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Targeting relevant sampling areas for human biological traces: Where to sample displaced bodies for offender DNA?

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ABSTRACT

Sampling strategy is one of the deciding factors in DNA typing success rates. Small amounts of bodily fluid traces and (skin) contact traces are currently not visualized in standard forensic practice. Trace recovery is usually based on the information available in a particular case and on the experience and 'forensic common sense' applied by the trace recovery expert. Interactions between an offender and a victim may have characteristic features, resulting in specific trace patterns. Understanding these interactions, and their resulting trace patterns, might improve crime related trace recovery as well as DNA typing success rates.

In this study, we examined the interactions between offender and victim when a body has been relocated from one position/location to another. The contact between the hands of the offender and the body of the victim was visualized using a fluorescent dye in a lotion that was applied to the hands of the individual undertaking the relocation. The contact locations were scored and patterns were analyzed based on both victim and offender characteristics (height, weight, age, gender). The resulting patterns were compared to current trace recovery practices in the Netherlands. The results of this large-scale study facilitate evidence-based sampling supporting both investigative and evaluative forensic examinations.

1. Introduction

The increased sensitivity of the newer generations of forensic STR DNA typing systems has led to the possibility of sampling of surfaces that may contain minute amounts of human DNA. A large proportion of these traces are of an unknown biological source and are often not visible. The means by which these minute biological traces have been transferred to the sampled surface area are generally not known. The efficiency of recovery of latent cellular material therefore depends on the sampling strategy applied [1]. This strategy is composed of two elements: (1) accurately targeting the sampling location, and (2) the sampling method used. The first element depends on our ability to find these traces, either by visualization methods or based on specific information received in the case (e.g. witness statement or CCTV imagery). The second element is determined by the method of collection that is applied. The latter has been the subject of studies addressing the recovery efficiency of different types of swabs [2], as well as other collection methods such as tape lifting [3–8] or vacuuming [9,10]. Based on these (and other) studies choices can be made for the most appropriate sampling method.

Targeting the relevant sampling location is normally based on any of (or a combination of) three approaches: (1) Retrospective analysis of success rates in other cases, (2) visualizing trace deposits, and (3) information (in the broadest sense) on the activities that may have taken place.

1.1. Retrospective analysis of success rates

Retrospective analysis of success rates has mainly been directed at determining the success rates of DNA profiling on a range of items [11,12], or of different sampling strategies for similar items [13]. These studies may facilitate prioritization of items to be examined. The data may also be used to identify the relevant locations to be sampled. However, these studies address items for which the method of handling is elementary (holding a gun or knife for instance), making the sampling strategy relatively straightforward. The current studies on success

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Fig. 1. Experiment setup at 'A campingflight to Lowlands Paradise' 2015 music and performing arts festival. 1A - Victim starting position at a ninety-degree angle to the direction of movement. 1B - Black tent with its entry positioned at the end of the experiment 'runway'. This tent was used for photography under UV light. 1C - Offender moving a victim, with two forensic scientists observing. 1D - Volunteer under UV light (photographed using a 450 nm longpass filter), showing locations of contact with fluorescent dye (blue-green).

rates are limited to items sampled at the forensic laboratory. This is possibly due to the lack of documentation on sampling methodology and the sampling strategy at crime scenes.

1.2. Visualizing trace deposits

The visualization of traces could be a way forward in directing the sampling strategy, when the activity that led to the deposition of traces is unknown. Although various methods are in use to visualize contact stains, e.g. either forensic light sources or detection techniques to visualize fingermarks and cellular material [14–16], these methods yield varying results and are not (yet) common practice. Moreover, these techniques do not distinguish between contacts by the offender and other legitimate contacts.

1.3. Information on previous activities

The selection of the sampling location is usually based on the information available in a particular case and on the expertise and experience of the forensic practitioner. Experience in each type of case will be limited to the few cases that are submitted to the laboratory and/or to the cases that the Scene of Crime Officer (SOCO) encounters in practice. However, the lack of feedback between SOCO and forensic laboratory may limit an evaluation of best practice methods and success rates. Hence, the sampling method selected may be directed based on a limited set of information that is also not uniformly distributed across the forensic practitioners. The targeting of sampling locations of 'invisible' deposits of human cell material might be optimized (and more uniform) if it is 'data driven', i.e. based on scientific experiments.

Optimizing the targeting of sampling locations will result in gains in both investigative and evaluative forensic examinations. The success rate of DNA profiling for investigative purposes will increase, simply because better traces lead to more and better investigative leads. For the question "how did the DNA get there?" trace patterns are interpreted in the context of propositions describing certain activities such as dragging the victim. The three elements for optimizing the sampling strategy will assist in identifying locations where offender DNA could be expected given a certain activity, but also where offender DNA may NOT be expected. These latter locations may be of interest as 'control locations' if DNA from the suspect is expected in certain alternative propositions (e.g. a prior interaction between accused and victim).

This study is aimed at identifying the preferred locations of contact when a body is moved by single or multiple offenders. We selected the activity of relocating a body as a proxy for activities that may lead to a complex pattern of traces. This activity was selected as it is regularly encountered at homicide crime scenes (personal communication with Dutch Police). To facilitate reading we will use the word offender to indicate the person who relocated the body. We emphasize that, in a real case, it is important to make a distinction between offender and relocator, as they may be different persons. The same holds for the word victim which we use for the body.

In this study, we will address the following three questions:

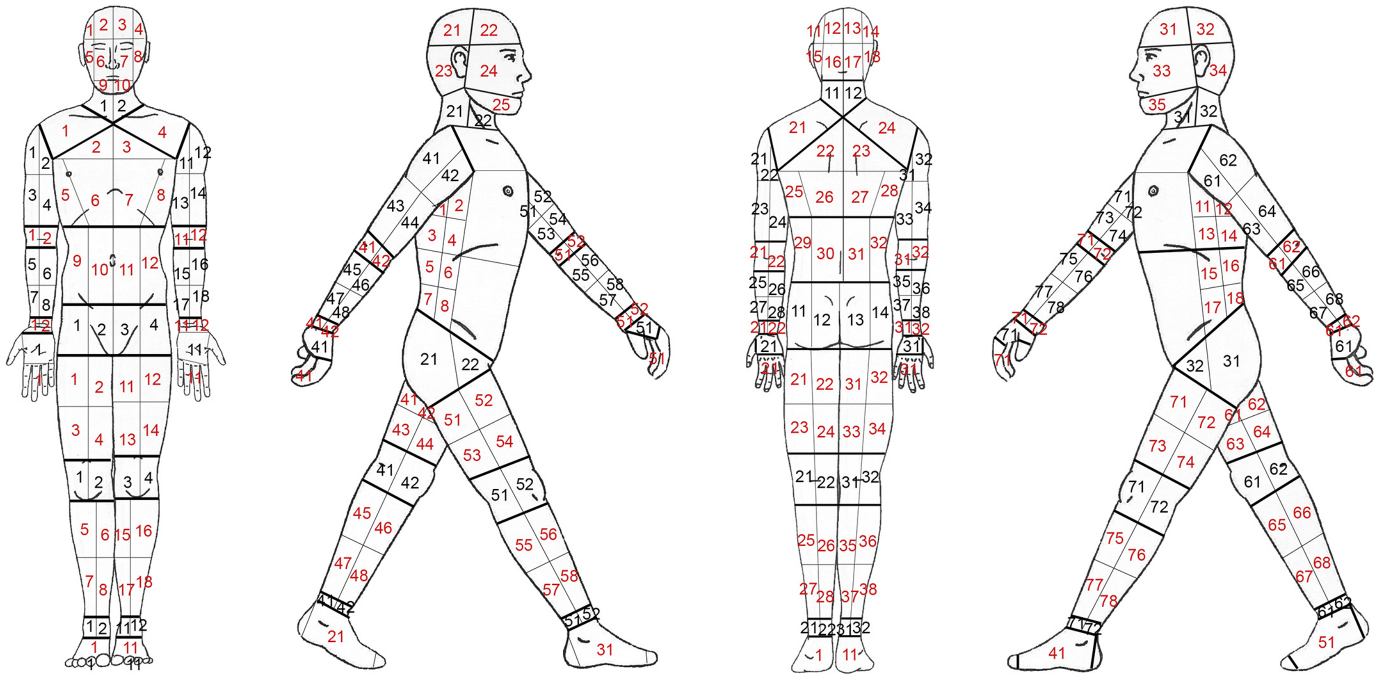

Fig. 2. Grid used for scoring presence/absence of fluorescent dye. Bold lines indicate borders of main body locations, hairlines indicate sublocations. The depicted numbers are the labels of the specific sublocations in relation to the main body location. Drawing of human anatomy adapted from original (Pieter van Driessche/NFI).

1. Which locations do offenders touch (have contact with) when relocating the body of a victim?
   Firstly, we identify locations on the body that are touched by an offender. These locations can be targeted in order to increase the potential for retrieving DNA from the offender after the incident. Secondly, we identify those locations that are not touched by the offender within this specific activity. Samples from these locations may serve the assessment of the DNA typing results under competing propositions at activity level.
2. Can patterns be identified that provide information on the characteristics of the offender?
   Using recorded background information on both victim and offender, can the applied methodology be used to obtain investigative leads from the patterns of traces found on the body of the victim?
3. How do the findings relate to current trace recovery practice in the Netherlands?

2. Material and methods

This project was facilitated through the 2015 Lowlands Science program. Lowlands Science is a citizen science project initiated by the annual ‘A campingflight to Lowlands paradise’ music and performing arts festival in the Netherlands. This collaboration under the name ‘Crime Lab’ allowed us to access a large number of volunteers from the general public, willing to participate in the experiments.

2.1. Experimental design

Between two or three volunteers participated in a simulated relocation. One participant was asked to be the victim, the other(s) acted as the offender(s). The objective was to move the body of the victim along a ‘runway’ over a distance of approximately 10 m (see Fig. 1).

The experiment participants were treated as anonymous, however some personal information was recorded. For the victim: age, height, weight and gender were recorded. For the offenders: age, height, weight and gender were recorded, as well as any experience or training in first aid and whether they performed physical exercise more than once a week.

The participants were given the following instructions: The victim was to act incapacitated, and to stay limp and unresponsive. The only consideration was to shout ‘stop’ if there was any severe inconvenience or pain. The victim was then asked to lay down either on their back or front, perpendicular to the transport ‘runway’ (see Fig. 1).

The offender was instructed to move the body as quickly as possible, but within 20 s. The time limit was applied at the start of the experiment in order to introduce a stress factor in the study. The decision on the manner of transport was left to the offender. He/she was also instructed not to touch the victim after displacement or after 20 s.

Participants were able to observe the actions of prior participants while waiting in line. It was observed that the participants were discussing their methodology prior to the start of the experiment. However, the observations made during the experiments have shown that the unexpected stress factor (time constraint) interfered with plans made prior to the activity. Also, based on observations during the experiments there did not appear to be a learning effect through observation. This has however not been tested.

Normally, forensic DNA typing would be performed on the samples taken. However, the large number of (unknown) participants with a lot of social interactions prior to the experiment, limited the use of DNA typing results to identify the relevant locations. Furthermore, it would be too costly to type and analyze over 1000 samples. Therefore, we used a lotion on the hands of the participant to identify the locations of contact. We assume that DNA traces from the offender are more likely to be found at locations that were touched than at any other random location. The visualization of the points of contact was achieved through the use of a fluorescent hand lotion (UV Glow lotion, Deb Skincare Products, Nexus Cleaning Supplies, United Kingdom). This lotion contains fluorescent pigments that emit light in the green region when excited with UV-A radiation. Common blacklights (emitting mainly UV-A radiation) were used as excitation source. The points of contact were photographed with a Nikon D4 camera (aperture of f/5.6, shutter speed of 1/60 s, high ISO speed) equipped with a yellow (450 nm) longpass filter (Black & White Filter 021, Schneider Optics, Germany).

The photographs were analyzed by a single analyst with no specific minimum training requirements. The locations indicated by the presence of hand lotion were manually scored using predetermined set of rules and a uniform grid based on body anatomy (see Fig. 2). For this the height of the victims was normalized visually. The reliability and reproducibility of the photograph interpretation were checked by duplicating the analysis by the same analyst for a random selection of 10% of victims. When analyzing the detection of lotion on the various locations on the body of the victim, we assumed that DNA traces from the offender are more likely to be found at locations where there was an indication of touching, rather than at any other random location.

The age distribution and gender ratio of the "offenders" was compared to the population structure of people convicted for murder or manslaughter in the Netherlands [17,18].

The current practice in targeting sampling areas on the bodies of victims suspected of having been relocated was obtained from questionnaires sent to Police Units in the Netherlands (available as supplementary material). Team leaders of 11 Police Units in the Netherlands were asked to distribute the questionnaires to their teams of SOCOs. The current practice was compared to the results from the experiments.

2.2. Statistical analysis

Fig. 2 shows all locations on the human body as they were identified and scored for the presence or absence of lotion. Sublocations on body parts were combined for some of the statistical analyses. These combined analyses refer to the body parts as 'main locations' (e.g. the main location 'Arms' refers to all locations on both the left and right arm). The main locations are identified in Fig. 2 by the bold lines.

As described above, for each victim i (i = 1…, 310), the variable "lotion recovered" with 0/1 values representing "no" and "yes" was recorded for each sublocation. From this, the variable $Y_{i,j}$ was created for each victim i, with 0/1 values representing "no" and "yes" for each main location j (j = 1,..0.18), with "yes" if lotion was recovered at one or more sublocations within the main location, and "no" otherwise. Furthermore, the variable "single offender" was recorded with 0/1 values representing "no (two offenders)" and "yes (one offender)".

Using SPSS® version 23 [19] a repeated measures logistic regression model was fitted with Y as response variable and main location as the within-subject effect (repeated measures), and with the factors: main location, single offender, and their interaction.

This model can be written mathematically as a generalized linear model:

- $Y_{i,j} \sim \text{Bin}(1, p_{i,j})$,
- $g(p_{i,j})$ = intercept + main location$_j$ + single offender + (main location * single offender)$_{i,j}$,
- the link function g is the logit $g(x) = \ln(x/(1\text{-}x))$.

The Wald chi-square statistic was used to assess significance, using a significance level of 5% (level used throughout the paper) [20].

The effect of the number of offenders on the lotion detection was further investigated separately for each main location with a (two-sided) Fisher exact test. Also, the association between the four different combinations of detection (or not) of lotion at arms or legs (including armpits, ankles, etc.), and the number of offenders was tested with a (two-sided) Fisher exact test [20].

The various characteristics of the victim (age, weight, height, gender) and offender (age, weight, gender, physical exercise, first aid training) were recorded. Their effect on whether or not lotion was recovered at the main locations was modeled with a repeated measure logistic regression model similar to the one above which included main location and all these characteristics as (co)factors. This was done only for those 225 victims with a single offender, as otherwise the effect of e.g. first aid training if only one of two offenders had this training is difficult to interpret. Wald chi-square was again used to assess significance of model parameters [20].

To investigate the possible interaction effects with the factor main location, e.g. main location*first aid experience, we would like to include them in the model as well. However, since this would result in 18 additional parameters to be estimated for each factor this was practically not feasible. We therefore studied these interaction effects with a series of models, including only location and one interaction effect. Again, Wald chi-square was used to assess significance [20].

Significance tests were used in order to identify potentially interesting effects. We emphasize that the forensic interpretation and evaluation of observations for casework requires a likelihood ratio analysis. This kind of analysis is touched upon in the discussion.

3. Results

A total of 705 individuals participated in the study, in a total of 310 experiments. 225 experiments were performed with a single offender, 85 experiments were performed with two offenders.

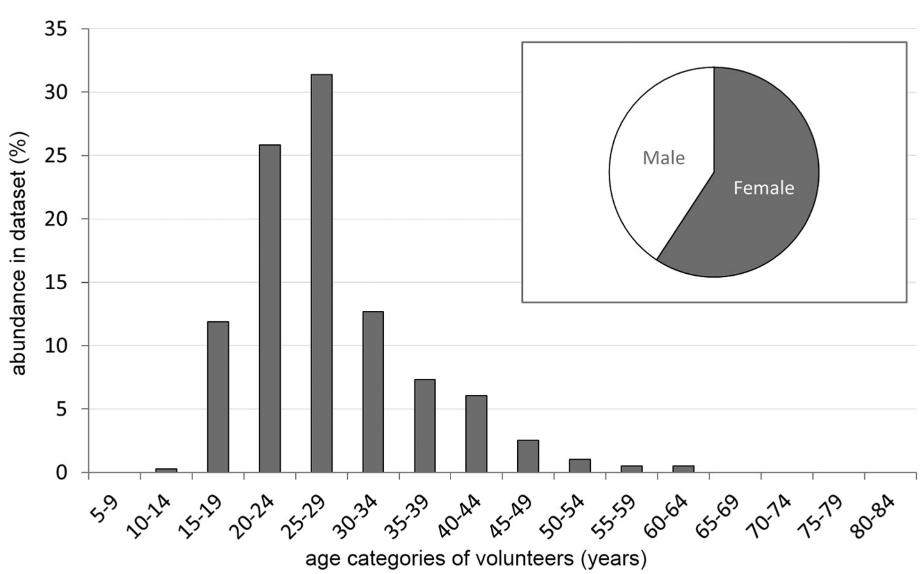

Fig. 3. Age distribution (bar chart) and gender distribution (pie chart) of volunteer offenders (N = 395).

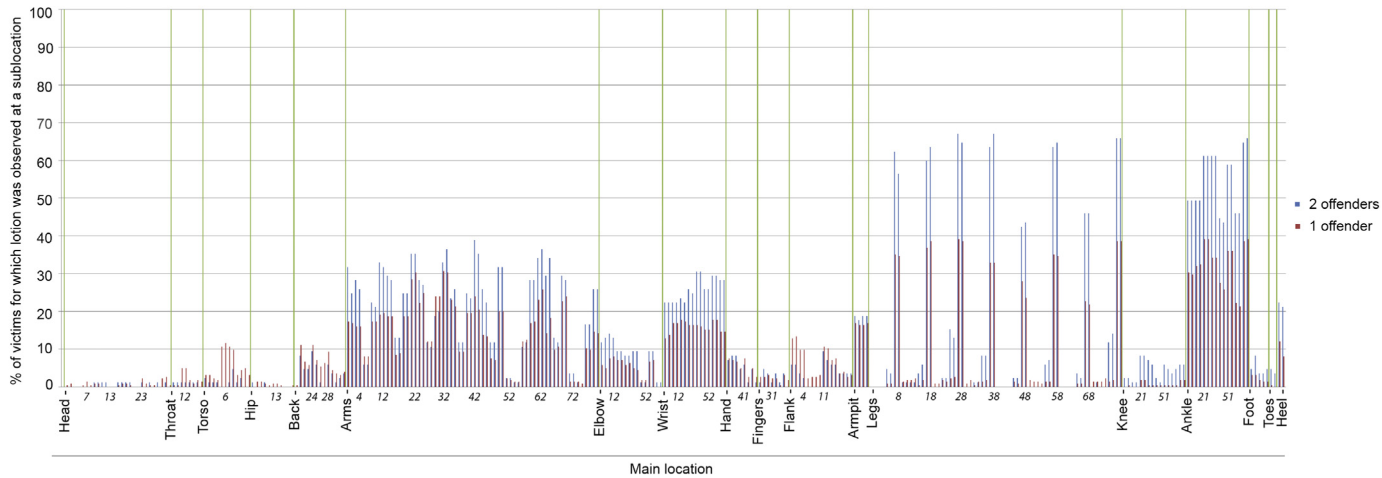

Fig. 4. Contact pattern for two groups of victims: 225 victims with one offender (red bars) and 85 victims with two offenders (blue bars). Bars represent the percentage of victims in each group for which lotion was observed at a certain sublocation (incidentally shown by an italic number in correspondence with the labels as depicted in figure 2). Sublocation labels are grouped into main locations, separated by green lines. Main location labels are positioned at the left of the group, e.g., first group of sublocations belong to the head.

3.1. Participant demography

Fig. 3 shows the age distribution and gender distribution of participating volunteers as 'offenders' (n = 395).

The age distribution correlates with data on convicted offenders of homicides in The Netherlands [17,18]. Both groups have the highest percentage of offenders in the age categories between 20 and 30 years of age. We, therefore, consider our sample from the Dutch population representative in this respect for the true offender population. However, where the proportion of male convicted offenders is 90% in the true offender population, females dominate with 59% in the population of volunteers.

3.2. Locations of contact and identified patterns

Fig. 4 and Fig. 6 show the percentage of victims for which lotion was recovered on the various sublocations on the body. The percentage is calculated separately for victims displaced by one or two offenders. Fig. 4 shows that lotion is observed on some body parts much more often than on other body parts. It also shows, not surprisingly, that lotion is observed more often when there are two offenders than when there is one offender for almost all sublocations. We see for example that lotion is observed on the lower parts of the legs in about 60% of victims where two offenders were involved, and in about 35% of victims where only one offender was involved.

To investigate the effect of the main location, number of offenders, and their interaction on the detection of lotion at a certain main location, a repeated measure logistic regression model was fitted using these as factors (see Section 2.2). This resulted in a significant effect to all factors (Wald chi-square test, p-values < .05). Hence, this model showed that at some locations the probability of recovering lotion was significantly higher than at others; and that this probability is significantly larger when there are two offenders than when there is only one; and that the pattern of contact for two offenders is significantly different from a single offender. In particular (Fisher's exact test, two-sided p-value < .05), at the main locations Arms, Legs, Knees, Ankles, Toes and Heels lotion is observed significantly more often when there are two offenders than when there is a single offender. Interestingly, at the main location Torso the opposite is observed: lotion is observed significantly more often with a single offender (albeit low; about 10%).

These results are in concurrence with the common understanding that two offenders will touch at more places than one offender (see Fig. 4). The study shows that this is primarily at the end of the arms (wrists) and legs (ankles) where offenders are expected to grab their victim in order to drag or carry (in case of two offenders) him/her. The results also showed that for all but one victim lotion was observed at the main locations Arms (including armpits, elbow, wrists, hands and fingers) and/or Legs (including knees, ankles, heels, feet and toes). In experiments with two offenders the lotion was transferred in descending order of frequency to both main locations Arms and Legs, to Legs only, or to Arms only. A single offender transferred the lotion in the opposite order: to Arms only, to Legs only, or to both Arms and Legs. These contact patterns differed significantly between one and two offenders (Fisher's exact test, two-sided $p < .05$), see Fig. 5.

There are several locations on the body that were not touched at all by single offenders: around the hip, the upper legs, inner elbow, the front of the knee and the top of the head (see Fig. 6). These locations may be of interest for control samples of background DNA on clothing/skin. It is evidently important to consider the different exposure of body parts to the environment and (social) interaction. There may be substantial differences in the contact with the front versus back of the body, of the upper body parts compared to the lower body parts. The most touched and least touched locations are shown in Fig. 6.

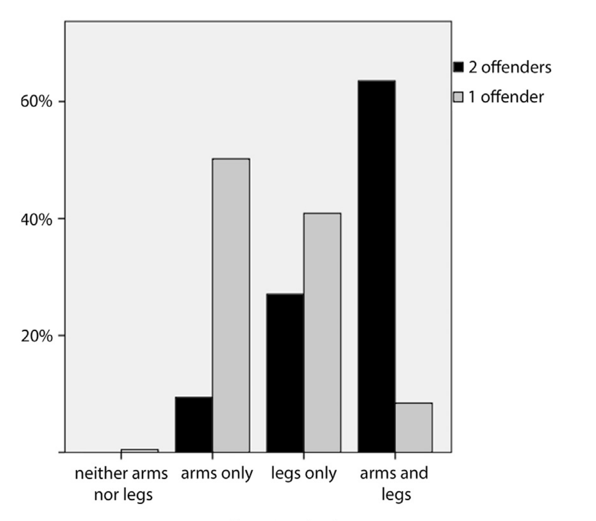

Fig. 5. Percentage of volunteer sets that touched neither main locations arms or legs, arms only, legs only, or both arms and legs for one or two offenders.

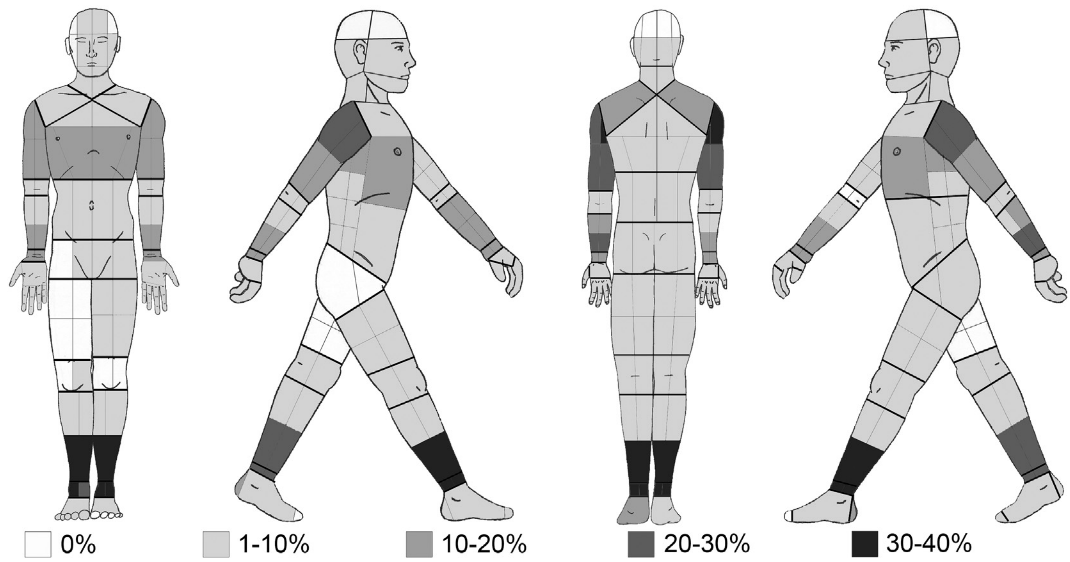

Fig. 6. Most and least contacted locations on the victims upon relocation by a single offender. Drawing adapted from the original (Pieter van Driessche/NFI).

3.3. Single offender: patterns given victim and offender characteristics

An interesting question is what effect the various characteristics of the victim (age, weight, gender) and offender (age, weight, gender, physical exercise, first aid training) have on lotion detection at the main locations. A repeated measure logistic regression model was used to model the probability of recovering lotion as a function of the main location and all victim and offender characteristics (see Section 2.2). Only the main location, gender of offender and victim weight had a significant effect on the probability of lotion detection (Wald chi-square, p-value < .05). Although statistically significant, the effect of the gender of the offender on pattern was practically negligible. Averaged over all locations, lotion was recovered for 20% of locations with female offenders versus 18% of locations for male offenders. Fig. 7 shows the effect of a substantial difference in weight (here: 15 kg) between offender and victim on the contact pattern.

Fig. 7 suggests an interaction effect of weight difference and main location: relatively heavy victims have a different contact pattern than the other victims. To investigate this and other possible interaction effects, we studied a series of models (see Section 2.2). Of the victim and offender characteristics, only first aid training, offender weight, victim weight and height showed significant interaction effect with location. That is, only those characteristics significantly affected the contact pattern.

Offender weight, victim weight and height are all associated with the difference in weight between offender and victim. A model that included location and the interaction of location with weight difference class (as in Fig. 7) confirmed the significant effects of both: relatively heavy victims have a higher detection probability at the main locations: Throat, Legs, Ankles, and Heel and a smaller probability at Arms, Armpits and Back compared to the relatively light victims (Wald chi-square test, p-value < .05). This suggests that offenders tend to grab

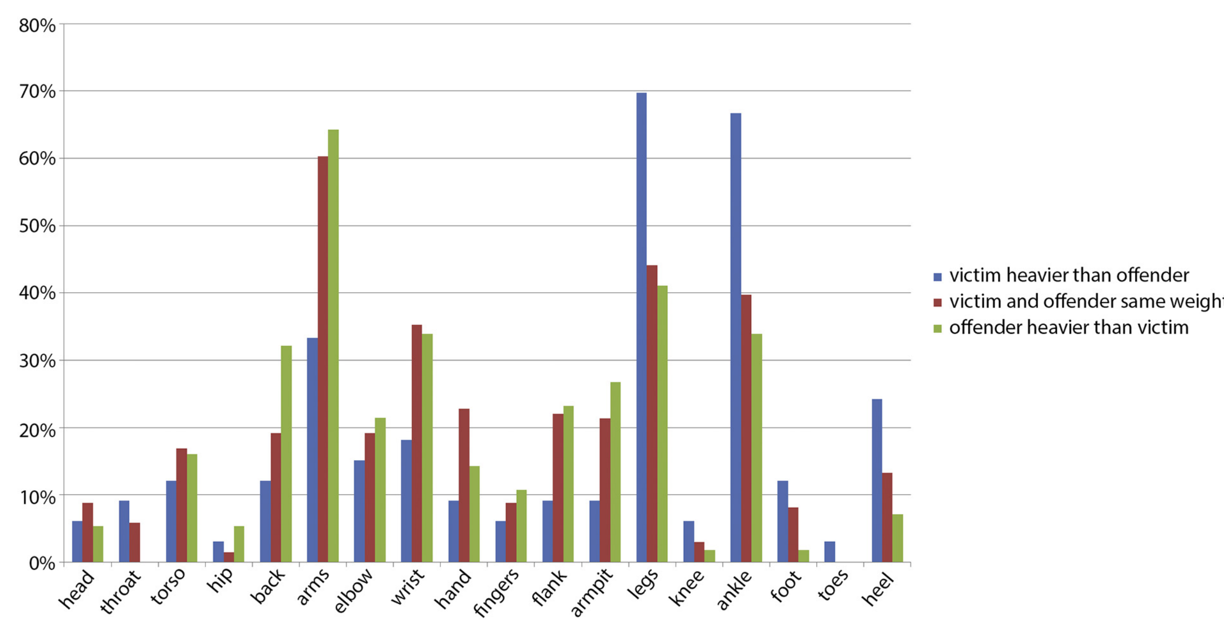

Fig. 7. Contact pattern for three groups of victims and a single offender: 33 relatively heavy victims who were at least 15kg heavier than the offender (blue); 56 relatively light victims who were at least 15kg lighter than the offender (green); 136 comparable weight victims where the weight difference with the offender was within 15kg (red). Bars represent percentage of victims within each group for which lotion was recovered at a certain location. The difference in weight (offender - victim) is abbreviated as w.

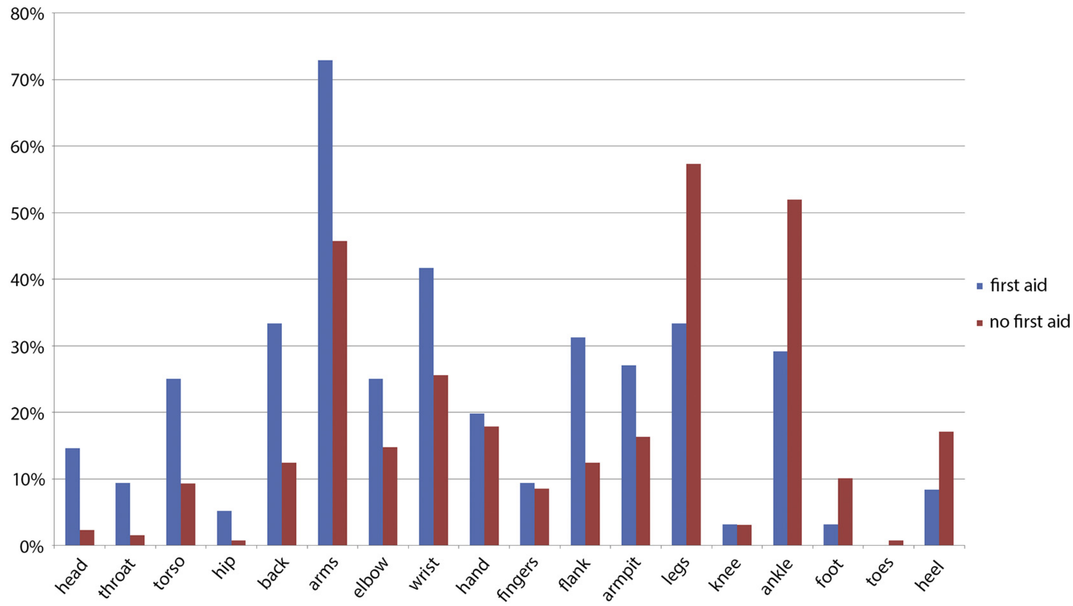

Fig. 8. Contact pattern for two groups of victims and a single offender: 96 victims where the offender was experienced in first aid (blue); 129 victims where the offender was not experienced in first aid (red). Bars represent percentage of victims within each group for which lotion was recovered at a certain location.

relatively heavy victims by the legs rather than by the arms.

Fig. 8 illustrates the effect of first aid training.

For offenders with first aid training, more lotion was recovered at the main locations: Arms, Throat, Head, Armpit, Wrist, Torso, Back and Flank, and less lotion at the Legs and Ankles. This difference in contact pattern may be explained by the fact that training in first aid includes a way to relocate victims by using the Rautek grip resulting in rubbing contact at arms, throat, head, armpit, wrist, torso, back and flank. The application of the Rautek grip by perpetrators trained in first aid was observed frequently by the scientists during the experiments.

3.4. Questionnaire results

Team leaders of all 11 National Police units in the Netherlands were asked to forward the questionnaire to SOCOs in their teams. 21 SOCOs from 6 Police units responded to the questionnaire. Their experience at crime scenes varied from 4 to 30 years (average 12.8 years). All SOCOs have experience with sampling bodies of deceased individuals at the crime scene. This varies from 0.5 to 20 bodies per year (average 3.7). The SOCOs indicated that in 7% to 67% of those cases there was an indication that the body was displaced/moved (average 11%).

The SOCOs provided several factors that may indicate relocation of the body:

- Disturbed pattern of traces (particularly blood).
- Disturbed clothing (including tears/markings).
- Position of the body (including non-matching postmortem lividity).
- Location of the body (‘Dumped’, buried or packaged/‘bagged’).
- Dragging marks on the scene or ‘staged crime scene’.

Regarding locations that are sampled on the body the SOCOs indicated that there are locations that are (nearly) always sampled, regardless of the conditions of the case. These are the nails (cuticles and under nail) and hands. If the cause of death is not apparent, the throat and neck are also sampled.

The majority of respondents indicated that the additional sampling locations differ for each case. They will reason - based on ‘common sense’ - how they would displace the body themselves. Based on their reconstruction of events they will sample the relevant locations. Three SOCOs specified that if there is an indication for displacement of the body, they would generally sample wrists and ankles (either skin or clothing if present). Armpits and knees were two other locations that were specified.

4. Discussion

The experiments focused on a specific activity (e.g. moving a body). Depending on case circumstances it may be reasonable to expect that the offender has interacted with the victim prior to moving the body (i.e. a struggle or the act that led to the death of the victim as in strangulation or stabbing). A true crime generally is a complex series of interactions, not a static situation. These prior interactions may have led to the deposition of DNA from the offender or removal of background DNA from the body or clothing of the victim. These prior interactions will result in a trace pattern themselves, which may influence or obscure the transfer and recovery of DNA of the offender through the act of relocating the body. Furthermore, it could be that actual relocation deviates from the simulation, because harmful contact was avoided during the experiments. It is therefore crucial to assess the findings of a forensic biological examination in a formal probabilistic framework at activity level to address questions on the timing and method that led to the deposition and recovery of the biological traces [22].

4.1. Transfer and persistence of DNA

We wish to stress that the transfer of the hand lotion (or the intensity of the fluorescence) has no bearing on the probabilities of transfer, persistence and recovery of DNA (e.g. a probability ‘z’ of observing lotion at a certain location does not necessarily equal a probability ‘z’ of recovering DNA from the offender at that location). These probabilities would strongly depend on sampling efficiency and DNA analysis and interpretation methods that are applied to a sample. We refer the reader to van den Berge et al. [23] for information on DNA recovery under a dragging scenario.

4.2. Investigative leads

The trace patterns that were retrieved from the bodies of the victims in this study could provide investigative leads. We address the reader to paragraph 3.3 for examples of such investigative information. The experiments that have been undertaken only explored the potential of this experimental methodology to provide investigative leads. Dedicated experiments are required to obtain more substantiated investigative information and to assess their evidential strength. Particularly other scenarios covering types of interaction other than body displacement should be included to assess the probative value of the findings.

4.3. Control sample location

A particularly useful addition of this study is the identification of 'control sample' locations given this particular scenario of body displacement. Control samples taken at these locations may inform alternative scenarios, depending on alleged prior interactions between victim and offender. At present these types of control samples are not regularly taken or submitted for DNA analysis. The last decade we have seen a shift in discussion in court from source level issues (whose DNA is it?) to activity level issues (how did his DNA get there?). This places an increasing pressure on forensic scientists to evaluate their findings given activity level propositions [24]. To be able to assess the weight of the findings given alternative propositions, the distribution of traces may be a crucial factor. Rather than resorting to generalized information on levels of background DNA, control samples from the actual victim should preferably be used to assess this factor. It is therefore important to consider potential alternative scenarios at the scene of crime and collect 'control' samples accordingly.

Note that such control samples are only of value when precautions are in place to prevent any relocation or loss of DNA during recovery, packaging, transportation, analysis and storage [25]. In addition, more research should be undertaken to study the prevalence of DNA on the victim and his clothing.

5. Conclusions

5.1. Which locations do offenders touch (have contact with) when relocating the body of a victim?

Based on our observations and analyses we suggest that the optimal sampling strategy to recover DNA from the offender of a relocation should include samples taken from the ankles, wrists and upper arm, particularly the area around the back of the armpit (see Fig. 6).

Substantial amounts of DNA of the victim may be present at these suggested sampling locations also. When large areas of the body or clothing are sampled, this may result in large amounts of victim DNA being collected. These large amounts of DNA might mask the smaller amounts of DNA of the offender that may be present at those locations [21]. Especially at locations where DNA from the victim is assumed to be present in relatively large amounts, it is advisable to restrict sampling as much as possible to those areas that are likely to have been contacted by the offender. This strategy is likely to yield higher success rates than simply sampling large areas.

5.2. Can patterns be identified that provide information on the characteristics of the offender?

As shown in paragraph 3.3, the methodology that we used has the potential to generate investigative information for intelligence purposes.

5.3. How do the findings relate to current trace recovery practice in the Netherlands?

Based on the information provided by the SOCOs (and assuming that their responses can be considered representative for all SOCOs in the Netherlands) we can conclude that the current casework practice in the Netherlands is adequate for recovering traces from offenders after displacement of a body. However, with the detailed information on contact locations provided by this study, the targeting of sampling locations may be further optimized.

Both SOCOs in casework and forensic scientists performing studies into DNA transfer and recovery in body relocation scenarios, may benefit from targeting locations identified in this study.

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