Wind influence on a blood droplet and trajectory

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Acknowledgments

“She can tell you the height of the attacker from the trigonometry of the blood spatter, while i'm fuzzy on what trigonometry is.”

Ilona Andrews

I thought the quote from Ilona Andrews was appropriate for this study. A very complex subject, wind influence on a blood droplet, which I had a big question mark about in the beginning. Now, 6 months later, a beautiful study has been rolled out with results that can be included in a bloodstain pattern analysis.

Foremost, I would like to acknowledge the support of my supervisors during my graduation internship. Special “Thank you” goes to Martin Eversdijk and René Gelderman, for the valued opportunity, expertise, guidance and all the chances that they have offered me. My sincere thanks for all the interesting things I have learned about the profession during my internship at Loci Forensics B.V., the time for discussion and advice. I personally went through a development during my internship at Loci Forensics, which I never expected. I laughed, cried, enjoyed and learned a lot during my internship. Because of you, I know what my dreams are and how to deal with them. I will always be grateful! In addition, I would like to thank Christy Haurissa (student at University Van Hall Larenstein), Romy Regterschot (student at Saxion University of Applied Sciences), Richard Sahanaja (Operational Expert bloodstain pattern analysis Dutch police force) and Jasper van der Duin (forensic investigator Dutch police force) for the collaboration and all the fun and educational conversations! Despite the various subjects we are researching, we were still able to support each other where necessary. I would like to thank Jacintha Knapen (ex-internship partner and Senior FO dactyloscopy Dutch police force) for her critical review on my thesis. Finally, I would like to thank my supervisors at Saxion University, Nicole ten Broeke and Odyl ter Beek, for the supervision. The feedback and the short but enthusiastic conversations made the supervision very instructive.

During this research several experiments were carried out with the high-speed camera. Unfortunately, these could not be included in the final report, but are available.

Marlène Többen

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Abstract

Violent crimes involving bloodshed may result in the formation of a number of blood drops that move through air and impact onto a surface producing a bloodstain pattern. Bloodstain Pattern Analysis (BPA), the analysis of the distribution, size, positions and morphology of the stains within the pattern present at the crime scene, may provide information about the events that gave rise to the bloodshed. The origin of the blood, the position of the victim at the time of injury, is very important. This can be estimated by the size, shape, position and direction of the blood drop, as well as the forces acting on the blood drop and its trajectory. The last of the enumeration is difficult to realise in practice.

This study investigated the influence (external energy) of wind on a blood drop, deformation and the trajectory. Due to a small wind tunnel and turbine compressor, a drop of blood could enter an air stream in a limited environment. Various variables were tested: height, speed, wind force, volume of the blood drop and impact of the drop. The results showed that wind can influence the deformation and trajectory of a blood drop. The deformation of the blood drop and changes in its trajectory depend on the force of the wind (Beaufort scale) and the blood drops own speed/volume, resulting from the height of release from the pipette. In addition, an impact pattern has the same external phenomena as the results of a blood droplet influenced by external energy (wind). It is worthwhile to do more research into the influence of wind on a drop of blood and the trajectory, as well as the external characteristics on different substrates. The chosen variables of this study can be expanded or changed.

Keywords: Blood droplets, Deformation, Trajectory, Impact pattern, Wind.

Abstract Dutch

Gewelddadige misdaden met bloedvergieten kunnen leiden tot de vervorming van een aantal bloeddruppels die door de lucht bewegen en op een oppervlak landen, waardoor een bloedvlekkenpatroon ontstaat. De analyse van het bloedvlekpatroon (BPA), de analyse van de verdeling, de grootte, de posities en de morfologie van de vlekken op de plaats van het misdrijf aanwezige patroon, kan informatie opleveren over de gebeurtenissen die aanleiding hebben gegeven tot het bloedvergieten. De herkomst van het bloed, positie van slachtoffer op moment van verwonding, is van groot belang. Dit kan worden geschat door de omvang, vorm en richting van de bloeddruppel, evenals de krachten die inwerken op de bloeddruppel en haar traject. De laatste van de opsomming is in de praktijk moeilijk te realiseren.

Deze studie onderzocht de invloed (externe energie) van wind op een bloeddruppel, haar deformatie en de vluchtroute. Door middel van een kleine windtunnel en turbine compressor kon een bloeddruppel in een beperkte omgeving in een luchtstroom terecht komen. Hierbij werden er verschillende variabelen getest: hoogte, snelheid, windkracht, volume van de bloeddruppel en impact van de druppel. De resultaten toonden aan dat wind de deformatie en traject van een bloeddruppel kan beïnvloeden. De deformatie van de bloed druppel en verandering van het traject zijn afhankelijk van de windkracht (schaal van Beaufort) en de eigen snelheid/volume die de bloeddruppel heeft. Daarnaast heeft een impact patroon dezelfde uiterlijke verschijnselen als de resultaten van een bloeddruppel beïnvloed door externe kracht (wind). Het is de moeite waard om meer onderzoek te doen naar de invloed van wind op een bloeddruppel en de vluchtroute met daarbij de uiterlijke kenmerken op verschillende ondergronden. Daarbij kunnen de gekozen variabelen van deze studie worden uitgebreid of veranderd.

Steekwoorden: Bloeddruppels, Deformatie, Vluchtroute, Impact patroon, Wind.

1. Introduction

After a report from the police, a Forensic Team is called in for a crime scene in America. The briefing indicates that a car chase has taken place where both the police and the driver of the other car have fired a firearm. Unfortunately, the suspect died. According to the prosecutor, a Bloodstain Pattern Analysis (BPA) investigation is needed. The suspect's car was a convertible with an open roof. There are bullet holes in both cars and shards of glass are scattered everywhere. Blood spatter is found in several places, but the convertible and the crash barrier also have remarkable bloodstains. According to normal guidelines and science, the blood spatter cannot have gotten there with the normal gravity or logical external energy. Calculating the angles and locations does not match the other patterns. The researchers call in an expert. After approval by the Public Prosecutor, the expert comes to the scene and starts the investigation again. The expert does not come up with a statement either. How can these exposed blood spatters be explained?

When individuals become injured and then move, or bloody items moved within a scene, blood trails are likely to occur. The drops resulting from these dripping actions strike the surrounding floors and surfaces. They are moving with the same momentum and in the same direction as the item from which they fell, as they break free. The combination of gravity and this momentum causes the drops to impact the ground at varying angles. The resulting stains in the blood trail show evidence of this angle and its direction [1]. When individuals run and there is aerodynamics, are the results the same? There are a lot of researches about respiratory derived blood spatter distributions [2] and predicting the trajectory of blood drops in typical crime scenes indoor [3], but can the findings also be applied to normal (passive or impact) blood drops with different wind forces? Can the results or findings improve BPA in her studies?

The aim of this research is to find to what extent does wind influence a free-falling blood droplet (deformation) and the trajectory. This will be achieved by creating a small wind tunnel to recreate an environment. The blood droplet will be captured by a high-speed camera. The results on the substrates will be photographed with a normal camera. Different variables will be included in the results. With a special measuring device, accurate numbers come out of the appliance over the aerodynamics. Before the experiments will start, a power analyse will be carried out. The results will be analysed and conclusions will be drawn from the analysis.

Research questions

A number of research questions were drawn up in preparation for the study, which could be answered during the research. Through the main and sub-questions, the research was set up with a certain strategy and methods. This led to results that, with conclusions, could provide answers to the questions. Table 1 gives an overview of the main and sub-questions that were drawn up for this study.

Table 1, An overview of all the main and sub-questions that have formed a common thread for this study. The table on the left shows whether it concerns a main or sub-question. The right-hand table shows the specific question.

Main-question	**To what extent does wind (aerodynamics) influence a blood droplet and trajectory?**
Sub-question 1	What is aerodynamics?
Sub-question 2	Which stages does a bloodstain have from the moment it releases a person or item until it touches the surface?
Sub-question 3	On a drop of blood different forces work (trajectory), a person or item is usually the second energy. To what extent can aerodynamics change this? Nowadays this is rarely used in a BPA investigation.
Sub-question 4	How does a blood droplet react on various forces of aerodynamics?
Sub-question 5	How will the blood droplet react when the size of the droplet changes by different scales of Beaufort?

2. Literature Background

Aerodynamics

Aerodynamics describes how air move around an object. The shape of an object has a great influence on the flow behaviour of the "gas" through which it moves. Often aerodynamics tests are done in a wind tunnel. The Beaufort scale is used to indicate the speed of the wind. It was established in 1805 by the Irishman Francis Beaufort. Its full name is the Beaufort wind force scale [4]. Beaufort based the wind force on the amount of sail a large ship could carry in a weak breeze, storm or hurricane. The wind pressure was expressed in kilograms per square metre. Therefore, the scale applies to the pressure of the wind [5]. Table 2 shows the wind forces and the corresponding speeds. Appendix C will give more specifications about the scale of Beaufort, which is used to indicate the speed of the wind.

Table 2, Beaufort scale (force) and the equivalent speed (km/h)

Force (Beaufort scale)	Equivalent speed (km/h)
0	0-1
1	1-5
2	6-11
3	12-19
4	20-28
5	29-38
6	39-49
7	50-61
8	62-74
9	75-88
10	89-102
11	103-117
12	118-133

A Turbulent flow is a flow which does not move in layers, but in vertebrae. Perpendicular to the main stream, there is a lot of flow. The opposite is a laminar flow. Laminar flow is a flow in which the layers of gas move parallel to each other. A combination is also possible. See Figure 1 for a schematic representation of flows [6]. The upper illustration shows a laminar flow. The lower illustration shows a turbulent flow. Turbulent flow takes place at higher flow rates, if the speed decreases, the type of flow can change to laminar. The moment at which this can change is characterised by the Reynold number (Re). This number depends on the speed and viscosity. At a low Re, the flow is laminar, smooth and constant. At a high Re, the flow is turbulent [7].

Turbulence is in this research is the main reason why fluid dynamics are complicated. Flows become turbulent if non-linear forces dominate. The non-linear forces cause instability of the flow and ultimately chaotic behaviour. The formulation of turbulence is still not complete, and will probably never be fully addressed analytically. Turbulence can only be analysed mathematically by approximation [8]. General theories of turbulence are lacking for non-Newtonian fluids, and the development of mathematical and computational models is not well advanced [9]. In this study, a turbine compressor will be used, which will spray air evenly into the wind tunnel. This allows the air to be laminar before hitting the blood drop, but a turbulence flow will occur behind the blood drop. Appendix D will give more information and illustrations about turbulence on a blood jet.

Turbulent currents can be applied to different objects. The flow of air around all kinds of objects, such as a baseball, can be made visible in a wind tunnel by means of smoke strings as shown in Figure 2 [10]. From the left of the baseball the air flows in parallel lanes, all at the same speed; here there is a constant air pressure and the air flow is laminar. The air coming centrally towards the ball is slowed down, deviates and flows along the surface of the ball. Here a thin boundary layer is created which causes friction losses. The thickness of this boundary layer and the losses it causes are determined by the smoothness of the surface. From the centre of the ball the air stream no longer runs along the surface, but loosens itself, creating a chaotic turbulent space behind the ball where the air swirls at high speed [11].

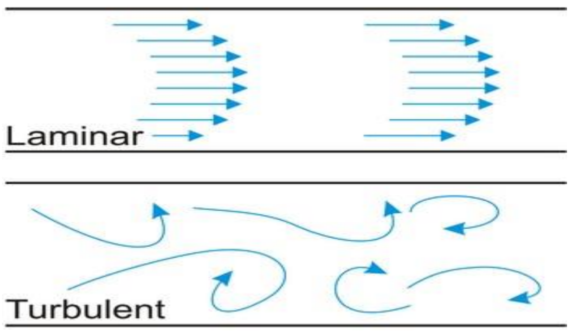


Figure 1, The difference between laminar and turbulent flows. The upper illustration shows a laminar flow. The lower illustration shows a turbulent flow.

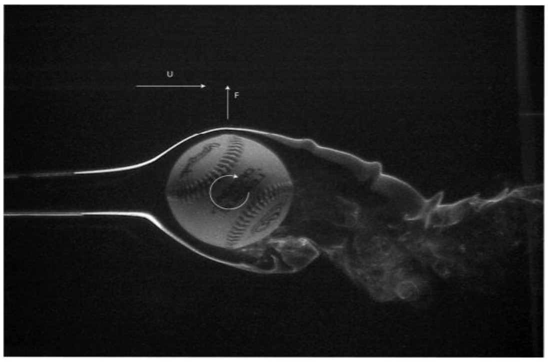


Figure 2, A baseball in a uniform wind tunnel flow. The flow direction is from left to right and the ball rotates clockwise ('slice'). The force on the ball in this picture is from bottom to top

Drops are not necessary travelling in still air before impacting a surface. Indoor or outdoor air currents or winds add to the drop relative velocity, and, consequently, may alter the drag force experienced by a drop and its trajectory [3] [12]. The effects of air movement on drop flight depend on the air velocity magnitude and directionality as well as drop size (weight) and velocity. Naturally, the greater the velocity of a drop the less pronounced the effects of air movement on its flight. Larger drops experience more drag, but also have greater inertia. The validated model was used to study the effect of indoor air currents and outdoor winds on the trajectories of representative blood drops. The trajectories of drops moving with a tailwind are generally longer and less curved, than for the same drop moving through still air. In turn, the trajectory of a drop moving into a head wind may curve more compared to the same drop moving through still air. In some cases, a drop may even reverse its movement and be blown back towards its source. Downward air currents may reduce and flatten drop trajectory. All these effects may lead to drop impact angle, impact velocity, stain morphology and stain position differing from those which would result from the same drop moving in still air. If, when a stain pattern at a crime scene is being analysed, still air is assumed, the area of origin inferred may be in error [12].

Blood

When a bloodshed activity has taken place, described in the introduction, the police try to answer questions which can give an answer to a scenario what could happened. Questions to be answered by police are: What happened? How did this happen? Who are involved? When did the event took place? Where did it happen? Investigators will do their research and try to answer these questions. Bloodstain pattern analysis (BPA) is the interpretation of bloodstains at a crime scene in order to recreate the actions that caused the bloodshed. They examine the size, distribution, shape and location of the bloodstains to form facts about what did or did not happen [13]. BPA uses principles of physics (cohesion, capillary action and velocity), biology (behaviour of blood) and mathematics (geometry, distance and angle) to assist the investigators**.** Appendix A and Appendix B will give more information about the terminology and BPA.

Fluid mechanics is the study of fluid movement and applied forces, fluid dynamics is the study of fluid flow. As a fluid, blood had physical properties similar to the properties of water. Blood is affected by physical forces much as water is affected by physical forces. Blood is a Rheopectic pseudoplastic non-Newtonian fluid. Blood has a non-linear relationship between viscosity and shear rate [12]. That means that the viscosity of blood decreases with the increases in velocity, so if blood is exposed to higher rates of shear, blood becomes less viscous thus improving the rate of flow. Non-Newtonian fluids are fluids whose flow properties cannot described by a single constant value of viscosity that depend on temperature only. Rheopectic means time thickening, viscosity increases with time. Pseudoplastic means shear thinning, viscosity decreases with increases of shear rate [14]. However, some fluids (such as blood, toothpaste, ink, paint), called non-Newtonian, possess nonlinear relationships between the stress and strain tensors [9]. It is convenient to define so called 'apparent viscosity' $\mu_a = \frac{\tau}{\gamma}$ which is a function of the current shear rate value for so called purely viscous or time-independent fluids. For these fluids the constitutive equation is $\tau = f\ (\gamma)$. Depending on the form of the function f this class of non-Newtonian fluids can be divided into shear-thinning, or pseudoplastic, for which the apparent viscosity decreases with the rate of the applied shear, shear-thickening, or 17 dilatants, with the increase in μ_a with the shear rate and viscoplastic having the characteristic yield stress τ_0 that must be exceeded to cause the fluid deformation or movement [12]. Human and mammal (cow) blood have approximately the same viscosity.

The most elementary drop formation mechanism is dripping of a liquid from an orifice or nozzle into an immiscible ambient fluid, such as, for example, water or blood dripping into ambient air [12]. The following stages of a drop formation process can be distinguished. The first stage (static stage) of ripping is a slow growth of the mass of a liquid adhering to the orifice due to interfacial tension forces. If the weight of a hanging drop exceeds interfacial tension forces hanging drop starts to mowing downward forming a liquid neck. Under the gravity the neck elongates in to a cylindrical bridge (ligament), which becomes narrow enough and breaks in one or several places. This is a consequence of the instability of a liquid cylinder when its length exceeds circumference [15]. It breaks at the lower end near the detaching drop (end-pinching) and the main drop is formed and continues to move downward. Then the ligament contracts vertically and experiences spatial oscillations due the capillary waves. The droplet may break in several places forming smaller satellite, or will be accompanying other droplets [16]. These oscillate in shape and may move upwards and merge or bounce from the residual mass adhered to the source, collide or bounce from each other [17] and may move with different velocities and trajectories.

Existing non-Newtonian drop flight studies are limited to the investigation of drop motion in surrounding fluid media (typical for settling applications). The drop launch conditions may also affect the way drop deformation affects its flight. Sufficient drop travel times, and distances, are needed for the effects of air resistance forces and, with it, drop deformation to influence its flight path [18]. Therefore, those drops which originated, for example, at optimal angles for the furthest flight to have longer trajectories before impact with a surface and would be more susceptible to the effects of deformation. The effects of drop deformation may result in significant drop trajectory curving and impact angle and velocity alteration. However, the downward-moving drops are expected to target the floor at angles close to 90° and are rarely useful for the area of origin calculation. The effect of drag force (and deformation, in particular) on falling drops is to slow them down, not to deflect their trajectory [12].

A bloodstain on a solid surface occurs when the blood penetrates, chemically reacts, or just adheres and dries onto the solid surface. When a droplet impacts the surface, it spreads out to a maximum extent and then may or may not retract to some degree back toward the centre of impact. If the blood droplet does not penetrate, chemically react, or adhere to the solid surface, its final static shape after the spreading and retraction process would be a spherical cap with a circular edge characteristic on the solid surface. In this case, the initial impact information is lost except for the initial droplet size, which would correlate to the final diameter of the circular edge characteristic. Part of any forensic analysis of blood spatter would be to recognize if the impact process in question behaved in accordance to this working definition. Otherwise, there would be little point in proceeding further because most of the initial conditions of the droplet impact would be obscured [19]. By releasing a drop of blood, the blood drop has to deal with gravity and air resistance. The higher the blood drop is released, the higher its own speed becomes vertically downwards. Up to the point, the downwards force is equal to the air resistance, the bloodstain reaches its terminal velocity**.** As soon as this drop enters the air stream, it receives external energy due to the enormous force**.** Figure 3 shows a schematic representation of a blood droplet and the forces (gravity and external forces).

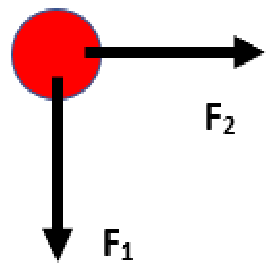


Figure 3, A schematic representation of gravity, velocity and energy on a drop of blood. Here F1 is gravity and F2 is the external energy (wind force).

High-speed camera

The investigation of the features of drop formation is complicated by the small time and spatial scales [14]. Due to relativity small sizes and high velocities of typical blood drips it is also a challenge. High-speed imaging is capable of capturing events with short time frames [20]. High-speed photography can be considered as the opposite of time-lapse. Due to the extreme number of frames being shot in a very short time, the camera cannot capture enough light. Backlighting is a simple used technique capable of providing images with high contrast, which is important if the object's shape and/or size of interest. The blood drop size, velocity and shape characteristics are one of the major parameters of interest for blood spatter investigation. For accurate qualitative analysis of the spatter by means of high-speed imaging a high-quality photographic images are essential.

3. Strategy

Goal

The aim of this research is to find to what extent does wind influence a free-falling blood droplet (deformation) and the trajectory. This will be achieved by creating a small wind tunnel to recreate an environment. The blood droplet will be captured by a high-speed camera. The results on the substrates will be photographed with a normal camera. Different variables will be included in the results. With a special measuring device, accurate numbers come out of the appliance over the aerodynamics. Before the experiments will start, a power analyse will be carried out. The results will be analysed and conclusions will be drawn from the analysis.

Strategy

Before results will be achieved, the wind tunnel must first be assembled. A small white wind tunnel will be built. The wind will be simulated by a compressor and this air is blown into the wind tunnel from a narrow hose. The average wind force in the Netherlands is between three and eight, scale of Beaufort [21]. By pipetting or making impact patterns, blood drops are released in the wind tunnel, here the blood drops will follow their own path. The impact patterns are simulated by a blood jet. In the methodology an extensive version is written about how the wind tunnel will be assembled and which parts are present. All dimensions and set-up are chosen with the reason that this study is a basis research. This investigation is framed, due to the limitations of time and requirements. The wind tunnel will be also used for the impact patterns (made by a blood jet). The blood droplets fall in the wind flow and land somewhere in the tunnel on a floor tile or wall. Different variables are chosen for this study and will be examined. The variables that are chosen, can be linked to certain sub-questions that were asked in advance of the research, to be read in the introduction: research questions. The variables of this study are: weight/volume of the blood droplets, height at which the blood drop will be released, speed of the blood drop, the impact of the blood drop, and the force/speed of the compressor mimicking the wind. Table 3 gives an overview of all variables with the selected components and explanations.

Table 3, Explanation of variables with the selected components.

Variables	Description
Weight / Volume of the blood droplets	Needle (1,1 mm), Small Pipet (3,5 mm) and a Pipet (5,0 mm)
Height Releasing the blood droplet	25 cm – 50 cm – 75 cm – 100 cm – 150 cm – 200 cm
Speed of the blood droplet	Maximum speed resulting from the selected height
Impact of the blood droplet	Passive droplets or impact
Scale of Beaufort	Scale of Beaufort (force) between three and eight

Variation of the pipettes can change the weight, volume and size of the blood drop. This way, different sizes of blood drops are taken into account, which can occur at a crime scene, depending on the crime. The chosen heights can be combined with practical examples, for example in the case of lying, sitting and standing victims. The different speeds of a passive drop will be achieved by varying the height. These speeds can be compared with crimes in practice. The impact of the blood drop depends on its own speed and force. A passive drop only has the force of gravity, but a drop coming from an impact pattern has an additional force. Those can be compared to a ray of blood or the use of a mechanism. A wind meter can measure the speed, according to six forces, scale of Beaufort. This wind meter is waterproof, has an accuracy of 3% and can display both average and maximum speed. Another advantage of the Skywatch Eole was that its 3D rotor system (instead of blades or cups) makes it entirely dependent on the wind direction) [22].

Table 4 shows an overview where each variable is linked to a sub-question. A brief description is given of the sub-question and the effects.

Table 4, Each variable is linked to a sub-question with a small explanation of its importance for this research. The height and speed of the own droplet is merged.

Variables	Reason for research and sub-question
Weight / Volume of blood droplet	Sub-question 5 | Size of blood drop depends on volume, to which the weight can be linked again. Volume of drops are important for the examination and assumptions.
Height releasing blood droplet | Speed droplet	Sub-question 2 | The higher a blood drop is released, the more velocity this blood drop gets. . The higher the blood drop is released, the higher its own speed becomes vertically downwards. Up to the point, the downwards force is equal to the air resistance, the bloodstain reaches its terminal velocity**.** A drop's own speed can change a pattern.
Impact droplet (Passive or impact)	Sub-question 2 | The higher a blood drop is released, the more velocity this blood drop gets. . The higher the blood drop is released, the higher its own speed becomes vertically downwards. Up to the point, the downwards force is equal to the air resistance, the bloodstain reaches its terminal velocity**.** A drop's own speed can change a pattern. External energy can also have an influence on this. Sub-question 3 | Own speed influenced by external energy and its trajectory.
Scale of Beaufort (Wind force)	Sub-question 1 | The action of wind on objects and external phenomena. Sub-question 4 | Wind can be a large external energy, which can influence gravity and its trajectory.

With a high-speed camera, the trajectory of the blood drop and the formation will be recorded. The deformation and the trajectory of the blood drop can be better mapped out, by filming with a high-speed camera. Due to the extreme speed, it is not possible to capture it with a normal camera. While filming with the high-speed camera, two studio lights are used to increase the contrast with the drops. Due to the extreme number of frames and shooter speed, there is only a limited absorption of light. By letting the environment consist of white material, there is a lot of reflection of light. The results on the floor tiles are photographed and used for the results. All photos are saved raw, to prevent losing details. For the publication, JPG photos will be used. Fixed arrangements are used for photographing and filming, as a consequence, no factors can change in the results.

For this study, only blood of mammal origin (cow) with EDTA will be used. Mammal blood is chosen because it comes from one donor, can be stored for a long time and remains consistent. EDTA stands for ethylenediamine tetra-acetic acid and is an anticoagulant in blood collection tubes: the free calcium in the plasma is bound by EDTA. Calcium is necessary for blood coagulation, if the calcium is taken from the blood by EDTA it will inhibit clotting. This keeps the blood liquid and could be used for analysis [23]. Before starting the experiments, the blood will be centrifuge in order to prevent clots, which could have arisen when it is stored in the freezer. The temperature of the blood will be 21 degrees Celsius while using it in the wind tunnel. During the experiments, the blood will be kept stirred. Between uses, the blood will be kept covered with freshly wrapped foil, at a temperature of 5 degrees Celsius. By covering it, the amount of oxygen is limited, this allowed to use the blood longer without bacteria.

Hypothesis

Three hypotheses have been drawn up for this research, which will be examined. All the hypotheses will be examined on the passive and impact droplets.

Hypotheses 1:

The blood drop (liquid) is actually deformable by external energy. Depending on the amount of external energy (wind force) the blood drop will deform in the air and eventually on the surface.

Hypotheses 2:

The blood drop will split through the wind and movement in the air. The blood droplet will enter the air as a ball formation, spherical shape, but due to the energy, gravity and viscosity it will split into multiple drops and come down as multiple blood spatters on the surface.

Hypotheses 3:

The blood drop will change direction in the trajectory due to the external energy and gravity. The energy will be variable, depending on the wind force. The energy on the blood drop will cause the trajectory the blood drop will normally travel to be modified.

4. Methodology

Wind influence on a blood droplet experiment

In order to achieve results, one set-up was made. A metal construction on both sides holds two white planks [1,2 meter long] together. Of one plank, a part has been cut out to place a glass plate [1 meter long] there. The glass plate allowed space and visibility to capture the drop with the camera [Sony RX10 III]. Three smooth white floor tiles [Sanitair Meijer, 30x60 cm] were used in the wind tunnel. Two floor tiles in the wind tunnel, and one floor tile at the end of the tunnel. In total, the length of the tunnel was 180 cm long. Behind the last floor tile, there was a wall. The wall was covered with white paper, to catch the droplets if the wind tunnel was not long enough. The top of the wind tunnel was open. At the front of the tunnel, a construction was placed that could continuously and gradually blow air into the tunnel. The scale of Beaufort (force) was simulated by a turbine compressor. The compressor blew air through a plastic blue ribbed hose; the end of the hose is made from metal. An adjustable stand was standing five centimetres in front of the compressor. By moving the compressor further away, the scale of Beaufort decrease. The stand of the pipettes was fixed to a table, so no movement was possible. Figure 4 shows a representation of the set-up that was used.

Figure 4, Setup for Blood droplet experiment. On the right is the compressor placed in to a stand with a fixed mechanism. The wind is blown into the wind tunnel of different distances to imitate the correct wind force. Blood drops are release from the pipette, which will follow a trajectory in the wind tunnel. The wind tunnel has a maximum distance of 180 centimetres with a vertical rigging behind it where blood drops can be collected on a white background. The needle can be replaced by three other pieces that vary in volume.

The heights of the pipettes vary. A blood drop was released at six different heights: 25 cm - 50 cm - 75 cm – 100 cm – 150 cm – 200 cm. In addition, different pipettes were used in this experiment. Three different pipettes were used: a needle (1,1 mm), pipette (3,5 mm) and a bigger pipette (5 mm). Before the blood drop fell into the wind tunnel, the weight/volume of the blood drop was weighed adequately. The weight was calculated by dropping drops of blood on scales. In Appendix F, more details about the calculation of the weight are given.

Under the stand of the pipettes in the wind tunnel, a Skywatch Eole wind meter was placed. The wind meter displayed the wind speed/power that was used. Measuring the different speeds could be linked to a wind force. The blood drop was released from the pipette and needle (different sizes) and continued its way into the wind tunnel. By using a laser, the exact position could be determined. The same method was applied to an impact pattern. To create an impact pattern, a jet of blood was pipetted into the wind tunnel under force (emptying a needle). The ray (individual drops) was exposed to two external energy's. In the case of an impact pattern, an external force was created only at a height of 25 centimetres. In addition, only wind force six was used to provide a realistic representation. To compare the impact pattern with an impact pattern without external energy (wind), blood was applied outside on an ice hockey puck, same amount, which was then beaten with a rubber hammer. An impact pattern was created on a floor tile, because of the enormous force on the bloody puck.

Mammal blood was used in all experiments. Especially in the experiment the blood was centrifuged in a mixer to remove all lumps or clots, then this was sieved. The "clean" blood was used for the experiments. This blood was stirred to prevent clot formation or clotting. Between all experiments, all floor tiles were cleaned with cold water and bleach. These were dried with paper.

Photographing and filming

All results in the wind tunnel were photographed with a Sony RX10 III camera. A fixed arrangement was used for this, so that the photos were all exposed equally well. Two photographing lights were used for optimal illumination. Table 5 the settings are shown that were used photographing the floor tiles.

Table 5, An overview with all used settings for the camera setup.

ISO	Aperture	Lens setting
800	6.3	50

During the experiment a high-speed camera was used. The high-speed camera was able to record short time frames, capturing relatively small sizes and high velocities of typical blood drops. For this experiment, the Sony RX10 III was used to capture the blood drops. Sony RX10 III is a full frame camera. The camera was placed at an angled angle at the beginning of the tunnel. The camera had a range of two floor tiles to capture. Two photo studio lamps shone [6500 kelvin – white light] from above to create a good contrast with the drop of blood. A fixed arrangement was used for filming the volume of the drops, so that the photos were all exposed equally well, shown in Table 6.

Table 6, An overview with all used settings for high-speed captures of the volume from a droplet and filming the deformation.

ISO	Aperture	Distance camera
800	5.0	42 cm

Statistical calculations

After the first results have been obtained, a power analysis was carried out. This analysis ensures that sufficient results were ultimately achieved on the basis of a standard deviation. Therefore, the calculations are more reliable and the research more reproducible.

$$calculated\ sample\ size = (\frac{current\ SD}{desired\ SD})^2 * current\ sample\ size$$

Appendix E will give more details about the calculations of the power analysis. Table 7 shows the average of the power analysis. According to the calculations, an average of four samples should be carried out for accurate calculations and results.

Table 7, The average of the power analysis with 108 the number of experiments

Number of experiments	Average Power Analysis
108	3,07

5. Results

The aim of this research was to find to what extent does wind influence a free-falling blood droplet (deformation) and the trajectory. Therefore, the research is divided into three parts, of which the results will be shown in this chapter.

As can be read in the method, the wind tunnel consisted of several substrates. In the wind tunnel, for example, there were three floor tiles and behind them there was a wall. A total of four parts on which blood spatters could end up. All the results can be found in Appendix G. Only the floor tiles that actually had bloodstains on them are visible here, other floor tiles have been omitted for the overview. The height and scale of Beaufort are displayed to the left of the images.

Scale of Beaufort

A certain amount of air is blown into the wind tunnel. This wind is again equal to a certain wind force. The further the wind is in the tunnel, the more the speed decreases. Figure 5 displays a graph of the scale of Beaufort (force) on each floor tile in the tunnel. In Appendix C, more details about the calculations of the wind force are given.

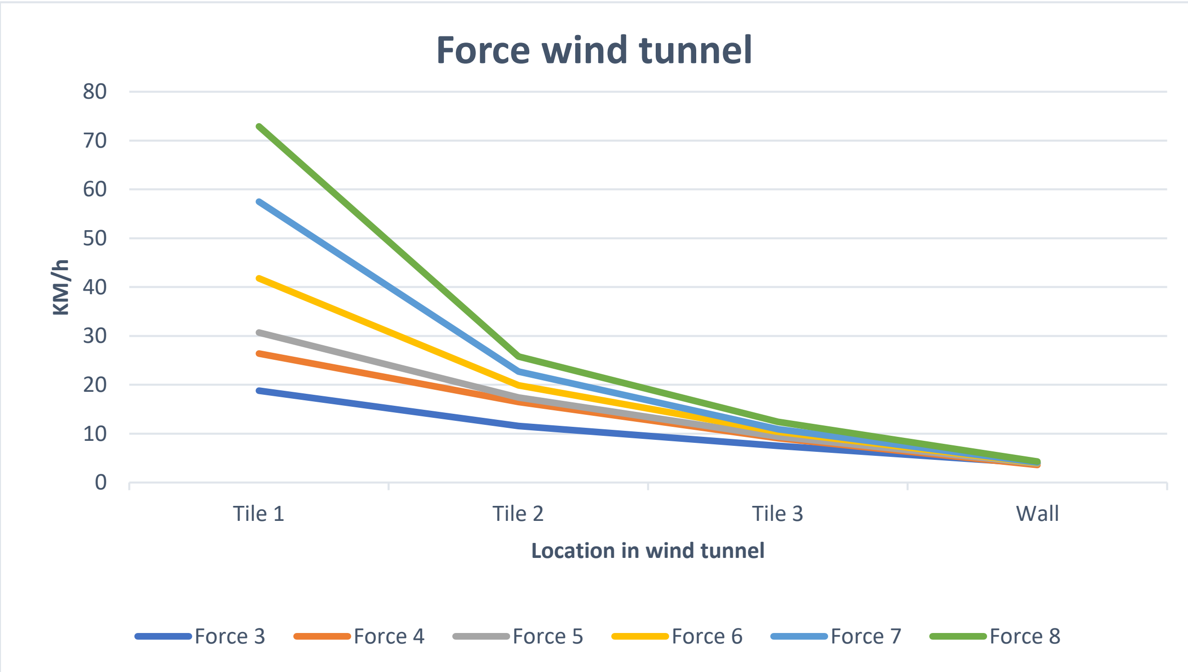


Figure 5, An overview of all the wind forces in the tunnel with the decreasing force of the wind as the distance increases. Vertically the wind in km/h and horizontally the distance in floor tiles used during the study.

The graph shows that the wind decreases in the wind tunnel because the compressor does not have the range to the end. At the second floor tile, all the wind forces decrease and before the second floor tile most of the blood drops touched the surface. At the wall, the wind force (wind speed) was not very high, but blood drops could still end up perpendicular to the wall. Table 8, Table 9 and Table 10 give an overview of the scale of Beaufort (force) and the blood droplet touching the floor tiles of the wall. The relation between the force, blood droplet and the results, are relating to the deformation of the de droplet and the trajectory that changed because of the external forces. If the droplet hit the wall, the height of the release is shown in the table. Especially the lower altitudes where a drop of blood was released, could travel a longer distance.

Table 8, Overview of the deformation and distance travelled of a passive blood drop, needle volume, at different wind forces.

Scale of Beaufort	Needle 1.1 mm deformation	Blooddrops on the wall	Height releasing (cm)
0	NO	NO	
3	NO (only a satellite from the pipette)	NO	
4	YES	NO	
5	YES	NO	
6	YES	YES	50
7	YES	YES	50/100
8	YES	YES	25/50/75/100

Table 9, Overview of the deformation and distance travelled of a passive blood drop, pipet 3.5 volume, at different wind forces.

Scale of Beaufort	Pipet 3.5 mm deformation	Blooddrops on the wall	Height releasing (cm)
0	NO	NO	
3	NO (only a satellite from the pipette)	NO	
4	YES	NO	
5	YES	NO	
6	YES	YES	25
7	YES	YES	25/50/75/150
8	YES	YES	25/50/75/100/150

Table 10, Overview of the deformation and distance travelled of a passive blood drop, pipet 5.0 volume, at different wind forces.

Scale of Beaufort	Pipet 5.0 mm deformation	Blooddrops on the wall	Height releasing (cm)
0	NO	NO	
3	NO	NO	
4	YES	NO	
5	YES	NO	
6	YES	YES	50
7	YES	YES	50/100
8	YES	YES	25/50/75/100

Volume and deformation

For the experiments, as explained in the methodology, three different pipettes were used. These pipettes vary because the diameter of the mouth differs, resulting in a difference in volume and therefore the weight of the blood drop.

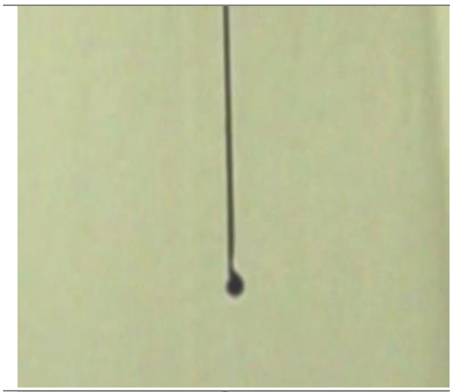
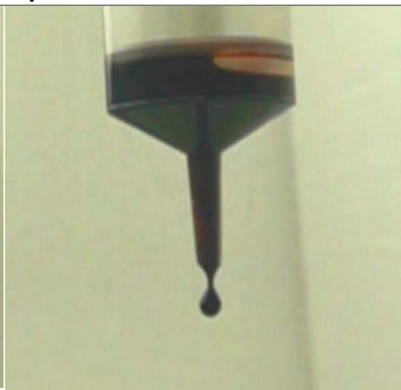
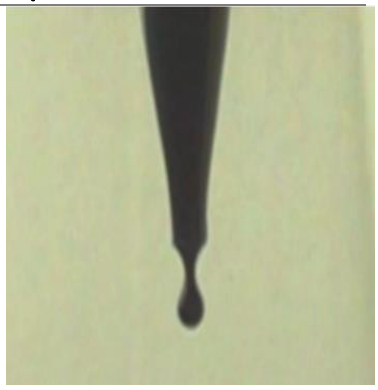
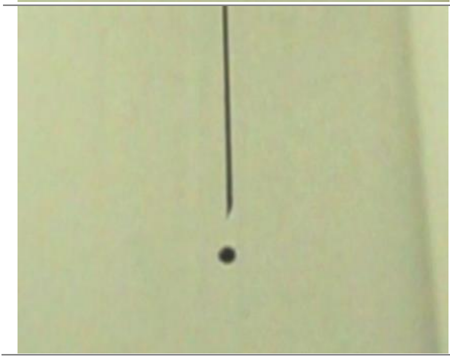
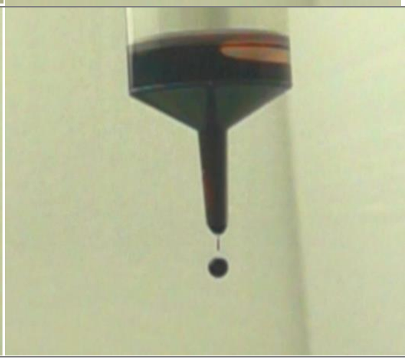
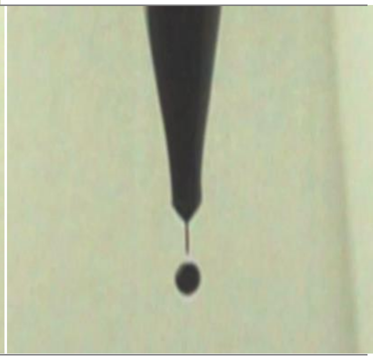
To determine the volume (size of blood drop), the weight was also calculated. The weight of the blood droplets, a test calculated carried out in duplicate, can be found in Appendix F. This weight was calculated by taking an average. The weight of twenty drops of blood was converted to one drop of blood. Table 11 shows the average weight of a blood drop.

Table 11, Average weight of a blood drop coupled to the corresponding pipette with size.

Pipet	Weight one droplet (milligram)
Needle (1.1 mm)	0.02
Pipet (3.5 mm)	0.06
Pipet (5.0 mm)	0.08

In addition, the blood droplet was photographed by filming the droplet releasing from the pipette. The volume of the droplet increases by the diameter of the mouth of the pipette. Table 12 shows the photographs of the volume from different pipettes.

Table 12, A close-up recording of the blood drop released by different pipettes. Two moments were photographed: drop with neck and free fall drop. From left to right: Needle 1.1 mm, Pipet 3.5 mm and Pipet 5.0 mm. Top to bottom: drop with neck and free-falling drop.

Needle 1.1 mm	Pipet 3.5 mm	Pipet 5.0 mm
		
		

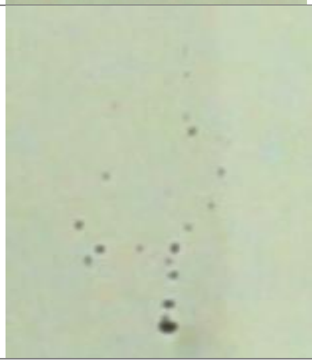
A passive drop of blood was released during the experiments in a wind tunnel. The wind (External energy) differed between wind forces three to eight, scale of Beaufort. Appendix C contains a table with the corresponding speeds and descriptions of these forces. The blood drop enters the air stream like a ball formation, spherical shape, but due to the energy, gravity and viscosity, this drop splits in multiple blood spatters that descend on the surface. The blood drop (liquid) was actually deformed by external energy. Depending on the volume of the blood drop and the wind force exerting on the blood drop, deformation occurs. The larger the blood drop (volume), the more satellites are created at the junction of the original drop. Depending on the amount of external energy (wind force), the blood drop will deform in the air and eventually hit the surface. In addition, the external phenomena, the results, also depend on the volume. A blood drop with more volume (pipette 5.0), shows larger drops on the floor tiles than a smaller volume (needle). Due to the fact that a needle has a very small volume, even smaller drops are popped apart by external energy. For the pipette applies, larger volume in which external energy blows the blood drop apart in large and small drops. Table 13 and Table 14 shows the deformation of a large drop of blood. It shows that small but also large drops of blood are formed.

The deformation of a droplet due to the external energy (scale of Beaufort – wind force) happened in a split second, which was hardly visible with the bare eye and impossible to photograph with a normal camera due to the frames and speed of the camera. Using a high-speed camera, it was possible to capture the deformation in the air and the moment the droplet spilt into several spatters. Four seconds of filming, with a lot of frames, the image (pause of the video) is grainy. This may cause the photos to appear blurry. In Table 13 and Table 14, the deformation of nine photos is drawn. From the moment of a ball formation, spherical shape, to the deformation: split into several blood spatters (large, small and mist).

Table 13, An overview of the deformation of a droplet with external energy. From left to right the deformation in steps. One single droplet split into several spatters with different volume and size. Pipet 5.0 with scale of Beaufort 8.

Deformation droplet	**High-speed captured**	
		
		
		

Table 14, An overview of the deformation of a droplet with external energy. From left to right the deformation in steps. One single droplet split into several spatters with different volume and size. Pipet 5.0 with scale of Beaufort 4.

Deformation droplet	**High-speed captured**	
		
		
		

As one drop of blood explodes into several small blood spatters, an impact pattern is created on the surface. Figure 6 shows an example of deformation and its appearance on a surface. In this case, one blood drop is split into several blood drops (large, small and mist). The floor tile shows larger drops of blood, smaller satellites with tails and tiny drops, also known as mist. An impact pattern can consist of different blood spatters: large, small and mist. Due to the external force the droplets all take their own direction. In addition, it can land not only on the surface, but also on the end and the walls of the tunnel. Figure 7 and Figure 8 show two floor tiles with a blood spatter pattern on them. In Figure 7, multiple drops (blood jet) with wind force (scale of Beaufort) six where released into the wind tunnel. Floor tile 2 in the wind tunnel is highlighted in Figure 7. To be seen in the picture: Different blood spatters with different directions, angles and sizes. Figure 8 shows a floor tile on which an impact pattern has been made by a mechanism (rubber hammer on a bloody ice hockey puck). To be seen in the picture: different blood spatters with different directions, angles and sizes. Two different external energies (Figure 7: scale of Beaufort on a droplet and Figure 8: impact from a mechanism on a bloody object) have the same outcomes with relation to external phenomena. Assumptions about external energy depend on the location and other findings that can be made at the crime scene. Wind (external energy, example figure 7) can be excluded or included in the report and conclusions.

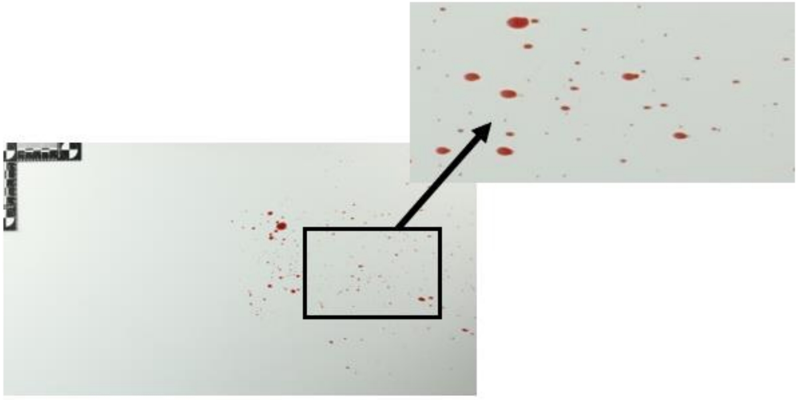


Figure 6, Influence of wind on a blood droplet with a scale of Beaufort 8, volume of pipet 5.0 on a height of 100 cm. One single droplet explodes into several blood spatters on the floor tile. The ball formation, spherical shape, splits in multiple spatters due to energy, gravity and viscosity. Single blood droplet split into several drops: large, small and mist. Energy direction is from left to right.

Figure 7, A pattern created by several blood drops (blood jet) released at wind force 6 in a wind tunnel. Floor tile 2 is highlighted in this image. Different directions of the blood drops with different sizes can be recognised. Only large blood drops can be found on floor tile 1. Energy direction is from left to right.

Figure 8, A pattern created by a mechanism (rubber hammer) that struck a bloody ice hockey puck. Different directions of the blood drops with different sizes can be recognised. Energy direction is from left to right.

Trajectory

Blood behaves according to the laws of physics. When in liquid phase and in motion, the properties of blood can be described according to the laws of physics, in particular those of ballistics. The blood drops were released at different wind forces and heights. This made it possible to look as widely as possible in a limited investigation. The external phenomena depend on the speed of the blood drop and the external energy that exerts force on the drop, which causes deformation. The results show that the drops are less affected by the wind when their own speed is high. This means that the blood drop, which is released from a higher altitude, is less affected by the external energy. The blood drop does split into several drops in the air, but the trajectory of the blood drop is less affected. The blood drop will travel a smaller distance because its own energy is pressed into the "ground" and the blood drop will therefore end up on the surface sooner. The blood drops are more likely to descend to the surface. Due to the turbulence that comes into existence, the droplets get their own direction and so it can land not only on the surface, but also on the wall and the walls of the tunnel. See Table 15, Table 16 and Table 17 for an example of the influence of height in combination with external energy (wind). This shows the floor tiles in the tables that contains blood spatter from the experiment (linked to height and pipette). The tables show that the higher the blood drop is released, the more own energy the blood drop has downwards and is therefore less influenced by the external energy (wind).

Table 15, Blood drop released from different heights at wind force 8. From top to bottom: 25 cm and 200 cm. The photos show the result on the floor tiles of the wind tunnel. Because a blood drop of 200 cm has more speed of its own, external energy has less influence on the distance travelled. The blood drops are more likely to descend to the surface.

Scale of Beaufort | height | Pipet	Results
Force 8 | 25 cm | Pipet 5.0	
Force 8 | 200 cm | Pipet 5.0	

Table 16, Blood drop released from different heights at wind force 8. From top to bottom: 25 cm and 200 cm. The photos show the result on the floor tiles of the wind tunnel. Because a blood drop of 200 cm has more speed of its own, external energy has less influence on the distance travelled. The blood drops are more likely to descend to the surface.

Scale of Beaufort | height | Pipet	Results
Force 8 | 25 cm | Pipet 3.5	
Force 8 | 200 cm | Pipet 3.5	

Table 17, Blood drop released from different heights at wind force 8. From top to bottom: 25 cm and 200 cm. The photos show the result on the floor tiles of the wind tunnel. Because a blood drop of 200 cm has more speed of its own, external energy has less influence on the distance travelled. The blood drops are more likely to descend to the surface.

Scale of Beaufort | height | Needle	Results
Force 8 | 25 cm | Needle	
Force 8 | 200 cm | Needle	

The purpose of a bloodstain pattern is to test hypotheses that may explain part of the circumstances of a possible bloodshed activity. This takes place on the basis of information obtained from research into the location, shape and extent of blood traces. In addition, a detail was spotted at various results. This phenomenon emerged with various results. Based on the shape of the blood spatter that occurs when the drop hits a surface, one can determine the direction in which the blood drop moved. A bloodstain points in the direction in which the blood has moved.

Blood trail patterns are predictable and reproducible. The results clearly show the direction of the blood. Due to the turbulence that has occurred, a drop of blood has split into small droplets that follow its own trajectory. Most of the blood spatter lands in the direction in which the compressor blows the air. These droplets vary in size due to the splitting caused by the external force. The droplet changes by deformation. As shown in Figure 9, a floor tile is highlighted (needle: Height 150 cm). Two blood spatters have been highlighted in the image. The lower one in a blood spatter that takes on a tail in the direction of the right. This is correct according to physics, mathematics calculations. The upper blood spatter, on the other hand, is not correct. It has a tail at the front and a satellite at the back. On multiple substrates and multiple results, this satellite can be recognized among all the other blood spatter. In Appendix G: photos of the Needle over 75 cm (wind force four or higher), Pipette 3.5 over 25 cm (wind force four or higher) and Pipette 5.0 all can be recognised (wind force four or higher). This satellite can be explained because the energy in the satellite was so big that it actually rolled over the surface and was not pressed into the ground until later. The wind ensures that the airflow is not laminar, which means that there can be rotations that can cause blood drops to fall. With a higher wind force, the external energy (wind) has more influence on the blood drop and its trajectory, which can change patterns and make assumptions and conclusions more difficult. Due to the extreme amount of energy in a small drop, together with the turbulence that causes the blood drop to change its trajectory, the blood drop can first end up with the tail and then with the blood splash. It cannot be excluded that at lower altitudes with a wind force higher than four this cannot be found. In all samples with smaller heights, it has not been found, but perhaps with a different turbulence it can be found. In a control experiment with an impact pattern made without wind, this special satellite can also be found. The external energy (force on a drop of blood) is an explanation for this satellite. The drop of blood rolls through and only later ends up "still" on the surface, leaving a tail first. The bloodstain has a linear shape which can indicate it was produced in a different direction. A cast-off pattern can be given as an explanation.

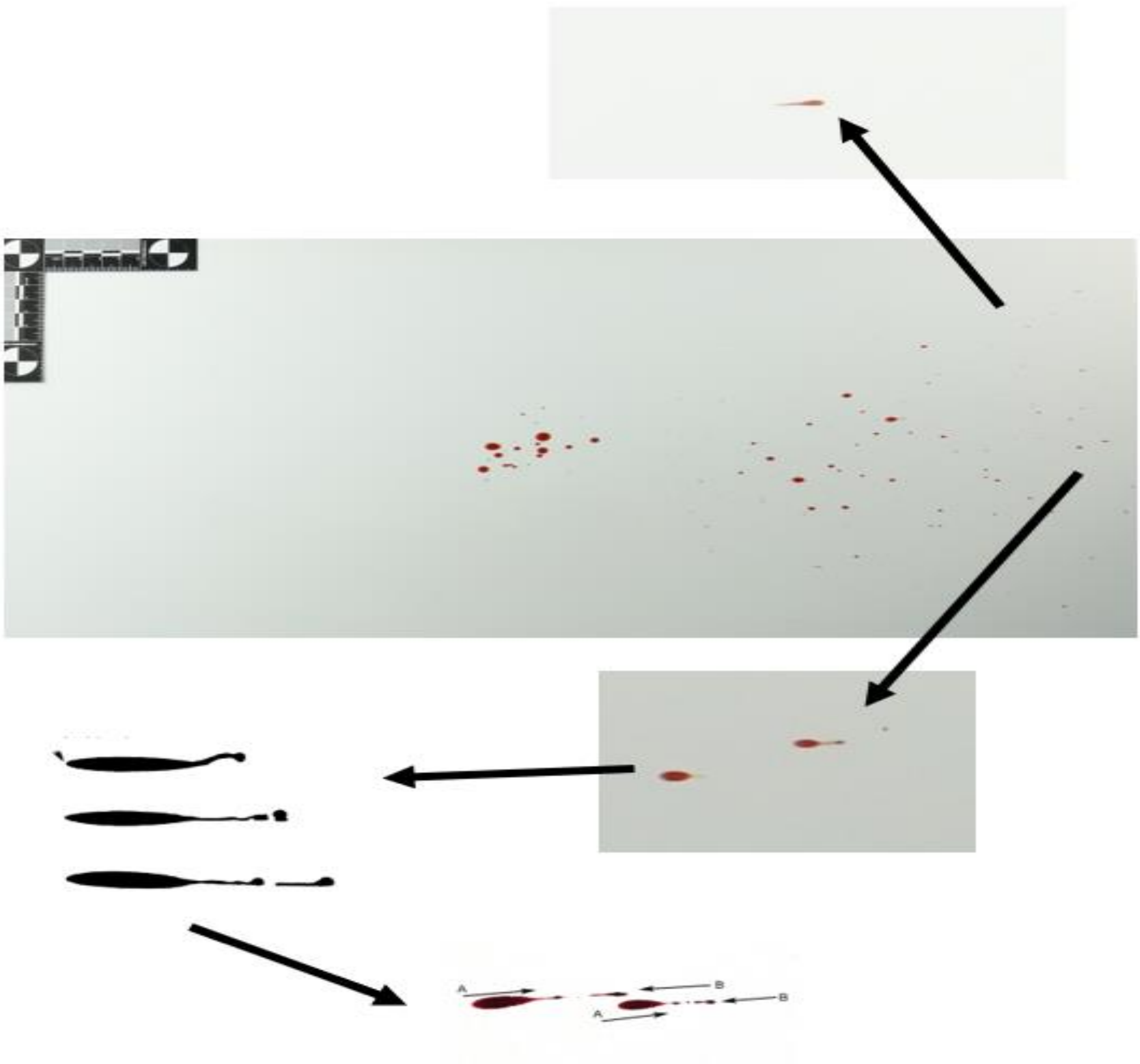


Figure 9, A floor tile highlighted with several blood spatters. The large image consists of two parts: the lower photo (normal blood spatter, elliptical shape) and the upper photo (linear result). At the bottom of the photo, a schematic representation is given of how a drop of blood comes down and how the energy is distributed. The upper photo shows a blood spatter which, according to physics and mathematical calculations, cannot be calculated towards the original source [14]

6. Discussion

The aim of this research was to find to what extent does wind influence a free-falling blood droplet (deformation) and the trajectory. The goal of the research has certainly been achieved. Before starting the research, three hypotheses were made. ***Hypotheses 1:*** The blood drop (liquid) is actually deformable by external energy. Depending on the amount of external energy (wind force) the blood drop will deform in the air and eventually on the surface. ***Hypotheses 2:*** The blood drop will split through the wind and movement in the air. The blood droplet will enter the air as a ball formation, spherical shape, but due to the energy, gravity and viscosity it will split into multiple drops and come down as multiple blood spatters on the surface. ***Hypotheses 3:*** The blood drop will change direction in the trajectory due to the external energy and gravity. The energy will be variable, depending on the wind force. The energy on the blood drop will cause the trajectory the blood drop will normally travel to be modified. The hypothesis that was drawn are correct, based on this research. Recommendations will be made in order to further support (accredit) the achieved results.

There are some limitations to this research which should be kept in mind. At first, some methods and strategies were changed due to the Covid-19 virus. The original plan was performing the research with human blood without EDTA. On Behalf of the Covid-19 virus, it was not possible to take human blood. For the safety and hygiene of the researchers, mammal blood was ultimately used. Human and mammal blood are both a rheopectic pseudoplastic non-Newtonian fluid. Due to this, human and mammal blood is approximately the same, so the results were not significantly affected.

Prior to the study, a power analysis was carried out with test results to find out how many samples are needed to receive reliable results. This resulted in an average of four samples, taken from 108 different variables. This indicates that a reliable result can be given with four samples, but this depends on the position of the compressor. The compressor has a certain width that can supply it with air. Here the air is constant, but after 60 cm the power of the air decreases. The positioning of the compressor and pipette is very important. Because of this important positioning of the compressor and pipette, the reliability can be questioned whether the pipette and compressor actually had the same position each time. This also comes to the fore in the power analysis. The lower the height of the pipette, the better the analysis, in contrast to higher positions of the pipette. At each position, the pipette is read with a laser, but the droplet is released by a person who can apply varying force to the pipette or needle.

For this experiment, a compressor was used that supplies air to an airbrush. This air-brush, just like the compressor, can be accurately adjusted to the amount of bar and air diffusion. However, the compressor and airbrush had limitations to the exact wind speeds at the wind forces described in Beaufort's table. As the compressor cannot gradually give the same wind force for a long time, it was decided halfway through the experiment to replace the compressor for a turbine compressor. In between, a total of four compressors were tested on purpose, but not all of them could improve the results. This compressor has a larger area that disperses wind, furthermore this compressor continuously has the same wind force and amount of air that is blown through the wind tunnel. By changing the distance between the opening of the compressor and the pipette, the wind force decreases. This made it possible to test each wind force (wind forces three to eight) without being variable. As a result, the experiment remained reproducible. As the wind force was not constant over the entire wind tunnel with any compressor, measurements were linked to the height and volume of the droplets to test the air force during the flight path. Unfortunately, as a result, the results can vary with the reality in the open air. After prolonged use of the turbine compressor, the air that comes out becomes warmer in temperature. This factor has not been included because there are many more experiments and variables attached to this factor; viscosity and environment [24].

Another limitation is the surface in the wind tunnel. In the wind tunnel, three loose white smooth floor tiles were laying, on which the blood droplets ended up during the experiment. These floor tiles were cleaned in between with cold water and a dash of bleach. After the experiment progressed, the floor tiles absorbed more moisture. As a result, some of the floor tiles slightly warped at the edges, so that the surface was no longer smooth. The producer of the floor tiles gives as an explanation that is could be a production error. This caused some satellites of the blood drop to get into the edges of the floor tiles. These satellites were not included in the photography and blood image analysis. However, these satellites may be important during the analysis. Nevertheless, it was not too great an obstacle, so no action was taken. In addition, only smooth non-absorbent substrates were considered during the experiments. Limited distance and limited angles have been used. However, research has shown that bloodstains have different effects on different surfaces, including different angles and distances [25] [26] [27]. Since it is a basic research, factors have been defined in advance in order to avoid time constraints or limitations. Therefore, the results cannot be applied to absorbent substrates that may occur at a crime scene. In addition, the top of the wind tunnel was open during the experiments. The top of the tunnel was left open for practical reasons, such as photographing the drop of blood. Nevertheless, no statements can be made about results achieved in a closed tunnel.

During the experiments, attention was paid to ensure that only one drop was released into the wind tunnel. While looking at the high-speed images (four sec, 1000 frames) it became clear that sometimes a satellite was released because the ligament did not bounce back into the pipette with a small drop. While photographing the individual floor tiles a satellite was spotted in some cases. In Appendix G, more cases are shown: Needle 25 cm + 50 cm, Pipet 3.5 50 cm +75 cm, Pipet 5.0 50 cm + 75 cm + 100 cm. However, on a crime scene, these satellites can also occur [28] [14]. The trajectory of the satellite as of the drop of blood has been changed by the wind, a certain distance travelled. Among the results, wind force and distance travelled, it was striking that at wind force seven, with regard to all pipettes and needles, certain heights were missing, while other lower or higher heights of release were mentioned. Reason for these missing heights may be that the blood drop did not fall into the correct flow of the compressor, or that it was given little speed to travel the distance.

7. Conclusion

This chapter contains the conclusion regarding the overall results from this study. First, the aim of this research is repeated. Afterwards, the results are listed from which a conclusion is drawn.

The aim of this research was to find to what extent does wind influence a free-falling blood droplet (deformation) and the trajectory. Therefore, several research questions were drawn up. It was examined by pipetting blood droplets, linked to different variables, into a wind tunnel where different wind forces could perform external energy on the droplet.

The results of this thesis show that wind has influence on the deformation of the droplet and the trajectory. Therefore, the hypothesis as stated in this thesis are supported. External energy (scale of Beaufort, force) causes the drop, enter the airstream as a ball formation, spherical shape, split into multiple drops and follow their own trajectory. The trajectory that the droplet(s) travels depends on the force projected on the droplet and the turbulence caused by the air flow behind the blood drop. From scale of Beaufort force four, the external energy on the blood drop was greater than the force of gravity which allowed it to disintegrate. The blood drop splits into large and small droplets resulting in an impact pattern on the surface. Here large and small bloodstains were found, but also a mist pattern that was spread over the surface. The patterns on the floor tiles, created by wind on a drop of blood), correspond to the patterns that can be created by an impact pattern, for example: external energy on bloody objects or persons. The same characteristics can be recognised: angles of blood drops, directions and external features such as sizes. Depending on the volume, the pattern varies. In addition, there are satellites (small) in both patterns that have the tail in the opposite direction to where the drop of blood went. The bloodstain has a linear shape, instead of an elliptical shape, which can indicate it was produced in a different direction. A cast-off pattern can be given as an explanation. The droplet has less energy in the surface instead of a droplet which create a bloodstain with an elliptical shape. As a result, this drop leaves first a tail and then a bloodstain on the surface.

The results show that the wind force decreases after about 60 cm and therefore the drop falls towards the ground. Depending on the consistency of the wind force, this distance can vary, which the blood drop can cover minimally and maximally. The blood drops could travel a maximum distance of 180 cm in the wind tunnel, but several drops were found perpendicular to the wall with a scale of Beaufort force six or higher. This proves that the blood drop could travel further than the maximum distance. The laws of physics are correct according to the results. The higher the speed of the blood drop itself, the less influence the external energy has on the trajectory. The distance the blood drop travels without its own energy is reduced when the blood drop does have its own energy. This also changes the deformation. Larger droplets emerge from one drop, in contrast to a drop that has little energy of its own.

Concluding, this research shows that wind has influence on a blood droplet and the trajectory. A blood drop (liquid) is deformable by external energy (scale of Beaufort (force)). External energy above scale of Beaufort force five can deform a passive drop of blood. The droplet enters the air as a ball formation, spherical shape, and will split into multiple drops. The external energy (scale of Beaufort, force), gravity (speed of the droplet) can lead to a different trajectory. The energy on the blood drop ensures that the trajectory the blood drop follows normally (according to laws or physics) is adjusted. In addition, the volume of the blood drop affects the characteristics on the substrate. The conclusions drawn from the study of the influence of wind on a blood drop underline the importance of good assumptions in a BPA investigation. In future, the influence of wind should be excluded or taken into account in BPA investigations that take place outside on crime scene. In addition, the results of an investigation are better substantiated and well explained during a comparative lawsuit.

8. Recommendation

In order to achieve even more improved results based on this study, the following recommendations are made.

A first suggestion for future research is the expansion of the wind tunnel. During this study, a limited wind tunnel was used. As a result, it was only possible to look at the distances covered by the blood drop to a limited extent. As well, all tests were written for a small wind tunnel, but practical cases were not included. Using a larger and wider wind tunnel, the results can extend with more data. As a result, more attention can be paid to a continuous wind force flow and the dispersion of all blood drops. It also allows more experimentation with impact patterns, running people or wind from multiple sides. Consideration could also be given to the fact that the tunnel can also be closed at the top. The University of Toronto (Canada) is happy to take over the research to carry out these tests on a larger scale in a large wind tunnel (specially made for aircraft).

For further research it is recommended to use human blood (COVID-19 proof). There are restrictions on the use of human blood (EDTA or no EDTA) and these must come from the same donor for reproducibility. Results that will emerge from the research can be better compared with reality, a crime scene. During the examination we used blood at room temperature, 21 degrees Celsius. Human blood normally has a temperature of 37.5 degrees Celsius. As a follow-up suggestion it is recommended to carry out experiments with human blood at body temperature.

In addition, the air blown into the wind tunnel became warmer after prolonged use. Therefore, the air could be warm at the moment the blood drops enters the air stream. However, when the droplets land on the ground, it could have a different temperature. As a follow-up suggestion, it is recommended to keep the air heat constant, this in combination with the changed viscosity, temperature of the blood drop and the height of release in a new examination.

The deformation of blood drops was recorded with a high-speed camera. However, the results were limited due to the fact that the high-speed camera could not get enough pixels. In order to capture the deformation even better, it is recommended to use better high-speed cameras. The University of Toronto (Canada) is happy to take over the research to carry out these tests on a larger scale in a large wind tunnel (specially made for aircraft). They have much better high-speed cameras that can capture the deformation from different angles.

The sample of this study consisted only smooth non-absorbent substrates (floor tiles). However, absorbent substrates are not included in this study, but can produce other results. For further research it is recommended to set up experiments with absorbent substrates, such as: carpet, clothing, but also substrates such as concrete and sand. On a crime scene, impact patterns can be created at different angles and at different distances. For further research, it is recommended to extend the experiments by adding different angles and distances in order to optimise and expand the results.

For a correct position, the pipette is read each time with a laser whether it is at the correct height and distance from the compressor and whether it hangs in the middle of the compressor. In this case, a person has operated the pipette or needle; varying forces may have taken place here. For further research it is recommended to build several wind tunnels with fixed positions for the pipette to prevent fluctuations in the pressure. In addition, it is recommended that the pipette be operated with a machine in order to maintain the correct force, direction of the pipette each time to release the blood drop.

Finally, it is recommended to disseminated the results of this thesis to the judiciary, police and universities. The results from this study can be a good addition to an advanced course. This can improve the BPA investigations and make it easier to justify cases in court.

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Appendix A

The Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) has developed and defined a list of recommended terminology for use in BPA.

- **Accompanying Drop**: A small blood drop produced as a by- product of drop formation.
- **Altered Stain**: A bloodstain with characteristics that indicate a physical change has occurred.
- **Angle of Impact**: The acute angle (alpha), relative to the plane of a target, at which a blood drop strikes the target.
- **Area of Convergence**: The area containing the intersections generated by lines drawn through the long axes of individual stains that indicates in two dimensions the location of the blood source.
- **Area of Origin**: The three- dimensional location from which spatter originated.
- **Back spatter Pattern**: A bloodstain pattern resulting from blood drops that travelled in the opposite direction of the external force applied; associated with an entrance wound created by a projectile.
- **Blood clot**: A gelatinous mass formed by a complex mechanism involving red blood cells, fibrinogen, platelets, and other clotting factors.
- **Bloodstain**: A deposit of blood on a surface.
- **Bloodstain pattern**: A grouping or distribution of bloodstains that indicates through regular or repetitive form, order, or arrangement, the manner in which the pattern was deposited.
- **Bubble Ring**: An outline within a bloodstain resulting from air in blood.
- **Cast-off Pattern**: A bloodstain pattern resulting from blood drops released from an object due to its motion.
- **Cessation Cast-off Pattern**: A bloodstain pattern resulting from blood drops released from an object due to its rapid deceleration.
- **Directionality**: The characteristic of a bloodstain that indicates the direction blood was moving at the time of deposition.
- **Directional Angle**: The angle (gamma) between the long axis of a spatter stain and a defined reference line on the target.
- **Drip Pattern**: A bloodstain pattern resulting from a liquid that dripped into another liquid, at least one which was blood.
- **Drip Stain**: A bloodstain resulting from a falling drop that formed due to gravity.
- **Drip Trail**: A bloodstain pattern resulting from the movement of a source of drip stains between two points.
- **Edge Characteristic**: A physical feature of the periphery of a bloodstain.
- **Expiration Pattern**: A bloodstain pattern resulting from blood forced by airflow out of the nose, mouth, or a wound.
- **Flow Pattern**: A bloodstain pattern resulting from the movement of a volume of blood on a surface due to gravity or movement of the target.
- **Forward Spatter Pattern**: A bloodstain pattern resulting from blood drops that travelled in the same direction as the impact force.
- **Impact Pattern**: A bloodstain pattern resulting from an object striking liquid blood.
- **Insect Pattern**: A bloodstain resulting from insect activity.

- **Mist Pattern**: A bloodstain pattern resulting from blood reduced to a spray of micro-drops as a result of the force applied.
- **Parent Stain**: A bloodstain from which a satellite stain originated.
- **Perimeter Stain**: An altered stain that consists of the peripheral characteristics of the original stain.
- **Pool**: A bloodstain resulting from an accumulation of liquid blood on a surface.
- **Projected Pattern**: A bloodstain pattern resulting from ejection of a volume of blood under pressure.
- **Satellite Stain**: A smaller bloodstain that originated during the formation of the parent stain as a result of blood impacting a surface.
- **Saturation Stain**: A bloodstain resulting from the accumulation of liquid blood in an absorbent material.
- **Serum Stain**: The stain resulting from the liquid portion of blood (serum) that separates during coagulation.
- **Spatter Stain**: A bloodstain resulting from a blood drop dispersed through the air due to an external force applied to a source of liquid blood.
- **Splash Pattern**: A bloodstain pattern resulting from a volume of liquid blood that falls or spills onto a surface.
- **Swipe Pattern**: A bloodstain pattern resulting from the transfer of blood from a blood-bearing surface onto another surface, with characteristics that indicate relative motion between the two surfaces.
- **Target**: A surface onto which blood has been deposited.
- **Transfer Stain**: A bloodstain resulting from contact between a blood- bearing surface and another surface.
- **Void**: An absence of blood in an otherwise continuous bloodstain or bloodstain pattern.
- **Wipe Pattern**: An altered bloodstain pattern resulting from an object moving through a pre-existing wet bloodstain.

Appendix B

BPA experts are often asked to report their findings to the court and to comment on particular scenarios of the evidence interpretation of relevance to defence or prosecution of a defendant with a high level of reliability and expertise required. The findings may potentially help to incriminate or exculpate a suspect and support or dispute witness' statements. Bloodstain interpretation is based on the understanding of the natural laws that govern formation of bloodstains. Bloodstain formation may be viewed as a sequence of events from blood drop generation and drop flight to its deposition on a surface. Bloodstains available for examination represent the end product of this sequence and implicitly contain the information about the events that led to its formation. At certain conditions this information can be extracted from the stain analysis in a form of the drop impact conditions estimates, such as, for example, the volume and velocity of the blood drop resulted in this bloodstain. If the phenomena involved in drop flight prior to impact on a surface as well as the characteristics of blood drop formation mechanisms relevant to BPA are known, the blood drop of the estimated size and velocity may, subsequently, be traced back to its possible origin.

Bloodstain pattern analysis is the study of the shapes, sizes and locations of bloodstains in order to determine the physical events which gave rise to their origin. A bloodstain pattern is a group or distribution of bloodstains that indicates through regular or repetitive form, order or arrangement the manner in which the pattern was deposited. Deposition of blood on a surface is a bloodstain. Some facts that are important during the analysis are:

- Blood will behave according to the laws of physics.
- Bloodstain patterns are predictable and reproducible.
- The appearance of a bloodstain depends on the surface on which it is deposited.
- A direction of movement can usually be told by the appearance of the bloodstain.

The examination of a bloodstain may determine by:

- Location of an impact.
- Minimum number of impacts.
- Mechanism of impact.
- Movement and direction of assailant/ victim and/ or objects while there was blood shed.
- Positions of persons and/ or objects during blood shedding.
- Sequence of events.

There are a few terms and concepts which are really important during the analysis. The surface tension, cohesion, adhesion, gravity, force / stain size, velocity / stain size and target surface. Cohesion is the intermolecular attraction between like – molecules, while adhesion the intermolecular attraction between unlike – molecules is. The gravity, mass and external force must overcome the adhesion and cohesion for drop formation.

Blood can leave the body in many different ways, depending on the type of injury inflicted. Bloodstains are divided in tree main categories: **Passive** bloodstains, **spatter** bloodstains and **altered** bloodstains. A passive stain include drops, saturation, free falling volume, flows and pools. They typically the results of gravity acting on an injured body. Transfer stains results from objects coming into contact with existing bloodstains and leaving wipes, swipes or pattern transfers behind. Spatter stains, also called impact stains, results from blood projecting through the air and are usually seen as a spatter, but may also include gushes, splashes and arterial spurts. The characteristics of blood spatter depends on the speed at which the blood leaves the body and the type of force applied to the blood source. Other spatter bloodstains are gunshot spatter, cast-off pattern and expirated spatters. Altered bloodstains could be clotted blood, diluted blood, dried blood, diffused blood, activity of insects and voids [13].

An area of origin is a three-dimensional location from which spatter originated (See Figure 10). The area will provide information about the approximate area of the victim during a bloodshed incident. A well formed bloodstain is considered to be a symmetrical bloodstain along its long and short axes. By examining the long axis of the ellipse, the directionally of the selected bloodstains can be determined. The tangent method can be used to find the area of origin.

In order to use this method, the investigator needs the following information about the impact:

- The angel of impact (width: length sin -1)
- Distance start
- Bloodstain to area of convergence (X-axis)

The height of the Z-axis (area of convergence to the area of origin) could be calculated. For example:

- Length bloodstain = 6 mm
- Width bloodstain = 3 mm
- Distance front bloodstain to area of convergence is 90 cm.
- Angel of impact = 3 : 6 x sin-1 = 30 degrees.

Z- axis = tan 30° x 90 cm = 51.96 cm. With all the calculated information, the investigator is able hang a ball on a cord from the ceiling to represent the area of origin. This prevents damage to the wall and does not cause strings to hang everywhere.

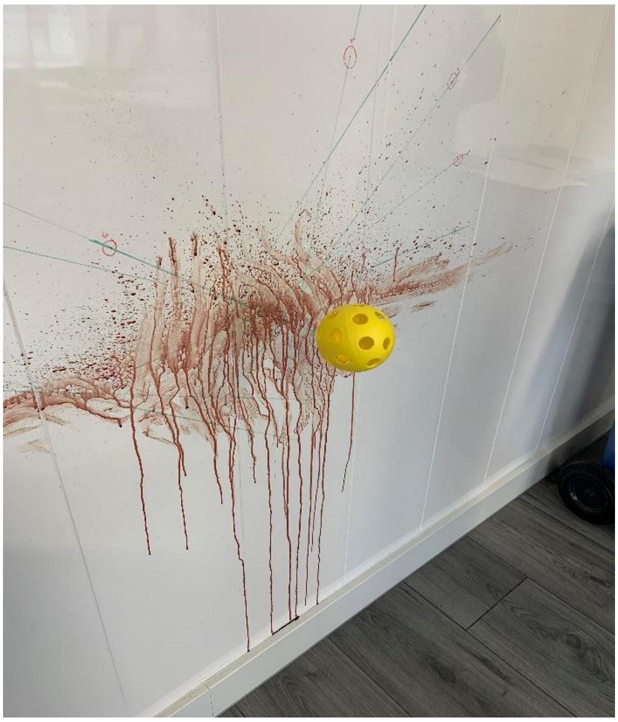


Figure 10, Tangent Method used in a BPA Course 2020. After calculations, the original source (area of origin) has been traced. The yellow ball is the original source, and behind the blood spatter pattern is shown.

Appendix C

The Beaufort scale is used to indicate the speed of the wind. It was established in 1805 by the Irishman Francis Beaufort. Its full name is the Beaufort wind force scale. Beaufort based the wind force on the amount of sail a large ship could carry in a weak breeze, storm or hurricane. The wind pressure was expressed in kilograms per square metre. The scale therefore applies to the pressure of the wind [21]. Between 1831 and 1835, the Beaufort wind scale was officially used during the Beagle expedition. The scale was mandatory since 1838 on all Captains and Commanding Officers of Her Majesty's Ships and Vessels. In the forties of the nineteenth century Beaufort became known for its wind scale. It was not until 1873 that it was internationally accepted. Beaufort did not experience this himself anymore and was unaware of the importance of his find. See Table 18 for more details about the scale [4].

Table 18, The Beaufort wind force scale.

Force (Beaufort scale)	Equivalent speed			Description	Specifications for use at sea
	mph	knots	km/h		
0	0–1	0–1	0–1	Calm	–
1	1–3	1–3	1–5	Light air	Ripples with the appearance of scales are formed, but without foam crests.
2	4–7	4–6	6–11	Light breeze	Small wavelets, still short, but more pronounced. Crests have a glassy appearance.
3	8–12	7–10	12–19	Gentle breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered.
4	13–18	11–16	20–28	Moderate breeze	Small waves, becoming larger; fairly frequent white horses.
5	19–24	17–21	29–38	Fresh breeze	Moderate waves, taking a more pronounced, longer form; many white horses are formed. Chance of some spray.
6	25–31	22–27	39–49	Strong breeze	Large waves begin to form; the white foam crests are more extensive everywhere. Probably some spray.
7	32–38	28–33	50–61	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.
8	39–46	34–40	62–74	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift. The foam is blown in well-marked streaks.
9	47–54	41–47	75–88	Severe gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over.
10	55–63	48–55	89–102	Storm	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. The whole surface of the sea takes on a white appearance. The "tumbling" of the sea becomes more immense and shock-like. Visibility affected.
11	64–72	56–63	103–117	Violent storm	Exceptionally high waves (small and medium-size ships might be, for a time, lost to view behind the waves). The surface is covered with long white patches of foam lying along the direction of the wind. Everywhere, the edges of the wave crests are being blown into froth. Visibility affected.
12	73–83	64–71	118–133	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.

Source: Kemp, 2011.

A certain amount of air is blown into the wind tunnel. This wind is again equal to a certain wind force. The further the wind is in the tunnel, the more the force decreases. Table 19 gives an overview of the wind force per floor tile (three floor tiles in total).

Table 19, An overview of the wind force per counter linked to the wind force emitted by the compressor. The number of kilometres per hour is measured with a skywatch, which can be converted back to forces using the scale of Beaufort. These are shown in brackets behind the number of kilometres per hour.

Wind force	Start floor tile 1	Start floor tile 2	Start floor tile 3	Start wall
3	18,8 km/h (3)	11,6 km/h (2)	7,5 km/h (2)	3,4 km/h (1)
4	26,4 km/h (4)	16,5 km/h (3)	9,1 km/h (2)	3,6 km/h (1)
5	30,7 km/h (5)	17,4 km/h (3)	9,4 km/h (2)	3,9 km/h (1)
6	41,8 km/h (6)	19,9 km/h (4)	10,4 km/h (2)	4,0 km/h (1)
7	57,5 km/h (7)	22,7 km/h (4)	10,9 km/h (2)	4,1 km/h (1)
8	72,9 km/h (8)	25,8 km/h (4)	12,4 km/h (3)	4,3 km/h (1)

Appendix D

Tanasawa and Tyoda (1955) characterized jet breakup regimes using the Jet number based on the jet inlet velocity v and density ρ a of surrounding gas (air). Dripping of a liquid from a nozzle occurs at Je < 0.1 . For $0.1 < Je < 10$ breakup occurs due to longitudinal jet oscillations (laminar and laminar to turbulent transition breakup). At $10 < Je < 500$ jet oscillates laterally. Due to the air friction narrow membranes and/or fine ligaments are formed on the jet surface which quickly separates into drops. After this spray regime follows when the jet core breaks up into fine droplets surrounded by larger droplets produced during the ligaments and membranes shattering [12].

The curve begins with a dripping region (OA) at low velocities. Once the jet is formed L increases with increasing jet velocity (AB) corresponding to a laminar jet. Here the breakup length also increases with the jet diameter, liquid density and viscosity and decreases with surface tension. At some point it reaches the maximum denoting the transition between varicose to sinuous jet breakup regime and/or dominance of air resistance according to Weber and/or the onset of turbulence. This transition point shifts to lower jet velocities for liquid with higher viscosity. The breakup length decreases with further increase in jet velocity (BC) where the flow in a jet changes from laminar to turbulent. Further along the curve L increases with the velocity up to a maximum value after which it stats to decrease with the jet velocity [12]. See figure 11 for the jet stability curve.

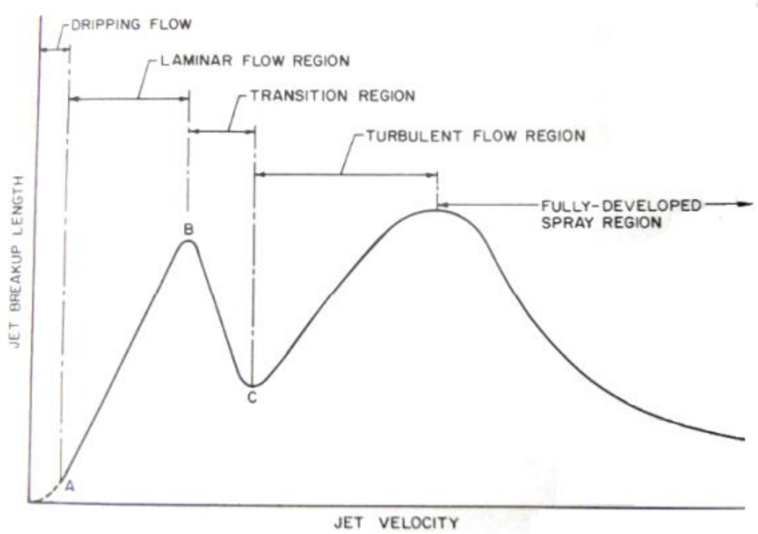


Figure 11, Jet stability curve

Appendix E

As indicated in the strategy, the number of samples have been predetermined. The samples have been calculated using the "test results" of a few drops.

After the first results have been obtained, a power analysis was carried out. This analysis ensure that sufficient results were ultimately achieved on the basis of a standard deviation. The consequence of this, makes the calculations more reliable and the research more reproducible.

$$calculated\ sample\ size = (\frac{current\ SD}{desired\ SD})^2 * current\ sample\ size$$

See Table 20, Table 21, Table 22, Table 23, Table 24 and Table 25 shows the number of power analyse and the standard deviation.

Table 20, Power analyse calculated; Force 3 on different pipette.

Variable Force 3 Needle 1.1	**Current SD**	**Desired SD**	**Current sample size**	**Samples need to be taken**
Height 25 cm	1,59	3,15	10	2,547
Height 50 cm	1,096	2,925	10	1,404
Height 75 cm	0,775	1,075	10	5,197
Height 100 cm	0,982	1,75	10	3,1488
Height 150 cm	1,131	1,967	10	3,306
Height 200 cm	0,783	1,93	10	1,6459
Variable Force 3 pipet 3.5	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	1,0983	4,28	10	0,658
Height 50 cm	2,120	3,74	10	3,213
Height 75 cm	1,088	2,83	10	1,478
Height 100 cm	1,773	2,53	10	4,911
Height 150 cm	1,045	2,17	10	2,319
Height 200 cm	0,653	1,21	10	2,912
Variable Force 3 pipet 5.0	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	0,717	2,55	10	0,790
Height 50 cm	0,885	1,2	10	5,439
Height 75 cm	0,248	1,05	10	0,557
Height 100 cm	0,873	1,725	10	2,5612
Height 150 cm	0,346	1,2	10	0,831
Height 200 cm	0,567	0,975	10	3,381

Table 21, Power analyse calculated; Force 4 on different pipette.

Variable Force 4 Needle 1.1	**Current SD Standard Deviation**	**Desired SD**	**Current sample size**	**Samples need to be taken**
Height 25 cm	1,247	6,9	10	0,3266
Height 50 cm	1,766	2,7	10	4,278
Height 75 cm	0,981	1,95	10	2,53
Height 100 cm	1,241	1,78	10	4,860
Height 150 cm	0,566	1,987	10	0,811
Height 200 cm	1,034	2,83	10	1,3349
Variable Force 4 pipet 3.5	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	1,262	4,36	10	0,8378
Height 50 cm	1,983	3,21	10	3,816
Height 75 cm	1,556	3,09	10	2,535
Height 100 cm	0,982	1,90	10	2,67
Height 150 cm	0,673	1,58	10	1,814
Height 200 cm	1,278	1,35	10	8,961
Variable Force 4 pipet 5.0	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	1,5509	3,0	10	2,672
Height 50 cm	2,096	3,3	10	4,034
Height 75 cm	2,633	3,15	10	6.986
Height 100 cm	1,53	2,2125	10	4,782
Height 150 cm	0,975	1,35	10	5,216
Height 200 cm	1,348	1,575	10	7,325

Table 22, Power analyse calculated; Force 5 on different pipette.

Variable Force 5 Needle 1.1	**Current SD Standard Deviation**	**Desired SD**	**Current sample size**	**Samples need to be taken**
Height 25 cm	1,8	6,75	10	0,711
Height 50 cm	1,33	2,85	10	2,177
Height 75 cm	1,788	3,375	10	2,8066
Height 100 cm	1,098	2,36	10	2,1646
Height 150 cm	1,66	2,34	10	5,0325
Height 200 cm	1,823	2,63	10	4,804
Variable Force 5 pipet 3.5	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	3,992	8,56	10	2,174
Height 50 cm	2,002	4,12	10	2,361
Height 75 cm	1,287	2,96	10	1,890
Height 100 cm	0,788	2,73	10	0,833
Height 150 cm	1,223	2,54	10	2,318
Height 200 cm	0,657	1,79	10	1,347
Variable Force 5 pipet 5.0	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	1,15	3,0	10	1,469
Height 50 cm	1,929	2,325	10	6,883
Height 75 cm	1,875	2,475	10	5,739
Height 100 cm	1,359	2,175	10	3,904
Height 150 cm	1,846	2,925	10	3,983
Height 200 cm	0,974	1,83	10	2,832

Table 23, Power analyse calculated; Force 6 on different pipette.

Variable Force 6 needle 1.1	**Current SD Standard Deviation**	**Desired SD**	**Current sample size**	**Samples need to be taken**
Height 25 cm	1,46	7,575	10	0,42
Height 50 cm	1,999	4,575	10	1,909
Height 75 cm	2,096	4,125	10	2,5818
Height 100 cm	1,533	2,47	10	3,852
Height 150 cm	0,973	2,17	10	2,01
Height 200 cm	1,557	3,32	10	2,19
Variable Force 6 pipet 3.5	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	2,019	6,74	10	0,897
Height 50 cm	1,813	4,68	10	1,5007
Height 75 cm	1,099	3,61	10	0,9267
Height 100 cm	1,802	4,12	10	1,91
Height 150 cm	0,667	2,70	10	0,6102
Height 200 cm	1,27	1,79	10	5,033
Variable Force 6 pipet 5.0	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	2,183	3,975	10	3,016
Height 50 cm	4,354	4,95	10	11,698
Height 75 cm	1,768	2,4	10	5,426
Height 100 cm	1,673	2,1	10	6,346
Height 150 cm	1,593	2,1	10	5,754
Height 200 cm	0,803	1,86	10	1,8638

Table 24, Power analyse calculated; Force 7 on different pipette.

Variable Force 7 Needle 1.1	**Current SD Standard Deviation**	**Desired SD**	**Current sample size**	**Samples need to be taken**
Height 25 cm	4,04	14,925	10	0,7327
Height 50 cm	2,987	4,725	10	3,996
Height 75 cm	2,346	5,025	10	2,179
Height 100 cm	2,113	4,38	10	2,371
Height 150 cm	1,967	3,48	10	3,194
Height 200 cm	2,019	3,15	10	4,108
Variable Force 7 pipet 3.5	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	3,673	6,81	10	2,909
Height 50 cm	3,111	5,58	10	3,108
Height 75 cm	2,698	5,13	10	2,7659
Height 100 cm	2,145	3,52	10	3,713
Height 150 cm	1,986	2,46	10	6,5176
Height 200 cm	1,071	1,8	10	3,54
Variable Force 7 Pipet 5.0	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	1,95	4,2	10	2,1556
Height 50 cm	0,529	2,325	10	0,5176
Height 75 cm	0,359	3,075	10	0,1363
Height 100 cm	1,148	3,0	10	1,464
Height 150 cm	0,479	1,857	10	0,652
Height 200 cm	1,305	1,87	10	4,87

Table 25, Power analyse calculated; Force 8 on different pipette.

Variable Force 8 Needle 1.1	**Current SD Standard Deviation**	**Desired SD**	**Current sample size**	**Samples need to be taken**
Height 25 cm	5,055	15,23	10	1,10
Height 50 cm	2,467	4,81	10	2,6305
Height 75 cm	2,87	6,375	10	2,026
Height 100 cm	2,09	4,595	10	2,0688
Height 150 cm	1,557	3,878	10	1,6119
Height 200 cm	2,987	4,38	10	4,650
Variable Force 8 Pipet 3.5	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	3,098	9,26	10	1,119
Height 50 cm	2,458	7,24	10	1,1526
Height 75 cm	2,15	4,96	10	1,8789
Height 100 cm	1,885	4,25	10	1,967
Height 150 cm	1,768	3,49	10	2,566
Height 200 cm	0,782	2,325	10	1,131
Variable Force 8 Pipet 5.0	Current SD Standard Deviation	Desired SD	Current sample size	Samples need to be taken
Height 25 cm	2,647	3,75	10	4,98
Height 50 cm	2,553	2,85	10	8,02
Height 75 cm	2,379	3,45	10	4,75
Height 100 cm	1,909	2,775	10	4,73
Height 150 cm	1,8879	2,1	10	8,08
Height 200 cm	1,348	1,95	10	4,778

Appendix F

This appendix provides more information on the weight of a blood drop linked to the diameter of a pipette. This weight can be used to improve reproducibility.

Calculation weight drops:

$$Calculated\ weight\ droplet = (\frac{Weight\ 10\ droplets}{10})$$

Control weight drop calculation:

$$Calculated\ weight\ droplet = (\frac{Weight\ 20\ droplets}{20})$$

Table 26 and Table 27 shows the results and weight of the calculation of de blood droplets.

Table 26, Overview and calculation weight of a blood drop linked to the diameter of a pipette. The weight of ten drops together has then been converted into one drop of blood. As a check on the ten drops, a calculation was also made on the twenty drops of blood that were pipetted into a cup.

Pipet	**Weight one droplet**	**Weight ten droplets**	**Weight twenty droplets**
Needle (1.1 mm)	0,018 / 0,0185	0,18	0,37
Pipet (3.5 mm)	0,069 / 0,0715	0,69	1,43
Pipet (5.0 mm)	0,079 / 0,0805	0,79	1,61

Table 27, Overview and calculation weight of a blood drop linked to the diameter of a pipette. The weight of one drop of blood has been measured on the scales. Then nine drops were pipetted and a weight for ten drops of blood came out. The same was done for the twenty drops of blood and their weight.

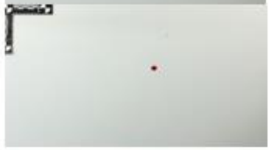
Pipet	**Weight one droplet**	**Weight ten droplets**	**Weight twenty droplets**
Needle (1.1 mm)	0,02	0,19	0,39
Pipet (3.5 mm)	0,06	0,66	1,36
Pipet (5.0 mm)	0,08	0,83	1,70

Appendix G

Needle 25 cm

Force 0

Force 3



Force 4

Force 5

Force 6

Force 7

Force 8

Needle 50 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Needle 75 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Needle 100 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Needle 150 cm

Force 0

Force 3

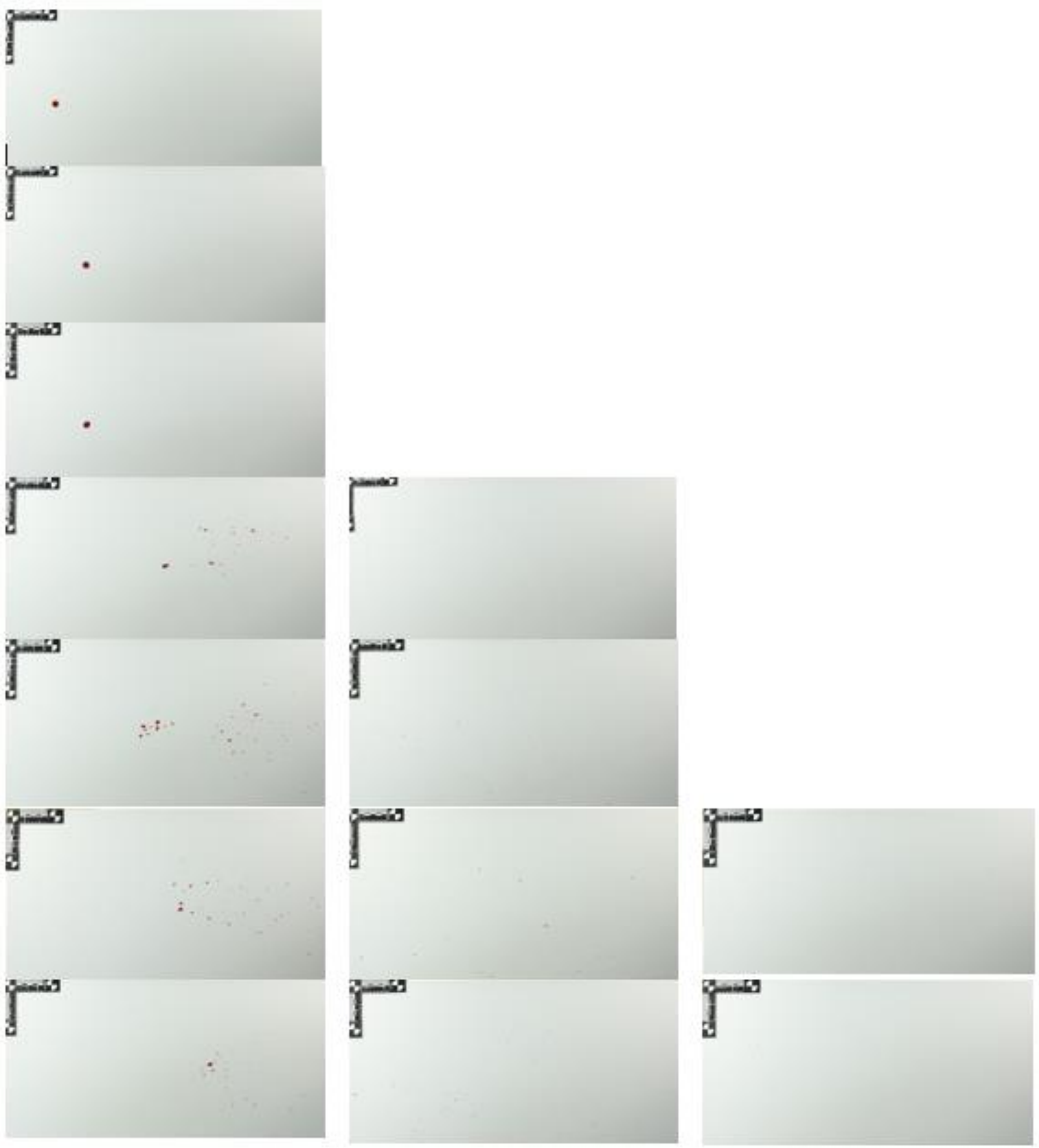
Force 4

Force 5

Force 6

Force 7

Force 8



Needle 200 cm

Force 0

Force 3

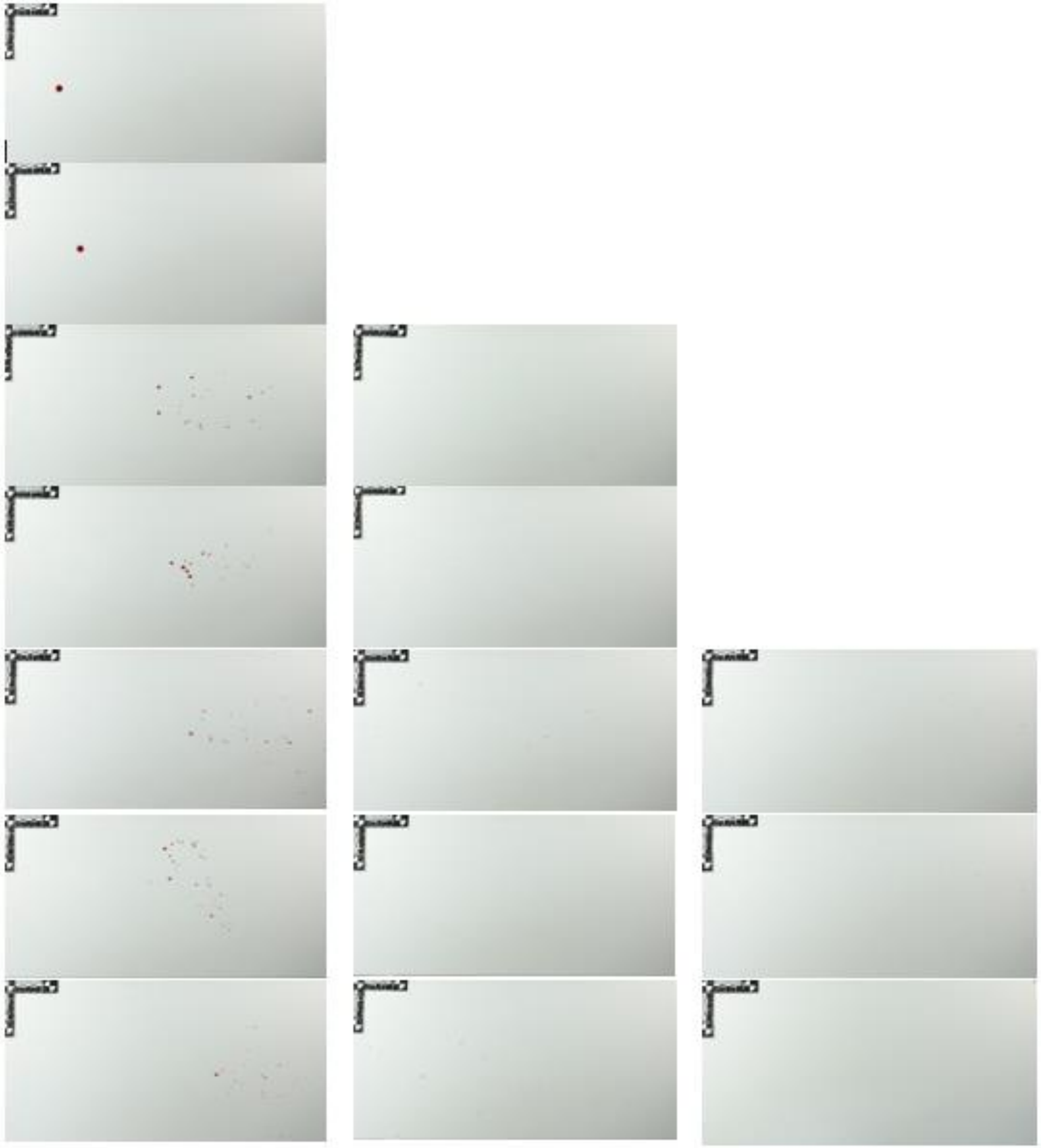
Force 4

Force 5

Force 6

Force 7

Force 8



Pipet 3.5 25 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 3.5 50 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 3.5 75 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 3,5 100 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 3.5 150 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 3.5 200 cm

Force 0

Force 3

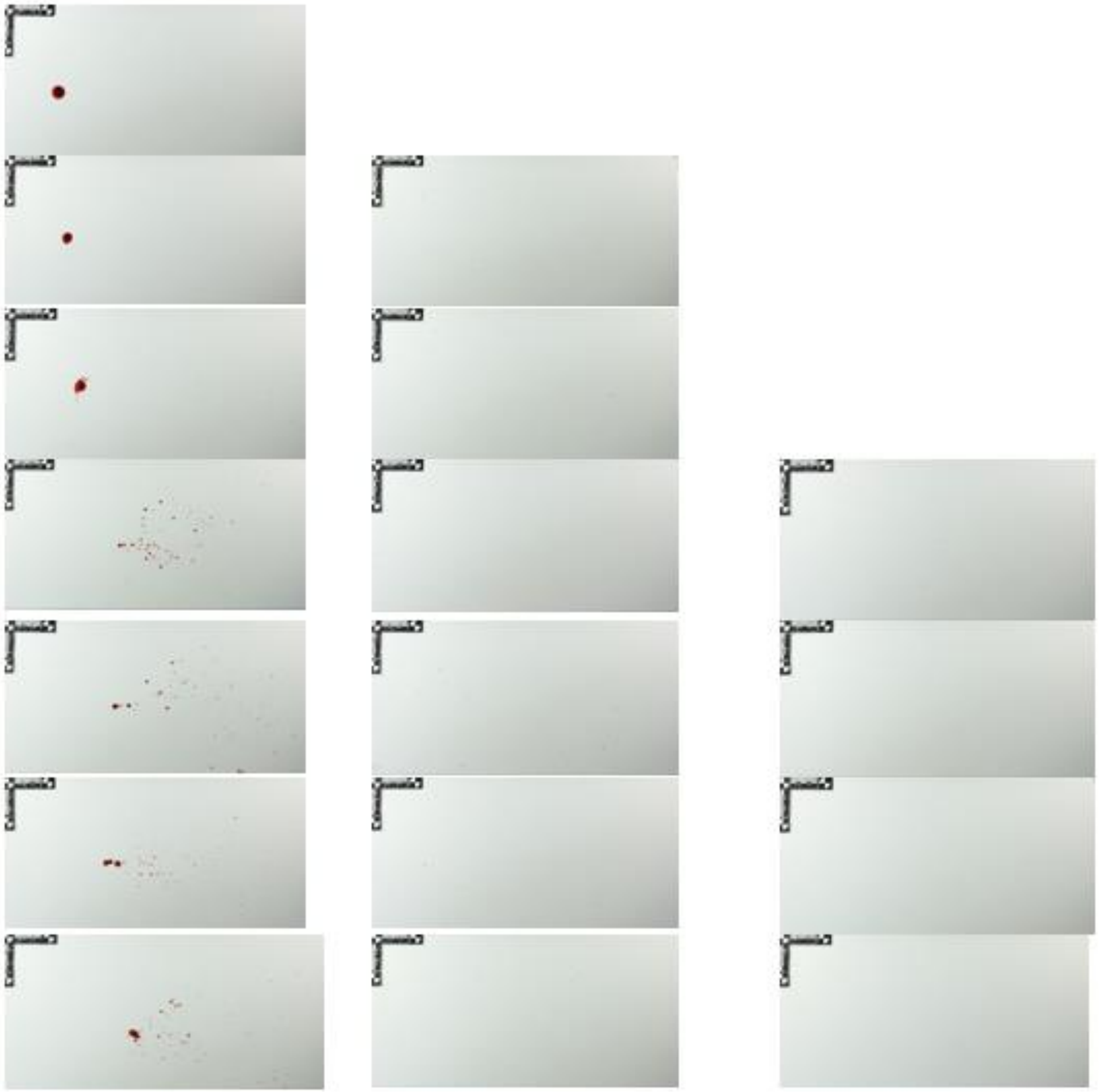
Force 4

Force 5

Force 6

Force 7

Force 8



Pipet 5.0 25 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 5.0 50 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 5.0 75 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 5.0 100 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 5.0 150 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8

Pipet 5.0 200 cm

Force 0

Force 3

Force 4

Force 5

Force 6

Force 7

Force 8