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Loss and replacement of small particles on the contact surfaces of footwear during successive exposures

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ABSTRACT

On the contact surfaces of footwear loosely, moderately and strongly held particle fractions were separated and analyzed in an effort to detect different particle signals.

Three environmental exposure sites were chosen to have different, characteristic particle types (soil minerals). Shoes of two types (work boots and tennis shoes) were tested, accumulating particles by walking 250 m in each environment. Some shoes were exposed to only one environment; others were exposed to all three, in one of six different sequences.

Sampling methods were developed to separate particles from the contact surface of the shoe based on how tightly they were held to the sole. Loosely held particles were removed by walking on paper, moderately held particles were removed by electrostatic lifting, and the most tightly held particles were removed by moist swabbing.

The resulting numbers and types of particles were determined using forensic microscopy. Particle profiles from the different fractions were compared to test the ability to objectively distinguish the order of exposure to the three environments.

Without exception, the samples resulting from differential sampling are dominated by the third site in the sequential footwear exposures. No noticeable differences are seen among the differential samplings of the loosely, moderately and strongly held particles: the same overwhelming presence of the third site is seen. It is clear from these results (1) that the third (final) exposure results in the nearly complete removal of any particles from prior exposures, and (2) that under the experimental conditions loosely, moderately and strongly held particles are affected similarly, without any detectable enrichment of the earlier exposures among the more tightly held particles.

These findings have significant implications for casework, demonstrating that particles on the contact surfaces of footwear are rapidly lost and replaced.

1. Introduction

1.1. Statement of the problem

Very small particles are ubiquitous in our environment. These "VSP" are particle dusts which, as noted by Gross [1], are our "environment or surroundings in miniature," and as noted by Locard [2] "may be formed of all the debris and all kinds of bodies . . . all the substances, organic or inorganic, existing on the earth." Everywhere people walk, VSP transfer to and from their footwear. The mere presence at a crime scene requires this contact and transfer, and the particles are known to persistent for long periods of time [3,4]. Even though criminals necessarily track dusts to and from every crime scene, dust particles on a suspect's shoes are very seldom used as evidence linking the accused to the crime. There is an extraordinary, untapped potential to exploit VSP found on footwear and in footwear impressions.

At the same time, there are significant challenges to unlocking this potential. Most fundamentally, VSP on footwear evidence are invariably a mixture of materials that can originate before, during, or after any event or period of forensic interest [3,4]. Their usefulness depends on our ability to separate a reliable, relevant evidentiary "signal" from background noise (or signals from other exposures). As an additional practical challenge, the VSP mixture is composed of many different particle types, which must be collected and analyzed efficiently.

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Methods have been developed to efficiently analyze VSP using either an iterative forensic approach [5] or a particle profiling approach [6–8]. An iterative forensic approach begins with a multidisciplinary screening of particle types. This is followed by assessment of possible contributions to case resolution that could result from specialist examinations. Choices of which particles to analyze are made based on this assessment. The results of these analyses are then used to re-assess the possible contributions of additional specialist examinations of additional particle types. A particle profiling approach proceeds through the simultaneous characterization of many particles. This results in a profile representing the population of particles in a specimen. These profiles allow the application of computational methods showing the potential to measure strengths of associations between VSP specimens and to determine linkages among items of evidence based on their adhering VSP [7,8].

The application of these methods to VSP on (for example) shipping containers, clothing, and improvised explosive devices (IEDs) has consistently involved comparing VSP at different locations or different "layers" as one opens an item. The outer layer typically has VSP from the most recent exposures. The innermost layer has VSP from earlier exposures. Intermediate layers have exposures whose relative timing depends on how and when the item was handled, assembled or opened.

On footwear the problem is more complex, as there are not physically separated layers (as there are in layers of packaging, or an assembled device). However, research focused on the persistence of trace evidence generally [9–13], and on footwear specifically [4,14–16], strongly supports the hypothesis that, after transfer to an item, some particles are tightly held (and retained longer), while others are loosely held (and more rapidly lost). Morgan et al. [17] have specifically found that for sediments on footwear there is a "trend of two/three stage decay . . . , with subsequently less rapid loss . . . , followed by a period of much lower decay." Importantly, we observe that this explanation implies that *particles from* ***earlier*** *exposures will be more concentrated among the particles that are more tightly held*. From this strongly supported supposition, we hypothesized that, if we use differential sampling of footwear (which separates loosely held, moderately held, and strongly held particle fractions) we will recover *physically separated or enriched* particle fractions that originated from different exposures. This project explored the use of differential sampling of VSP from the soles of footwear as a potential method for the separation for these signals.

1.2. Background and context

1.2.1. Footwear evidence generally

Trace evidence examiners encounter footwear as part of clothing examinations. Trace evidence commonly found on footwear includes the major types of fragmentary material traces: glass, paint and fibers [18,19], as well as accumulations of soil. Trace evidence within shoe impressions is only rarely utilized as part of the comparison, although the potential to compare this form of trace evidence with footwear is well-recognized [20]. As methods in forensic geoscience have developed [3,21–25], such cases are being reported [26].

1.2.2. Soil and dust on footwear

Accumulations of soil on footwear or other items of evidence (such as digging tools and vehicles) have long been exploited for comparisons with reference samples of possible origin [27]. The long-standing focus has been on fairly large accumulations of soil that can reasonably be expected to be minimally mixed, or that are clearly layered, so as to allow physical separation of discrete samples. Only then can comparisons be reliably made using bulk properties of soil (such as color, particle size distributions and elemental composition). In cases where significant mixture has occurred, analysis of soil evidence is frequently stopped short. This is because preliminary analyses indicate disparities in the bulk properties (e.g. color) that are typically used to screen for comparable specimens. Restriction of analyses to unmixed specimens severely restricts the numbers of applicable cases.

The work of Morgan, Bull and co-workers [3,4,28–31] has addressed this limitation, setting forth a conceptual framework for forensic geoscience [3]. This framework includes specific emphasis on analytical methods that can recognize mixtures and that are applicable when mixtures are present. They describe these methods as "visual techniques" and have exploited quartz grain surface analysis for this purpose. Quartz occurs very widely in sediments and the physical appearance of quartz grains depends on fundamental geological mechanisms relating to their origin and transportation [32]. When two different sources of soil are mixed, expert quartz grain surface analysis can, with reasonable probability, detect this mixture. Comparisons of the different types of quartz grain surfaces can be made even though the sources are mixed.

This approach need not be limited to a single mineral type, or specifically to mineral particles, and it need not depend on the presence of one particle type (e.g. quartz) in each of the mixed sources [33]. What is essential is that recognizable varieties of minerals (or other particles) be exploited efficiently. Visual microscopical techniques do this: different soil or dust samples will have different suites of VSP. The presence and variety of VSP is a character that is recognizable within a mixture and meets the fundamental requirements for "visual techniques" [3,4].

1.2.3. Studies of particle transfer and persistence on footwear

Morgan et al.'s approach to recognition and analysis of mixed soil samples has continued with applied research directed at understanding mechanisms of transfer, persistence and mixing of particles deposited on footwear [4,14]. Experiments have been conducted using test substances (Plasticine) as well as using specific particle types (pollen or quartz grains). Specific case-related research has also been conducted [30]. These studies have demonstrated that (1) particles persist for a long period of time on footwear, (2) that mixing of particles from successive exposures routinely occurs on the soles of footwear, and (3) that following exposure, some particles are loosely held (and more rapidly lost), while others are tightly held (and retained longer).

1.2.4. Alternative sampling methods as opposed to differential sampling

Staged, alternative sampling methods are often employed in trace evidence analysis [34–37]. One purpose is to employ an initial method (such as picking individual fibers or paint chips) to collect loosely held traces as they are recognized. These traces might otherwise be lost or redistributed as the examination proceeds. Another purpose is to preserve and document the location from which trace evidence was recovered (as in the regional taping of clothing in the recovery of fibers). Again, different methods may be used for alternative particle types (such as taping for fibers, followed by vacuuming to recover fine particles, or washing to recover pollen). However, there has not been a protocol for *differential sampling* and recovery of trace evidence with the express intention to fractionate loosely and tightly held particles, so that these populations can be compared and contrasted.

2. Materials and methods

This project was designed to test the separation of particle signals on the contact surfaces of footwear by applying a series of