Statistical Aspects of Likelihood Ratio (LR) Calculation in Gunshot Residue (GSR) Analysis

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It is widely accepted that evaluation of forensic findings should be based on the assignment of likelihood ratios (LRs) [1]. The LR compares the probability of the findings under the assumption that the prosecutor's proposition is true with the corresponding probability under the assumption that the defense proposition is true. The LR, thus, expresses how many times more likely it would be for such an evidence to originate from one model (the alternative model) than from the other (the null model). Such utilization of LRs allows experts to use probabilities for deriving a measure of evidential value as recommended by the ENFSI report mentioned above [1]. Additionally, the measurement of the evidence uncertainty through rigorously conducted studies has been recently identified, for instance, by the National Research Council, as a basic need of forensic science [2].

When a firearm is discharged, a variety of materials are emitted through the muzzle and from other apertures in the weapon. These include primer discharge residues, gunpowder (propellant) residues and metal particles from the bullet and the cartridge case. These substances, known as gunshot residues (GSRs), may adhere to the shooter, to persons or objects in the near vicinity of the weapon and to the target. For the purpose of the present discussion, the term GSR is limited to primer discharge residue particles. The detection and identification of such particles can be of great significance in the investigation and prosecution of gun-related offences. Scanning electron microscopy, combined with X-ray spectrometry (SEM/EDX), is the state-of-the-art method for analyzing GSR samples.

This presentation focuses on statistical aspects in calculating LRs, and demonstrates the importance of using the data at hand to choose the statistical model and to account for sampling errors when evaluating the scientific value of the evidence. These statistical aspects are discussed for GSRs, which are used as evidence for involvement in shooting incidents. In the case of GSR evidence, the LR compares the probability of observing the GSR evidence given that the suspect was involved in a shooting to the probability of observing the GSR evidence given that the suspect was not. LR values higher than 1 support the prosecutor's proposition that the suspect was involved in the shooting, while LR values smaller than 1 support the defense proposition. In general, the larger the LR, the stronger the evidence against the suspect.

The current presentation uses data from a controlled experiment conducted by Cardinetti *et al* [3] on GSR particles, in order to demonstrate the statistical analysis required for estimating LRs and constructing confidence intervals for them. As the data set is small (59 shooters in 2 groups – A and B, and 81 non-shooters), we consider here only relatively simple regression models. More complicated methods may be applied to larger data sets and for other types of forensic evidence, but the principles discussed here should always guide the analysis. We analyze two competing statistical models for the number of GSR particles, based on the Poisson and the Negative Binomial (NB) distributions, discuss model building and model checking and describe how estimation of the models can be used to construct

confidence intervals for LRs.

It is shown that the Poisson model, considered by Cardinetti *et al* [3], is inappropriate and that a Negative Binomial model (Fig. 1) fits the data much better. The statistical error arising from the fact that models are estimated based on small sampled data is discussed, as well as the importance of accounting for this error. We conclude that only with a large database can statistical models be estimated accurately and LR's be treated as valid scientific measures.

To conclude, in order to meet the rigorous standards of the National Research Council noted at the beginning of this paper [2], case files should include goodness of fit results and court reports should take into account the confidence intervals describing the uncertainty in the estimated LR (Fig. 2), for example - by using the lower limit of the confidence interval. These confidence intervals may be wide when based on small data sets, reflecting a high degree of uncertainty. Nonetheless, application of the LR method in practice requires additional research, in which the performance and robustness of the method is investigated.

References:

[1] The ENFSI (European Network of forensic Science Institutes) Guideline for evaluative reporting in forensic science, version 3.0, part of the monopoly 2010 research programme Strengthening the Evaluation of Forensic Results across Europe (STEOFRAE), 2015, available at www.enfsi.eu.
[2] National Research Council, "Strengthening Forensic Science in the United States: a Path Forward", 2009, available at www.nap.edu.
[3] B Cardinetti, C Ciampini, S Abate, C Marchetti, F Ferrari, D DiTullio, C Donofrio, G Orlando, L Gravina, L Torresi, and G Saporita, Scanning **28** (2006), p. 142-147.
[4] This presentation is based on Kaplan-Damary, N, Mandel, M, Levin, N and Izraeli, E, "Calculation of Likelihood Ratios for Gunshot Residue Evidence - Statistical Aspects", Law, Probability and Risk, accepted for publication, January 2016.
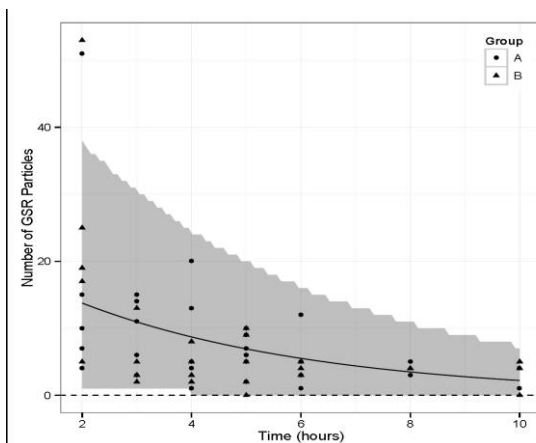
Figure 1. Data from Cardinetti *et al* [3]. The circles represent data from Group A and the triangles represent Group B. The solid line is the estimated mean using NB regression, and the grey area represents the predictive intervals of 95% confidence level.
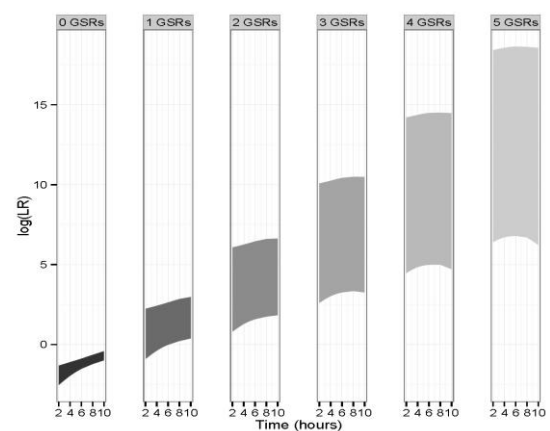

Figure 2. Confidence intervals simulated for the LR's at different times and for different numbers of GSRs (log scale). Each column represents the confidence interval for finding a given number of GSR partials on a suspect.