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EDUCATION AND TRAINING ACTIVITIES IN FORENSIC AND BIOMEDICAL SCIENCES: THE LASER SCANNER TECHNOLOGY

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ABSTRACT. The paper reports the results of training experiences in the field of education in forensic and biomedical sciences carried out during two editions of summer schools. Two simulated serious crimes, involving dummies used as victims, were prepared for practitioners in outdoor places. The scenes simulate a suspect murder case of homicide with staging and a corpse concealment with dismembered human remains found into a clandestine grave, respectively. During the simulations, laser scanning technology was applied to reproduce the outdoor crime scenes in order to verify the capacity of the innovative technique as advantageous tool during educational and forensic training. Judicial inspections conducted during the simulation provided preliminary physical evidence, in the fields of forensic medicine, forensic geology, and engineering, highlighting the importance of the multidisciplinary approach. These experiences, through the use of the laser scanner that allowed for the recreation of virtual environments in which practitioners were able to confront crime scenes, demonstrated how such an approach can be useful in education and training activities.

1. Introduction

Forensic science has as its primary task the intercalation of scientific concepts within the legal system by aiming at the resolution of court and juridical cases (Picozzi and Intini 2009). Different techniques and methodologies can be used in scientific investigation. Investigations may involve several aspects and disciplines, as it happens in the Crime Scene Investigation (CSI), in which legal medicine, forensic odontology, toxicology, entomology (Byrd and Sutton 2023), dactyloscopy, ballistics, computer forensics, geology, botany, engineering, computer forensics, and others branches are applied (Saferstein 2017). The fundamental principles related to evidence sampling, the preservation and chain of custody of physical evidence, the role of the forensic expert, and the process of evaluating evidence in court are fundamentally important concepts in forensic science education. The main goals of forensic science are related to determine the evidentiary value of physical and trace evidence collected from the crime scene and the objective reproducibility of the dynamics of events. Science therefore assumes an important and unique role in the justice system, a role that refers to the forensic expert's ability to provide accurate and objective information on the events/facts that occurred during the execution of an event/historical fact/crime. Before arriving at expertise, it is necessary to go through specific education and training programs in forensic science. So education in the field of forensic and biomedical sciences may be corroborated by means of training activities with simulated experiences (Reed 2001) involving the use of dummies. In recent times, the realization of hyper-realistic "human patient simulators" allowed to furnish new advances in such experiences (Hoang *et al.* 2020). The use of these human simulators may be a beneficial educational method for improving and facilitating the learning of practice during training experiences. The traditional dummies and "human patient simulators" used in forensic science trainings became versatile tools. This type of simulation is very useful because it provides a training experience that is much closer to reality, which in turn helps to prepare practitioners to deal with real situations. The experience encourages more natural handling (Ock *et al.* 2020) allowing to reach a new level of realism, with high levels of engagement, responses emotions, and memory creation. The experts in criminalistics may be forensic engineers, physicists, geologists, botanists, among many others (Monti *et al.* 1999; Telling *et al.* 2017). The experts can work in team in order to primary support the coroners, providing useful data on the characteristics of the places and the complex interactions among the victim and the surrounding environment, on the base of the results of the simulation. These experiences may be very valuable also for the students because help to better prepare themselves for real-life situations. If human simulators look like human victims, the whole experience will be much more realistic to practitioners.

The judicial inspection represents a delicate phase of trial and forensic investigations. The activity requires intervention of professionals provided with specific skills. The skills may be acquired during the course of study, under the guidance of tutors. However, having to preserve the scene, only experts may carefully manipulate with a proper approach the environment, included traces and corpse. When faced with real situations often the student, inexperienced and still in training, does not have the opportunity sometimes to access the *scena criminis*, limited by the importance of the events. For this reason, the possibility of interacting with hyper-realistic dummies, positioned and structured in such a way as to simulate a crime, helps in the training - formative process of young forensic students, who have the opportunity to interact without altering the scene and without causing damage to the investigation, important for legal purposes. The multidisciplinary approach provided by the protocol implements the expertise of all practitioners involved in forensic activities. The manipulation of the dummies will be able to allow analysis of both the thanatological phenomena and the injury present in the body, and, at the same time, hypothesize and rehearse the possible dynamics of the event. Educational and training activities, simulating a judicial inspection with the use of hyper-realistic dummies, may be carried out in simulated indoor and outdoor crime scenes. For a most realistic description of the state of the places, and in particular for accurate acquisition of the environment and "crime" scene, the laser scanning technology may be very helpfully applied. Such method allows to reproduce the three-dimensional (3D) virtual models of the targets analysed, crystallizing all the related details. This technology is used to quickly and accurately capture large amounts of data, which can be used for creating detailed virtual models for later reconstruction and analysis

also for training purposes.
In the present paper, the results of training experiences were discussed through reporting two case studies regarded simulated serious crimes, involving hyper-realistic and traditional dummies as victims. During the simulation of the judicial inspection, the laser scanning technology was applied for reproducing the outdoor crime scenes in order to verify the capacity of laser scanner technology as advantageous tool during forensic training and simulations with dummies. The dummies were used to simulate a suspect murder case of homicide with staging and a corpse concealment with dismembered human remains found into a clandestine grave, respectively.

2. Materials and methods

The dummies involved in the training experiences were a dressed hyper-realistic dummy of a man and an undressed torso of a clothing mannequin in plastic material of a woman posed inside a green plastic garbage bag. The hyper-realistic dummies are tools reproducing the real shape and size of the human body that can be utilized for simulating realistic situations, such as car accidents, falls, shootings, and other accidental or criminal events that can cause physical injuries (Carella Prada and Tancredi 2010; INTERPOL 2023). In such a way, experts and practitioners may contribute for reproducing the event dynamics or safety tests for scientific or educational purposes. These hyper-realistic dummies are usually built with strong and durable materials such as inorganic polymers (silicone), plastic, rubber or resin, and can be equipped with sensors, recording systems and other devices allowing to collect accurate data on the force, speed, and impact of forces on the body (Christensen 2004) and posture (Barberi *et al.* 2023). These data can then be analyzed to determine the cause and consequences of an event, and to evaluate the effectiveness of safety systems, such as seat belts, helmets, airbags, and other personal protective equipments. These simulators can also be used to train healthcare professionals, such as doctors and nurses, on how to perform medical procedures, such as cardiopulmonary resuscitation or endotracheal intubation (Stratton *et al.* 1991), drug administration, or the measurement of temperature (Foda and Sirén 2012). These tools were originally designed to improve the effectiveness of medical training providing to practitioners the ability to experience their skills in realistic situations where the dummies mimicked the natural human bodies. These tools were also designed to allow training experiences in safety, as dummies do not expose practitioners to risk. The negative aspects in involving these dummies are related to the elevated costs, ranging the prices of hyper-realistic human simulators from 25,000 to 100,000 USD, based on the different technological level of the product.
The training experience reported in the first case study involved the use of a hyper-realistic dummy mimicking the natural human body with realistic details (Figure 1), including reproductions of veins and underlying structures, hair, and anatomical airways (Dufaux 2022). The characteristics of the dummy were reported in table 1.

TABLE 1. The main characteristics of the hyper-realistic dummy of male sex were reported.

Age (year)	45
Weight (kg)	37
Height (cm)	180
Chest dimension (cm)	52-54
Hips (cm)	52
Shoe' number	44

FIGURE 1. Image of the hyper-realistic human simulator (*Centro di Simulazione e di Didattica Innovativa* - SIDI centre, University of Messina), before preparing the simulation setting (a), placed in the simulated crime scene (b and c). Details of the skin, veins, and hairs are easily observable in the photographs.

The two simulations with dummies were carried out in the countryside of the Messina university campus during the training activities of the summer schools in forensic geology and criminalistics, dating back to 2022 and 2017, respectively. During the experiences, a team of experts (coroners, forensic engineers, geologists, and botanists) explained firstly the aims and modality of the judicial inspection with particular attention to the external examination of the corpse and to the collection techniques of geological and botanical evidence. For the fundamental phase of crystallization of the crime scene, the modern technology of the laser scanning was used, after explanation of the method. Experiences were organized in small groups of students and young law enforcement officers. 3D virtual models of crime scenes may be created by applying the laser scanner technology (Komar, Davy-Jow, and Decker 2012; Almerich-Chulia and Moreno-Puchalt 2022). The 3D laser scanner may acquire precise data on the geometry of three-dimensional objects and surfaces (Baldino *et al.* 2023a,b). The laser scan device is able to acquire a large amount of data creating 3D point clouds digitally reproducing targets and places with great precision (Barone, Paoli, and Razionale 2012; Naether *et al.* 2012; Olsen and Kayen 2012; Chias *et al.* 2019; Luhmann *et al.* 2019; Ogawa and Hori 2019). Laser technology works by measuring the return time of a laser light pulse that is directed to the target; the instrument employs a Time-Of-Flight (TOF) which uses LiDAR (Light Detention And Ranging) technology. This technique is non-destructive, repeatable, and what is more important, does not alter the state of the places. A motorized head moves the scanner light with two angular degrees of freedom, declination, and right ascension, in order to sweep the detection area. The 3D scanning allows to freeze in time the entire detected geometry and performs analyses of georeferenced geometries, dimensions, and positionings. The fundamental requirement for the laser scanner survey is the framing of at least 3 contemporary markers from each position of the laser scanner. Once the scan data have been acquired, a 3D modelling software processes the information collected creating a virtual model. This process involves the reconstruction of the shape and geometry of the study targets, using the information collected during laser scan survey and an algorithm of 3D reconstruction. Finally, the virtual model can be customized with appropriate textures for giving greater realism to the model (Brown 2000; Cucinotta *et al.* 2018; Cucinotta, Raffaele, and Salmeri 2021a; Lo Giudice *et al.* 2022; Somma *et al.* 2023a).

The accuracy of the laser scanners depends on the distance between the station point and the acquired surfaces (Nelis *et al.* 2018). The instruments permit to obtain two different types of images: panoramic and spherical images with an acquisition field of 360° - 300° by means of three integrated HDR and thermographic cameras (Damage Assessment of Different FDM-processed materials adopting Infrared Thermography), due to the presence of an integrated thermal imaging system. The laser scanner performs a photographic overview, and then begins to acquire the points using the laser beam.

The laser scanner used in the scene related to the first case study was a Leica BLK 360 model (Figure 2 a). This instrument allows to acquire up to a maximum of 360,000 points per second, creating point clouds with millimetre precision. The device may measure at distance lower than 45 m, with a point positioning accuracy of 4 mm at 10 m, 7 mm at 20 m of distance, and 12 mm at 45 m.

The laser scanner used in the scene related to the second case study was a Leica Nova MS50 MultiStation model (Figure 2 b). This instrument allows to acquire up to a maximum of 1000 points per second, creating point clouds with millimetre precision. The device may measure at distance lower than 50 m, with an accuracy of 8 mm at 20 m of distance, and 25 mm at 50 m. Two different scanners were used for the two case studies, being the investigations carried out in 2022 and 2017. Consequently, there was an update in the instrumentation. The Leica BLK 360, being the newest model, was employed in 2022 for scanning the mannequin, allowing the use of more recent technologies and improving the accuracy and reliability of the acquired data. The point clouds of the various setups related to both case studies were reassembled into a single overall cloud utilizing the Leica Cyclone Register 360 software.

FIGURE 2. Laser scanners: Leica BLK 360 model (a) and Leica Nova MS50 MultiStation (b) of the Department of Engineering of the University of Messina.

3. Results

During the educational activities of the summer schools in Forensic Geology and Criminalistics held at the University of Messina, practitioners, before field experience, acquired basic knowledge on the main principles and methods of forensic geology and science, through theoretical lessons regarding studies reported in the wide literature (Murray and Tedrow 1975; Lombardi 1999; Ruffell and McKinley 2009; Saferstein 2017; Puleio *et al.* 2020; Caccianiga *et al.* 2021; Donnelly *et al.* 2021), flipped-classroom experiences (Spoto, Somma, and Crea 2021; Somma 2022), and presentations of reports from cases followed by most of the authors (Somma *et al.* 2018; Somma and Costa 2022; Marra 2023; Marra, Di Silvestro, and Somma 2023; Morabito, Mondello, and Somma 2023; Morabito and Somma 2023; Somma 2023a,b,c; Somma *et al.* 2023a,b; Somma and Costa 2023; Somma and Maniscalco 2023; Somma *et al.* 2023c; Somma, Sutton, and Byrd 2023; Spoto 2023; Spoto, Barone, and Somma 2023; Tagliabue *et al.* 2023).

3.1. Case Study No.1. During the V edition of the summer school "Tiziano Granata" in Forensic Geology and Criminalistics (June 2022) held at the University of Messina, the practitioners were involved in an outdoor simulated crime scene where a corpse of a man, represented by a hyper-realistic dummy, was found hanged with a rope to a tree. The victim was examined on-site during a judicial inspection by the team of forensic experts, whose approach was holistic and multi-disciplinary. The topic of the training, leaded by coroners, consisted in observing injuries on the corpse, relationships between the victim and the surrounding place, applying protocol and all precautions for avoiding dispersion and contamination of physical evidence. Particular attention was paid to observe the ligature mark on the neck of the victim and sampling possible geological and botanical traces on the victim (shoes, hands, and clothes showing soil traces) and soils from the scene. Obviously, there has been an inability to reproduce classic thanatochronological phenomena, such as hypostatic spots and rigidity that are due to vital phenomena. An expeditious examination of the ligature mark on the neck of the victim observed by means of eye lens indicated that the ligature mark was impressed on the victim presumably *post-mortem*. A first expeditious comparative examination by means of portable stereomicroscope of colours and textures of the geological traces found on the victim and soils on the crime scene indicated that the specimens were not comparable. After these first training experiences, the team and the practitioners were involved in the laser scanning survey of the scene. This was performed realizing 150 scans. The laser scanner was positioned in such a way to scan the hyper-realistic dummy and the scene from all possible angles. To capture the scene exhaustively, five stations were carried out (setup 32 - setup 36). The laser scanner was positioned at variable distances from each other. The station 1 (setup 32) was placed behind the manikin, to its right at a distance of 2.39 m. The station 2 (setup 33) was placed, again behind the dummy, but to the left at a distance of 1.88 m. The station 3 (setup 34) was placed in front of the manikin, to its left, at a distance of 1.67 m from it. The station 4 (setup 35) was placed in front of the manikin and to its right at 4.53 m. The station 5 (setup 36) was in front of the dummy and to its right, 1.55 m away from the dummy (Figures 3, 4).

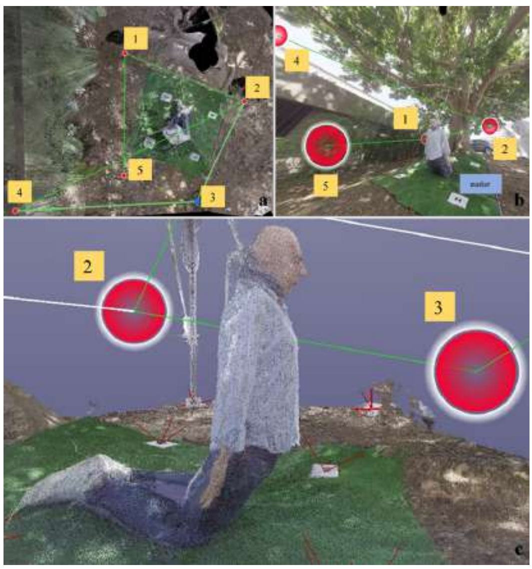

FIGURE 3. Case study 1. 2D map (a) and different views of the 3D virtual model (b and c) of the simulated crime scene where the victim was simulated by a hyper-realistic dummy. The red spheres indicated the position of the stations.

The scans were carried out at high resolution (dot density and HDR images) through acquisitions lasting six minutes and ten seconds. The individual clouds, acquired at maximum resolution by the instrument, were reassembled using the Leica Register 360 software.

FIGURE 4. Case study 1. Different view of the 3D virtual model of the simulated crime scene where the victim was simulated by a hyper-realistic dummy. The red spheres indicated the position of the stations.

The connections between the setups were as follows:
Setup 32 - Setup 33 distance 3.06m, point cloud overlay 38.23%;
Setup 33 - Setup 34 distance 2.67m, point cloud overlay 41.89%;
Setup 34 - Setup 35 distance 4.98m, point cloud overlay 21.12%;
Setup 35 - Setup 36 distance 6.33m, point cloud overlay 23.06%.
The overall cloud consisted in 256,480,945 points obtained by the stations with 5 links (Figures 3, 4). An overall point cloud with group error of 0.01 m, overlap of 34% and robustness of 82% was generated, merging five clouds of points, by means of Leica Register 360 software used in a PC tablet straight on the field and available for the practitioners. During post processing of the point cloud, no point manipulation operation was performed for avoiding to change the certified precision. The obtained 3D model was observed in real time by the participants on the scene, which were able to measure also sizes and distances of investigative interest, as the hight of the tree branch with respect to the ground, on which the rope was localized (more difficult to obtain with traditional methods). The scene could be played back without altering the tracks multiple times and with ease, allowing virtual interaction for practitioners and students. Based on preliminary circumstantial evidence above reported, found on the victim and the scene by the team of experts in legal medicine, geology, and engineering, the practitioners had to hypothesise if the man was victim of a suicide for hanging or rather of homicide for which a staging was set up by the perpetrator.

3.2. Case Study No.2. During the II edition of the summer school (June 2017), the practitioners were involved in an outdoor simulated crime scene where dismembered human remains of a woman, simulated by a *torso* of a plastic mannequin contained in a garbage bag, was found buried in a shallow homicide grave (Figure 5).

FIGURE 5. Case study 2. Simulated crime scene with a homicide grave containing human remains. Photograph of the grave before the stratigraphic digging (a), after stratigraphic excavations and discovering of the remains (b). Images of the grave after the laser scanner survey (c, d, e). Topographic map of the site extracted by the point clouds (f).

In this training experience were also involved other professionals, such as anthropologists and archaeologists, together with the same team of forensic experts represented by coroners, engineers, and geologists, which started the examination with the practitioners of the site when the grave was closed (Somma 2022). Experts explained with a holistic multidisciplinary approach, the different modalities for obtaining stratigraphic and archaeological digging with a correct recovery of human remains concealed in the ground, in order to avoid damages of the remains, contamination, and loss of evidence. The practitioners, under the supervision of the team, dug carefully the terrain by means of appropriate tools (trowels and brushes), complying an archaeological stratigraphic digging ended with the finding of the remains. Once the grave was empty and the terrain collected for further laboratory investigations, it was possible to observe the grave shape as originally dug by the concealer. The shape of the empty grave was crystallized also in this case by means of a laser scanner survey (Figure 5 c-e).

In this case only one station was necessary to fully detect the target. At each acquisition the texture and the point cloud for the virtualization of the hole were detected. Overall, the point cloud consisted of 600,000 detected points. During post processing, no point manipulation operation was performed for avoiding the change of the certified precision. For this reason, only the geometrical and topological properties of the excavation were measured and the topographic map was also obtained.

4. Discussion and conclusions

The educational activities accomplished during the judicial inspections related to the presented case studies allowed practitioners of the summer schools to acquire competences on the fields of legal medicine, forensic engineering, geology, botany, and archaeology applied to crime scene investigation. The general outcome of the experimental trials was positive overall. In the first case presented, the performing of a multidisciplinary approach, through the analysis of the characteristics of the ligature mark on the neck of the victim, the lack of compatibility of the geological and botanical evidence, the arrangement of the corpse and dimensional parameters of the rope used for the hanging, allowed practitioners to hypothesise that the subject was victim of a possible homicide where the perpetrator set up a staging of hanging. The experiences lived during the trainings demonstrated as a such multidisciplinary approach may be very effective during the judicial inspection, giving the possibility to communicate timely preliminary first data to the on-call magistrate for the consequent judicial actions or reducing also the possibility of investigative errors. Forensic simulations and real crime scenes require a high level of precision and accuracy, and the 3D virtual models performed by laser scanning are a useful tool for investigators and forensic experts. The resolution of 3D scans is crucial in forensic applications, influencing the quality, reliability, and detail of the results. Higher resolution scans allow higher precision in reconstructing crime scenes and analysing elements such as blood traces and positions of objects or bodies. The resolution of 3D scans directly affects the reliability of measurements made on the virtual crime scene. A higher resolution enables more accurate and reliable measurements, which is crucial for the analysis and interpretation of data collected in a forensic investigation. Low-resolution scans and a number of stations not adeguate can produce shadows and leave hidden areas not correctly sampled in the virtual crime scene. This can lead to a lack of crucial information and potentially impact the outcome of a forensic investigation. In contrast, high-resolution scans and an efficient number of stations can significantly reduce the presence of shadows and ensure more uniform and complete coverage of the crime scene. However, high resolution implies longer scanning and processing times and greater storage requirements. Investigators must balance accuracy and practicality, carefully considering factors such as time, processing, and resources to choose the appropriate resolution in each specific situation. Coroners can use these models to perform and teach to practitioners virtopsies or to explore violent causation injuries in more detail and realistically (Ebert *et al.* 2014). These virtual models can be used to evaluate different working hypotheses, provide evidence for a detailed understanding of the dynamics of events, causes of physical damage and injuries (Ren *et al.* 2018), preventive solutions, and evaluation of the effects on various scenarios (Flor 2011; Rusman and Popova 2020; Chen *et al.* 2021). Hyper-realistic human simulators are promising tools for experiential learning, but their use also entails certain limitations. One key limitation is their vulnerability to be damaged, given their composition. Notwithstanding, the possibility to apply a rapid prototyping with Fused Deposition Modeling (FDM) technology (D'Andrea *et al.* 2022) may solve such problems creating parts of these hyper-realistic "human patient simulators", in cases of damage (Sieberth *et al.* 2019). FDM printers can help enhance forensic education by providing highly detailed and lifelike anatomical models (Cucinotta *et al.* 2022) and mannequins that can be used for student skill and skill development (Cucinotta, Raffaele, and Salmeri 2021b; Barberi *et al.* 2022). The storage of the dummies is also a concern, as the simulators are sensitive to extreme hot and cold temperatures that can cause deterioration. Additionally, their physical characteristics and weight, which can exceed 30 Kg, can make it challenging to transport and use them in outdoor environments. The physical characteristics and weight of these mannequins can make quite difficult the transport and collocation of them in the outdoor scene or simulated training environments, which can often be impervious in the case of simulated crime scenes. The lower weight of the dummy compared to that of a human being could impact the simulation of the scene reconstruction. To address this issue, one might consider using adjustable-weight dummies or adding weight to the existing dummy to achieve a more accurate simulation in future research. Moreover, the elevated price of hyper-realistic human simulators, being considerable compared to non-hyper-realistic mannequins, may limit their applications. Another problematic aspect concerning the use of dummies is related to the evaluation processes related to their life cycle, for identifying opportunities to improve environmental sustainability, as their production, use and disposal for their environmental impact (Yoganandan, Sances, and Pintar 1989; Barone, Cucinotta, and Sfravara 2017; Cucinotta *et al.* 2021; Prestipino *et al.* 2021; Di Bella *et al.* 2022). When the mannequins are no longer usable, it is necessary to evaluate the environmental impact of the disposal and verify that this takes place in a sustainable way. By the way the 3D virtual model of the scene and hyper-realistic dummy produced a satisfactory outcome in both case studies capturing detailed images of study targets from multiple angles and distances. The dummy's material reacted well to the laser light, although there was a chance that the synthetic sweat on the dummy's skin, which gives a slightly shiny look, could have caused some noise or inaccuracies in the scanning process. The shape of the grave was correctly captured by the laser scanner, although its performance was lower in terms of accuracy and overall performance than the scanner used in the first case study. The 3D reconstruction of simulated crime scenes may be very useful also for obtaining further opinions from other forensic experts or in cases of telemedicine (Puccini 2003). The use of virtual models represents a constantly evolving technology, with innumerable advantages that can revolutionize the relationship between experts. Furthermore, the 3D scan of the outdoor places offers a further advantage in the constant faithful reproducibility of the places, even after some time from the discovery of the crime. The survey may be repeated in the case of not favourable weather conditions for the measurements, ensuring a better quality of the collected data. The use of hyper-realistic human simulators in forensic experiences has enabled the development of an innovative teaching model involving the use of mannequins in the evaluation of simulated external expert reports and judicial inspections. This teaching model aims to improve forensic training by providing trainers with a more realistic and close-to-reality training experience. Outdoor simulations helped to prepare practitioners to properly approach outdoor settings, appropriately addressing victim management and preservation of physical evidence. The introduction and implementation of these additional methods of teaching and learning, with a significant practical and realistic component, thanks in part to the use of hyper-realistic dummies, can increase confidence in daily practice, thereby improving the quality of outdoor *post-mortem* examination (West *et al.* 2020; Flössel *et al.* 2021; Cecchi *et al.* 2022).

Author Contributions

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Competing interests

Conflicts of Interest: The authors declare no conflict of interest.

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