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FINAL RESEARCH REPORT

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Analysis of Small Particles Adhering to the Edges of Duct Tape as a Means to Make Associations in a Way that is Independent of Manufactured Characteristics

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I. SUMMARY OF THE PROJECT

A. Goals, Objectives, and Research Questions

The forensic analysis of duct tape is important in the investigation and prosecution of major crimes where it occurs as blindfolds, bindings, and ligatures. Laboratory methods of examination and comparison are focused on physical and chemical properties of tape backings, adhesives and reinforcing materials. Correspondence in properties provides very strong evidence that two specimens share a common manufacturing source. However, as for any mass-produced commodity, the associative value is limited to a class association. This concern was specifically identified in the 2009 National Academy Sciences report *Strengthening Forensic Science in the United States: A Path Forward*, together with the suggested remedy that analytical methods be developed to exploit characteristics acquired post-manufacture, during an item's use.

Once a roll of tape is put into use, the exposed adhesive along the sides of the roll presents an ideal opportunity for collection, and most importantly retention, of the very small particles (VSP) that are ubiquitous in our environment. These particles occur with tremendous variety, and prior research has shown that they can provide a powerful means of association that is independent of manufacturing characteristics.

The research question addressed by this project was whether the adhesive along the edges of duct tape collects sufficient numbers and variety of VSP, acquired post-manufacture, to (1) allow comparisons and measurable discrimination among tape segments from different rolls, and (2) allow meaningful, quantitative associations among tape segments from the same roll.

There were four specific project objectives:

1. Develop a practical and effective harvesting protocol for VSP trapped within the adhesive along the edges of duct tape.
2. Harvest VSP from the edges of a population of duct tape specimens, sufficient to test their potential to address the 2009 NAS concerns and support or refute the association of one piece of tape with another.
3. Apply laboratory methods to analyze these VSP and distinguish those particles acquired post-manufacture from those particles present as manufactured components of duct tape adhesives.
4. Use previously developed statistical and interpretive methods to measure the discrimination and potential evidential value of VSP acquired post-manufacture along the edges of duct tape.

B. Research Design, Methods, and Analytical Techniques

Thirty partially used silver-colored duct tape rolls appearing neither new nor heavily used were collected from residences within Fairfax County, Virginia. Three circumference-length segments from each roll were sampled, and particles were harvested separately from opposite edges of the tape segments by applying an ethyl cellulose solution which dried into a clear film. The dry film was peeled away, lifting the particles trapped in the adhesive at the tape edge.

Particles present as manufactured components of the duct tape adhesive (used as a "filler" in the adhesive itself) were sampled directly from unexposed interior portions of the tape (away from the exposed edges).

Particles were recovered for analysis by dissolving the ethyl cellulose film and adhesive, followed by filtration. The elemental profiles of hundreds to thousands of individual particles in each specimen were characterized by scanning electron microscopy using energy dispersive x-ray analysis (SEM/EDS).[1]

Specimens from the tape segment edges necessarily include a mixture of adhesive filler particles and acquired tape edge particles. The particle types in the adhesive filler were determined using the unexposed adhesive samples taken from the tape interior. Corresponding particle types seen in the (mixed) tape edge specimens were removed from the dataset, leaving the acquired tape edge particles (ATEPs).

For data analysis, the first and second tape segments from each roll were considered as "unknowns" (representing evidence tape segments collected at a crime scene). The third tape segment from each roll was considered as "known" (representing a roll of tape collected by police investigators to be tested as a possible source of crime scene segments). Statistical methods developed as part of prior NIJ research [2] were used to test whether the ATEPs show sufficient numbers and variety to discriminate among tape segments from different rolls and provide a quantitative association between segments from the same roll.

C. Expected Applicability of the Research

The most direct contributions from this project are new methods for harvesting, characterizing, and comparing acquired VSP from the edges of duct tape. These methods are extendable to other varieties of tape and adhesive products that can acquire particles post-manufacture.

The methods of particle characterization can also be applied to particles that are included within adhesive fillers, providing an additional method to characterize and compare duct tapes (as manufactured). The methods for harvesting particles from tape edges can also be applied to the recovery of traditional trace evidence, such as hairs, fibers and paint fragments from tape edges.

More broadly, this project

(1) demonstrates one means to address the National Academy of Sciences suggestion to exploit characteristics acquired post-manufacture,

(2) extends the research and development effort toward quantitative trace evidence associations based on VSP, and

(3) serves as a foundation for follow-on research into prototype casework applications for tape and other adhesive materials that accumulate VSP post-manufacture.

II. PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

Stoney Forensic, Inc. is a small business, incorporated in Virginia, doing business since 2000. Stoney Forensic is an applied R&D company with specific expertise in identification, analysis and interpretation of particles, dusts and trace evidence. In prior NIJ-funded research we have (1) characterized very small particle (VSP) combinations using analytical instrumentation and expertise commonly available in forensic laboratories, (2) developed statistically rigorous measurements of the strength of correspondence between VSP profiles comprised of the combinations of particles present, (3) measured the probative value of the resulting associations within well-defined experimental parameters, (4) demonstrated the presence of highly selective VSP profiles “riding piggy-back” on the surfaces of physical evidence, and (5) developed methods allowing the recognition and deconvolution of mixtures of VSP arising from different sources. This research has resulted in 16 major peer-reviewed publications and more than 45 presentations at national and regional professional meetings.

On this project the principal Investigator was David A. Stoney, PhD. He has a Ph.D. in Forensic Science from the University of California, Berkeley, and has served as Principal Investigator on five directly related NIJ Awards.

Paul Stoney participated as Program Manager and Research Development Director, contributing specific scientific program management and systems analysis expertise. He has an MBA from Stanford University and has managed all Stoney Forensic research and development programs for the past 20 years, including the successful development of particle-based source attribution, overseeing the processes from concept through R&D to operational deployment. He was the Program Manager on five directly related NIJ Awards.

III. OUTCOMES

A. Activities and Accomplishments

1. New Methods for Harvesting VSP from Adhesive Materials

Methods were developed that efficiently harvest VSP from the adhesive along the tape edges, integrate well with forensic tape examination protocols currently in use, and include separate sampling of the adhesive filler particles that are present within duct tape adhesives as part of their manufacturing process. As noted above, VSP are harvested from duct tape edges using an ethyl cellulose film. The film can be examined directly using a stereomicroscope and larger particles (such as fibers and other conventional trace evidence) can be detected easily and removed as an initial step.

2. Characterization of Filler Particles in Duct Tape Adhesives

Particles included as fillers in duct tape adhesives were characterized for each of the 30 duct tape rolls based on a sampling of 2500+ particles from each roll. This resulted in the *Adhesive Filler Particle Datasets*. Each particle is characterized by a set of particle size and shape parameters, x-ray elemental analysis data, and the calculated percentages of each of the 18 specified elements (Al, Ca, Cl, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, S, Si, Ti, V, Zn). Particle Types representing 97+% of a roll's composition were defined based on percentages of 18 target elements.

3. Characterization of Particles from Duct Tape Edges

Particles harvested from each of 180 duct tape edges (opposite sides of each of three segments from each of 30 rolls) were each characterized based on a sampling of 3000-5000 particles. This resulted in the *Tape Edge Particle Datasets* (with the same information listed above for each particle).

4. Removal of Filler Particles from Tape Edge Particle Datasets

Particles attributable to the adhesive filler (based on the Particle Types defined in 2 above) were removed from each Tape Edge Particle dataset, leaving the acquired tape edge particles (ATEPs).

5. Classification of Duct Tapes using Acquired VSP

The ability of ATEPs to discriminate among the 30 tape rolls was tested using one of three tape segments taken from each of the 30 rolls (the third segment, representing a roll of tape collected by police investigators to be tested as a possible source of crime scene segments). The matching ability of the ATEPs was determined using a training set (2/3 of the particles from each ATEP dataset) to train the model and using the other 1/3 of the particles to test whether these could be correctly matched to their respective source. This test was performed three ways (1) using ATEPs from only one side of the tape, (2) using only ATEPs from the other side, and (3) using ATEPs from both sides combined.

6. Associations of Tape Segments to Rolls using Acquired VSP

The ability of ATEPs to associate duct tape segments to a roll of duct tape was tested by using the other two duct tape segments (representing evidence tape segments collected at a crime scene) to see if the model trained by the third duct tape segment (above) could correctly match the segments to their respective source. As with the roll classifications, this test was performed 3 ways:

using ATEPs from only one side of the tape, (2) using only ATEPs from the other side, and (3) using ATEPs from both sides combined.

B. Results and Findings

1.Classification of Duct Tapes using Acquired VSP

High correct classification rates of 93.3% (28/30) were achieved when using acquired tape edge particles (ATEPs) from both sides of the tape. Lower rates (73.3% and 81.6%) resulted when ATEPs from only one side of the tape were used. Specimens with higher particle numbers were more likely to be classified correctly, with incorrectly classified specimens showing average particle numbers 30 to 40% less than those that were classified correctly.

The results show that ATEPs often show sufficient numbers and variety to discriminate among tape segments from different rolls.

2. Associations of Tape Segments to Rolls using Acquired VSP

Correct association rates (for tape segments to rolls) were lower than seen for the roll classification, ranging for single sides of the tape from 46.7% to 66.7% and from 70% to 98.3% when both sides of the tape were used. However, correct associations resulted uniformly (100%, 23/23) when all three results indicated one source (both sides of the tape individually, as well as their combined particle sets). When two or three of the tests indicated the same source, correct association resulted 93.3% of the time (42/45). Overall, the correct source was indicated in one or more of the tests 95% of the time (57/60).

The results show that very small particles (VSP), acquired post-manufacture and trapped in the adhesive along the edges of duct tape rolls, often show sufficient numbers and variety to correctly classify tape segments to their source roll and provide a quantitative association between segments from the same roll.

C. Limitations

1. Not all Tape Rolls and Segments have Sufficient Numbers and Variety of ATEPs for Strong Associations

Although most of the duct tape rolls in this study showed sufficient numbers and variety of ATEPs for classification and association, this will not be the case for all duct tape rolls. Rolls from a newly opened package, for example, can be expected to have little accumulation of ATEPs. This is a fundamental limitation for any kind of evidence: it may not be present under the specific circumstances of a case.

2. Not All Particles are Detected and Different Particles May Look the Same

The SEM/EDS elemental analysis protocol used in this research employs a fixed set of 18 elements. Furthermore, the quantitative analysis of elements by SEM/EDS is affected by particle dimensions and detection limits of a few percent. This method will necessarily fail to detect some types of particles and fail to differentiate particles that share the same major elemental composition.

Nonetheless, the method is a good fit for testing program hypotheses because inorganic chemical composition, as measurable by SEM/EDS, is known to characterize a broad, highly informative range of particle types, including soil minerals, building materials, household products and environmental contaminants that contribute to the VSP that are commonly found. Particles detected and characterized by SEM/EDS are a major component of VSP, and a component that has been established in prior research to allow quantitative comparisons between sources and traces.

This limitation can be addressed, to the extent required for a particular application, by modifications to the analytical protocol.

3. Some Particles will be Lost or Altered by the Harvesting Methods

The use of solvents is necessary to dissolve the duct tape adhesives during the VSP harvesting process. This will result in some particles being lost by dissolution or altered by chemical interactions. However, most inorganic materials, which are the subject of this study, will not be affected in this way.

This limitation can be addressed, as needed, by directly analyzing particles as they are seen within the ethyl cellulose film or by using alternative methods to recover particles from the films. Fiber evidence, for example, that might be affected by the solvents, can be located and removed during examination of the film under a dissecting microscope, prior to dissolving the film to recover the other ATEPs.

4. Computational Assumptions

The classification rates reported here, and strengths of correspondence on which they are based, are subject to specific assumptions made in the context of the research. Most notably these are the assumptions of a closed set of 30 possible sources and that before conducting the tests, each of the sources is equally likely. The present research shows the form, feasibility, and methods to utilize ATEPs to classify tape rolls and quantitatively associate tape segments with a candidate source. However, the meaningfulness of these measurements, outside of the specific research context of this program, will only come from the expansion of the numbers of reference sources, better understanding of within-item vacation, testing the assumptions of population representativeness, and validation using relevant operational specimens.

IV. ARTIFACTS

A. List of Products (to date)

(Presentation)

Stoney, D.A. and Stoney, P.L., "Analysis of Small Particles Adhering to the Edges of Duct Tape as a Means to Make Associations in a Way that is Independent of Manufactured Characteristics," 2022 National Institute of Justice Forensic Science Research and Development Symposium, March 1, 2022.

(Presentation)

Stoney, D.A. and Stoney, P.L., "How Particle Combination Analysis is Being Used to Address the Need for a New Approach to Trace Evidence Analysis," NIJ Advancements in the Analysis of Forensic Trace Evidence (Hosted Session), Pittcon 2021 Conference & Expo, March 11, 2021.

B. Data Sets Generated

Adhesive Filler Particle Datasets (90)
Tape Edge Particle Datasets (180)
Process Control Particle Datasets (32)

Stoney, David (2022), “EDS Data for Duct Tape Adhesives and Tape Edge Specimens”, Mendeley Data, V1, doi: 10.17632/nkmdb4n3m5.1

V. REFERENCES

[1] D.A. Stoney, C. Neumann, and P.L. Stoney, Discrimination and Classification among Common Items of Evidence Using Particle Combination Profiles, *Forensic Science Int.* **289**, 92-107 (2018).

[2] C. Neumann, Forensic Analysis and Inference of the Source of VSPs, R Package ‘VSParticles’, (2016).