Gait analysis in forensic medicine

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ABSTRACT

We have combined the basic human ability to recognize other individuals with functional anatomical and biomechanical knowledge, in order to analyze the gait of perpetrators as recorded on surveillance video. The perpetrators are then compared with similar analyses of suspects. At present we give a statement to the police as to whether the perpetrator has a characteristic gait pattern compared to normal gait, and if a suspect has a comparable gait pattern. We have found agreements such as: limping, varus instability in the knee at heel strike, larger lateral flexion of the spinal column to one side than the other, inverted ankle during stance, pronounced sagittal head-movements, and marked head-shoulder posture. Based on these characteristic features, we state whether suspect and perpetrator could have the same identity but it is not possible to positively identify the perpetrator. Nevertheless, we have been involved in several cases where the court has found that this type of gait analysis, especially combined with photogrammetry, was a valuable tool. The primary requisites are surveillance cameras recording with sufficient frequency, ideally about 15 Hz, which are positioned in frontal and preferably also in profile view.

Keywords: Gait analysis, gait recognition, forensic medicine, biometric, recognition, joint angles, posture.

1. INTRODUCTION

The ability to recognize other individuals is fundamental to human life. Identification by gait is a part of this process. Shakespeare made use of this in his play "The Tempest" where Ceres said: "High'st queen of state, Great Juno, comes; I know her by her gait". Psycho physiological studies have proved that the human being can recognize the sex of a walker [1] and friends and colleagues [2,3] with a success rate up to 70-80%. The fast development of data technology has now made it possible to generate computer models which can identify people's gait with more than 90% success, e.g. [4] and [5], but these models are still based on a small number of people and require optimal conditions seldom found outside the laboratory [6].

At the Institute of Forensic Medicine in Copenhagen we are often asked to help the police identify perpetrators based on surveillance recordings of a quality unable for automatic recognition. Instead we combine the basic ability to recognize people with biomechanical knowledge and give statements whether or not a suspect could have the same identity as a perpetrator in a given case by comparing the suspect's posture and joint angles during gait with the perpetrator's.

This approach to gait analysis in forensic medicine started with the Aalsgaarde Case [7] where we found concordances in the gait pattern between suspect and perpetrator with respect to pronounced side-to-side movements of the head and hyper extension in the knee joints as shown in Fig. 1. In this paper we will describe and discuss our further work based on another case study.

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Videometrics IX, edited by J.-Angelo Beraldin, Fabio Remondino, Mark R. Shortis,
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 6491, 64910M, © 2007 SPIE-IS&T · 0277-786X/07/$15

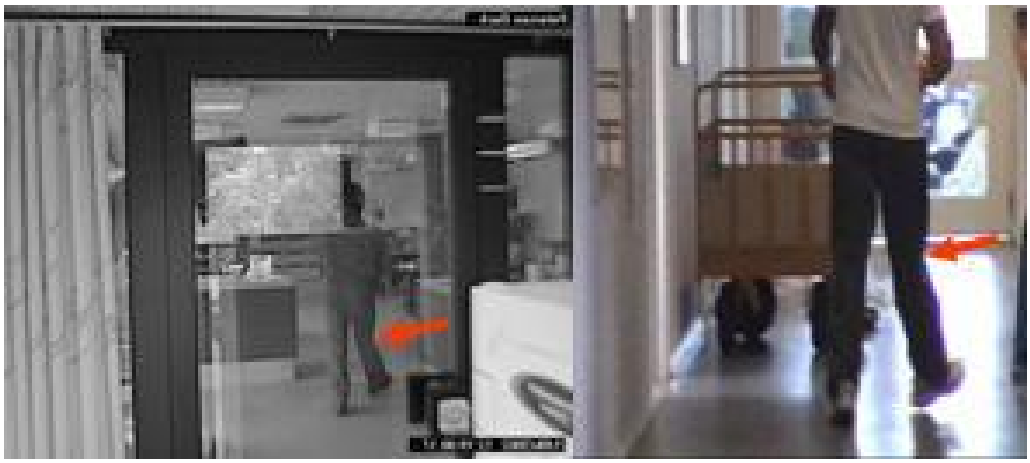

Fig. 1. The perpetrator (left picture) and suspect in the Aalsgaarde case. The hyper extension in the knee joint are illustrated with the arrow.

2. THE NOERAGER CASE

In December 2004 a perpetrator robbed a bank in Noerager, Denmark. The robbery was recorded by two surveillance cameras. One camera was placed at the entrance, recording the robber in frontal view: walking in, standing and walking in the bank during the robbery, and leaving the bank. The recording frequency was about 5 Hz. The other camera was placed inside the bank recording the cashier's desk from behind and did not record any of the perpetrator's gait. We were contacted by the police to do a gait analysis and we instructed the police to do a – for the suspect unknown – recording from the same angles as the surveillance recordings for comparison.

We have developed a check list for forensic gait analysis (Table 1). We first record the general characteristics for the perpetrator's gait and next we analyze each of the joint rotations and segment movements listed in Table 1. These are movements we have by trial end error found relevant for forensic gait analysis. When we have made this profile of the perpetrator, we compare each item of the list to the recording of the suspect and state whether we find agreement (A), no agreement (N), or incomparability (-). An item can be incomparable either because the joint rotation/movement can not be analyzed due to poor quality of the surveillance recordings, or because the recording of the suspect differ in some way from the recording of the robbery. In this case, the suspect walked with his hands in his pockets and thereby elevated the shoulders so the shoulder angle in the frontal plane became incomparable. We mention such circumstances in the last field of the check list.

In this case the gait analysis revealed positive matches between the perpetrator and the suspect, so we concluded that they could be identical to each other. In our statement to the police we pointed out which features in the analysis we found to be indicative of characteristic concordances between the perpetrator and the suspect. These characteristic features are shown in bold and italicized in Table 1, e.g.: the greater flexion of the lateral column to the left (Fig. 2); outward rotated feet and inverted left ankle during stance (Fig. 3); and the posture of the upper body during walking with prominent neck lordosis (Fig. 4). Subsequently , we were asked in court to present these features using images and video-clips in order to illustrate the findings in our statement.

The gait analysis was combined with a similar analysis of posture during stance and photogrammetry which also showed concordance between the perpetrator and suspect except very few incongruities in the posture during stance which we proposed could be caused by differences in anxiety state between the perpetrator and suspect. We stated in our conclusion that the perpetrator and suspect might well be identical to each other but we stressed that these methods did not constitute identification in terms of, e.g., DNA typing or fingerprinting [7].

Table 1. Check list for gait analysis. The perpetrator in the Noerager case was described and compared to the recording of the suspect.

	A: Agreement N: No agreement -: Incomparable	
General		
Long/short steps, stiff/relaxed gait with narrow/wide distance between the feet.	***Stiff gait with "heavy" feet***	***A***
Signs of pathologic gait	None	A
Feet/ankle joint		
Outward rotation	***Marked outward rotation*** (Fig. 3)	***A***
Inversion/eversion	Neutral at heel strike	A
	Inversion, left ankle in stance phase (Fig. 3)	***A***
	Right ankle could not be evaluated – missing recording angle	-
Dorsal/plantar flexion at heel strike	Could not be judged on basis of the existing material	-
Degree of "push-off" at toe-off	Could not be judged on basis of the existing material	-
Knee		
Varus / valgus	Neutral	A
Knee flexion during stance	Could not be judged on basis of the existing material	-
Hip/pelvis		
Pelvis Abduction/adduction	Could not be judged on basis of the existing material	-
Pelvis Rotation	Very little	A
Pelvis tilt	Neutral/Slightly backward	-
Upper body		
Lateral flexion of spinal column	***Asymmetry. Larger flexion to the left side*** (Fig. 2)	***A***
Forward/backward leaning	Neutral to slightly forward leaning (Fig. 4)	-
Rotation of the upper body during walk	None	A
Shoulders		
Angle in frontal plane	Relatively large angle – shoulders was "hanging"	-
Forward/backward rotation	Neutral/slightly forward rotated (Fig. 4)	A
Neck/head		
Posture in sagittal plane	***Head positioned anteriorly, neck lordosis appeared prominent*** (Fig. 4)	***A***
Head movements in frontal plane	***Relatively large movements of the head from side to side***	***A***
Quality of recordings/other precautions	There was little material available to evaluate the perpetrator's gait due to limited walking area in the bank, the robber open doors etc. The recording frequency of the robbery was low, so some of the parameters (especially foot/ankle) could not be evaluated. The suspect walked with his hands in his coat pockets and thereby lifted the shoulders so the shoulder angle in the frontal plane could not be compared to the robbery. The suspect was wearing a long coat covering his pelvis so it was not possible to compare pelvis tilt and pelvis abduction/adduction.	

Fig. 2. Both the perpetrator (shown from behind) and suspect had greater lateral flexion of the spinal column to the left side (a) during left leg's stance phase than to the right side (b) during right leg's stance phase.

Fig. 3. Both perpetrator (left picture) and suspect showed inverted left ankle (b) during left leg's stance phase and markedly outward rotated feet.

Fig. 4. Concordance between perpetrator and suspect with respect to: upper body neutral/slightly leaned forward, neutral/slightly forward rotated shoulders, and anteriorly positioned head, so the neck lordosis appeared prominent (c).

3. DISCUSSION

We have developed a check list to gait analysis to help systematize biomechanical gait analysis in forensic cases where the material is of such quality that automatic identification processes are precluded. In the statement to the police we always end the analysis by listing which features of the gait that were in concordance/incongruity between the suspect and perpetrator and we summarize which features, if any, there may be specific or characteristic on a personal level.

In other cases we have found characteristic features such as: limping, narrow gait with long steps, varus instability in the knee at heel strike, no outward rotation of the feet, eversion in the stance phase, marked flexion in the knee during stance, and signs of bow-legging.

Geradts et al [8] studied which gait parameters that could be used to distinguish between 11 subjects and found very few parameters which could satisfy this criterion. These included the foot angle (degree of outward rotation), the step length, and the mean hip joint angle. We have found several other characteristic features. But some of the marked features we have found were not included in the study of Geradts et al such as: inversion/eversion in the ankle, lateral flexion in the dorsal column, and the knee angle in the frontal plane which would show lateral instability of the knee and signs of a person being bow-legged/knock-kneed. Furthermore, some of the characteristic features we have found were so special, such as limping, that we would not necessarily expect to find them present between 11 random selected subjects.

Geradts et al [8]found that the hip, knee and joint angle are unsuitable for identification separately. Preliminary results from our Gait laboratory show that identification might be possible based on these three joint angles if they are studied together. This suggests that making a conclusion based on all the found features together will be better than looking at each feature isolated.

Based on our work we find that the most features can be examined with the camera placed in frontal view. This is in concordance with the work of Jokisch et al [3] who investigated from which recording angle individuals best could recognize friends and colleagues and found that the frontal angle are superior to half-profile and profile view. Ideally this camera should be supplemented with a camera in profile view to record the joint and segment angles in the sagittal plane. Geradts et al [8] suggested a camera placed above the head filming the suspect/perpetrator in transversal view to record the degree of outward rotation of the feet and step length. We find, based on our experience, that a camera placed

in this position nearly always exclude the study of other features than these two which often can be seen from a camera placed in frontal view. Therefore we do not recommend this camera position unless it is combined with recordings from other angles.

We find that the recording frequency ideally should be about 15 Hz allowing the examining of dynamic features such as lateral instability in the knee at heel strike. Others have found a similar frequency sufficient for obtaining joint angles [8] and for automatic recognition of gait [5]. Lower recording frequencies can also be sufficient for examining more static features as in the Noerager Case described in this paper. In fact, it was only three parameters (dorsal/plantar flexion at heel strike, degree of "push-off" at toe-off, and knee flexion during stance) which we were unable to examine due to the 5 Hz recording frequency. We have had another case which was recorded with about 2 Hz and therefore basically was simply a series of still images. However, the perpetrator was recorded in one of the pictures showing a bow-legged left knee. This means that even just one single image of the gait can sometimes be useful, if the gait feature captured can be deemed characteristic.

This type of analysis requires that the police have found a suspect which can be recorded and compared with the perpetrator. In our work we have both overt and covert recordings of the suspect. There might be a potentially problem in using overt recordings if the suspect consciously tries to modify the gait pattern during recording. We have therefore changed the procedure for recording of a suspect so we always get a covert recording and ideally also a overt recording if the suspect will participate. In an overt recording we then record the perpetrator from the front, from the back, in profile, and from the same view as the robbery. Furthermore we instruct the suspect in walking with a speed which matches the velocity of the perpetrator, because the gait speed may influence some of the features. For example, a lateral instability in the knee will be more pronounced with a higher gait speed.

At present we do not find it possible to positively identify a perpetrator based on image analyses. In our statements we conclude whether or not a suspect can have the same identity as the perpetrator. We can list characteristic features that favors the possibility of congruent identity but we can not state in court that no other person could have, for instance, the same gait pattern or the same anthropometric measurements.

Gait analyses will probably never be evidence as strong as fingerprint or DNA but they may be useful if no conclusive evidence is available [7,9]. On the other hand, these analyses may be used (especially photogrammetry) to exclude one or more suspects. This may obviously also be a useful tool for the investigation of a crime.

We have been involved in several cases where the court has found that the gait analysis presented here, especially combined with photogrammetry, was a valuable tool. We have several times been allowed to show pictures and video in court to illustrate our findings. This may actually present a problem. When a person is shown two pictures of other people, he or she will unconsciously try to compare them and build a relationship between the two pictures. It follows that if many images of a perpetrator and a suspect are shown side-by-side in court, this may potentially, even perhaps just unconsciously, lead the jury members to decide that there is a definite relationship between the perpetrator and suspect. We were once asked to compare the perpetrator from two different robberies with a suspect who had confessed to one of the robberies. Based on poor material we could only conclude that the perpetrator and suspect were of the same height (photogrammetry) and that they had the same bodily proportions, especially a pronounced abdominal region and broad shoulders, – and that the two perpetrators hold their face mask in the same way as shown in the two pictures to the left in Fig. 5. We did not find this very substantial, and stressed this, but the prosecutor in the case said afterwards that he was sure that these two pictures convinced the jury. Two month later we got a new case including the picture shown to the right in Fig. 5 which indicates that this way of holding the face mask might not have been as good evidence as the prosecutor thought it was. We are thus very careful when showing images in court, and we never morph pictures of suspects into pictures of perpetrators.

This case underlines the need for developing more quantitative tools to analyze images so the present analyses can be supplied with methods which can subtract information which can not be perceived by the human eye and brain [10]. This also stresses the need for better surveillance recordings of potential crime scenes with cameras positioned so they can record the perpetrator: with out any obstacles in the way; from frontal, sagittal, and maybe transversal view; and with adequate recording frequency.

Fig. 5. Pictures might seem to be better evidence than they are. We had once compare the perpetrator from the two pictures to the left with a suspect who had confessed to one of the robberies. Based on poor material we could only conclude that the perpetrator and suspect were of the same height (photogrammetry) and that they had the same bodily proportions, especially a pronounced abdominal region and broad shoulders, – and that the two perpetrators hold their face mask in the same way as shown here. We did not find this very substantial, and stressed this, but the prosecutor in the case said afterwards that he was sure that these two pictures convinced the jury. Two month later we got a new case including the picture shown to the right which indicates that this way of holding the face mask might not have been as good evidence as the prosecutor thought it was.

4. CONCLUSION

Gait analysis based on biomechanical knowledge can be used as a valuable tool in forensic medicine especially when combined with other methods such as analyses of stand, facial recognition and photogrammetry to conclude that the suspect might be identical to the perpetrator.

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