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PAPER

CRIMINALISTICS

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Improving the Point of Origin Determination in Bloodstain Pattern Analysis

ABSTRACT: In bloodstain pattern analysis, it is important to know the point of origin (PO) of an impact pattern. This point can be estimated by means of the stringing method, the tangent method, or by commercially available computer programs. In this study, the accuracy of two computer programs was investigated under different conditions. Impact patterns were created by means of a modified mouse trap, and subsequently the PO was calculated. By examining the characteristics of single bloodstains, the influence on the deviation could be determined. To improve the estimation of the PO, it is important to select bloodstains that lie close to the presumable location of the blood source, that are large (width >1.5 mm) and that show an elliptical form. If possible, bloodstains from different walls should be taken into account. Our recommendations may improve the PO determination of impact patterns.

KEYWORDS: forensic science, bloodstain pattern analysis, impact pattern, stringing method, point of origin, directional analysis, BackTrack, HemoSpat

Bloodstain pattern analysis (BPA) is an effective approach to reconstruct the events that happen at a crime scene. Among the different bloodstain patterns that can be distinguished, an impact pattern may be of special interest. An impact pattern is a bloodstain pattern resulting from an object striking liquid blood (1) and can be described as a radiating pattern of small individual drops (2). Different methods exist to estimate the position of the blood source (the point of origin [PO]) from the radiating distribution of stains. Most of these methods are based on the assumption that the path of a blood drop away from the blood source follows a straight line, hereby neglecting influence of gravity and air resistance. By measuring the directional angle γ, the impact angle α, and the x-, y-, and z-coordinates of the bloodstain (for an explanation of the different angles and the coordinate system, see [3]), a linear function can be formulated that describes the path of the corresponding blood drop. By subsequently drawing strings from all bloodstains, the PO can be estimated from the intersection of the strings in space ("stringing method") (4). In addition to the stringing method, two commercially available computer programs exist that calculate the PO by means of directional analysis, as described by Carter (3): HemoSpat and BackTrack. It is important to note that in these programs the contribution of gravity and air resistance to the path of the blood drop is neglected. Different validation studies have been performed to investigate the accuracy of these programs (3,5,6). The results of these studies consistently show that the z-coordinate (i.e., the height) of the blood source is overestimated. This is unfortunate, because the z-value is often the most important parameter for forensic purposes, because this may, for instance, distinguish between self-defense and murder, depending on the position of the victim. Apart from the z-coordinate, the results of the validation studies furthermore show deviation in the estimates of the x-coordinate (distance to the front wall).

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In this study, the conditions are investigated under which the assumption that blood drops travel in a straight line still provides good PO estimates. By studying the characteristics of single bloodstains, we were able to give recommendations as to which bloodstains can be used best for PO calculation. In addition, the deviation was investigated with respect to the distance of the blood source to the front wall and with respect to the number of walls from which bloodstains were selected.

Materials and Methods

Experiments

Nine different experiments corresponding to nine different bloodstain patterns were performed. The distance of the blood source to the front wall was manipulated, as well as the number of walls on which bloodstains were projected (depicted in Fig. 1*A*). Several bloodstains were selected from each pattern by trained analysts having finished at least the advanced bloodstain pattern analysis course of the Ontario Police College (OPC; Aylmer, ON, Canada). The bloodstain selections were made according to the OPC's method (12 stains with a negative γ value, 12 stains with a positive γ value, stains caused by fast upward moving drops, and stains with a regular, elliptical form). Each bloodstain selection consisted of at least 24 bloodstains. The bloodstain pattern analysts did not know the actual position of the blood source. For each bloodstain selection, at least one analysis was performed using HemoSpat.

The first three experiments were performed with the blood source placed at a distance of 50 cm from the front wall (position "A" in Fig. 1*A*), and bloodstains were only projected to the front wall. For the first two experiments, stain selection was carried out by two bloodstain pattern analysts. For the third experiment, stain selection was carried out by seven analysts. All selections were analyzed in both HemoSpat and BackTrack, resulting in 22 analyses.

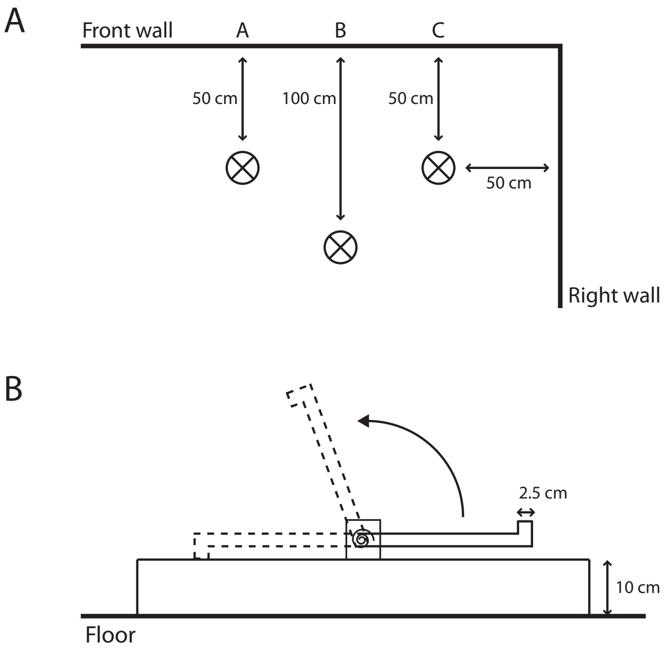

FIG. 1—*(A) Three different sets of experiments were performed. In situation A, the mouse trap was placed 50 cm from the front wall. For B, it was placed 100 cm from the front wall. In situation C, the mouse trap was 50 cm away from front as well as right wall and bloodstains from both walls were analyzed. (B) Side view of the modified mouse trap. The handle was pulled to the back and after release, it hit the trespa surface on which the blood was pipetted.*

In the next series of three experiments, the blood source was placed 100 cm away from the front wall (position "B" in Fig. 1*A*). Again, the source was placed such that the bloodstains were only visible on the front wall. For the first of these experiments, stain selection was carried out by three bloodstain pattern analysts and these selections were analyzed with both HemoSpat and BackTrack. For the last two experiments, selections were made by three and one analyst(s), respectively, all analyzed only in HemoSpat.

In the last series of three experiments, bloodstains were projected onto both front and right wall that were positioned at an angle of 90° to each other and the blood source was 50 cm away from the front as well as the right wall (position "C" in Fig. 1*A*). For all three experiments, the PO was calculated first with 30 bloodstains on the front wall alone and then with 60 bloodstains on both walls (30 on the front and 30 on the right wall). Each selection was analyzed with HemoSpat only.

Blood

Human blood of one person was used, not more than 4 weeks old, stored at 4°C; 4.5 mL of blood was mixed with 0.5 mL (0.105 M) sodium citrate (BD Vacutainer, REF 367714; BD, Heidelberg, Germany) during blood collection. The blood was heated to 37°C and stirred to prevent blood clotting, and subsequently 1.5 mL blood was pipetted onto the flat and horizontal surface of a mouse trap, always on the same circular area with a diameter of 4.5 cm.

Modified Mouse Trap

To project blood onto the wall, a custom-built modified mouse trap was used (see Fig. 1*B*). A device, made of trespa (flat panel, based on thermosetting resins; Jongeneel, Den Haag, The Netherlands) and resembling a hammer, was attached to a spring, such that the head of the hammer (with a diameter of 2.5 cm) hits the flat surface from above. The spring ensured that the force applied to the blood pool remained constant for all experiments. The wall on which the blood drops landed was also made of trespa. This flat surface ensured that the elliptical form of the bloodstains was easily recognized. According to trained bloodstain pattern analysts, the patterns created resembled patterns encountered at crime scenes.

Bloodstain Analysis

For all experiments, the analyses in HemoSpat and BackTrack were performed by one person. After the bloodstain selection was made, the *x*-, *y*- and *z*-coordinates of the bloodstains were measured by means of a laser measuring device (Disto™ A5; Leica Geosystems, Wateringen, The Netherlands). The plumb line was determined by means of a digital protractor (Pro 360; Mitutoyo, Veenendaal, The Netherlands) and drawn near the bloodstain. Also, a scale was stuck next to the bloodstain. Photographs of the bloodstain were taken with a digital camera (D200; Nikon GmbH, Düsseldorf, Germany) with a fixed focal distance of $f = 60$ mm. A self-built device was used to keep the camera at a fixed distance from the wall and at a fixed angle (90°) to the wall. The photographs were saved as high-quality jpg.

BackTrack and HemoSpat

BackTrack was developed in 1992 by A.L. Carter (Forensic Computing of Ottawa, Inc., Ottawa, ON, Canada). It consists of one program to analyze the photographs and to create the strings and another program to analyze the strings and to determine the PO. HemoSpat (FORident Software, Inc., Ottawa, ON, Canada) was developed by K. Maloney and A. Maloney in 2006. The difference with BackTrack is the ability to automatically fit an ellipse to the bloodstain. The photographs of the bloodstains were imported into HemoSpat or BackTrack. For each bloodstain, the *x*-, *y*-, and *z*-coordinates and the scale had to be provided, the plumb line had to be drawn in the program along the line visible on the photograph, and an ellipse was fit to the bloodstain. Calculation of the PO is based on the method of directional analysis, as described by Carter (3). Both HemoSpat and BackTrack report the PO along with its standard deviation.

Results

First, an overview of the overall deviation in the *x*-direction (perpendicular to the front wall), *y*-direction (parallel to the front wall), and in the *z*-direction (height), for all analyses on the front wall, is presented in Table 1. This table may aid in getting a first impression of the size and direction of the deviation. The minimum, maximum, and mean deviation are based on the 32 analyses derived from the first six experiments with bloodstains projected only onto the front wall (see previous section). From this table, it becomes

TABLE 1—*Overview of the minimal, maximal, and mean deviations, based on 32 analyses of the first six experiments.*

	Minimum (cm)	Maximum (cm)	Mean (cm)	SD (cm)
x	−2.6	−13.1	−5.6	2.7
y	−1.8	2.3	−0.05	1.0
z	6.0	44.6	17.9	10.3

clear that in the *x*-direction, a negative deviation is observed, which means that the calculated value of the *x*-coordinate lies too close to the front wall compared with the actual PO. For the *y*-coordinate, the range of deviations is much smaller, covering both negative and positive values, resulting in a mean *y*-deviation of all combined experiments close to zero. The deviation of the *z*-coordinate is largest and ranges from 6.0 to 44.6 cm. The height of the blood source is thus always overestimated.

The large deviations of the calculated PO from the actual PO in *x*- and *z*-direction motivated us to analyze the sources of this in detail. Several sources may be identified that could be responsible for the deviation. The first source is the software program itself, that is, HemoSpat versus BackTrack. The second source is the specific bloodstain selection. We investigated the correlation between different characteristics of the bloodstains and the deviation from the actual PO to find the bloodstains causing the least deviation. Finally, external influences such as the distance of the blood source to the front wall and the number of walls could be contributing to the observed deviation. In the next sections, these sources are investigated.

Software

For the comparison of HemoSpat and BackTrack, 14 bloodstain selections, originating from four different experiments (see Materials and Methods) were analyzed with HemoSpat as well as with BackTrack. The analyses were performed by the same data analyst in HemoSpat as well as BackTrack. For all analyses, the deviation of the calculated PO from the actual PO was determined. Figure 2 presents the mean deviation in the *x*-, *y*-, and *z*-direction for both HemoSpat (dark gray) and BackTrack (light gray). The three small graphs at the bottom enlarge the differences between HemoSpat and BackTrack. These are 0.34 cm ($t = 2.12$; $p = 0.054$), 0.24 cm ($t = 1.95$; $p = 0.073$), and 0.29 cm ($t = 1.82$; $p = 0.091$), for the *x*-, *y*-, and *z*-coordinate, respectively. Student's *t*-tests show the differences to be not significantly different from zero. (The same results were obtained by means of the nonparametric Mann–Whitney test. Significance level equals 0.05 for each test in this study.) As a matter of fact, these differences are also very small for forensic purposes. A minor movement of the body can easily result in a deviation of 0.5 cm in the determination of the PO. Based on these results, a reasonable conclusion is that both programs perform the estimation of the PO equally well. Therefore, all of the following analyses were performed in just one software program (HemoSpat).

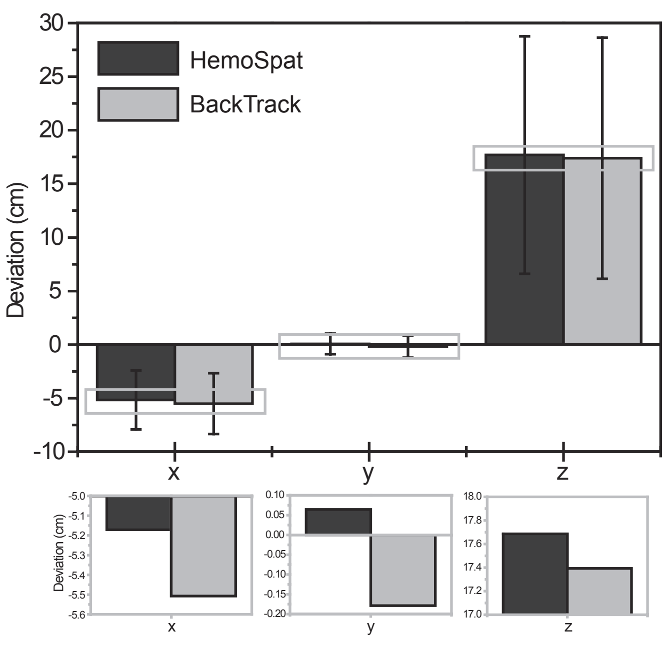

FIG. 2—*Difference between BackTrack and HemoSpat. The bars represent the mean deviation measured for 14 analyses performed using HemoSpat (dark gray) or BackTrack (light gray). The error bars represent the standard deviation. The difference between HemoSpat and BackTrack is enlarged in the small graphs on the bottom. The measured differences are so small that they are forensically not relevant.*

Bloodstain Selection

For the investigation of the influence of bloodstain selection, from one experiment, seven different bloodstain selections were made by seven different bloodstain pattern analysts. The analysts did not know which bloodstains were selected by other analysts. For each bloodstain selection, the deviation between estimated PO and actual PO was determined. These values are shown in Table 2. Obviously, there is a large variation in deviation between different bloodstain selections. Three of the stain selections generated a deviation of around 10 cm. However, for selection 3, a deviation of 19.55 cm is observed, and for selection 5, the deviation is only 6.54 cm. This implies that selection 5 contains "better" stains than selection 3. Thus, selection 5 contains bloodstains of which the corresponding "string" lies closer to the actual PO than the "strings" corresponding to the stains of selection 3.

Given these results, an interesting question may be the following: Which stains have a corresponding string lying closest to the actual PO? The shortest distance between string and actual PO is a perpendicular line between both. This distance is designated as $d(x,y,z)$. For perfect strings, $d(x,y,z)$ is zero. Thus, small values of $d(x,y,z)$ correspond to stains with a corresponding string lying close to the actual PO (see Fig. 3).

For all bloodstains originating from the first three experiments with a distance to the front wall of 50 cm ($n = 241$), different variables were studied with regard to $d(x,y,z)$. The correlation between $d(x,y,z)$ and the bloodstain's height (h), directional angle (γ), and impact angle (α) is presented later. For all variables, small violations of normality were observed. Therefore, nonparametric correlations were also computed. They did not differ substantially from their parametric counterparts. Experiments with the blood source further from the wall resulted in comparable correlations.

The correlation between $d(x,y,z)$ and the height of the bloodstains is presented in Fig. 4. For larger heights, larger $d(x,y,z)$ values are observed. The correlation was equal to $r_{d(x,y,z),h} = 0.58$ ($p < 0.001$). So, the lower the bloodstains are on the wall, the smaller is the deviation from the actual PO. Although the value of the correlation is quite high, and corresponding to a large effect size (7), it can be seen in the scatter plot of Fig. 4 that the bivariate distribution is rather heteroscedastic: the larger the *h* values, the broader the range

TABLE 2—*Difference in deviation between bloodstain selections.*

Bloodstain Selection	Deviation (cm)
1	10.19
2	12.77
3	19.55
4	14.76
5	6.54
6	10.49
7	11.01

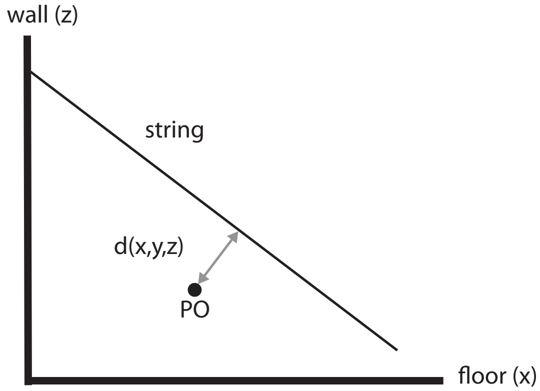

FIG. 3—*2D representation of the distance d*(x,y,z)*. From a bloodstain on the wall, a linear function (the "string") points out, representing the path of the blood drop. The minimal, perpendicular, distance between the string and the point of origin (PO) is designated as d*(x,y,z)*. d*(x,y,z) *is thus a measure of the accuracy of the string of a bloodstain. Ideally, this distance should be zero and the string should cross the PO. Note that d*(x,y,z) *is, in fact, a distance in 3D.*

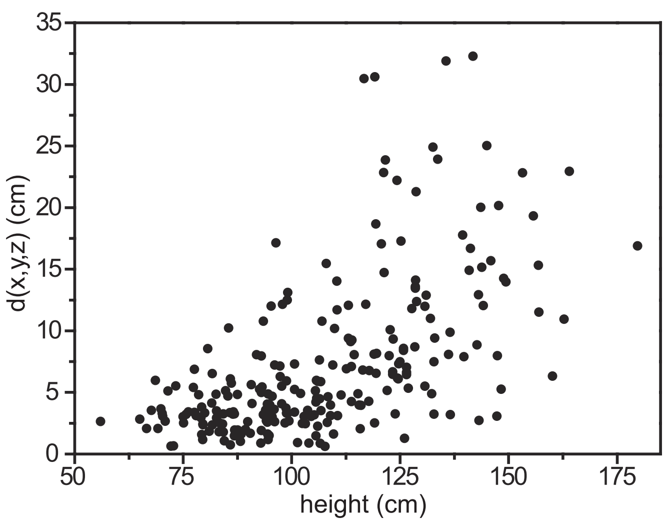

FIG. 4—*Relation between d*(x,y,z) *and* h *(height of a bloodstain). 241 bloodstains were analyzed with respect to d*(x,y,z) *and h. Larger heights correspond to large d*(x,y,z) *values. The correlation of d*(x,y,z) *and* h *amounted to* $r_{h,d(x,y,z)} = 0.58$ *(*$p < 0.001$*). This means that the higher the bloodstain is on the wall, the larger the deviation.*

of corresponding d(*x,y,z*) values. Thus, d(*x,y,z*) may not only be dependent on *h* but also on several other variables.

The next bloodstain characteristic to be studied was the surface area of the bloodstain. The surface area of the elliptical fit of the bloodstain can be calculated by ¼ *π**w***l* (*w* = minor axis of the ellipse, *l* = major axis of the ellipse). The bloodstain selection used in this experiment displayed a negative correlation between *h* and surface area ($r_{h,\mathrm{surface}} = -0.18$; $p = 0.005$). Therefore, the correlation between d(*x,y,z*) and surface area was corrected for *h*. The resulting partial correlation is equal to $r_{d(x,y,z),\mathrm{surface}|h} = -0.25$ ($p < 0.001$). To give a graphical representation of this relation, the data were split at the 33rd and 67th percentile of *h*, resulting in the following three groups: $h \leq 94.5$ cm, 94.5 cm $< h \leq 118$ cm, and 118 cm $< h$. Figure 5 shows the plots of d(*x,y,z*) versus bloodstain surface area for these three categories. The three plots show a rather large heteroscedasticity. While small deviations may be found for all surface areas, large deviations are much less likely for larger surface areas. In other words, large surface areas (in this study *w* = 1.5–3.2 mm) will result in more reliable PO estimates.

The angle α correlated very strongly with *h* ($r_{h,\alpha} = -0.62$; $p < 0.001$). So, the lower the bloodstains are on the wall, the higher the value of α. Because we were only interested in the "pure" relation of d(*x,y,z*) and α, we again corrected for *h*, resulting in a partial correlation equal to $r_{d(x,y,z),\alpha|h} = 0.29$ ($p < 0.001$). This means that stains with a smaller value of α have smaller corresponding values of d(*x,y,z*). In other words, "more elliptical" bloodstains (bloodstains with a larger major axis) give less deviation from the PO.

The value of γ was the last variable to be studied. The correlation with *h* was again quite strong ($r_{h,\gamma} = -0.41$; $p < 0.001$), and the partial correlation of d(*x,y,z*) with γ is equal to $r_{d(x,y,z),\gamma|h} = 0.31$ ($p < 0.001$). This means that stains with a smaller angle γ have smaller corresponding values of d(*x,y,z*).

These results show that the accuracy of a string is dependent on many variables. The strongest correlation was found between d(*x,y,z*) and height, which means that bloodstains higher on the wall are the largest source of error. Apart from height, also small surface areas, high α values, and high γ values contribute to the deviation.

External Influences

With respect to the external influences on the deviation from the PO, two sources were investigated: the distance of the blood source to the front wall and the number of walls from which bloodstains were selected. In the previous section, it was shown that the stain selection—in particular the height of the bloodstains—largely influences the deviation from the actual PO. Therefore, for the experiments performed in this part, only bloodstains under a certain height were considered. In this way, a clean comparison of experiments was ensured, ruling out influences owing to the selection of stains.

The first variable to be studied was the distance of the blood source from the front wall. Bloodstain selections from the three experiments with the blood source *x* = 50 cm from the front wall and from the three experiments with the blood source *x* = 100 cm from the front wall were analyzed. For each experiment, the deviation of the calculated PO from the actual PO was determined in the *x*-, *y*-, and *z*-direction. The deviations were averaged for *x* = 50 cm ($n_{50} = 3$) and *x* = 100 cm ($n_{100} = 3$), and the resulting values are presented in Fig. 6. The dark gray bars represent the deviations for *x* = 50 cm and the light gray bars for *x* = 100 cm. The deviations in *x*- and *z*-direction are larger for a distance of 100 cm than for a distance of 50 cm, and the deviations for *y* are the smallest. The differences were rather large compared with the corresponding standard deviations. Mann–Whitney tests resulted in significant differences for the *x*- and *z*-direction ($p = 0.05$). For the *y*-direction, the difference was not significantly different from zero ($p = 0.28$). It is to be noted that the statistical power is rather small, because of the very small sample sizes. Effect sizes for the *x*-, *y*-, and *z*-direction were 4, 0.7, and 4, respectively, corresponding to medium-to-large effects.

The second external influence we studied was the number of walls from which the bloodstains were selected. The last three experiments were performed with the blood source 50 cm away from the front wall as well as from the right wall. For these experiments, first, an analysis was performed using bloodstains selected only from the front wall, and the deviations in the *x*-, *y*-, and *z*-direction were determined. Afterward, bloodstains were selected from both walls, analyzed, and again the deviations in the *x*-, *y*-, and

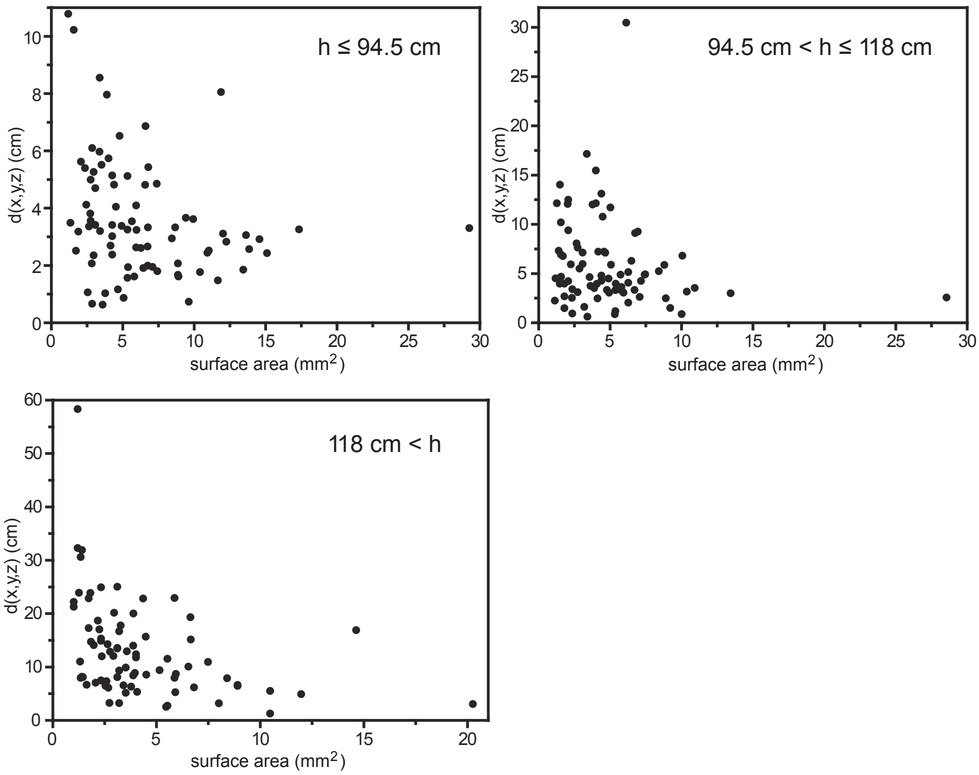

FIG. 5—*Relation between* d(x,y,z) *and surface area of a bloodstain for three different categories of* h. *For* h ≤ *94.5 cm, 94.5 cm* < h ≤ *118 cm and* h > *118 cm,* d(x,y,z) *was plotted versus the bloodstain surface area. A correlation between* d(x,y,z) *and surface area can be observed and equals* $r_{d(x,y,z),surface|h} = -0.25$ (p < *0.001). Larger bloodstains thus correspond to less deviation.*

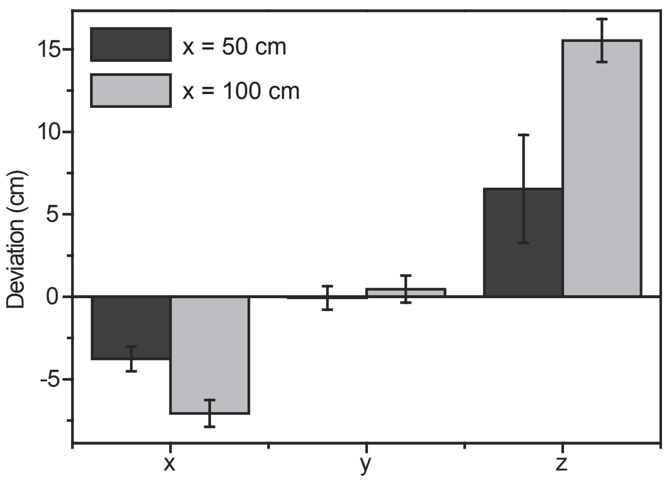

FIG. 6—*Deviation for the blood source placed at* x = *50 cm (dark gray) and at* x = *100 cm (light gray) away from the front wall. The deviation of the estimated point of origin (PO) from the actual PO is plotted for all three coordinates* (n = *3). In the* x- *and* z-*direction, a clear decrease in deviation is observed for* x = *50 cm.*

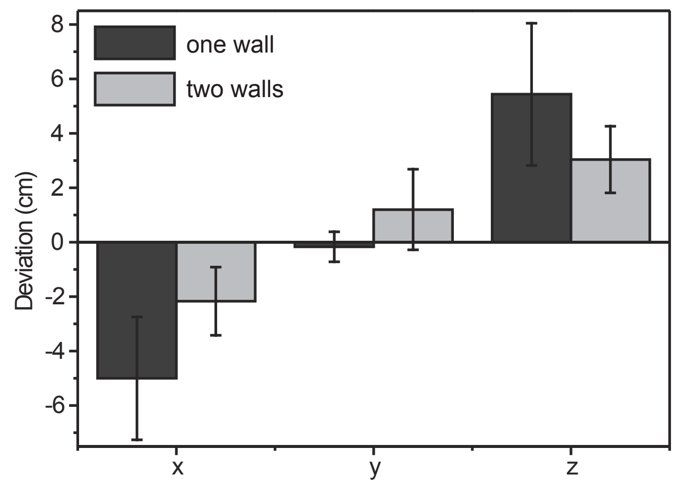

FIG. 7—*Deviation for bloodstain selections from one wall (front wall, dark gray) and for bloodstain selections from two walls (light gray). The deviation of the estimated point of origin (PO) from the actual PO is plotted for all three coordinates* (n = *3). In the* x- *and* z-*direction, selections from two walls distinctly correspond to less deviation. In the* y-*direction, a slight increase is visible. See text for explanation.*

z-direction were determined. The results of the three experiments were averaged for both groups (i.e., one wall vs. two walls) and are presented in Fig. 7. The dark gray bars correspond to the bloodstain selection of one wall (front wall), and the light gray bars correspond to the bloodstain selection of two walls. From this figure, it can be seen that the deviation in *x*- and *z*-direction is decreased when the number of walls increases. Again, the differences were rather large compared with the corresponding standard deviations. (Mann–Whitney tests resulted in significant differences for the *x*- and *y*-direction ($p = 0.05$). For the *z*-direction, the difference was not significantly different from zero ($p = 0.51$). Effect sizes for the *x*-, *y*-, and *z*-direction were 2, 0.7 and 2, respectively.) Thus, the accuracy is increased in *x* and *z* but is decreased slightly in *y*. Note that the difference in accuracy is larger in Fig. 6 than in Fig. 7.

In summary, the results presented in this study demonstrate that the PO estimated by the software programs HemoSpat and BackTrack displays a clear deviation from the actual PO, especially in the *x*- and *z*-direction. Three categories of influences on this calculation were studied. First, the software itself was investigated. Second, the bloodstain selection and finally external influences were examined. The results show that the deviation is for a large part caused by the height of the bloodstains and by the distance of the blood source to the wall.

Discussion

In this study, the accuracy of the impact pattern software programs HemoSpat and BackTrack was examined under different conditions. To our knowledge, this is the first time that a direct comparison between HemoSpat and BackTrack was made and that the accuracy of both programs was tested under different conditions. In addition, we studied the characteristics of single bloodstains and the corresponding influence on the calculation of the PO.

HemoSpat and BackTrack are both used at crime scenes to estimate the PO of an impact pattern. The origin of an impact pattern gives information about the spatial position of the blow. This position is very important, because it may help to reconstruct the events that occurred during a crime. The forensically most important parameter is the height of the blow, because this may distinguish between statements about whether the victim was standing or sitting, which may indicate self-defense or murder. Unfortunately, in our study, the *z*-coordinate (reflecting the height) showed the largest deviation, with a maximum value of 44.6 cm. This emphasizes the importance of the recommendations in this study to minimize the deviation in the *z*-direction. As the stringing method relies on the same assumption as HemoSpat and BackTrack (neglecting influence of gravity and air resistance), it is very likely that the deviations observed in this study also appear during the stringing method.

All experiments were performed with the same force of the mouse trap spring. Although different results may be expected when the blood pool is hit with a different force and the values of the correlation may change, no change in tendency of the correlation is expected (i.e., positive correlations to become negative and vice versa). A larger force may lead to a larger initial velocity of the blood drops, reducing the influence of gravity and, accordingly, the deviation.

In general, the values presented in Table 1 are somewhat larger than the values presented in other studies (5,6), which may be caused by the experimental conditions of the different studies. In our study, some impacts were 100 cm away from the wall. As shown in the Results section, for these impacts, large deviations were found. The impacts studied in (5) and (6) were all much closer to the wall and showed accordingly less deviation.

For the software-related analysis, no difference was found in the deviation of the PO estimated by BackTrack or by HemoSpat. Given the fact that both BackTrack and HemoSpat make use of directional analysis (3), and thus have the same mathematical basis, this result is not unexpected. Hence, both programs perform the estimation of the PO equally well.

Two additional software-related parameters are the angles α and γ of the bloodstains. An interesting question is what happens when these are over- or underestimated, and for which stains this might happen. A more detailed study on this subject is planned in the future.

The largest sources of deviation were the height of the bloodstain as well as the distance between the blood source and the front wall. These variables both represent the distance a blood drop has to travel. The results showed that a larger traveling distance (i.e., larger height or larger distance from the wall) corresponds to larger deviation. Thus, the deviation may be linked to the trajectory of the blood drop. In HemoSpat and BackTrack, the trajectory of a blood drop is considered to be a straight line, although in fact the trajectory more resembles a parabola. Under the sole influence of gravity and considering the blood drop as a rigid sphere (8), the trajectory would be a parabola (9). This problem has been recognized before (10) and leads to an overestimation of the *z*-coordinate (3). For longer pathways, the influence of gravity is larger, and so the deviation from a straight line will be larger. Thus, blood drops that cover larger distances show a larger deviation. In line with that, bloodstains should be selected that are closest to the presumed location of the blood source (which is often close to the highest density of (almost) circular bloodstains in that particular impact pattern). In addition, PO estimates should be interpreted with caution when the blood source is probably more than 50 cm away from the front wall.

A second variable influencing the deviation is the size of the bloodstain. We showed that bloodstains with a larger surface area correspond to less deviation, in accordance with a recent study by Reynolds et al. (11). The reason for this may be a very trivial one: The smaller the bloodstain, the more difficult it is to distinguish the edges of the bloodstain. Thus, the error in the measurement of length and width of α is larger. This has been recognized by Pace before (12). It is therefore important to select larger ($w > 1.5$ mm) bloodstains. Note, however, that small surface areas do not necessarily result in bad PO estimates (compare the heteroscedasticity of Fig. 5).

With respect to α, lower α values (more elliptical bloodstains) correspond to lower values of $d(x,y,z)$. Again, the measurement error in length and width plays a role, because these get smaller for lower values of α (12,13). The more elliptical a bloodstain is, the easier an ellipse is fit to it.

The last variable was the number of walls. When bloodstains from two walls (in our case front and right wall) were considered, the deviation in *x*- as well as *z*-direction was decreased. The situation of two walls shows that estimating the *x*-coordinate from bloodstains on the right wall equals the estimation of the *y*-coordinate from bloodstains on the front wall. The *y*-coordinate estimation from the front wall was very accurate (see Table 1) and so is the *x*-coordinate estimation from the right wall. As a consequence, the value of the *x*-coordinate is more accurate when the right wall is also taken into account. The same argument is valid for the estimation of the *y*-coordinate. Thus, with two walls the deviation of the *x*-coordinate seems to be dispersed over x and y. The smaller *z*-deviation measured for bloodstains from two walls is a direct result of the more accurate value of x. By projection of the strings in the x, z-plane (side view), the linear relation between x and z is clear: by increasing the x value, z is decreased.

In short, taking bloodstains of different walls (in our case front and right wall) into account decreases the deviation in x, increases the deviation in y, and decreases the deviation in z.

In summary, this is the first time that the accuracy of the PO calculation is tested under different conditions by considering the deviation of single bloodstains. To reduce the deviations in *x*- and *z*-direction when estimating the PO of an impact pattern by HemoSpat or BackTrack, the following recommendations are made (it is to be noted that these recommendations are made based on the bloodstain selection by OPC-trained bloodstain pattern analysts):

- Choose bloodstains that are closest to the presumed position of the blood source.

- Choose large bloodstains (width >1.5 mm).
- Choose bloodstains that have a distinct elliptical form.
- Use bloodstains from more than one wall.
- Be cautious in using HemoSpat and BackTrack when the blood source is presumably more than 50 cm away.

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