

Forensic Gait Analysis in Criminal Investigative Practice

Possibilities, Limitations, and Requirements for Appropriate Use

Video material plays a central role in modern criminal investigations and generates high expectations regarding the identification of suspects. In practice, however, video recordings are often of poor quality, captured from unfavourable perspectives, or provide only brief visual contact, making classical identifying features such as facial characteristics unusable. Against this backdrop, human gait has increasingly come into focus as a potential comparative feature. Forensic gait analysis examines walking movement patterns to derive indications regarding a person's identity.

Video Evidence Between Expectations and Reliability

Video material has become indispensable in modern criminal investigative practice (Golda, Cormier & Beyerer, 2022; Tuma, 2016). Public video surveillance, private cameras, so-called dashcams, drones, and mobile phones provide visual information about potential criminal events and the individuals involved in a wide range of investigations. Along with this development and the large volume of available data, high expectations regarding the identification of suspects have emerged (Adiarte, 2018).

In practice, however, often a different picture emerges: recordings are blurred, captured from unfavourable perspectives, or show the suspect only briefly, from a considerable distance, and under challenging lighting conditions. Classical identifying features such as facial characteristics are often unusable. Against this background, investigators and courts increasingly focus on human gait as a possible comparative feature, either for the purpose of identifying an unknown suspect (e.g., through database comparison)¹ or for comparison to material from a known suspect (e.g., through the collection of a *gait sample*). Forensic gait analysis, as it is commonly referred to, examines movement patterns of a person's gait and enables investigators to derive possible indications regarding an individual's identity. Strictly speaking, walking refers to the fundamental movement used for locomotion, whereas gait describes the specific patterns, style, and way a person walks (Birch, Vernon, Walker & Young, 2015). Gait encompasses the coordinated sequence of leg and arm movements, reflects rhythm and particular characteristics of balance transfer, and is influenced by numerous factors such as health, injuries, or even mood (Birch, Birch & Lall, 2021; Birch, Nirenberg, Vernon & Birch, 2020). This context dependency limits its suitability as a sole individualizing identification feature. Current scientific evidence is insufficient to support unequivocal recognition of individuals based solely on gait.

Investigators therefore face the question of whether and to what extent gait analysis can nevertheless contribute reliably to criminal investigations, or whether its use involves specific risks.

¹ Databases exist, for example, in the Netherlands, but not in Germany.

Human Gait as a Forensic Feature

Human gait is a complex movement pattern resulting from the interaction of anatomical characteristics, muscular control, and neuromotor processes. Differences between individuals can indeed be observed in gait patterns, for example with respect to stride length, rhythm, posture, or arm movement (Michelini, Eshraghi & Andrysek, 2020). However, such interindividual differences are contrasted by considerable intraindividual variability. Human gait is influenced by general, individual, and situational factors, which are briefly outlined below.

A person's gait is shaped by individual biological factors (genetic predisposition), health-related factors (e.g., injuries, acute pain conditions), and personal factors (e.g., age, sex, situational influences). The gait pattern of a single individual changes depending on walking speed, surface conditions, footwear, clothing, physical condition, emotional state, or deliberate modification.

Simply carrying a bag, wearing specific footwear (e.g., high heels), or walking on uneven ground can significantly alter movement patterns. From a criminal investigative perspective, this means that gait is not a stable and immutable characteristic but rather highly context-dependent. This variability is the primary reason why human gait currently cannot be regarded as an exclusively individualizing identification feature in the forensic sense. Considering these factors, the scientific evidence is insufficient to assume unequivocal recognizability. Internationally, various methodological approaches to forensic gait analysis exist. Predominantly video-based methods use qualitative descriptions or combine measurements with comparative datasets. Standardized procedures as well as recognized training and certification programs are still lacking. The actual evidential value of these methods is generally limited to statements about the compatibility or incompatibility of gait characteristics rather than definitive identifications. Currently, several structured gait analysis methods are known and are utilized in Canada, the United States, the United Kingdom, the Netherlands, and other parts of Europe (Badiye, Kathane & Krishan, 2020; Cubie et al., 2017; Larsen, Simonsen & Lynnerup, 2008; Van Mastrigt, Celie, Mieremet, Ruifrok & Geradts, 2018). Although these approaches are based on common foundations in medicine, particularly orthopedics and biomechanics, and on fundamental forensic-scientific requirements, the variability of approaches as well as technical² and situational influencing factors complicate comparisons between commonly used methods (Nirenberg, Vernon & Birch, 2018).

Some gait analysts rely primarily on extensive qualitative descriptions. For this purpose, checklists are created to describe gait patterns comprehensively and in detail. One of the most commonly used instruments for such comparison analyses is the *Sheffield Features of Gait Tool*. In 14 sections containing a total of 113 parameters, individual gait components are observed separately and subsequently compared with those present in reference material (Birch et al., 2021; Birch et al., 2019). To increase analytical reliability, efforts have been made to create extensive comparative datasets of walking individuals (Birch, Gwinnett & Walker, 2016). In such cases, case-specific video material is compared with material from

² This refers to technical limitations of the video material (image quality).

the reference dataset to evaluate potential individualizing features. Gait characteristics may also be described exclusively from an orthopaedic or medical perspective. Furthermore, approaches have emerged that explore whether reliable measurements can be obtained through the application of three-dimensional human pose estimation. Ideally, the goal is to replace the considerable time required for qualitative methods by directly matching two individuals (offender and suspect) based on a single video recording of each (Richter & Labudde, 2024). In more advanced technology-based procedures, various computer-based measurement methods are being tested. These approaches allow specific measurable gait features to be compared with reference material in order to derive probabilistic statements regarding possible individualization (e.g., *3D Motion Analysis*) (Van Mastrigt et al., 2018).

An examination of international experiences shows that forensic gait analysis is employed in numerous countries. In some jurisdictions, it is regarded primarily as a supportive investigative instrument rather than as an independent identification procedure (e.g., Canada, the United Kingdom, and the United States). According to a currently unpublished European survey, forensic gait analyses are presently being conducted in Poland, Serbia, Italy, Switzerland, and the Netherlands.

In Germany, strict requirements concerning data protection, transparency, validation, and methodological traceability also highlight the necessity of critically evaluating forensic gait analysis methods. Although requests for gait analyses have increased noticeably during the last two years, only isolated forensic gait analyses have been conducted to date. Neither internationally nor nationally is there currently one universally accepted method, nor are there standardized training or educational programs in forensic gait analysis. This is even though some practitioners (e.g., in the United Kingdom) have been conducting gait analyses for more than 40 years within criminal investigation and prosecution processes, and requests for such analyses have increased steadily since 2000 (Birch et al., 2019; Birch et al., 2020). In the Netherlands, gait analyses have occasionally been presented in court over the past 20 years; in England, forensic gait analysis has been admitted as supporting evidence in court proceedings for more than 15 years; and in Denmark for more than 10 years (Van Mastrigt et al., 2018).

Methods of Forensic Gait Analysis and Their Evidential Value

In criminal investigative practice, predominantly video-based comparison methods are used (Tuma, 2016, 2022). Recordings of suspects are compared with reference material. This may involve either (a) recordings of an unknown comparison individual or (b) recordings of the suspect obtained at other, initially non-crime-related points in time (e.g., through covert investigative measures). The detailed analysis is usually conducted visually and may be supplemented by simple measurements based on the available video material. The actual evidential value of these procedures is limited. As a rule, only similarities or differences in specific movement features can be described. Such findings permit statements regarding compatibility or incompatibility but not definitive identification. Caution is required because seemingly distinctive features, such as special foot or joint positions, may also occur in other individuals or may be situationally induced (e.g., a particularly restricted arm swing resulting from an attempt to walk quickly).

Another problem is that video-metric approaches may create an impression of objectivity that is not actually warranted. Measurement accuracy and the possibility of obtaining measurements depend heavily on image quality, camera perspective, and the visible movement sequence. In many investigations, these prerequisites are not adequately met.

Currently, the Digital Imaging Working Group (DIWG), a subgroup of the European Network of Forensic Science Institutes (ENFSI), conducts online seminars twice a year focusing on forensic gait analysis. International experts and researchers present current developments, discuss established methods and practical experiences, and facilitate professional exchange within the European community. These activities are scientifically accompanied by surveys and scholarly documentation.

Evidential Strength, Sources of Error, and Perceptual Risks

The evidential strength of a gait comparison depends fundamentally on the quality of the underlying video material. Gait sequences that are too short (fewer than three complete gait cycles), occluded body parts, changing camera angles, or perspective distortions can significantly reduce evidential value. Furthermore, comparability is often limited because comprehensive crime-related and reference recordings are unavailable, particularly recordings showing the suspect under different clothing conditions or recording situations. Another central risk factor is cognitive bias. If an expert is aware of the investigative status or additional incriminating evidence, there is a danger of unconscious confirmation bias. The visual persuasiveness of video comparisons may further amplify this risk. In practice, a neutral and unbiased evaluation, along with the division of analytical tasks among several independent analysts, is therefore of particular importance.

Investigative Utility and Evidentiary Value

From a criminal investigative perspective, a clear distinction must be made between the utility of forensic gait analysis during investigations and its evidentiary value in court proceedings. As an investigative tool, it can provide useful indications, for example regarding the plausibility of involvement in an offense or the narrowing of a suspect pool. In this context, it can make a meaningful contribution. Moreover, the structured evaluation of video material enhances investigators' observational capabilities (Seckiner, Mallett, Maynard, Meuwly & Roux, 2019). Within judicial proceedings, however, forensic gait analysis has only circumstantial evidentiary significance. It may support other forms of evidence but cannot replace them (Macoveciuc, Rando & Borrión, 2019). An isolated determination of identity based solely on gait comparison is currently neither scientifically nor legally sustainable (Le Grand, Neuschatz, Golding, Jenkins & Cutler, 2022). Possible correspondences between comparison materials can only be expressed in probabilistic terms. Probabilistic or identification statements lacking empirical support are problematic because they may suggest an unwarranted level of evidentiary certainty.

Legal Framework and Judicial Evaluation

Under Section 261 of the German Code of Criminal Procedure (§ 261, StPO), the assessment of evidence is subject to the free conviction of the court (Eisenberg, 2008). This freedom, however, requires courts to critically examine the reliability of expert opinions. Case law

demands that expert reports be comprehensible, transparent, and explicit regarding their limitations, particularly when methods possess limited scientific validation. Judicial practice in dealing with gait comparison reports has so far been inconsistent. While some courts explicitly emphasize their circumstantial nature, other proceedings have attributed considerable weight to the method. The visual persuasiveness of video comparisons creates a risk of overestimation if scientific limitations are not adequately considered.

Responsibility of Investigators and Experts

Investigators and experts bear responsibility in the use of forensic gait analysis. Investigators should not regard the method as a substitute for traditional criminal investigative work but should always interpret its findings within the broader evidentiary context. Experts are obliged to work in a methodologically sound and transparent manner, openly acknowledge uncertainties, and avoid any form of implicit identification. Only a clear distinction between description and evaluation enables courts to conduct an independent and critical assessment of evidence.

9 Conclusion

Forensic gait analysis can be a valuable addition to criminal investigative practice, particularly during early investigative stages or as a supporting tool for generating leads and evaluating circumstantial evidence. However, significant limitations currently constrain its extensive application. As an independent means of identification, it is presently unsuitable without extensive comparative datasets. Appropriate and cautious application, together with realistic communication of its evidential value, is essential to avoid misinterpretations and to safeguard the rule-of-law quality of criminal investigative work (Mangone et al., 2023). Support for interdisciplinary research initiatives at the international level is necessary to establish standardized methods and guideline-compliant applications of forensic gait analysis throughout Europe (Van Mastrigt et al., 2018).



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