Forensic gait analysis

A PRIMER FOR COURTS

THE ROYAL SOCIETY

RSE
The Royal Society of Edinburgh
KNOWLEDGE MADE USEFUL

Forensic gait analysis: a primer for courts
Issued: November 2017 DES4929

ISBN: 978-1-78252-302-4

This primer is produced by the Royal Society and the Royal Society of Edinburgh in conjunction with the Judicial College, the Judicial Institute, and the Judicial Studies Board for Northern Ireland.

To request additional copies of this document please contact:

The Royal Society
6 – 9 Carlton House Terrace
London SW1Y 5AG
T +44 20 7451 2571
E law@royalsociety.org
W royalsociety.org/science-and-law

This primer can be viewed online at royalsociety.org/science-and-law

Contents

Science and the law primers
Foreword

The judicial primers project is a unique collaboration between members of the judiciary, the Royal Society and the Royal Society of Edinburgh. The primers have been created under the direction of a Steering Group chaired by Lord Hughes of Ombersley and are designed to assist the judiciary when handling scientific evidence in the courtroom. They have been written by leading scientists and members of the judiciary, peer reviewed by practitioners, and approved by the Councils of the Royal Society and the Royal Society of Edinburgh.

Each primer presents an easily understood, accurate position on the scientific topic in question, as well as considering the limitations of the science, and the challenges associated with its application. The way scientific evidence is used can vary between jurisdictions, but the underpinning science and methodologies remain consistent. For this reason we trust these primers will prove helpful in many jurisdictions throughout the world and assist the judiciary in their understanding of scientific topics.

The production of this primer on forensic gait analysis has been led by His Honour Judge Mark Wall QC and Professor Dame Sue Black DBE FRSE. We are most grateful to them, to the Executive Director of the Royal Society, Dr Julie Maxton CBE, the former Chief Executive of the Royal Society of Edinburgh, Dr William Duncan, and the members of the Primers Steering Group, the Editorial Board and the Writing Group. Please see the back page for a full list of acknowledgments.

Sir Venki Ramakrishnan
President of the Royal Society

Professor Dame Jocelyn Bell Burnell
President of the Royal Society of Edinburgh

1. Summary

Forensic gait analysis, the direct visual comparison of two or more video recordings to establish whether they are of the same individual or different individuals based on the gait pattern alone, is a relatively new form of evidence in the UK criminal courts. Its underpinning science is sparse and largely translated from the more developed fields of clinical gait analysis and biomechanics, with more recent insights from biometrics. Care is required, however, in assuming that techniques developed in one field can be applied in another with quite different objectives. The scientific evidence supporting forensic gait analysis, as currently practised, is thus extremely limited.

When forensic gait analysis is used as an aid to positive identification of a suspect, the following matters should be borne in mind:

- There is no evidence to support the assertion that gait is unique within current or foreseeable limitations of measurements used in forensic gait analysis.
- There is no credible database currently that permits assessment of the frequency of either normal or abnormal gait characteristics.
- There are no published and verified error rates associated with the current methodology.
- There are no published black-box studies of analyst reliability and repeatability.
- There is no standardised methodology for analysis, comparison and reporting of gait characteristics.

Excluding a suspect on the basis that their gait is different from that of the individual recorded on video should be less demanding than making a positive identification. However, there is even less evidence to support the use of video in this context. There are several factors that may cause individuals to walk differently on different occasions and these require accounting for before a suspect could be reasonably excluded, and such research is sparse.

A wide range of professionals may present as a Gait Analyst, which is not a legally protected title. There are no academic qualifications in forensic gait analysis per se, and so professionals involved in the field may hold qualifications in a wide range of related areas. The professional or academic background, qualifications or professional registration of an individual are thus unlikely to give unambiguous confirmation of their competence to act as an expert witness in relation to forensic gait analysis evidence.

This report is limited to visual comparisons. Automated methods of extracting data from video and making comparisons are being developed for biometric purposes and the potential for adapting these for forensic purposes is being explored. While these may hold considerable promise for the future, rigorous testing will still be required to validate their use for evidential admissibility.

2. Introduction and scope

The rather loose Oxford English Dictionary definition of gait as the 'manner of walking' encompasses the word's common usage. Many people walk with a distinctive gait and the assumption that this may assist in identifying someone is reasonable. Gait analysis was first admitted as evidence into criminal proceedings in the UK in 2000, in a case of armed robbery, *R v. Saunders*, heard at The Old Bailey Central Criminal Court in London (Kelly 2000). The evidence included closed-circuit television (CCTV) images which showed the defendant's alleged bow-legged gait which a podiatrist[1], acting as expert witness, stated would be expected in only 5% of the UK population. The admission of such evidence is still infrequent today but is likely to become more common as CCTV cameras become more prevalent in both public and private spaces. It is also likely that other forms of video recording (from mobile phones, for example) will be offered as evidence in the future, and this primer is intended to cover all forms of video recording.

While the desire to use video recordings in this way is reasonable, there is limited scientific research to assist a court in deciding whether such evidence is sufficiently reliable and/or of high enough quality to be admitted, and what safeguards are required to ensure that evidence is presented and used appropriately. Such evidence can be used in two contexts; to identify a suspect from a pool of possible suspects, or to exclude someone as a person of possible further interest. The aim of this primer is to present the latest scientific research in forensic gait analysis and provide guidance upon how such evidence may be used, based on an informed critique of that research.

Gait analysis means different things to different people (see Section 5). This primer will be restricted to the direct visual comparison of two or more video recordings by an expert witness to establish whether they are of the same individual or different individuals based on the gait pattern alone. It does not cover computer analysis of video images, which is known as biometric gait analysis[2], nor other aspects of podiatric gait analysis such as footprint analysis. Most of our current understanding of human walking has come from the fields of clinical gait analysis and biomechanics, with a smaller and more recent contribution from biometrics. While the focus of this primer is on forensic gait analysis, it has been necessary to make some reference to literature from these broader fields.

Video footage will capture more than just the gait pattern of an individual. For example, it may capture clothing and may include records of habits such as smoking. The richness of this visual material means that video evidence undoubtedly has importance beyond what can be concluded from the analysis of the way a person walks. This primer focuses solely on what information can be gained from video footage as it relates to the gait pattern.

1 See Section 5 for discussion of different professions involved in clinical gait analysis.

2 Biometric gait analysis is a rapidly developing field with a considerable and growing evidence base. Jain and Ross (2015) have, however, clearly delineated the 'gap' between biometrics and forensic analysis and it should not be assumed that techniques that are appropriate to one are necessarily transferrable to another. Bouchrika *et al*. (2011) have explored some of the issues experienced in applying techniques used in biometric gait analysis to forensic investigation but, in their conclusions, outline several barriers to routine implementation alongside their summary of the potential that the techniques offer. We are currently unaware of such techniques providing evidence that has been used in a criminal case.

3. Science

3.1 Definition

Different professional groups have focused on different aspects of gait analysis. It is important to recognise this, as an acknowledged expert in one area of gait analysis will not necessarily be qualified to provide an opinion in another. More detail about other areas of gait analysis and the professionals involved is included in Section 5.

The focus of this primer is forensic gait analysis. This has been defined as, 'The identification of a person or persons by their gait or features of their gait, usually from closed-circuit television (CCTV) footage and comparison to footage of a known individual' (Birch *et al*. 2015, Kelly 2000). It should also be extended to include the negative, ie to exclude the person captured on the footage as being the known individual. The focus of this primer is on the use of such evidence in court but the same techniques have the potential to be used as an intelligence-based investigative tool without forming part of the formal legal evidence.

Most analysis relies on expert subjective opinion regarding the similarity of specific gait features identified within certain frames of the video data. Such features, for example, might relate to whether an individual walks with bow legs or knock knees or has a foot pointing in or out. Although the focus of gait analysis is often on the lower limbs, it can also include consideration of joints and segments of the entire body. The analysis might also include the use of simple software tools to allow measurements of lengths or angles from individual frames of video recordings (Lynnerup and Larsen 2014)[3]. While such tools might report results to high precision (fractions of a degree, for example), their use generally requires manual identification of features on the video image and results are therefore dependant on individual expertise, which is likely to be far less precise. There are, however, no known studies describing accuracy of manual identification of these features.

3 It should be noted these are quite different from the sophisticated algorithms that extract more complex data from video recordings in biometric analyses.

3.2 Scientific evidence base: black-box studies

Forensic gait analysis is a young discipline and remains essentially subjective in nature. The best available method for establishing the scientific basis for subjective techniques in legal proceedings is a black-box study. In such a study, a range of practitioners would be provided with paired sets of video footage similar to that generally used in court proceedings. Some would be of the same individual and some would be of different individuals. The results would be used to calculate the frequency with which footage of different individuals was falsely identified as matching (the false positive rate), and the frequency with which footage of the same individual was not identified as matching (the false negative rate).

No large, high-quality black-box studies of forensic gait analysis have been published. The only study which comes close to this design is that of Birch *et al*. (2013a) which asked seven 'experienced analysts' to choose a match to one target individual from five suspect walkers. The failure rate on this exercise was 29% (ie the correct suspect was only identified in 71% of tests).

In summary, no directly relevant black-box studies have been performed to establish the validity of forensic gait analysis. The only indirectly applicable black-box study suggests that false positive rates are unacceptably high.

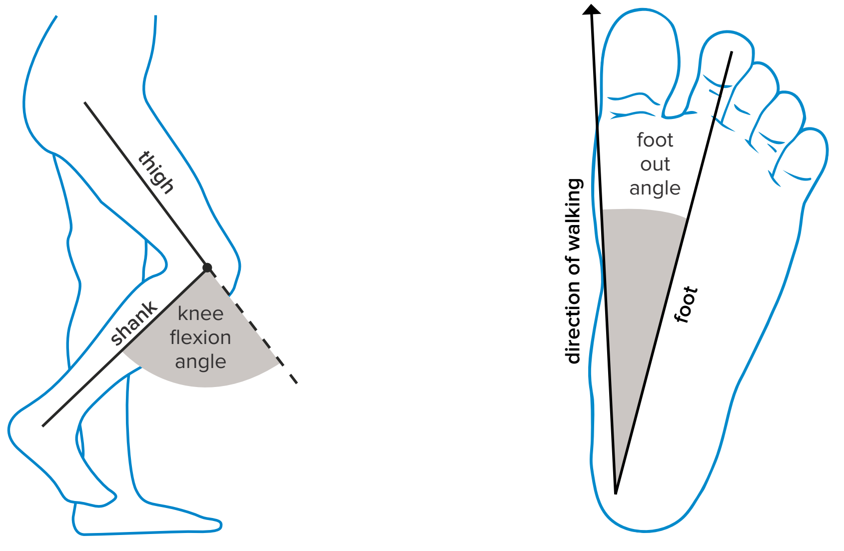
3.3 Scientific evidence base: indirect evidence

In the absence of more direct empirical evidence, the utility of forensic gait analysis is based on the underpinning science, which is largely derived from clinical gait analysis and biomechanics. One of the challenges of assessing the evidence base for forensic gait analysis is that it often requires interpretation of research that has been conducted for one purpose (clinical gait analysis) in the context of another (forensic gait analysis). This is further complicated by the adoption, within forensic gait analysis, of the framework and terminology that has been developed almost exclusively within the UK by podiatrists. This is, at times, quite different from that of the wider clinical gait analysis and biomechanics community, although there have been recent attempts to harmonise terminology (Birch *et al*. 2015). Such terminological issues may make it challenging for the judge or jury to assess whether an expert's opinion is genuinely evidence-based or more likely, opinion-based. It is also likely to lead to confusion if contrasting opinions are offered by more than one expert witness.

Clinical gait analysis also differs from forensic gait analysis in that the data capture here is planned, conducted under idealised conditions (with respect to such issues as lighting and camera positioning), with a cooperative subject (often partially dressed to remove the masking effect of clothing) and performing a standardised task (walking in a particular direction, in an uncluttered environment at a particular speed). Patients often have specific impairments which result in a gait pattern which is markedly different from the range of variation expected in the general population. Although direct comparison is not straightforward this generally means that the forensic gait analyst has considerably greater unregulated challenges to address than does the clinical gait analyst and it should not necessarily be assumed that results from clinical gait analysis can therefore be translated to forensic gait analysis.

FIGURE 1

Joint and segment angles. The knee flexion angle is the angle between the thigh and the shank. The foot out angle is the angle that the foot makes with the direction in which the individual is walking. Note that there is some subjectivity in where these lines are drawn and thus in the angle measured between them.



One of the aspects that links forensic and clinical gait analysis is that many of the features of interest are angles measured in degrees. This might be a joint angle such as the knee flexion angle, that between the thigh and the shank when observed from the side, or a segment angle, such as foot out angle, that between the foot and the direction of walking as viewed from above (Figure 1). In clinical gait analysis, angles are measured using sophisticated equipment capable of making three-dimensional measurements under ideal conditions. In forensic practice, angles are estimated from two-dimensional video, often under less than ideal conditions. Much of the science that has been developed from clinical gait analysis is thus applicable to forensic gait analysis but it is important to remember that the latter is inherently less precise and more subjective.

Scientific studies designed specifically to provide an evidence base for forensic gait analysis are only just beginning to emerge and are of variable scientific quality. There is a tendency to accept, as axiomatic, several statements for which there is little or no supporting evidence. One critical example is the assumption that every individual has a unique gait pattern (eg Krishan *et al*. 2015). Where citations are given, they are often to earlier documents that have also accepted these statements as axiomatic rather than providing empirical evidence of support. The following sections will thus examine the scientific evidence base for the key aspects of forensic gait analysis, both through objective and subjective assessment.

3.3.1 How unique is an individual's gait?

The claim that gait analysis can be used to identify someone unambiguously, has an underlying basic assumption that gait pattern is unique. Most papers either take this as axiomatic or cite secondary sources which trace back to the early work of Murray (1967) or Winter (1979, 2009) where the statement is unproven conjecture.

At one level, any continuous measure can be used as an identifier. If two individuals appear to have the same measurement, then that measurement can be examined with greater precision until a difference is eventually achieved. This, however, assumes that it is possible to take ever more precise measurements. The precision with which measurements can be made from video footage has not been established but the repeatability of measurements made during clinical gait analysis under idealised conditions (person partially undressed and via the use of sophisticated measurement systems to track the position of markers attached to the skin) has been well documented. In clinical gait analysis, the variability in measuring joint angles (the angle at which the knee is bent or foot turned out for example) can be as high as ±5° (technically the standard deviation, McGinley *et al*. 2009) using high-tech measuring systems and a little higher (±6°) when a physiotherapist performs a clinical examination of a patient (Fosang *et al*. 2003, McDowell *et al*. 2000). It is unlikely that measurements from video footage will be more reliable and on this basis a measurement error of ±5° is perhaps the best that can be expected. In comparison, the average variability in joint angles between adults is between ±4° and ±7° (Morel *et al*. 2017, Pau *et al*. 2014, Speciali *et al*. 2014). It can therefore be reasonably concluded that accuracy in forensic gait analysis techniques is considerably less than that required for an individual's gait pattern to be considered unique.

A related issue is the amount of variability shown by an individual's gait across time. Even if more precise measurements could be recorded, this would not help if the individual being measured varies between those measurements. The gait pattern of an individual walking indoors along a level walkway at their own chosen speed shows little variation (typically less than 1°), within a day or across a week (McGinley *et al*. 2014) or even several months (Matovski *et al*. 2012). However, an individual's gait pattern does vary quite markedly with walking speed (Kirtley *et al*. 1985, Schwartz *et al*. 2008, Yang *et al*. 2014a), characteristics of the walking surface (Fong *et al*. 2008, Menz *et al*. 2003, Wannop *et al*. 2014), in cluttered or crowded environments (Reed *et al*. 2006), carrying a load (Majumdar *et al*. 2010), or when fatigued (Radzak *et al*. 2017) and even while using a mobile phone (Seymour *et al*. 2016). It will also depend on the footwear being worn (Cronin, 2014, Franklin *et al*. 2015). Injury or intoxication by alcohol and other drugs also clearly have the potential to alter walking patterns as does a persistent injury or recovery from such. Finally, particularly as the use of forensic gait analysis comes more to the public's attention, it is possible that individuals may choose to walk differently to evade detection.

Based on both the limited precision of measurements and the variability of walking pattern in response to a wide range of factors, it is not currently possible to consider any individual's walking pattern to be unique. Birch *et al.* (2016a) acknowledged that if gait is unique then 'that uniqueness is at a level which requires precise measurements' and that, given the limitations in making measurements from video footage, 'forensic gait analysis, as currently practised, is not capable of identifying a person'[4]. They go on to state that 'the features of gait that can be identified are class-level features, which is to say a feature that occurs in a proportion of the population, and therefore demonstrate compatibility rather than uniqueness'. Larsen *et al*. (2008) make a similar point in concluding 'we are able to state with reasonable certainty whether the suspect could be the perpetrator, but it is not possible to identify the perpetrator positively.' If the lack of proof of uniqueness is accepted, then the incidence of specific characteristics within the population requires to be known to permit an error rate to be calculated.

4 It is worth noting that biometric gait analysis uses computerised extraction processes to obtain more complex and precise data (eg Larsen *et al*. 2010, Pataky *et al*. 2011) and it is this which makes its potential to identify individuals different to that of video-based forensic gait analysis as it is currently practised.

3.3.2 How common are individual gait characteristics?

Much forensic gait analysis focuses on identifying specific characteristics of gait (foot out angle is one example, see Figure 1) which are reported to be uncommon. If infrequent characteristics are observed in two or more clips of video footage, there is an increased likelihood that that footage is of the same individual than if commonly occurring characteristics had been observed.

A project to establish a database of the occurrence of gait features identified within forensic gait analysis in the UK population has recently commenced but the results have not yet been published (Birch *et al*. 2016a). However, there is a considerable volume of literature describing human gait pattern and its variation. Standard text books (Kirtley 2006, Rose and Gamble 2006) present data, often in the form of graphs, which record the average pattern of movement and represent the inter-individual variability. A recent study (Pinzone *et al*. 2014) has shown considerable agreement between such datasets collected independently in Australia and the USA in terms of the variability between individuals. Given that measurements such as the mean (indicating the average measurement) and standard deviation (indicating the range of variability) are known, the likely frequency of a given characteristic occurring within the population can be calculated. These data are available from instrumented laboratory-based gait analysis and could be used to estimate the frequency distribution of occurrence of observations made from video data. Why such information is rarely, if ever, presented by forensic gait analysts is unclear.

While such data are widely available for the movement of the joints and body segments of the pelvis and lower limbs, information about arm, upper body and head movement is less common. This is partly because the movement of the head and arms in everyday life is driven largely by the context in which an individual is walking (with someone else, holding an object, along a busy pavement, or up a steep incline) and not because they are necessarily an inherent part of an individual's gait pattern.

It is important to appreciate that some features have more potential to be useful in differentiating between individuals than others. For a feature to be useful it should be consistent within an individual, different between individuals and those differences should be measurable. Yang *et al*. (2014b) collected gait data from 12 healthy adult men walking in a gait laboratory. They reported that knee and ankle angles in the middle of the gait cycle varied least between individuals, while hip angles varied most, suggesting that the hip angles would be most useful in differentiating between individuals. Even so, the variation between individuals in hip angles is only 5° (standard deviation) which is unlikely to be detectable given the lack of precision of current video analysis techniques.

Another issue is the identification of multiple characteristics. If one characteristic is expected to occur in one in ten of the population and another in one in five of the population it is tempting to conclude that the combination of those features will only occur in one in 50 of the population (5 x 10 = 50). This is only true if the characteristics are statistically independent, which is rarely the case in gait analysis. Thus Birch *et al*. (2016a) found that 1 in 14 of a population had the right knee pointing inwards and 1 in 17 had a right foot pointing inwards. The combination of the two was present in the database as 1 in 27, not the 1 in 238 that might have been expected if the two characteristics had been independent. Until the level of dependence of such measures or features is known, estimates of how much certainty is added by identifying multiple uncommon characteristics should be regarded with caution.

3.3.3 How well can we recognise differences in gait?

Most people know someone who has such a distinctive gait that they are confident that the person could be recognised. It must be remembered, however, that recognition is generally multi-factorial and people will subconsciously combine information about the gait with other information, such as where they see the person, or what they are wearing, perhaps their size and stature or the sounds that are made by footwear or clothing. It is also worth noting that the very fact that some people stand out as having a characteristic gait is indicative that most people do not. Also, familiarity with the person is an important variable for consideration and one which generally does not apply in forensic gait analysis.

There are claims in the academic literature that humans are 'quite good' at identifying people from their gait (summarised in the Appendix). This is generally a rather liberal interpretation of results. Papers tend to focus on reporting the results of statistical tests which generally confirm that the results are unlikely to have occurred by chance. In criminal proceedings, where the standard of proof is high, the rate of incorrect identifications – which generally ranges between 20% and 50% (see Section 6 for references) – is an area of considerable concern.

It should be noted that these studies used an essentially continuous display of gait (a capture frequency of 20 frames per second or above). Modern video footage is often of a sufficiently low capture frequency to remove this sense of continuous movement (less than eight frames per second). Early work shows that it was virtually impossible to distinguish between people on the basis of static pictures of light point patterns[5] (Kozlowski and Cutting 1977), and more recent work confirms that the ability to identify gait features reduces as the video capture frequency (number of images per second) reduces (Birch *et al*. 2014).

3.3.4 How accurately do we grade our own ability to identify people using gait data?

In the absence of objective measures, a court will often rely on an expert witness' subjective self-assessment of the confidence they have in the analysis they present. No studies have examined this directly but two (Birch *et al*. 2016b, Kozlowski and Cutting 1977) have investigated the correlation between the confidence that individuals have in making decisions on the basis of gait data and the accuracy of those decisions. The accuracy of decision-making did improve with confidence but, even when analysts recorded the highest levels of confidence in their decisions, 1 in 6 decisions were wrong in the first study and 1 in 3 in the second. The participants in these studies were students but, in the absence of studies on professionals acting as expert witnesses, the results do suggest that caution is required in accepting a subjective self-assessment of confidence.

5 Light point studies presented the movement of point sources of light attached to the walker's body against a black background rather than full video.

4. Current best practice in forensic gait analysis

There is no published standardised approach for forensic gait analysis comparison, and a review of recent cases in which forensic gait analysis evidence was presented suggests that no formal or informal 'industry standard' approach to the analysis or presentation of evidence has yet evolved. No textbook focusing specifically on forensic gait analysis has yet been published though one is due to become available in 2017 (Kelly 2017). There is a chapter on the topic in a broader textbook on Forensic Podiatry (DiMaggio and Vernon 2011). It is also important to remember that textbooks are generally secondary reference sources and not primary sources which are most commonly found in peer-reviewed publications. The latter generally present a higher standard of scientific evidence as they are peer reviewed, whereas in a text, the author's views may be expressed even if unfounded and unsupported by the scientific community.

Forensic gait analysis is essentially the process of judging whether sample video footage taken of an unknown individual at or near the scene of a crime matches reference footage taken of a known individual at a different location. This requires an analysis of both sample and reference, and then a comparison of those analyses. Best practice in forensic matching generally is achieved when the analysis is performed on the sample and reference independently and then a comparison is undertaken. In an ideal world, both the analyses would be undertaken by independent observers and the comparison undertaken by a third observer. However, in the real world of forensic gait analysis, true independence is generally not possible and a single person is often responsible for all three processes. In this case, a few simple steps can be taken to ensure that the three processes are as independent as possible. The most obvious is to perform them sequentially, leaving a reasonable time gap between the three parts of the process. The sample data should always be analysed first to ensure that the analyst is not either consciously or subconsciously looking for specific features that are known from the reference data to characterise the individual. Documenting the date and time at which the three processes commenced and were completed will provide evidence of the attempted independence.

4.1 Analysis

Most forensic gait analysis starts with the presentation of video footage by the investigating authority or defence legal team. There will generally be two or more samples of video footage and the requirement is to determine, through a process of comparison, the likelihood that they are, or are not, of the same individual. When the analyst is supplied with the video footage they will also be informed of its context and of any subsequent alterations to the recordings (eg enhancement, compression, editing and/or truncation). Most analysts will expect to receive data in digital format and will anticipate a loss of quality if data has been transferred from analogue tapes or compressed to aid transferability. The original recordings should be available for comparison purposes when necessary.

The analyst will assess the video footage to determine if it is of adequate quality to facilitate a comparison with a second recording. DiMaggio and Vernon (2011) have prepared a tool to guide this assessment of quality, which is replicated below in Table 1, although little detail is given as to exactly how this should be used, or where, on the continuum represented by the double-headed arrows, optimum footage quality would sit. Although the original table caption (used here also) describes this as a tool for assessing quality objectively, its use is essentially subjective. A later paper (Birch *et al*. 2013) describes the process of further development of this tool but does not include any further detail of the tool itself.

In assessing the quality of the footage, the analyst may choose to enhance the image quality by adjusting contrast and other features to reduce the effects of poor lighting, shadows or reflections. A full data log of changes made to the working copy of the video footage will be retained in the case notes.

TABLE 1

Draft template for assessing the quality of a recording in the context of evidence provision (DiMaggio and Vernon 2011). It should be noted that while the preference is in general for factors on the left-hand side of this table, this is not always the case, as for example, 'too bright' can obscure detail just as much as 'too dark'.

Picture		
Very sharp	←——→	Very blurred
Very good contrast	←——→	Very poor contrast
Too bright	←——→	Too dark
Lighting		
Very good lighting	←——→	Very bad lighting
No shadow interference	←——→	Significant shadow interference
No reflection interference	←——→	Significant reflection interference
Direction of light source good	←——→	Direction of light source poor
Direction		
Directly from the side	←——→	Directly from the front or back
Frame rate		
Continuous flow of image	←——→	Series of still images
Subject		
Whole of upper body in shot	←——→	None of upper body in shot
Whole of lower body in shot	←——→	None of lower body in shot
Moving very fast	←——→	Moving very slowly
Ten steps or more in shot	←——→	Two steps or less in shot
Clothing good for gait analysis	←——→	Clothing poor for gait analysis

A first sweep of the video footage is performed to assess what information is available and which sections of the recording should be the subject of more detailed analysis. Those sections are then examined for evidence of general characteristics of the person's gait, followed by a more detailed description of specific anatomical joints and body segments. Some analysts will begin with a pre-defined checklist of gait features that they consider relevant to forensic gait analysis (Birch *et al*. 2016a, DiMaggio and Vernon 2011, Larsen *et al*. 2008), but there is considerable variation between these checklists both in overall structure and detailed application. DiMaggio and Vernon make a distinction between gait features (specific characteristics of a joint or body segment) and forms (more general patterns of movement spanning a range of joints). Their list is clearly influenced by a clinical background, and most of the forms and some of the features are unlikely to occur in individuals without a diagnosed medical condition (eg hemiplegic or paraplegic gait). Most forensic gait analysts tend to assess whether these characteristics are present but some indication of the frequency of such a characteristic would be of value. DiMaggio and Vernon (2011) also suggest that at this stage the analyst should assess whether the identification of the characteristics might have been influenced by factors relating to the recording (eg lighting level, viewing angle) or the person (eg walking over uneven ground or particularly quickly or slowly). Consideration of the viewing angle is particularly important as, while gait is three-dimensional, video is two-dimensional, and the information that can be gained about specific gait features will be highly dependent on how the camera is positioned in relation to the individual and the direction in which he or she is walking.

There appears to be little consistency in the formal recording or presentation format for forensic gait analysis reports. The report should include a general assessment of the quality of the recordings and of any issues within specific segments of the footage (this might be incorporated along with a description of findings or collated somewhere else if this improves the clarity of the report). The report should record the characteristics that have been identified, making clear reference to the segments of footage that support any observation. Often these will be 'dynamic' characteristics only apparent when the footage is viewed as video across some time interval. Less commonly, characteristics will be exemplified in specific frames of camera data which may be extracted as still images and inserted in the report to give support to conclusions drawn. In this case reference should be made as to whether the still frames are representative of the general pattern or of specific instances such as turning, starting or stopping etc. Ideally the report should be transparent in allowing the reader to understand fully how any conclusion has been reached.

4.2 Comparison

Once each video recording has been analysed and reported upon separately, then the analyst should compare both reports to establish whether they might relate to the same individual or whether exclusion is possible. This requires identification of the features that are present in both recordings and of those that are present in one and not in the other. The comparison also needs to take account of any concerns about data quality or other aspects, such as differences in how and when the different footage had been recorded, that might lead to incorrect conclusions. As with the analysis, the comparison should be recorded in a transparent fashion allowing the reader to follow how any conclusion has been reached.

Inclusion of images to support the comparison requires care, as exhibited by one well-publicised case (Larsen *et al*. 2007). In the comparison, pairs of images, or short video sequences, from different longer video recordings that seem very similar are presented. If these had both been identified as characteristic of the person in separate and independent reports on the two recordings, then the evidence of similarity would be compelling. If on the other hand the analyst had sifted through both recordings together to find the pair of frames that show the closest match, then the evidence may be flawed.

A variety of different approaches has been adopted to summarise the strength of the comparison. Larsen *et al*. (2008) rate the comparison merely as ‘agreement’, ‘non-agreement’ or ‘comparison not possible’ on the separate items in their checklist. They do not include ‘disagreement’ (videos are clearly from different individuals) which has different implications to ‘non-agreement’ (there is insufficient evidence to conclude that videos are from the same individual). An alternative might be to use the six-point scale recommended by the Association of Forensic Science Providers (2009) for use across the forensic sciences as reproduced in Table 2[6]. It should be noted that this is intended to be used to rate the overall conclusion rather than on a characteristic-by-

6 Light point studies presented the movement of point sources of light attached to the walker’s body against a black background rather than full video.

characteristic basis. The scale equates verbal equivalents to likelihood ratios (the ratio of the likelihood of a correct match to the likelihood of an incorrect match). Without black-box studies it is not possible to calculate formal likelihood ratios but an incorrect identification percentage of 17% (1 in 6), the lowest (best) from the series of studies in Table 3 (Appendix), equates to a likelihood ratio of 5 and thus to 'weak support for the proposition'. It is difficult to see how the use of any verbal equivalent other than 'weak support for the proposition' could be used to describe evidence provided by current approaches to forensic gait analysis. Use of tables such as Table 2 can also be criticised in that, if the likelihood ratio is known, simply quoting it gives the clearest indication of strength of agreement, and, if it is not known, there is no evidence for using any particular verbal equivalent.

DiMaggio and Vernon (2011) point out that the strength of the conclusion depends in part on how rare any identified characteristics are within the population and it should be borne in mind that currently, this is often only a subjective estimate. A particular advantage of using the list of characteristics as proposed by Birch *et al*. (2016a) is that a database is being compiled of how common these characteristics might be in the UK population (although the publication describes the methodology behind how the database has been developed rather than the information it contains).

TABLE 2

Scale of evidence proposed by the Association of Forensic Science Providers (2009)

Verbal equivalent	Value of likelihood ratio
Weak support for the proposition	less than 10
Moderate support	10–100
Moderately strong support	100–1,000
Strong support	1,000–10,000
Very strong	10,000–1,000,000
Extremely strong	more than 1,000,000

5. Professionals involved in gait analysis and qualification

Given the wide range of approaches to gait analysis, there are many different types of professionals that may present as Gait Analysts. This title is not legally protected so there is no formal definition of who is, or is not, permitted to do so. There are no academic qualifications in forensic gait analysis per se, so professionals involved in the field may hold qualifications in a wide range of related areas. It will rarely be clear from the qualification title how much training in gait analysis in general has been undertaken (and it is unlikely that there has been any specific requirement for training in forensic gait analysis). The professional or academic background, qualification or professional registrations of an individual are thus unlikely to give unambiguous confirmation of their competence to act as an expert witness in relation to forensic gait analysis evidence.

A small number of individuals have now developed a specific interest in presenting as expert witnesses and some have developed a formal style of preparing and presenting their material. There is no evidence, however, that their opinions are any more valid than those of individuals who may appear less often in court and present less formally.

5.1 Forensic gait analyst

The self-regulating Chartered Society of Forensic Sciences maintains an Expert Register of individuals who have achieved Accredited Forensic Practitioner (AcFP) status. At present (May 2017) three of a total of 16 registrants are described as *Forensic Gait Analysts*. There is, however, no formal requirement for people to be on this register to act as an expert witness.

The Society awards a Certificate of Professional Competence. This was developed by the Society with a small group of forensic podiatrists as a 'robust, fit for purpose certification model that tested their knowledge and competence to practice as a forensic podiatrist'. This model is currently being 'applied to the testing of competencies in all forensic disciplines'. The scheme for forensic podiatrists is only open to qualified podiatrists. Advertising literature for a current two-day weekend course implies that an individual who is interested in forensic podiatry will be provided with the 'basic preparation required to enable practitioners to undertake the Chartered Society's competency testing in the three areas of forensic podiatry' (of which forensic gait analysis is one).

The University of Huddersfield is currently the only higher education institute in the UK to offer an MSc in Forensic Podiatry, which is obtained through three years of part-time study for podiatrists registered with the Health and Care Professions Council (HCPC).

5.2 Clinical gait analyst

Clinical gait analysis provides information to doctors and other health professionals to allow them to refine the treatment they recommend to patients and to evaluate how effective this has been. Observational gait analysis relies on what the clinician sees in person and has always been important to orthopaedic surgeons, neurologists, physiotherapists, prosthetists (providing artificial limbs), orthotists (providing splints and braces), bioengineers and podiatrists. Over the last 40 years, the use of instrumented or 3D gait analysis has become more common in specialist centres using optoelectronic (specialised cameras) tracking systems and other equipment to measure how the patient moves. This is generally presented as gait graphs showing how the body moves during walking. Some clinicians also take video of patients to analyse walking, although this is not particularly common and most of the analysis of such footage is essentially subjective.

Perhaps the most important difference between all forms of clinical gait analysis and forensic gait analysis is that clinical gait analysis is intentional, controlled and standardised. Patients are generally asked to undress sufficiently to allow the relevant body parts to be seen and are asked to walk in a particular way in a standardised environment (generally barefoot in a straight line at their preferred walking speed across a level surface without obstacles). In observational gait analysis, it is advised that clinicians situate themselves to view the patient from standard reference positions and this principle is implemented more rigorously in video analysis by the careful positioning of the cameras in relation to the walkway.

In clinical gait analysis, it is also generally assumed that the variation between healthy individuals is small and the focus is on identifying abnormal features in the data that are characteristic of people with different health conditions. A limitation is that even in people with health-related conditions, these features can be too subtle to be distinguished from the full healthy range using even the most sophisticated technology.

Clinical gait analysts within the UK are normally either doctors who must be registered with the General Medical Council or allied health professionals who must be registered with the Health and Care Professions Council[7]. Orthopaedic surgeons, neurologists and specialists in rehabilitation medicine are the doctors who are most likely to have

7 In the UK, biomechanists involved within clinical gait analysis should be registered as clinical scientists or engineers with the HCPC, and are considered as 'allied health professionals' in this context.

expertise in gait analysis. Allied health professionals with expertise in gait analysis are most likely to be physiotherapists, prosthetists (who provide artificial limbs) and orthotists (who provide splints and braces), podiatrists (who focus on the health of the foot) or clinical scientists/engineers (who are experts in biomechanics). Entry to all these professions is now restricted to those with relevant honours degrees but some older allied health professionals entered the profession with alternative qualifications. Many clinical gait analysts will have Master's-level or PhD-level qualifications. A small number of universities now offer an MSc in Clinical Gait Analysis, Motion Analysis or similar, but these tend to focus on instrumented gait analysis.

It should be noted that formal training in gait analysis forms a very small component of most of these qualifications and most doctors and health professionals will have been able to gain their qualification without any formal assessment in the subject. Clinical gait analysis is taught as a method for assessing patients and guiding treatment decisions for people who have difficulty walking normally. Practitioners will have been taught about 'normal' gait but this material will almost always have focused on the features of walking which everyone shares, whereas the focus of forensic gait analysis is on the features of walking that differ between individuals. Clinical gait analysis is taught quite differently across the different health professions and terminology can vary widely.

5.3 Running gait analyst

Running gait analysis has become more common in sports shops over the last few years. Video recordings (and occasionally, instrumented 3D data) of how the customer runs on a treadmill are used to recommend particular footwear. Advice may also be given on specific training techniques that could be adopted to improve running style. This can be seen as a specific instance of a wider use of more general video and instrumented movement analysis techniques that aims to enhance performance and protect against injury across a wide range of sports.

There is no regulatory framework governing provision of running gait analysis in sports shops and no specific expertise can be assumed of staff operating such services. On the other hand, some very highly qualified individuals (PhD and beyond) are involved in scientific analysis of how athletes run or move more generally.

5.4 Biometric gait analyst

Biometric gait analysis assumes that a gait pattern is characteristic of the individual and that automated methods can thus be used to identify him or her. There is considerable interest in developing such techniques for use by both public and private providers of security or surveillance. The aim is to provide automated identification by extracting data from video recordings and using computers to analyse the overall pattern of movement. This differs from forensic gait analysis which is generally based on subjective expert opinion (rather than automated software) and on specific aspects of the gait pattern (rather than the gait pattern as a whole). It is important to understand that automated gait recognition thus makes use of a much richer dataset and sophisticated machine learning software which are not currently being applied in forensic gait analysis. Biometric gait analysis tends to be the preserve of statisticians and biomechanics researchers (PhD level and above). Modern applications use a variety of statistical approaches, including machine learning, to analyse gait data. Such analyses do not always require a deep understanding of human walking.

6. References

Association of Forensic Science Providers. 2009 Standards for the formulation of evaluative forensic science expert opinion. *Sci. Justice* **49**, 161–164. (doi:10.1016/j.scijus.2009.07.004)

Birch I, Birch T, Bray D. 2016b The identification of emotions from gait. Sci. Justice **56**, 351–356. (doi:10.1016/j.scijus.2016.05.006)

Birch I, Gwinnett C, Walker J. 2016a Aiding the interpretation of forensic gait analysis: Development of a features of gait database. *Sci. Justice* **56**, 426–430. (doi:10.1016/j.scijus.2016.06.009)

Birch I, Raymond L, Christou A, Fernando MA, Harrison N, Paul F. 2013a The identification of individuals by observational gait analysis using closed circuit television footage. *Sci. Justice* **53**, 339–342. (doi:10.1016/j.scijus.2013.04.005)

Birch I, Vernon W, Burrow G, Walker J. 2014 The effect of frame rate on the ability of experienced gait analysts to identify characteristics of gait from closed circuit television footage. *Sci. Justice* **54**, 159–163. (doi:10.1016/j.scijus.2013.10.002)

Birch I, Vernon W, Walker J, Saxelby J. 2013 The development of a tool for assessing the quality of closed circuit camera footage for use in forensic gait analysis. *J. Forensic Leg. Med*. **20**, 915–917. (doi:10.1016/j.jflm.2013.07.005)

Birch I, Vernon W, Walker J, Young M. 2015 Terminology and forensic gait analysis. *Sci. Justice* **55**, 279–284. (doi:10.1016/j.scijus.2015.03.002)

Bouchrika I, Goffredo M, Carter J, Nixon M. 2011 On using gait in forensic biometrics. *J. Forensic Sci*. **56**, 882–889. (doi:10.1111/j.1556-4029.2011.01793.x)

Cronin NJ. 2014 The effects of high heeled shoes on female gait: a review. *J. Electromyogr. Kines*. **24**, 258–263. (doi:10.1016/j.jelekin.2014.01.004)

Cutting JE, Kozlowsi LT. 1977 Recognizing friends by their walk: Gait perception without familiarity cues. *J. Psychon. Soc*. **9**, 353–356. (doi:10.3758/BF03337021)

DiMaggio JA, Vernon W. 2011 Forensic gait analysis. In: DiMaggio JA, Vernon W (eds) Forensic Podiatry: *Principles and Methods*. New York, USA: Springer Science + Business Media.

Fong DT, Mao DW, Li JX, Hong Y. 2008 Greater toe grip and gentler heel strike are the strategies to adapt to slippery surface. *J. Biomech*. **41**, 838–844. (doi:10.1016/j.jbiomech.2007.11.001)

Fosang AL, Galea MP, McCoy AT, Reddihough DS, Story I. 2003 Measures of muscle and joint performance in the lower limb of children with cerebral palsy. *Dev. Med. Child Neurol*. **45**, 664–670. (doi:10.1017/S0012162203001245)

Franklin S, Grey MJ, Heneghan N, Bowen L, Li FX. 2015 Barefoot vs common footwear: A systematic review of the kinematic, kinetic and muscle activity differences during walking. *Gait Posture* **42**, 230–239. (doi:10.1016/j.gaitpost.2015.05.019)

Jain AK, Ross A. 2015 Bridging the gap: from biometrics to forensics. *Philos. T. R. Soc. B*. **370**, 20140254. (doi:10.1098/rstb.2014.0254)

Kelly H. 2000 Old Bailey Central Criminal Court London. R v. Saunders.

Kelly H. 2017 *Forensic gait analysis*. Boca Raton, USA: CRC Press.

Kirtley C, Whittle M, Jefferson R. 1985 Influence of walking speed on gait parameters. *J. Biomed. Eng*. **7**, 282–288. (doi:10.1016/0141-5425(85)90055-X)

Kirtley C. 2006 *Clinical gait analysis – theory and practice*. Edinburgh, UK: Churchill Livingstone.

Kozlowski LT, Cutting JE. 1977 Recognizing the sex of a walker from a dynamic point-light display. *Percept. Psychophys*. **21**, 575–580. (doi:10.3758/bf03198740)

Krishan K, Kanchan T, DiMaggio JA. 2015 Emergence of forensic podiatry – A novel sub-discipline of forensic sciences. *Forensic Sci. Int.* **255**, 16–27. (doi:10.1016/j.forsciint.2015.06.012)

Larsen PK, Lynnerup N, Henriksen M, Alkjaer T, Simonsen EB. 2010 Gait recognition using joint moments, joint angles, and segment angles. *J. Forensic Biomech*. **1**, 1–7. (doi:10.4303/jfb/F100302)

Larsen PK, Simonsen EB, Lynnerup N. 2007 *Gait analysis in forensic medicine*. Paper presented at Videometrics IX, San Jose, CA, USA.

Larsen PK, Simonsen EB, Lynnerup N. 2008 Gait analysis in forensic medicine. *J. Forensic Sci*. **53**, 1149–1153. (doi:10.1111/j.1556-4029.2008.00807.x)

Lynnerup N, Larsen PK. 2014 Gait as evidence. *IET Biometrics* **3**, 47–54. (doi:10.1049/iet-bmt.2013.0090)

Majumdar D, Pal MS, Majumdar D. 2010 Effects of military load carriage on kinematics of gait. *Ergonomics* **53**, 782–791. (doi:10.1080/00140131003672015)

Matovski DS, Nixon MS, Mahmoodi S, Carter JN. 2012 The effect of time on gait recognition performance. *IEEE T. Inf. Foren. Sec*. **7**, 543–552. (doi:10.1109/TIFS.2011.2176118)

McDowell BC, Hewitt V, Nurse A, Weston T, Baker R. 2000 The variability of goniometric measurements in ambulatory children with spastic cerebral palsy. *Gait Posture* **12**, 114–121. (doi:10.1016/S0966-6362(00)00068-0)

McGinley J, Baker R, Wolfe R, Morris ME. 2009 The reliability of three–dimensional kinematic gait measurements: a systematic review. *Gait Posture* **29**, 360–369. (doi:10.1016/j.gaitpost.2008.09.003)

McGinley J, Wolfe R, Morris M, Pandy MG, Baker R. 2014 Variability of walking in able-bodied adults across different time intervals. *J. Phys. Med. Rehabil*. *Sci*. **17**, 6–10.

Menz HB, Lord SR, Fitzpatrick RC. 2003 Acceleration patterns of the head and pelvis when walking on level and irregular surfaces. *Gait Posture*, **18**, 35–46. (doi:10.1016/S0966-6362(02)00159-5)

Morel E, Allali G, Laidet M, Assal F, Lalive PH, Armand S. 2017 Gait Profile Score in multiple sclerosis patients with low disability. *Gait Posture* **51**, 169–173. (doi:10.1016/j.gaitpost.2016.10.013)

Murray MP. 1967 Gait as a total pattern of movement. *Amer. J. Physical Med*. 46, 290–333.

Pataky TC, Mu T, Bosch K, Rosenbaum D, Goulermas JY. 2011 Gait recognition: highly unique dynamic plantar pressure patterns among 104 individuals. *J. R. Soc. Interface* **9**, 790–800. (doi:10.1098/rsif.2011.0430)

Pau M, Coghe G, Atzeni C, Corona F, Pilloni G, Marrosu MG *et al*. 2014 Novel characterization of gait impairments in people with multiple sclerosis by means of the Gait Profile Score. *J. Neurol. Sci*. **345**, 159–163. (doi:10.1016/j.jns.2014.07.032)

Pinzone O, Schwartz MH, Thomason P, Baker R. 2014 The comparison of normative reference data from different gait analysis services. *Gait Posture* **40**, 286–290. (doi:10.1016/j.gaitpost.2014.03.185)

Radzak KN, Putnam AM, Tamura K, Hetzler RK, Stickley CD. 2017 Asymmetry between lower limbs during rested and fatigued state running gait in healthy individuals. *Gait Posture* **51**, 268–274. (doi:10.1016/j.gaitpost.2016.11.005)

Reed RJ, Lowrey CR, Vallis LA. 2006 Middle-old and old-old retirement dwelling adults respond differently to locomotor challenges in cluttered environments. *Gait Posture* **23**, 486–491. (doi:10.1016/j.gaitpost.2005.06.010)

Rose J, Gamble J. (eds) 2006 *Human walking*. 3rd ed. Philadelphia, USA: Lippincott Williams and Wilkins.

Schwartz MH, Rozumalski A, Trost JP. 2008 The effect of walking speed on the gait of typically developing children. *J. Biomech*. **41**, 1639–1650. (doi:10.1016/j.jbiomech.2008.03.015)

Seymour KM, Higginson CI, DeGoede KM, Bifano MK, Orr R, Higginson JS. 2016 Cellular telephone dialing influences kinematic and spatiotemporal gait parameters in healthy adults. *J. Motor Behav*. **48**, 535–541. (doi:10.1080/00222895.2016.1152226)

Speciali DS, Oliveira EM, Cardoso JR, Correa JC, Baker R, Lucareli PR. 2014 Gait profile score and movement analysis profile in patients with Parkinson's disease during concurrent cognitive load. *Braz. J. Phys. Ther*. **18**, 315–322. (doi:10.1590/bjpt-rbf.2014.0049)

Stevenage SV, Nixon MS, Vince K. 1999 Visual analysis of gait as a cue to identity. *Appl. Cognitive Psych*. **13**, 513–526. (doi:10.1002/(SICI)1099-0720(199912)13:6<513::AID-ACP616>3.0.CO;2-8)

Troje NF, Westhoff C, Lavrov M. 2005 Person Identification from biological motion: Effects of structural and kinematic cues. *Percept. Psychophys*. **67**, 667–675. (doi:10.3758/BF03193523)

Wannop JW, Worobets JT, Ruiz R, Stefanyshyn DJ. 2014 Footwear traction and three-dimensional kinematics of level, downhill, uphill and cross-slope walking. *Gait Posture* **40**, 118–122. (doi:10.1016/j.gaitpost.2014.03.004)

Winter DA. 1979 *Biomechanics of human movement*. New York, USA: John Wiley & Sons.

Winter DA. 2009 *Biomechanics and motor control of human movement*. 4th ed. Hoboken, NJ, USA: John Wiley & Sons.

Yang SX, Larsen PK, Alkjaer T, Lynnerup N, Simonsen EB. 2014a Influence of velocity on variability in gait kinematics: implications for recognition in forensic science. *J.Forensic Sci.* **59**, 1242–1247. (doi:10.1111/1556-4029.12490)

Yang SXM, Larsen PK, Alkjaer T, Simonsen EB, Lynnerup N. 2014b Variability and similarity of gait as evaluated by joint angles: Implications for forensic gait analysis. *J. Forensic Sci.* **59**, 494–504. (doi:10.1111/1556-4029.12322)

Appendix: Studies cited as evidence that humans can identify people by their gait

TABLE 3

Studies cited as evidence that humans can identify people by their gait

Study	Observers	Task	p-valuee	% incorrect
Light points[a]				
Cutting and Kozlowski 1977	7 friends[b] (undergraduates)	Choose target from 6 individuals	<0.005	62%
Kozlowski and Cutting 1977	6 friends[c] (undergraduates)	Specify gender	<0.05	37%
Troje *et al*. 2005	18 students	Learn to distinguish 7 individuals		
		after 1st training session	n/a	47%
		after 4th training session	n/a	17%
Video (CCTV) film				
Birch *et al*. 2013	7 'experienced analysts'	target[d] from 5 individuals	< 0.05	29%
		from same angle	n/a	21%
Stevenage *et al*. 1999 (Experiment 2)	48 'participants'	Choose target[d] from 6 individuals	<0.0005	50%

a Light point studies presented the movement of point sources of light attached to the walker's body against a black background rather than full video.

b 7 mutual friends who had to identify each other from light point gait data.

c Similar study but the task was to specify gender rather than identify individuals.

d Analysts were presented with video of a number of individuals and asked to identify which matched a different video of a target individual.

e A p-value is the probability that the result (or a more extreme result) could have occurred by chance. Statisticians generally assume that a p-value of less than 0.05 is required to conclude that this is unlikely.

The members of the groups involved in producing this primer are listed below. The members acted in an individual and not organisational capacity and declared any conflicts of interest. They contributed on the basis of their own expertise and good judgement. The Royal Society and the Royal Society of Edinburgh gratefully acknowledges their contribution.

Primer leads

His Honour Judge Mark Wall QC

Professor Dame Sue Black DBE FRSE

Editorial board

Sheriff Andrew Cubie

Professor Tim Theologis

Professor Daniel Wolpert FMedSci FRS

Writing Group

Professor Rami Abboud

Professor Richard Baker

Professor Julie Stebbins

Acknowledgments

This project would also not have been possible without contributions and support from a range of individuals. In particular we wish to thank:

The Rt Hon Lord Thomas of Cwmgiedd, Lord Chief Justice of England and Wales, 2012 – 2017

The Rt Hon Lord Carloway, Lord President of the Court of Session and Lord Justice General

Sir John Skehel FMedSci FRS, Vice President and Biological Secretary of the Royal Society

Primers Steering Group

Lord Hughes of Ombersley (Chair)

Professor Dame Sue Black DBE FRSE

Lord Bracadale QC

Dr William Duncan

Sir Charles Godfray CBE FRS

Dame Ottoline Leyser DBE FRS

Dr Julie Maxton CBE

Professor Angela McLean FRS

Professor Niamh Nic Daéid FRSE

Lady Justice Anne Rafferty DBE

Sir Muir Russell KCB FRSE

His Honour Judge Mark Wall QC

The Royal Society is a self-governing Fellowship of many of the world's most distinguished scientists drawn from all areas of science, engineering, and medicine. The Society's fundamental purpose, as it has been since its foundation in 1660, is to recognise, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity.

The Society's strategic priorities are:

- Promoting excellence in science
- Supporting international collaboration
- Demonstrating the importance of science to everyone

For further information

The Royal Society
6 – 9 Carlton House Terrace
London SW1Y 5AG

T +44 20 7451 2571
E law@royalsociety.org
W royalsociety.org/science-and-law

Registered Charity No 207043

The Royal Society of Edinburgh (RSE), Scotland's National Academy, is a leading educational charity which operates on an independent and non-party-political basis to provide public benefit throughout Scotland. Established by Royal Charter in 1783 by key proponents of the Scottish Enlightenment, the RSE now has around 1600 Fellows from a wide range of disciplines. The work of the RSE includes awarding research funding, leading on major inquiries, informing public policy and delivering events across Scotland to inspire knowledge and learning.

For further information

The Royal Society of Edinburgh
22 – 26 George Street
Edinburgh EH2 2PQ

T +44 131 240 5000
E info@theRSE.org.uk
W rse.org.uk

Scottish Charity No SC000470

ISBN: 978-1-78252-302-4
Issued: November 2017 DES4929