set. The most prominent colors among the samples were red, blue, purple, and pink. Available literature suggests that the most common paint colors in the general population are red, blue, green, and black[4,30], but these types of observations cannot be generalized as they only represent a limited time snapshot. Therefore, this color information is provided for illustrative purposes only.

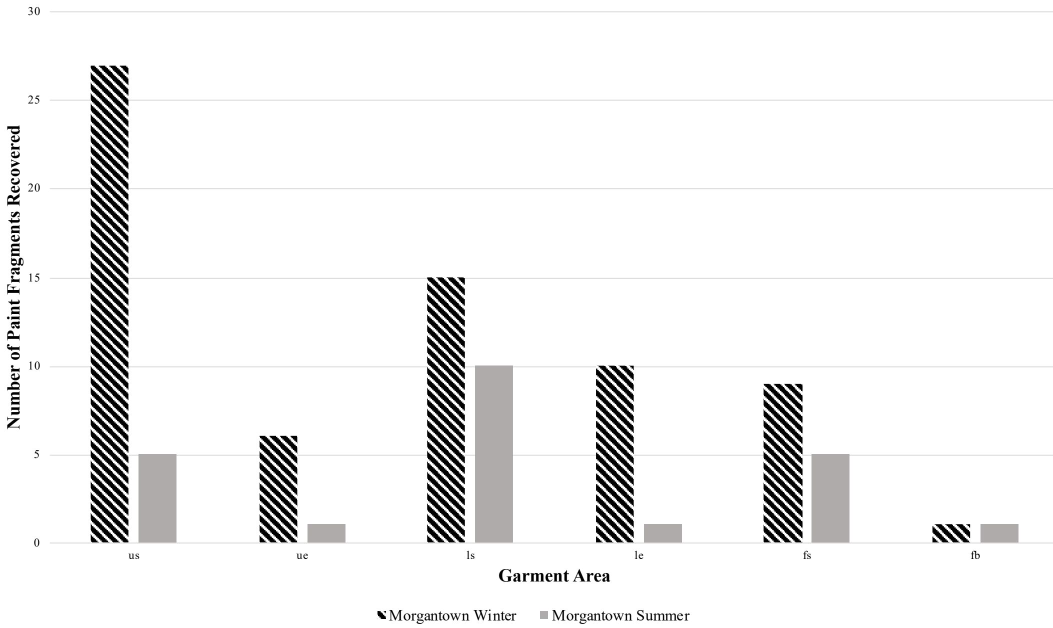

Figure 5. *Paint collection count by season for Morgantown winter and Morgantown summer collections.*

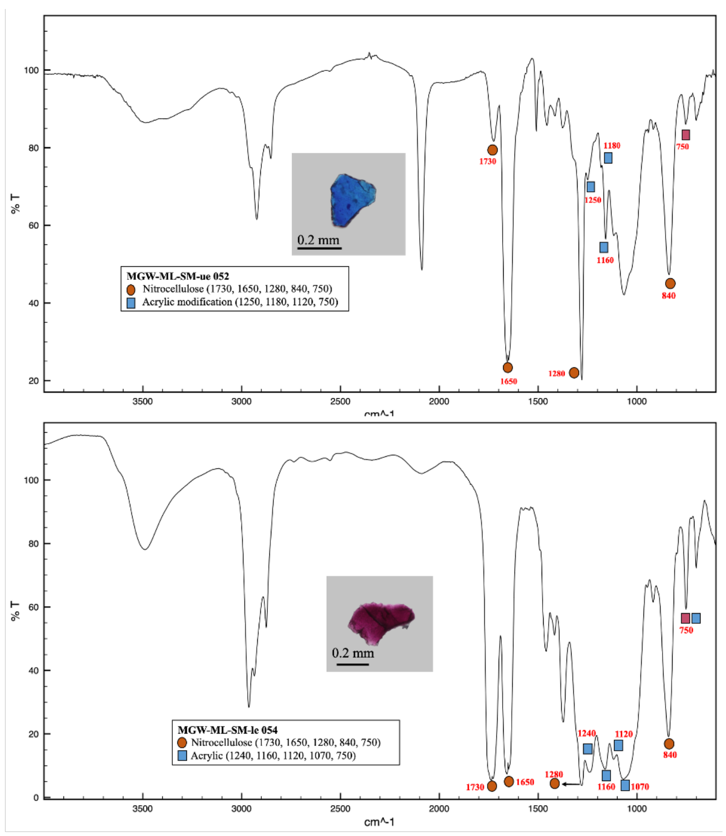

Figure 6. *Examples of μFTIR spectra of nitrocellulose-acrylic paints from the summer collection. Top: blue paint fragment recovered from individual 52 on the upper embedded area. Bottom: Red paint fragment recovered from individual 54 on the lower embedded area.*

Table 9. *Morgantown summer paint classification. Samples were organized by their sample ID and garment location. Most of the paint particles yielded a classification, but some were undetermined, although their characteristics indicated paint.*

Sample ID	Garment Location	Color	Size	Binder	Modification	Extender(s)		End-Use
001	us	Multi-colored	<0.5 mm	Epoxy	-	Calcium carbonate	-	Nail polish
010A	ls	Red	<1 mm	Nitrocellulose	Acrylic	Kaolin	Titanium dioxide	Automotive or Nail polish
012B	ls	Brown	<0.5 mm	Acrylic	Epoxy + Styrene-butadiene	Kaolin	-	Nail polish
015 Layer A	fs	Blue	<0.5 mm	Alkyd	Urethane	Titanium dioxide	-	Architectural
015 Layer B	fs	Blue	<0.5 mm	Styrene-butadiene	-	Titanium dioxide	Kaolin	Architectural
020	fs	Metallic pink	<0.5 mm	Nitrocellulose	Acrylic	-	-	Automotive
026	us	Red	0.5 mm	Orthophthalic-Alkyd enamel	-	Kaolin	Calcium carbonate	Architectural
031	ls	Red	0.2 mm	Acrylic lacquer	Styrene	Kaolin	Calcium carbonate	Automotive
039	ls	Red	0.5 mm	Acrylic lacquer	Styrene	Kaolin	-	Automotive
045	fs	Blue	<1 mm	Isophthalic-Alkyd enamel	-	Calcium carbonate	-	Architectural
048	us	Blue	<0.5 mm	Orthophthalic-Alkyd enamel	-	Kaolin	Calcium carbonate	Architectural
048	ls	Brown	0.2 mm	Nitrocellulose	Acrylic	Calcium silicate	Titanium dioxide	Automotive
052	ue	Blue	<0.5 mm	Nitrocellulose	Acrylic	Bentone	-	Architectural, Automotive, or Nail polish
054	le	Purple	0.5 mm	Nitrocellulose	Acrylic	Magnesium based silicate	-	Architectural
066	ls	Black	<0.5 mm	Acrylic-alkyd	-	Titanium dioxide	Kaolin	Architectural or Automotive
067	us	Blue	0.25 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Architectural or Automotive
084	fb	Blue	<2 mm	Nitrocellulose	Acrylic	Titanium dioxide	Calcium sulfate	Architectural or Nail polish
089A	ls	Red	<0.5 mm	Alkyd	-	Silica	Kaolin	Automotive
089B	ls	Red	<0.5 mm	Alkyd	-	Silica	Kaolin	Automotive or Nail polish
091	fs	Black	2 mm	Acrylic	-	Kaolin	-	Architectural or Tool
092	ls	Green	0.5 mm	Epoxy	-	Kaolin	-	Automotive
098	us	Orange	<0.5 mm	Styrene-butadiene	-	-	-	Architectural
107	fs	Red	<0.5 mm	Nitrocellulose	Acrylic	Calcium sulfate	Talc	Automotive or Nail polish
110	ls	Green	<0.5 mm	Styrene-butadiene	-	Barium sulfate	-	Architectural

Table 10. *The Morgantown winter paint classification table. Samples were organized by their sample ID and garment location. Most of the paint particles yielded a classification, but some were undetermined, although their characteristics indicated paint. Therefore, only a portion of the table is displayed below.*

Sample ID	Garment Location	Color	Fragment Size	Binder	Modifications	Extender(s)		Classification
002	ue	Brown	<0.2 mm	Styrene-butadiene latex	-	Kaolin	-	Architectural
002A	le	Blue, green, yellow	<0.5 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
002B	le	Red and yellow	<0.2 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
003	us	Green and yellow	<0.2mm	Styrene-butadiene latex	-	Talc	Calcium carbonate	Architectural
004	ue	Red and brown	<0.2 mm	Nitrocellulose	-	Kaolin	Calcium carbonate	Architectural
005	fs	Red	<1mm	Nitrocellulose	Acrylic	Kaolin	-	Arch, Auto or Nail polish
005A	le	Red	<0.5 mm	Nitrocellulose	Acrylic	Kaolin	-	Arch, Auto or Nail polish
005B	le	Red	<0.5 mm	Nitrocellulose	Acrylic	Kaolin	-	Arch, Auto or Nail polish
007A	fs	Blue, green, yellow	<1 mm	Acrylic	-	Barium sulfate		Other
007B	fs	Blue, green, yellow	<1 mm	Acrylic	-	Barium sulfate		Other
007C	fs	Blue, green, yellow	<1 mm	Acrylic	-	Barium sulfate		Other
008	us	Red	<0.2 mm	Acrylic	Styrene	Kaolin	Barium sulfate	Arch, Auto or Nail polish
010	fs	Brown	<0.5 mm	Nitrocellulose	Acrylic	Kaolin	-	Arch or Auto
012	us	Deep red	<0.2 mm	Epoxy melamine	-	Talc	Kaolin	Automobile
012A	ls	Deep red	<0.2 mm	Epoxy melamine	-	Talc	-	Automobile
012B	ls	Deep red	<0.2 mm	Epoxy melamine	-	Talc	-	Automobile
012D	ls	Red	<0.2 mm	Epoxy melamine	-	Talc	-	Automobile
021A	ls	Dark blue or black	<0.2 mm	Acrylic-alkyd urethane	-	K-Al silicate mica	-	Arch or Tool
022B	ls	Deep red	<0.5 mm	Acrylic lacquer	-	Kaolin	Titanium dioxide	Architectural
027 Black	us	Black	<0.3 mm	Acrylic lacquer	-	Calcium carbonate	Kaolin	Arch or Auto
027 White	us	White	<0.3 mm	Acrylic lacquer	-	Calcium carbonate	Kaolin	Arch or Auto
028	le	Lavender	<0.25 mm	Acrylic	-	Calcium carbonate	Kaolin + barium sulfate mixture	Architectural
030	fb	Blue	<0.2 mm	Alkyd-ortho enamel	-	Kaolin	Titanium dioxide	Architectural
031 Red	us	Red	<0.2 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Kaolin	Architectural
031 White	us	White	<0.2 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Kaolin	Architectural

Sample ID	Garment Location	Color	Fragment Size	Binder	Modifications	Extender(s)		Classification
033	ue	Blue/purple	<0.2 mm	Acrylic-alkyd	-	Calcium carbonate	Titanium dioxide	Arch, Auto or Nail polish
033A	us	Pink	<0.2 mm	Alkyd-ortho enamel	-	Calcium carbonate	Titanium dioxide + Kaolin	Architectural
033B	us	Pink	<0.25 mm	Styrene-butadiene + acrylic mixture	-	Titanium dioxide	-	Architectural
034	fs	Metallic and purple	<0.5 mm	Alkyd enamel	-	Dolomite	Talc	Other
038A	le	Blue	0.5 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Kaolin	Architectural
038A	us	Blue	<0.2 mm	Acrylic-alkyd (weak)	-	Calcium carbonate	Titanium dioxide + Talc	Arch, Auto or Nail polish
038B	us	Blue	<0.2 mm	Acrylic-alkyd	-	Calcium carbonate	Titanium dioxide + Talc	Arch, Auto or Nail polish
038C	le	Black	<0.2 mm	Nitrocellulose	Acrylic	Calcium carbonate	Kaolin + talc	Arch, Auto or Nail polish
038C	us	Pink	<0.2 mm	Nitrocellulose	Acrylic	Barium sulfate?	-	Arch, Auto or Nail polish
038D	us	Blue	<0.2 mm	Acrylic-alkyd	-	Calcium carbonate	Titanium dioxide + Talc	Arch, Auto or Nail polish
038E	us	Blue	<0.2 mm	Acrylic-alkyd	-	Calcium carbonate	Titanium dioxide + Talc	Arch, Auto or Nail polish
039	us	Blue/purple	<0.2 mm	Acrylic	-	Kaolin	-	Architectural
039B	ls	Black	<0.3 mm	Acrylic lacquer	-	Kaolin	-	Architectural
040	us	Blue/purple	<0.2] mm	Styrene-butadiene latex	-	Kaolin	-	Architectural
041	us	Black	<0.3 mm	Urea	-	Calcium carbonate	Kaolin	Automobile
041A	ue	Red	<0.5 mm	Acrylic-alkyd	-	Silica	Talc	Auto or tool
041F	ue	Blue/green	0.2 mm	Styrene-butadiene latex	-	Calcium carbonate	Barium sulfate	Architectural
042	fs	Purple	0.2 mm	Nitrocellulose	Acrylic	Barium sulfate	-	Arch, Auto or Nail polish
042A	le	Purple	<0.2 mm	Nitrocellulose	Acrylic	Calcium sulfate very little)	-	Arch, Auto or Nail polish
042A	ls	Red	0.2 mm	Nitrocellulose	Acrylic	Calcium sulfate (possible)	-	Auto or nail polish
042A	us	Multicolored	<0.5 mm	Acrylic	-	Calcium carbonate	Kaolin	Most likely tool
042B	ls	Purple	0.2 mm	Nitrocellulose	Acrylic	Calcium sulfate (possible)	-	Auto or nail polish
042C	us	Grey	<0.2 mm	Acrylic	-	Calcium carbonate	-	Architectural
042D	us	White	<0.5 mm	Nitrocellulose	Acrylic	Calcium carbonate	-	Arch or Auto
044 Red	ls	Red	<0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Kaolin	Architectural

Sample ID	Garment Location	Color	Fragment Size	Binder	Modifications	Extender(s)		Classification
044 Yellow	ls	Yellow	<0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Kaolin	Architectural
046	ls	Pink	1-1.5 mm	Nitrocellulose	Acrylic	Barium sulfate	-	Automobile
048	us	Black	0.2 mm	Acrylic	-	Kaolin	-	Auto or tool
052	le	Blue	0.3 mm	Acrylic	-	Kaolin	-	Automobile
061	us	Pink	0.25 mm	Acrylic	-	Kaolin	Calcium carbonate	Automobile
062	le	Pink	0.2 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
064	ls	Red	0.3 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
064	ue	Red	0.3 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
066A	ls	Purple	<0.5 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
066B	ls	Blue/purple	<0.5 mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
070	ls	Purple	<0.3mm	Polyvinyl acetate acrylic latex	-	Kaolin	-	Architectural
071	fs	Purple	0.5 mm	Styrene-butadiene latex	-	Silica (possible)	-	Architectural
073A	fs	Red	<0.5 mm	Nitrocellulose	Acrylic	Kaolin	-	Arch or nail polish
082B	us	Red	0.5 mm	Nitrocellulose	Acrylic	Barium sulfate	-	Arch, Auto or Nail polish
082C	us	Red	0.5 mm	Nitrocellulose	Acrylic	Calcium sulfate	-	Auto or nail polish
082D	us	Red	0.5 mm	Nitrocellulose	Acrylic	Calcium sulfate	-	Auto or nail polish
082E	us	Red	0.25mm	Nitrocellulose	Acrylic	Calcium sulfate	-	Auto or nail polish
082F	us	Red	0.25mm	Nitrocellulose	Acrylic	Calcium sulfate	-	Auto or nail polish
083	ls	Purple	0.2mm	Styrene-butadiene latex	-	Kaolin	-	Architectural
085	us	Purple	0.25mm	Urea	Acrylic	Calcium carbonate	-	Auto or tool
087	us	Blue	0.25 mm	Alkyd-iso enamel	-	Talc	Silica	Architectural

Figure 7 displays the frequency of various binders for the Morgantown collections, where the most common binder was nitrocellulose with acrylic modification for both the summer and winter sets. There were also various particulates classified as acrylics (with and without modifications), alkyds (iso and ortho), epoxies from the summer paint, and acrylics, polyvinyl acetate acrylics, styrene-butadiene, and ureas from the winter paint. The most common end-use was architectural and automotive paints, with other potential categories found in both sets (Figure 8). Few samples did not have a definitive classification due to common binders or microscopic physical features.

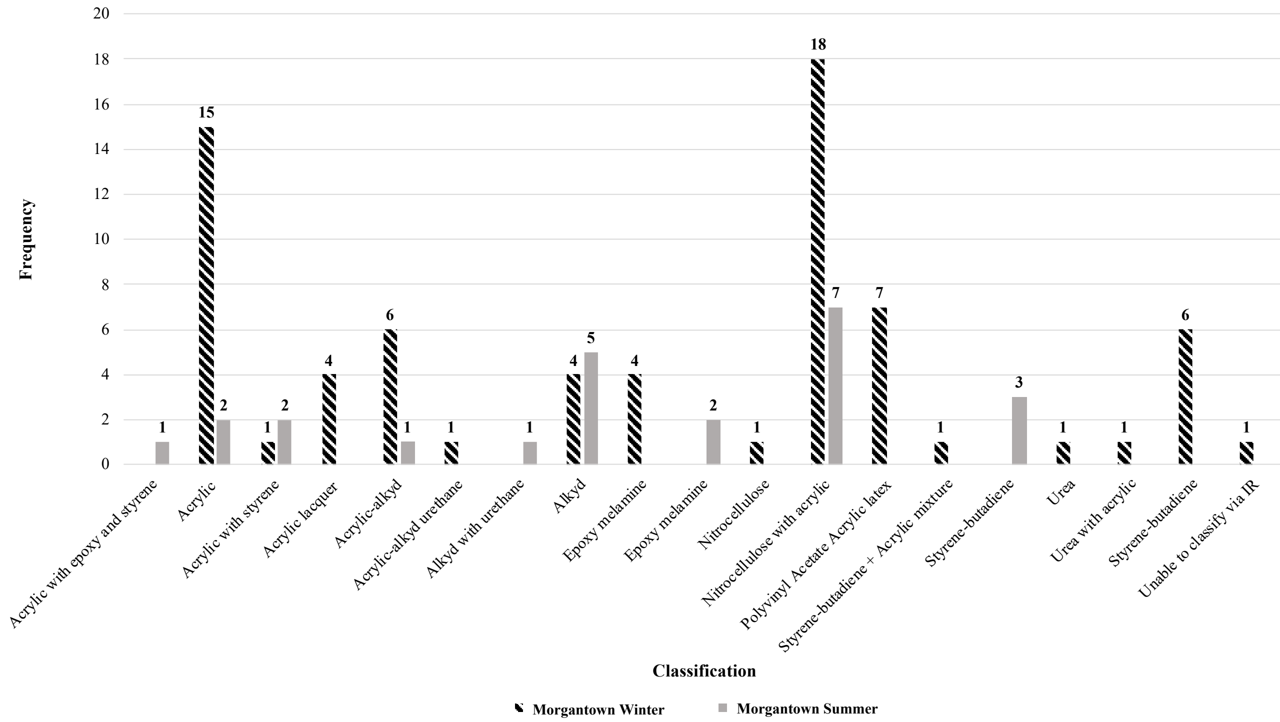

Figure 7. *The binder type of the 23 particulates from the summer set and the 68 particulates from the winter set. The winter set had more varied classifications than the summer set. The primary classification for both sets was nitrocellulose with acrylic.*

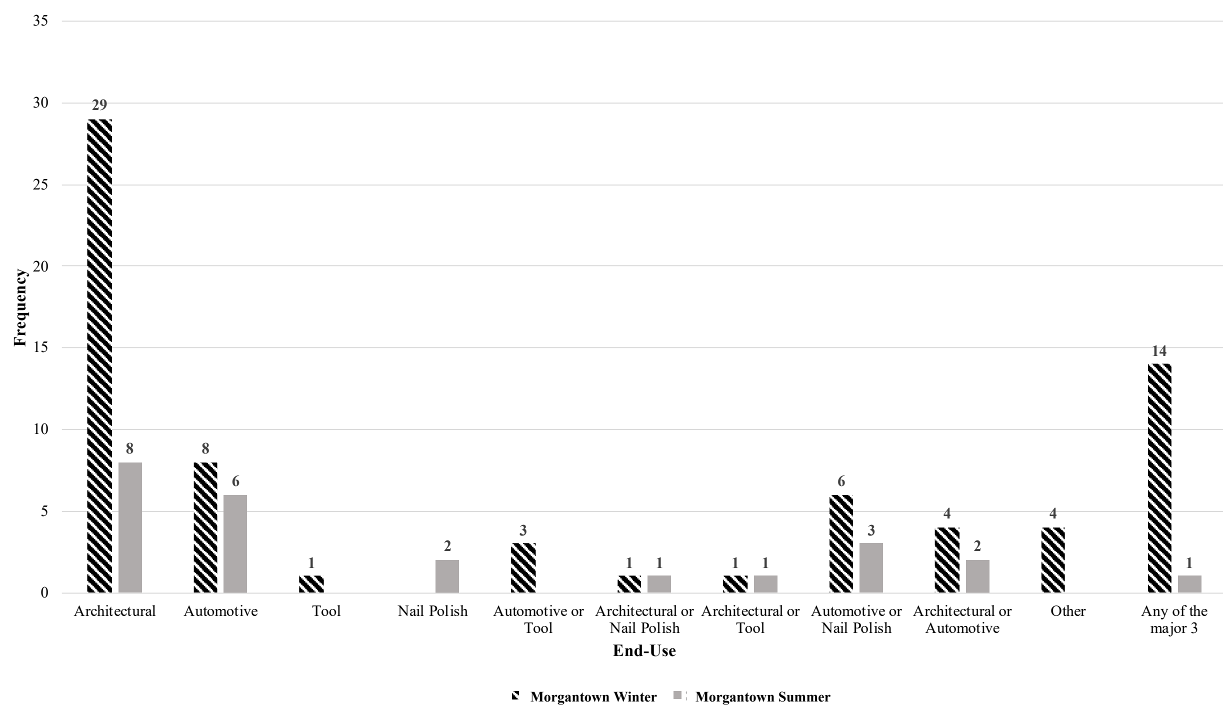

Figure 8. *The primary classification of the 23 fragments from the summer collection and the 68 fragments from the winter collection.*

Summary of Background Occurrence in Winter and Summer Collections

Overall, the sampling of glass and paint particulates in the Morgantown, WV area allowed for collection from a total of 1,038 garments and pairs of footwear. Glass was mainly recovered from the surfaces and soles of the footwear. In comparison, paint was primarily recovered from the upper and lower garment surfaces.

A comparison by trace, garment area, and footwear was made to illustrate the differences in the amount of glass and/or paint recovered from this city in two seasons (Tables 6 and 7). Ten glass fragments were recovered in the winter and one in the summer collections. For the percentage of individuals with traces, 7% of individuals in the winter and less than 1% in the summer bore at least one glass (Table 6).

Paint was more prevalent than glass, with 68 fragments found in the winter compared to 23 in the summer. In the study, 36% of individuals in the winter and 19% in the summer had at least one paint trace. A combination of factors, including the type of clothing worn and the indoor/outdoor activities in the winter and summer, affected the number of glass and/or paint fragments recovered from the individuals.

In addition, no simultaneous detection of glass and paint on the same individual and the sampled area was observed in any collection sets (table 6). This finding becomes relevant when assessing cases where both glass and paint are found on the alleged offender. Situations like hit-and-runs, break-and-entries, and other violent crimes can lead to the dual transfer of glass and paint sources.

This study is the first one of its kind to evaluate the effect of the season on the garment type and trace occurrence. However, these findings may depend on the different weather conditions during the summer and winter seasons in different regions. Morgantown experiences four distinct seasons year-round, with the summer defined as May-October with temperatures ranging from 61 °F to 84 °F and 21 °F to 44 °F in the winter, defined as November to late March. The effect of the seasons was substantial on the type of garment worn, the main modes of transportation, and the number of fragments recovered. These findings can play a critical role in understanding the relevance of finding trace materials in criminal events compared to the background presence in the general population.

2.2.3. Evaluation of the glass and paint occurrence in various U.S. cities

Another question of interest in these surveys was to evaluate if there were trends or dissimilarities between cities. Since the seasonal study showed that the winter and summer seasons influence recovery rates, in this section we compare the collections of the small and larger cities in the warmer season, where equivalent temperatures were observed during the sampling dates across the four locations.

When looking at the data per city, the Morgantown set yielded 23 total paint fragments from 21 individuals, with only one of the paint fragments presenting two layers. In the Morgantown set, blue and red were the most prominent colors, followed by black, brown, and green. The Huntsville summer collection had a total of 28 paint fragments from 25 individuals. Of these 25 people, one person held 4 fragments on their upper clothing, and one person held 2 fragments on the same garment area. In the Huntsville set, blue was the most prominent color, followed by orange, yellow, black, red, and white. Relatively similar occurrences of paint were observed in these two college towns with very similar demographics and multicultural diversity of the universities.

On the other hand, the occurrence of paint traces drastically varied not only between the small college towns and the two larger cities, but also between the Pittsburgh and Houston collections. For example, the Pittsburgh summer set yielded only four fragments from four individuals. From this collection, single-layer fragments were observed in blue, grey, purple, and red. Lastly, 56 paint fragments were recovered from the Houston summer set. Thirty-nine individuals held these fragments, with the most prominent colors being blue, red, and multicolor (more than 2 colors).

To understand these observed differences, we evaluated the trends on the type of clothing and modes of transportation as possible factors that influence the recovery rates in the sampled regions. For the upper surface garments, t-shirts or tank tops were worn most frequently in all four collections, followed by polo shirts and flannels, and sweaters, cardigans, and jackets. Very few individuals, if any, wore jumpers, dresses, or rompers. Lower surface garments consisted primarily of jeans or slacks in the Houston collection, and athletic shorts, jean shorts, or skirts in the Morgantown, Huntsville, and Pittsburgh collections. Leggings and sweatpants were also seen on a handful of volunteers. Lastly, sneakers or tennis shoes were observed the most in all four collections (72-84%), with 5-10% of individuals wearing sandals/flip-flops, and very few individuals wearing vans, converse, hiking/working boots, crocs, or chucks.

When looking at the predominant retention features of the apparel (excluding embedded areas), it is evident that, except for the winter season that is excluded from this comparison, the participants in the targeted cities wore clothing with relatively similar retention properties, with slightly higher retention features in the pants/shorts and shoes used in the metropolitan areas than in the smaller cities (Table 11). Therefore, the clothing and retention properties didn't explain *per se* the observed differences in frequency rates.

Table 11. *Summary of the predominant retention properties of the clothing and footwear worn by participants by city collection. (Retention H= high, M= medium, L=low)*

Garment Area	Morgantown Winter	Morgantown Summer	Huntsville Summer	Pittsburgh Summer	Houston Summer
us	H	L	L	L	L
ls	H	M/L	M/L	M/H	M/H
fs	M/H	M/L	M/L	M/H	M/H
fb	H	H	H	H	H

As detailed before in the seasonal section, another factor evaluated in this survey was the primary mode of transportation reported by volunteers in each city. Table 12 displays the common methods of transportation among the four collections. The modes of transportation vary drastically between the four sets. We observed the following trends in this study:

1) The Morgantown and Huntsville volunteers reported similar modes of transportation; the use of a personal vehicle was the most common mean of transportation, followed by walking. Also, in both of these small cities, public transportation was rarely used.

2) Drastic differences in transportation mode were observed between small cities (college towns) and big cities.
3) For the two larger cities, the Pittsburgh participants reported walking as their primary means of transportation, with very limited use of public transportation. In contrast, Houston volunteers had public transportation as the main mode of transportation, with no one reporting substantial walking.

Therefore, the data indicate that the primary contribution to the differences in the background presence of glass and paint may be attributed to the mode of transportation and related activities, which are closely related to the urban design of the cities.

Table 12. *The common modes of transportation and the number of individuals that used them for each collection. The major methods of transportation across the 4 sets were using a personal vehicle, public transportation, such as a bus, walking, using the PRT (Morgantown only- public campus transportation), and some combination of 2 methods.*

Mode of Transportation	**Morgantown**	**Huntsville**	**Pittsburgh**	**Houston**
Personal vehicle	70	57	10	74
Public transportation	2	6	14	26
Walk	29	37	65	0
PRT	4	N/A	N/A	N/A
Other	0	0	1	0
Combination of 2	5	0	10	0
Total	**110**	**100**	**100**	**100**

In summary, these findings considerably expand the knowledge base on the occurrence of glass and paint on various U.S. subpopulations and consider factors never assessed before under the controlled conditions utilized in this study.

Classification of paint and glass by composition and end-use

Glass samples were classified based on their elemental and microscopic features as a) container, b) sheet, c) container/sheet soda lime, or d) other. Most of the glass recovered from the Morgantown and Huntsville areas was classified as soda-lime-silicate glass (container and/or sheet glass). While the Houston set had a combination of unusual glass compositions including a zinc-phosphate glass (optical or medical uses) and others that were an undetermined category. The only Pittsburgh glass was classified as an alumino-silicate glass of similar elemental composition of a group of portable electronic devices in our in-house database (Table 13). Figures 9 and 10 illustrate examples of the spectra.

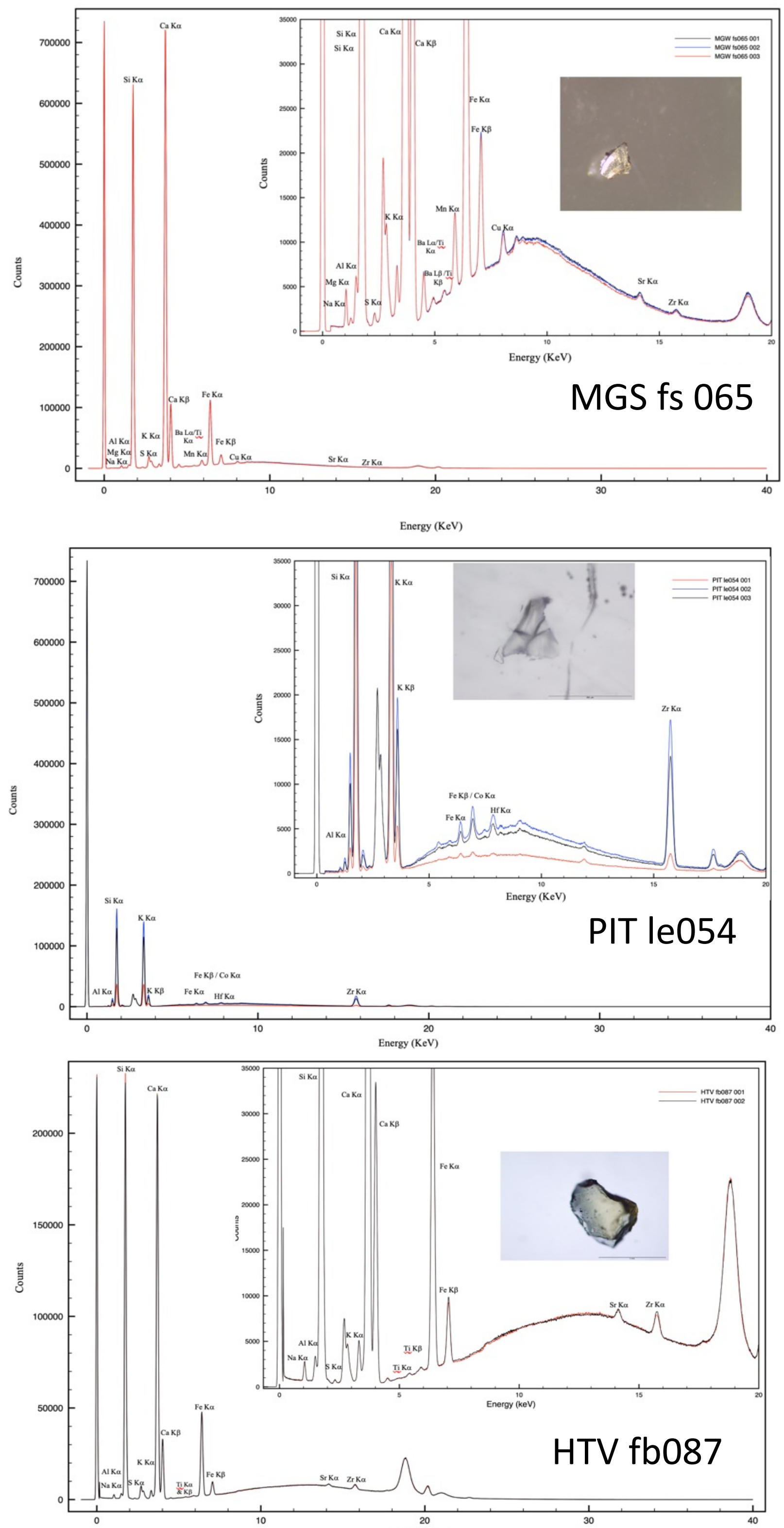

Figure 9. Micro-XRF spectra of samples from the summer collection in Morgantown fs065, Pittsburgh le054, and Huntsville fb 087. The Morgantown and Huntsville samples were classified as soda-lime-silicate container, while the Pittsburgh sample was identified as aluminosilicate glass.

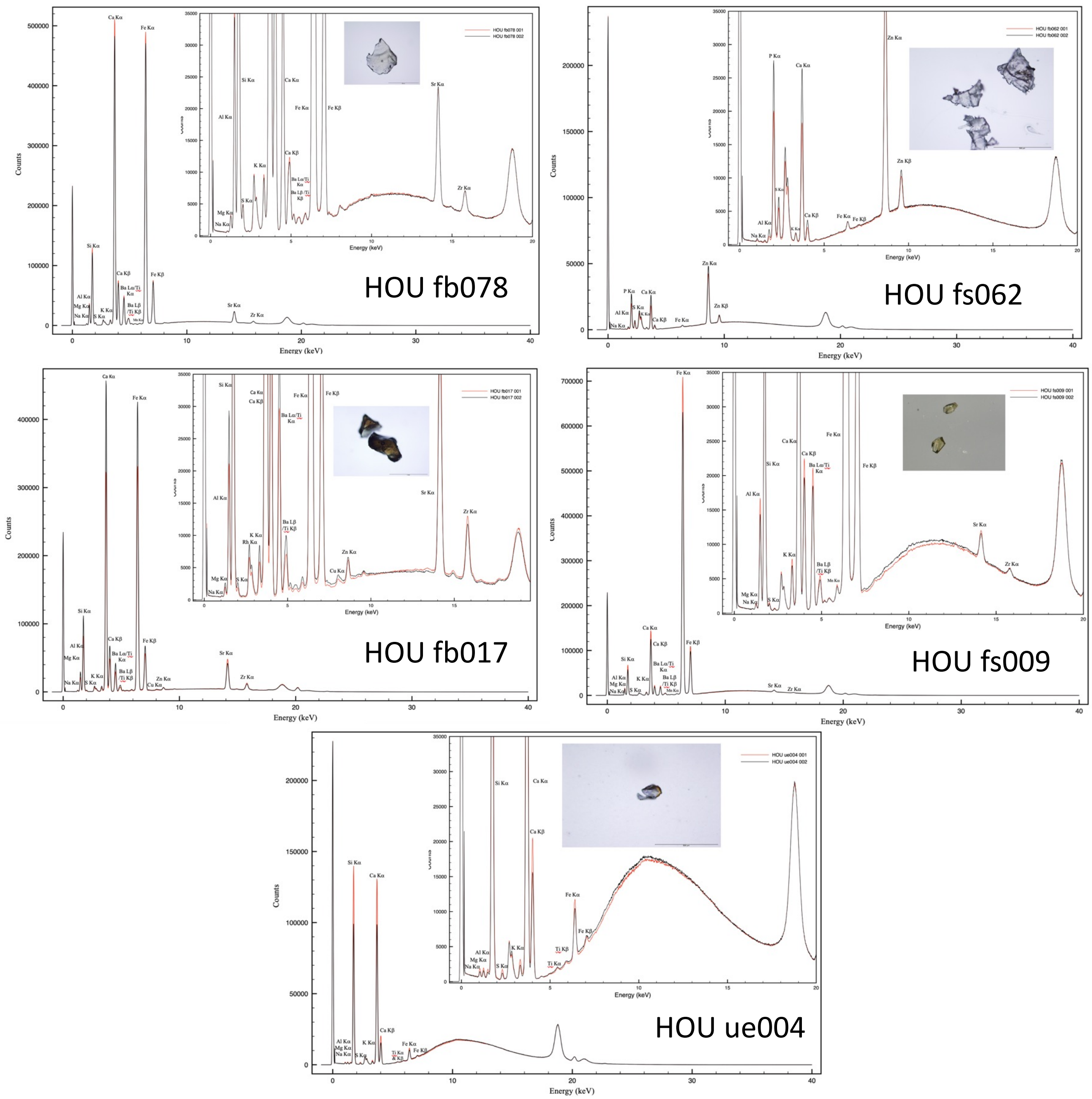

Figure 10. Micro-XRF spectra of samples from the summer collection in Houston, Samples fb089 and ue004 were classified as soda-lime-silicate container, while sample 0062 was classified as a zinc-phosphate glass, and the remaining samples were identified as other type of glass.

Table 13. *Glass end-use classifications for the multi-city summer collections.*

City/Season	Sample ID	color	Size	RI	Elements	Classification	Comment
Morgantown Summer	MGSfs065	colorless	0.1mm	1.52209	Na, Mg, Al, Si, S, K, Ca, Ba/Ti, Mn, Fe, Cu, Sr, Zr	soda-lime-silicate (container)	Elemental profile, Ca/Mg and RI suggest soda lime container.
Huntsville Summer	HTVfb087	brown	1.25mm	1.52152	Na, Al, Si, S, K, Ca, Ti, Fe, Sr, Zr	soda-lime-silicate (container)	Elemental profile typical of soda-lime-silicate glass, except no Mg was detected. The iron content is elevated and the color rules out sheet glass.
Pittsburgh Summer	PITle054	colorless	0.2mm	1.50895	Al, Si, K, Fe, Co, Hf, Zr	aluminosilicate glass (i.e., portable electronic devices)	Elemental profile very similar to some PEDs we have analyzed in our in-house database
Houston Summer	HOUfb078	colorless	0.75mm	1.52308	Na, Mg, Al, Si, S, K, Ca, Ba/Ti, Fe, Sr, Zr	soda-lime-silicate (container)	Elemental profile and RI suggest soda lime. More likely container due to low Mg. However, Si/Ca ratio is not typical of sheet or container. The air bubble artifact observed under the microscope is atypical of flat glass.
Houston Summer	HOUfb062	colorless	F1: 0.5mm; F2: <0.5mm; F3: 0.5mm	1.52278	Na, Al, P, S, K, Ca, Fe, Zn	zinc-phosphate glass (optical, medical)	Elemental profile indicates possible zinc-phosphate glass (optical glass, medical uses)
Houston Summer	HOUfb017	brown	F1: 1.25m; F2: 0.75mm	1.52231	Na, Mg, Al, Si, S, K, Ca, Ba/Ti, Fe, Cu, Zn, Sr, Zr	other	Brown glass color and transparency rule out sheet glass, very high Fe content. Elemental profile is atypical of container glass. Its possible a natural occurring glass like obsidian or ceramic
Houston Summer	HOUfs009	brown	~0.1mm	1.52282	Na, Mg, Al, Si, S, K, Ca, Ba/Ti, Mn, Fe, Sr, Zr	other	The combination of elevated Fe and Ba/Ti, and Al, and the low Na content is atypical of soda-lime-silicate glass, sheet or container.
Houston Summer	HOUue004	colorless	0.2mm	1.52321	Na, Mg, Al, Si, S, K, Ca, Ti, Fe	soda-lime-silicate-container	Ca/Mg and Ca/Fe consistent with soda-lime container glass

Paint samples were classified by their microscopic features and IR spectra as a) automotive, b) architectural, c) nail polish, d) tool, or e) another paint type. The tables below list the classifications for the various cities. A plot of the frequency of various binders with modifications for each collection is shown in Figure 11, where the most common classification was acrylic. There were also various particles classified as alkyds (with and without modifications, and including isophthalic and/or orthophthalic), epoxies, nitrocellulose, styrene-butadiene, and more. Many samples could be differentiated as architectural, automotive, and nail polish, based on a combination of microscopic features and IR spectra. When the physical and chemical properties didn't allow for a specific category, we labeled these as "other". Some paints were not specific to a single category and were labeled as "any of the major types". For instance, some nitrocellulose binders can be found in a variety of applications, such as automotive, architectural, or nail polish samples (Figure 12). Only two samples had a binder that was masked and therefore did not have a definitive classification. Ideally, further examination with Raman spectroscopy or pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS) could assist with a more thorough classification of the pigments and binders, but due to sample size and experimental design, these were outside of the scope of this study. Still, the microscopic and IR analysis provide an estimate of the occurrence of paint by main end-use, which can assist with the overall interpretation of the evidence.

Table 14. *The Pittsburgh paint classification table. Samples were organized by their sample ID and garment location. Most of the paint particles yielded a classification, but some were undetermined, although their characteristics indicated paint.*

Sample ID	Garment Location	Color	Size	Binder	Modifications	Pigment/extender		End-Use
019	us	Red	0.2 mm	Acrylic	Epoxy	Kaolin	-	Nail polish
044	fs	Blue	<0.2 mm	Acrylic	Epoxy	Calcium carbonate	Kaolin	Nail polish
055	ls	Purple	<0.2 mm	Styrene-butadiene latex	Acrylic	Kaolin	-	Architectural
096	us	Grey/Blue	2 mm	Acrylic	-	Calcium carbonate	Kaolin + Titanium dioxide	Architectural

Table 15. *The Huntsville paint classification table. Samples were organized by their sample ID and garment location. Most of the paint particles yielded a classification, but some were undetermined, although their characteristics indicated paint.*

Sample ID	Garment Location	Color	Size	Binder	Modifications	Pigment/extender		End-Use
002	us	White	0.2 mm	Acrylic	-	Mica (k-al-silicate)	Calcium carbonate + Titanium dioxide	Architectural or Automotive
006	us	Orange	0.2 mm	Acrylic with epoxy group	-	Calcium carbonate	Titanium dioxide + Clay	Nail polish
007-1	us	Green/blue	0.4 mm	Acrylic-alkyd	-	Calcium carbonate	Titanium dioxide + Talc	Architectural
007-2	us	Green	0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Talc	Architectural
008	us	Pink/white	0.3 mm	Isophthalic-Alkyd (polyester)	-	Calcium carbonate	Titanium dioxide	Architectural
013-2	ls	Blue	0.4 mm	Polyurethane acrylic	-	Talc	-	Architectural or Automotive
016-2	us	Purple/ multicolored	0.6 mm	Styrene-butadiene + acrylic	-	-	-	Architectural or Other (mixture)
017	us	Blue	0.4 mm	Orthophthalic -Acrylic-Alkyd	-	Calcium carbonate	-	Architectural or Automotive

Sample ID	Garment Location	Color	Size	Binder	Modifications	Pigment/extender		End-Use
019-1	us	Orange	0.2 mm	Acrylic	Urea	Calcium carbonate	-	Automotive
019-2A	us	Yellow	0.3 mm	Acrylic with epoxy group	-	Calcium carbonate	Titanium dioxide	Nail polish
019-2B	us	White	0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Any
019-2A/B	us	Yellow and white	0.3 mm	Acrylic with epoxy group	Melamine	Calcium carbonate	Titanium dioxide	Nail polish
023	ls	Black	0.3 mm	Styrene butadiene	-	Silica	-	Architectural
024	us	Blue	0.2 mm	Orthophthalic -Alkyd	-	Calcium carbonate	Titanium dioxide	Architectural or Automotive
025	ls	Orange	0.3 mm	Acrylic-epoxy	-	Calcium carbonate	Titanium dioxide	Any
028A	us	Blue	0.5 mm	Styrene butadiene	-	Aluminum silicate	Titanium dioxide	Architectural
031	ls	Light purple	0.3 mm	Nitrocellulose	Acetate cellulose butyrate	Clay	-	Any
036	us	Black	0.2 mm	Epoxy	-	Barium sulfate	-	Automotive
047	ls	Dark purple	0.3 mm	Acrylic	-	Calcium carbonate	-	Any
055	fb	Grey	0.5 mm	Acrylic	-	Titanium dioxide	-	Architectural
056	fs	Yellow	0.3 mm	Acrylic	-		-	Architectural or Other
066	us	Red	0.2 mm	Acrylic	-	Calcium carbonate	CI pigment red 254	Any
070	us	Dark red	0.2 mm	Acrylic	-	Calcium carbonate	CI pigment red 254	Any
077	us	Light blue	0.2 mm	Acrylic	-	Calcium carbonate	Kaolin	Architectural or Automotive
083	ls	Red	0.2 mm	Isophthalic-Acrylic-alkyd (polyester)	-	Calcium carbonate	-	Architectural or Automotive
086	ls	Yellow	0.2 mm	Acrylic	Melamine + styrene	Titanium dioxide	Calcium sulfate	Automotive
092	ls	Blue	1 mm	Alkyd	-	Calcium carbonate	-	Architectural
095	ls	Blue	0.3 mm	Orthophthalic -Alkyd	-	Calcium carbonate	Titanium dioxide	Architectural or Automotive

Table 16. *The Houston paint classification table. Samples were organized by their sample ID and garment location. Most of the paint particles yielded a classification, but some were undetermined, although their characteristics indicated paint.*

Sample ID	Garment Location	Color	Fragment Size	Main Binder	Modifications	Pigment/Extender		End-Use
005	fs	Orange	0.2 mm	Acrylic	Melamine	Calcium carbonate, clay		Other
007-1	us	Multicolored	0.3 mm	Orthophthalic-Alkyd + Isophthalic-Alkyd (polyester)	-	Calcium carbonate	-	Other (mixture)
007-2	us	Green	0.2 mm	Orthophthalic-Alkyd + Isophthalic-Alkyd (polyester)	-	Calcium carbonate	-	Other (mixture)
007-3	us	Yellow	0.2 mm	Acrylic	Melamine	Silica		Automotive
008	fb	Grey	0.5 mm	Acrylic	-	Talc	-	Any
010-1	us	Light purple	<0.2 mm	Orthophthalic-Alkyd + Acrylic	Styrene	CI pigment red 254	-	Any
010-3	us	Red with black	<0.2 mm	Orthophthalic-Alkyd + Acrylic	Styrene	CI pigment red 254	-	Any
010-4	us	Red	<0.2 mm	Orthophthalic-Alkyd + Acrylic	Styrene	CI pigment red 254	-	Any

Sample ID	Garment Location	Color	Fragment Size	Main Binder	Modifications	Pigment/Extender		End-Use
010-5	us	Red with black	<0.2 mm	Orthophthalic-Alkyd + Acrylic	Styrene	CI pigment red 254	-	Any
010-1	ls	Multicolored	0.2 mm	Acrylic		Aluminum silicate	Calcium carbonate	Other
011-1	ls	Dark blue	0.2 mm	Acrylic	Styrene	Aluminum silicate	-	Any
013-1	ls	Yellow and white	0.2 mm	Orthophthalic-Alkyd	-	Calcium carbonate	Titanium dioxide	Architectural or Other
014	ls	Silver	0.3 mm	Epoxy	-	Zinc phosphate	-	Automotive
020	ue	Yellow	0.2 mm	Orthophthalic-Alkyd + Polyurethane	-	Barium sulfate	Titanium dioxide	Automotive
021	ue	Purple	<0.2 mm	Acrylic-alkyd	-	-	-	Architectural or Automotive
023	le	Red	<0.2 mm	Acrylic	-	Calcium carbonate	Aluminum silicate	Any
026-1	us	Grey	0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Any
026-2	us	Red and white	0.2 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Any
027-1	us	Lt. Blue/white	0.3 mm	Acrylic-alkyd	-	Kaolin	Calcium carbonate + titanium dioxide	Architectural or Other
027-2	us	Lt. Blue/white	0.2 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Architectural or Other
027	fs	Dark blue and white	0.2 mm	Orthophthalic-Alkyd	-	Calcium carbonate	Aluminum silicate	Architectural
028-1	fs	Red and white	0.4 mm	Acrylic-alkyd	Melamine	Naphthol red (PR 170)	Ferric oxide	Automotive
028-2	fs	Red and white	0.4 mm	Acrylic-alkyd	Melamine	Naphthol red (PR 170)	Ferric oxide	Automotive
028-3	fs	Red and white	0.4 mm	Acrylic-alkyd	Melamine	Naphthol red (PR 170)	Ferric oxide	Automotive
028-4	fs	Red and white	0.4 mm	Acrylic-alkyd	Melamine	Naphthol red (PR 170)	Ferric oxide	Automotive
029-1	fb	Orange	0.5 mm	Orthophthalic-Alkyd	Melamine	-	-	Automotive
033	us	Blue and white	0.3 mm	Acrylic	-	Kaolin	-	Automotive or Architectural or Other
035-1	us	Red	0.2 mm	Terephthalic-Alkyd (Polyester) + Epoxy	-	Calcium carbonate	-	Architectural or Other
035-2	us	Green	0.3 mm	Terephthalic-Alkyd (Polyester) + Epoxy	-	Calcium carbonate	-	Architectural or Other
039	ls	Blue	0.3 mm	Isophthalic-Alkyd (Polyester)	-	Calcium carbonate	Kaolin	Architectural or Automotive
041	fs	Multicolored	0.4 mm	Orthophthalic-Alkyd + Acrylic	-	-	-	Architectural or Automotive
044	ls	Blue	0.3 mm	Acrylic	-	Calcium carbonate	-	Automotive
045	ls	Blue	0.2 mm	Acrylic	Melamine	Kaolin	-	Automotive
045-1	us	Red	0.3 mm	Binder masked	-	CI pigment orange 34	Calcium carbonate	N/A binder masked

Sample ID	Garment Location	Color	Fragment Size	Main Binder	Modifications	Pigment/Extender		End-Use
045-2	us	Red	0.3 mm	Acrylic	Urea	Calcium carbonate	-	Automotive
045-3	us	Red	0.3 mm	Acrylic	Urea	Calcium carbonate	-	Automotive
051	fs	Blue	0.2 mm	Styrene butadiene	-	Titanium dioxide	-	Architectural
056	fs	Multicolored	0.3 mm	Acrylic	-	Calcium carbonate	Aluminum silicate	Nail polish or Other
058	us	Red and white	0.4 mm	-	-	CI pigment red 254	-	N/A binder masked
059	us	Dark blue	0.3 mm	Orthophthalic-Alkyd	-	Calcium carbonate	Talc	Architectural or Automotive
060	fb	Purple	0.3 mm	Nitrocellulose	Acrylic	-	-	Any
065	ls	Pink	0.2 mm	PVA	-	-	-	Architectural
070	us	Dark blue	0.2 mm	Acrylic	-	Calcium carbonate	-	Any
073-1	ue	Multicolored	0.3 mm	Styrene butadiene	-	Aluminum silicate	-	Architectural
078	le	Green	0.5 mm	Epoxy	Acrylic	Talc	-	Automotive or Other
079	fb	Yellow	0.3 mm	Acrylic + Acrylonitrile Styrene	-	Titanium dioxide	-	Other
079	us	Blue and white	0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Architectural or Other
085	us	Light purple	0.5 mm	Styrene butadiene	-	Kaolin	-	Architectural
088	us	Orange and white	0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide	Architectural or Other
090-1	us	White	0.6 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Talc	Other
090-2	us	Purple	0.3 mm	Acrylic	-	Calcium carbonate	Titanium dioxide + Talc	Other
097-1	le	Multicolored	0.3 mm	PVA	-	Aluminum silicate	Titanium dioxide	Architectural or Other
097-2	le	Multicolored	0.4 mm	PVA	-	Aluminum silicate	Titanium dioxide	Architectural or Other
098-1	us	Red	0.5 mm	Acrylic	Urea	Calcium carbonate	Aluminum silicate	Automotive
098-2	us	Red	0.5 mm	Acrylic	Urea	Calcium carbonate	Aluminum silicate	Automotive
098-3	us	Light blue	0.5 mm	Acrylic	Urea	Calcium carbonate	Aluminum silicate + Talc	Automotive

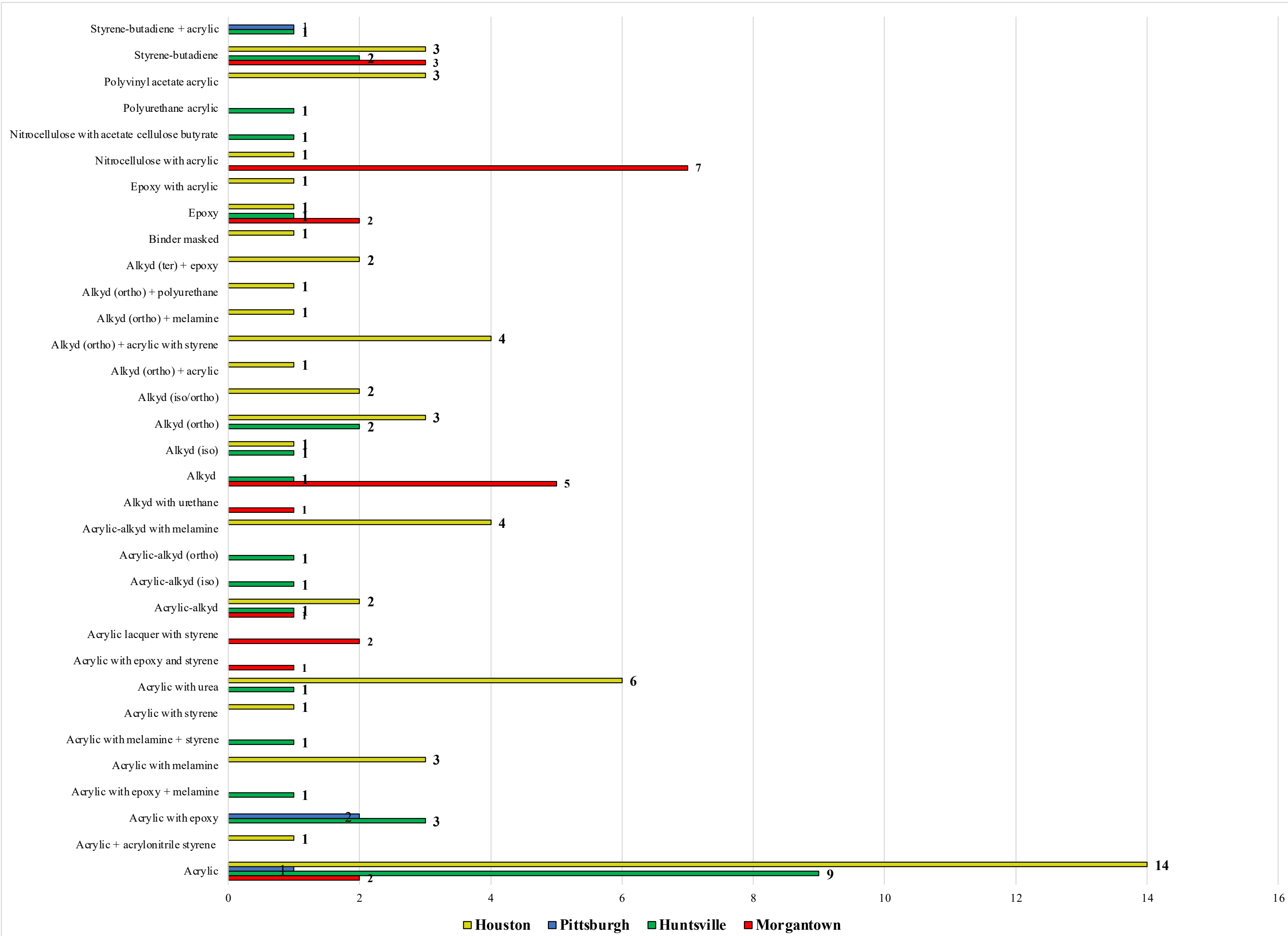

Figure 11. *The binder types for the 111 paint fragments from the four collections. Of these classifications, the majority were acrylics (with and without modifications), and alkyds (with and without modifications, and iso and/or ortho. Other classifications fell under epoxies, nitrocellulose, PVA, and styrene-butadienes.*

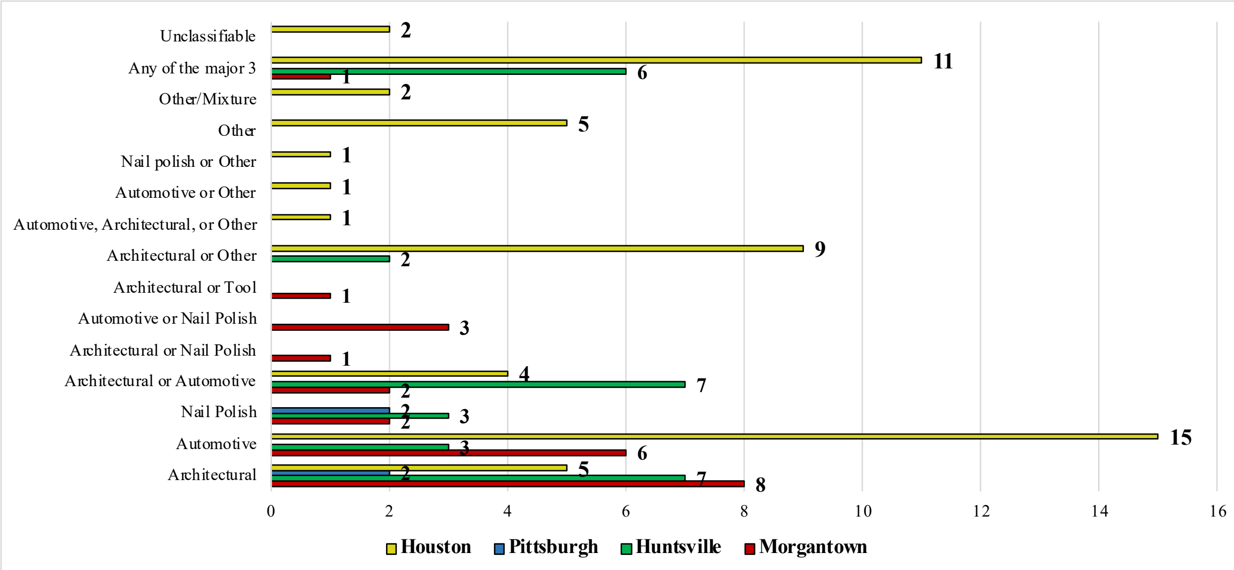

Figure 12. *The primary end-uses of the 111 fragments from the four collections. Most of the fragments from the Morgantown set were architectural or automotive, while the Huntsville set had mainly architectural, architectural/automotive, or samples deemed to be any of the major 3. The Pittsburgh collection had two architectural samples and two nail polish samples. Lastly, the Houston set had mainly automotive paint, samples classified as any of the major categories, and architectural or other.*

Illustration of use of survey data in the estimation of parameters P and S for evidence interpretation

The calculation of parameters *P* and *S* was carried out using maximum likelihood estimation (MLE) to estimate the shape parameter of a zeta distribution from the observed counts for the number of groups (P) and their size (S). The approach used by Coulson et al [54] was implemented and improved in this study, which led to development of the package *fitPS* (https://cran.r-project.org/web/packages/fitPS/fitPS.pdf) used within statistical software R.[68] This package improved on the estimation in that linear interpolation originally used by Coulson et al. was not required, and standard numerical optimization was used instead. The zeta distribution has probability mass function:

$$p(k) = \frac{k^{-s}}{\zeta(s)}$$

Where $\zeta(s)$ is the Reimann zeta function.

The calculations using the negative zeta distribution of parameters *P* (i.e., the probability to observe a given number of groups of fragments) and *S* (the probability that a group has a given size of fragments) are estimated for glass and shown in Table 17.

Table 17. *Estimation of parameters P and S for the recovery of fragments in the clothes and the shoes from summer and winter sampling surveys*

	Summer (410 subjects)			*Winter (100 subjects)*		
	Clothes	*Shoes*	*All garments*	*Clothes*	*Shoes*	*All garments*
P_0	0.9953	0.9884	0.9840	0.9726	0.9546	0.9314
P_1	0.0045	0.0107	0.0145	0.0238	0.0373	0.0530
P_2	0.0002	0.0008	0.0012	0.0027	0.0056	0.0099
P_3	0.0000	0.0001	0.0002	0.0006	0.0015	0.0030
P_4	0.0000	0.0000	0.0001	0.0002	0.0005	0.0012
P_5	0.0000	0.0000	0.0000	0.0001	0.0002	0.0006
S_1	1.0000	1.0000	1.0000	1.0000	0.8252	0.8888
S_2	0.0000	0.0000	0.0000	0.0000	0.1066	0.0778
S_3	0.0000	0.0000	0.0000	0.0000	0.0322	0.0187
S_4	0.0000	0.0000	0.0000	0.0000	0.0138	0.0068
S_5	0.0000	0.0000	0.0000	0.0000	0.0071	0.0031

As expected, the probability to observe no fragments on clothes and shoes was very high in the light of the low number of recovered fragments. The data also confirm that it is more likely to observe glass fragments on the shoes of an individual assumed not to be involved with crimes involving glass breaking. Though, the probability to observe glass fragments on shoes can still be considered a rare event and it is even less likely to observe more than one group of fragments in the general population. Comparisons between the number of fragments searched during the summer and winter sampling sessions show that the data slightly differed in the sense that the sampling in Morgantown WV held in winter yielded a higher number of recovered fragments than the totality of fragments recovered in the four cities during the summer sampling. In that winter session, ten fragments were recovered from 7 individuals: two fragments were recovered from the shoes of three individuals, one fragment from the shoes of one individual, one fragment from the lower garments of two individuals, and one fragment from the upper part of one individual. From Table 17 it is possible to note that although the probabilities P_1 and P_2 are higher for the winter than the summer sampling, the chances to randomly observe one group of fragments in the general population are still confirmed to be low. The validity of this consideration is assumed to be acceptable even if the winter sampling consisted of only 100 subjects against the 410 spanning the overall summer sampling in the four surveyed locations.

In the summer sampling, no more than one fragment per item were found. The calculation of parameter S resulted in an estimation of S_1 equal to one for all instances (i.e., clothes, shoes, and all garments). For the winter set, the calculation of S_1 for the recovery on clothes only also yielded a value of 1; on the other hand, in the light of the recovery of more than one fragment on the shoes of the subjects in the winter sampling, including one group of 2 matching fragments, the probability of observing a group of 1 fragment (S_1) dropped to approximately 0.83 due to the increased probability to observe a group of 2 fragments ($S_2 \approx 0.11$) on the shoes of an individual not suspected of a crime involving glass breaking.

The estimations of parameters P and S in this study reflected more closely the values obtained in previous studies conducted on the general population, (i.e., individuals assumed not be involved in some criminal activities involving glass breaking), like the ones by Pearson[55] or Lau et al.[57], rather than the surveys on garments seized from persons suspected of crime, like the ones by Lambert et al.[58] or Coulson et al.[54]

Irrespective of whether or not a likelihood ratio approach is used in the evaluation of scientific findings, forensic scientists need to be prepared to comment on activity-level considerations, including questions related to the random presence of glass on surfaces of interest. Although it is not unlikely that a forensic scientist be asked about activity-level aspects of their case at hand, this intellectual exercise should not be limited to advocacy (i.e., cross-examination in court). Parameters *P* and *S* depend on the particular scenario, from which an appropriate pair of competing propositions shall be clearly defined long before advocacy. A likelihood ratio approach as the one proposed by Evett and Buckleton[49] includes the proper use of parameters *P* and *S* which relate to background presence along with the other factors pertaining to transfer, persistence, and recovery efficiency (denoted *T*) and the rarity of the observed properties (or the estimation of probability density function for a continuous approach).

The data about parameters *P* and *S* produced in this study constitutes an addition to the body of knowledge on this particular topic: while it confirms most of the preexisting information reported in older studies conducted overseas, it shows that from the U.S. perspective too, it is unlikely to recover glass on the garments of individuals unconnected with criminal activities involving glass breaking and it is even less likely to find a large number of fragments. It is anticipated that this survey may assist forensic scientists to include activity-level interpretations when appropriate.

2.2.4. Final Remarks and Conclusions

Overall, this study allowed the collection of traces from 510 individuals and 2,391 garments. The findings are summarized for two main subsets: 1) the seasonal set, involving 210 individuals in the summer and winter seasons in Morgantown, and 2)the multicity set, involving 410 individuals from four different cities.

Overall, in the seasonal set we report the sampling of glass and paint particulates in the Morgantown, WV area, which allowed for collection from a total of 1,038 garments and pairs of footwear in the summer and winter seasons, from the upper surfaces, upper embedded areas, the lower surfaces, the lower embedded areas, the footwear surfaces, and the footwear embedded areas (soles). Glass was mainly recovered from the surfaces and soles of the footwear. In comparison, paint was primarily recovered from the upper and lower surfaces.

Glass and paint were more prevalent in the summer than in the winter season, with paint being more common in the general population than glass, regardless of season. Out of 100 volunteers sampled during the winter collection, seven bore glass fragments, 36 bore paint particulates, and only one had both glass and paint on their garments and footwear but not both traces in the same sampled area. In contrast, from the 110 individuals sampled during the summer collection, one bore glass fragments, 21 bore paint particulates, and there were no individuals with both glass and paint on them. In addition, there were no pairs of footwear with both glass and paint particulates from either population.

This study is the first one of its kind to evaluate the effect of the season on the garment type and trace occurrence in a city that shows substantial temperature changes in summer and winter. However, these findings may depend on the different weather conditions during the summer and winter seasons in different regions. The effect of the seasons was substantial on the type of garment worn, the main modes of transportation, and the number of fragments recovered. These findings can play a critical role in understanding the relevance of the transfer and persistence of trace materials in criminal events compared to the background presence in the general population.

Moreover, the sampling of paint particles in Morgantown, WV, Huntsville, TX, Pittsburgh, PA, and Houston, TX areas in the warmer season allowed for collection from a total of 1,883 garments and pairs of footwear from the surfaces, embedded areas, and footwear (surfaces and soles). From these articles of clothing and footwear, a total of 111 paint particles and 8 glass fragments were recovered and classified by end-use

Of the university small cities, the Morgantown collection yielded 23 paint fragments from 21 individuals, while the Huntsville collection had 28 particles from 24 individuals out of 110 and 100 volunteers sampled, respectively. Of the larger metropolitan areas, only 4 paint fragments came from the Pittsburgh set, while 56 were recovered from Houston (from 4 and 39 individuals, out of 100 sampled for each site, respectively). Of these 111 paint fragments recovered across the four sets, 45% were recovered from the upper surface, 29.5% were recovered from the lower surface, and 16.6% were recovered from the footwear surfaces. The remaining 8.9% came from primarily the footwear bottom, followed by the lower embedded areas, and the upper embedded areas. These results are consistent with previous studies stating that paint particles will likely be found on the upper and lower clothing of an individual, and less likely to be recovered from pockets, cuffs, and the bottom of footwear.

Interestingly, the number of paint particles recovered from Morgantown and Huntsville was comparable. With both cities being smaller college towns, it is somehow explainable to see similar amounts of paint recovered. On the other hand, the number of fragments recovered from the Pittsburgh and Houston sets was drastically different. With Pittsburgh being a larger area like Houston, we hypothesized that there would be a similar number of paint fragments found in these cities. However, that was not the case. Upon evaluation of the survey data, there were more fragments from Houston than the smaller cities altogether. However, the number of fragments recovered from the Pittsburgh set was much lower than expected.

In this study, the main question we wanted to answer was whether the background levels of paint (and glass and paint) were dependent on the area's demographics, the garment type and retention, and the main mode of transportation. The results of our study have confirmed that these factors have an effect on the number of fragments recovered.

We have also shown that the garment and footwear types worn and their retention properties play an important role in the transfer and persistence of paint particles; individuals wearing garments and footwear with medium to high retention properties held most of the fragments for each collection (ripped jeans, sweaters, t-shirts), whereas very few fragments were recovered from garments with low retention properties (silk or athletic wear).

Finally, urban design influences the transportation forms, which affects the activities and dynamics of the surrounding area, and thus the transfer and persistence of fragments on their garments and footwear. The study indicates that moving from one location to another by walking may decrease the likelihood of background persistence, while individuals who use personal vehicles as their primary form of transportation tend to retain more traces. This study also indicates that the local region plays an important factor that affects the number of traces recovered, which should be considered during the overall assessment of the weight of the evidence.

To summarize, cities and regions that favor walking activities tend to have lower frequencies of glass (< 1% of the individuals) and paint (4-24% of individuals) than those that predominantly use personal vehicles as their mode of transportation (5% and 30% of the individuals bore glass and paint traces, respectively). Although the clothing worn is a confounding factor, its effect was not substantial across cities, but it was found to be significant in seasons with different temperatures.

However, regardless of the observed variance between regions, general trends across the cities include: (1) paint has more occurrence (4-39% of individuals) than glass (1-5% of individuals) in the general population, (2) paint is primarily found on the surface of the garments and rarely on the soles of the footwear, (3) the most common type of paint is architectural paint and automotive paint, with the typical fragment size being 500μm or smaller, and single layer paints were primarily recovered as opposed to multiple layers, and (4) finding glass and paint on the same individual is rare (less than 1%) and even more rare to find them on the same garment or footwear area (none detected in 1,883 items analyzed), (5) it is more common to find single particles of glass and when more than one fragment is present the majority belong to different groups, and (6) it is more common to find single fragments of paint in the background population than multiple fragments on a single item.

The present study revisited a type of survey that was originally published in the early Seventies and saw the last study of the kind in 2009. This research re-evaluated the possibility of estimating the probability P to observe a certain number of groups of fragments on garments and the probability S to observe a given number of fragments for a given group, which resulted in the development of the *fitPS* R package.

This survey is one of its kind, and the first extensive study to evaluate the presence of glass and paint in the general public in U.S regions. The experimental design allowed for controlled variables and monitoring of factors that show influence in the recovery rates by city and season. This data now becomes available to expand its applicability in the interpretation of trace evidence in the U.S. courtroom.

2.3. Limitations

The main limitation encountered in this study was the restrictions derived from COVID pandemic prevented for several months sampling volunteers. This external factor required the solicitation of a no-cost extension to complete the totality of the proposed tasks.

III ARTIFACTS

3.1 List of products

3.1.1 Publications at scientific peer-reviewed journals and dissertations

We submitted the following manuscripts and are currently under revision:

1) LC Alexander, O Ovide, OC Duffett AD Lewis P Buzzini, J Curran, T Trejos. The Random Presence of Glass and Paint on the Clothing and Footwear of Members of the General Population: A US Baseline Survey at Various Seasons. Submitted to J Foren Sci 2022. In Review
2) AD Lewis, LC Alexander, O Ovide, OC Duffett, J Curran, T Trejos, P Buzzini,. A Comparative Study on the Baseline of Glass and Paint in Various Regions in the United States Part 1: The Frequency of Occurrence of Glass in the General Population. Submitted to Forens. Sci. Int. 2022. In Review.
3) LC Alexander, AD Lewis, OC Duffett, P Buzzini, J Curran, T Trejos. A Comparative Study on the Baseline of Glass and Paint in Various Regions in the United States Part 2: The Frequency of Occurrence of Paint in the General Population. Submitted to Forens. Sci. Int. 2022. In Review.

3.1.2. Presentations at Scientific Meetings

1) September 20-22, 2022. Andra Lewis, Lauryn Alexander, Patrick Buzzini, Tatiana Trejos. A comparative study on the background presence of glass and paint in various populations and seasons in the US. Presented at the Inter/Micro 2022 conference. McCrone Research Institute, Chicago, IL. (Oral presentation)
2) September 17th, 2022. Lauryn Alexander, Oriana Ovide, Olivia Duffett, Andra Lewis-Krick, Patrick Buzzini, Tatiana Trejos. Evaluation of Glass and Paint Traces on Clothing and Footwear of the General Public in Various U.S. Regions and Seasons. MAFS 51st Annual Fall Meeting, a Joint Meeting with ASTEE. Des Moines, Iowa. (Oral presentation)
3) February 2022, Lauryn C. Alexander, Oriana Ovide, Olivia Duffett, Andra Lewis-Krick, Dr. Patrick Buzzini, Dr. Tatiana Trejos, A Comparative Study on the Background Presence of Glass and Paint in Various Populations and Seasons in the United States, American Academy of Forensic Sciences Annual Conference, Seattle, WA. (Oral Presentation).
4) October 2021, Lauryn C Alexander, Oriana Ovide, Olivia Duffett, Tatiana Trejos. The Background and Relevance of Microscopic Traces of Glass Evidence in Forensic Investigations, 2021 Brazilian Winter School Conference, (Virtual oral presentation)
5) October 2021, Lauryn C Alexander, Oriana Ovide, Olivia Duffett, Tatiana Trejo. Why does it matter to understand how common it is to find paint and glass microparticles in the regular population- A forensic perspective, 2021 9th Annual Black Doctoral Network Conference (Poster & Oral Presentation)
6) September 23, 2021, Lauryn Alexander, Oriana Ovide, Olivia Duffett. How common is it to find glass and paint residues in a member of the general U.S. population? A preliminary study. Mid-Atlantic Association of Forensic Scientist and ASTEE joint meeting (Oral presentation)

7) July 29th, 2021. Olivia Duffet, Lauryn Alexander, Oriana Ovide, Tatiana Trejos. Survey of Glass and Paint in the General Population to Assess their Evidential Value**.** 13th Annual summer undergraduate research symposium, Morgantown, WV (Poster presentation)
8) July 28th, 2021. Lauryn Alexander, Oriana Ovide, Olivia Duffet, Tatiana Trejos A Study of Frequency of Occurrence of Glass and Paint in the U.S. Population: Preliminary Findings. Current Trends in Forensic Trace Analysis 2021 Online Forensic Symposium. (Poster presentation)

3.1.3. Website(s) or other Internet site(s)

Development of the package *fitPS* (https://cran.r-project.org/web/packages/fitPS/fitPS.pdf) used within statistical software R for interpretation of baseline data.

3.2. Data sets generated

According to our data management plan, the data resulting from all the instrumental analysis was curated and compiled into a centralized dataset. The dataset consists of the main data folder labeled 2019-DU-BX 0015 Data, and the secondary data folder is called RESEARCH SURVEY. This main folder contains two subfolders split by the traces of interest, glass and paint (see Figure). Each folder is further broken down into the 5 collections, and the raw and processed data associated with each trace. Figure 12 describes the structure for the data storage and an SOP is provided in the appendix.

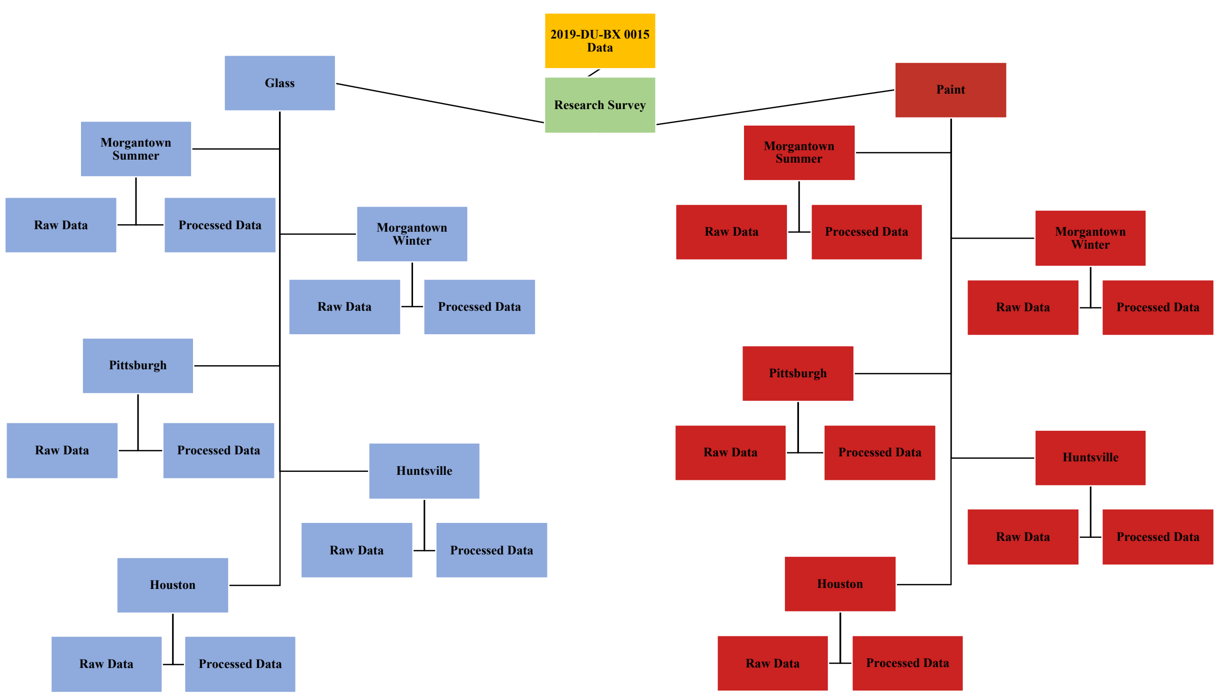

Figure 12. *2019-DU-BX 0015 Data folder structure diagram for the glass and paint data storage.*

3.3. Dissemination activities

To date, the main dissemination routes have been the publication of manuscripts in scientific journals and presentation of research results at scientific meetings, as described in 3.1.

IV PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

This research has provided a robust platform for training the next generations of forensic scientists in methods to collect, examine, and interpret glass and paint evidence. This research has provided research opportunities for undergraduate students and graduate students (Master and Doctoral). Table X lists the main participants and collaborators.

Moreover, this project's resources and research settings have provided all undergraduate and graduate students the unique opportunity to present their results at scientific venues. The opportunities provided to undergraduate researchers, some of the first-generation university students or minority students, have served as an essential foundation to their professional development. One of our undergraduate researchers joined graduate school, and two graduate students joined the workforce. These student's achievements and STEM professional preparation are, in our opinion, the most valuable product of NIJ-funded efforts like this one.

This project also allowed a valuable collaboration across three universities, University of Auckland, Sam Houston State University and West Virginia University, exposing the students and faculty to an enriching multi- and inter-disciplinary environment to develop solutions for our criminal justice system.

Table 18. *List of main participants and collaborating organizations*

Participant Name	Affiliation	Role	Contributions
Tatiana Trejos	West Virginia University	Principal investigator	Managed the project and directly supervised students on sample collection, the analysis by SEM-EDS, μXRF, refractive index, miscroscopical analysis, and statistical interpretation of the data. Supervised dissemination plans, data curation and management plans.
Patrick Buzzini	Sam Houston State University	Co-Principal investigator (subaward)	Supervised research related with collection and interpretation of data for the Texas sites. Managed data collection plans and assisted with reports, and manuscripts.
James Curran	University of Auckland	Statistician Collaborator	Collaborated as expert in statistical analysis of forensic materials and probabilistic assessments of evidence. Dr. Curran provided key support in the statistical analysis and interpretation of the data and as co-author of manuscripts.
Lauryn Alexander	West Virginia University	Graduate Student (PhD)	PhD graduate student working at the Trejos's group. Lauryn main

Participant Name	Affiliation	Role	Contributions
			contribution was in the coordination of all sampling collections the data acquisition, analysis and interpretation. She has been a primary contributor to the manuscripts and dissemination of results.
Andra Lewis	Sam Houston State Univerity	Graduate Student (PhD)	PhD graduate student working at the Buzzini's group. Andra main contribution was in the coordination of sampling collections in Texas, the data acquisition, analysis and interpretation. She has contributed in the manuscripts and dissemination of results.
Oriana Ovide	West Virginia University	Graduate Student (MSFS)	Oriana is a graduate student at WVU-FIS Department under Trejos' group, who completed her MS degree in May 2022. Oriana main contribution was in the collection in Morgantown and Pittsburgh and the glass examination by RI and μXRF.
Jessica Friedel	West Virginia University	Undergraduate student	Jessica Friedel worked during the Spring of 2021 as part of fulfillment of RAP program and 40 hours per week in the summer of 2021 in fulfillment of her internship for the WVU forensic chemistry program. Her most important contribution was analysis and data organization from the SEM-EDS (task 2 and 3)
Paige Smith	West Virginia University	Undergraduate student	Paige contributed to the collection and microscopic examination tasks
Olivia Duffett	West Virginia University	Undergraduate student	Olivia contributed to the collection and microscopic examination tasks, as well as the FTIR examinations

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V CHANGES IN APPROACH

Nothing to report

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