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Technical Note

Height estimations based on eye measurements throughout a gait cycle

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ABSTRACT

Anthropometric measurements (e.g. the height to the head, nose tip, eyes or shoulders) of a perpetrator based on video material may be used in criminal cases. However, several height measurements may be difficult to assess as the perpetrators may be disguised by clothes or headwear. The eye height (EH) measurement, on the other hand, is less prone to concealment. The purpose of the present study was to investigate: (1) how the eye height varies during the gait cycle, and (2) how the eye height changes with head position.

The eyes were plotted manually in APAS for 16 test subjects during a complete gait cycle. The influence of head tilt on the EH was investigated in 20 healthy men. Markers were attached to the face and the subjects were instructed to stand relaxed, tilt their head to the right, to the left, forward and backward. The marker data for the right eye were used to calculate the EH. The respective deviation and SD from the relaxed standing EH and the EH in the Frankfurt plane, left tilted, right tilted, forward tilted and backward tilted, in addition to the corresponding head tilt angles were calculated.

There was no correlation between the height of the subject and the maximum vertical displacement of the EH throughout the gait cycle nor between height of the subjects and the variation of the EH throughout the gait cycle. The average maximum vertical displacement for the test subject group was 4.76 cm (±1.56 cm). The average EH was lower when the subjects were standing in the relaxed position than in the Frankfurt plane. The average EH was higher in the relaxed position than when the subjects tilted their heads, except when they tilted their heads backwards. The subjects had a slightly larger range of motion to the right than to the left, which was not significant.

The results of this study provide a range for eye height estimates and may be readily implemented in forensic case work. It can be used as a reference in height estimates in cases with height measurements based on time of the gait cycle and based on the degree of head tilt from video material. Our data also provide descriptive statistics which may be helpful when comparing eye height measurements of a perpetrator with one or more suspects.

1. Introduction

Anthropometric measurements of a perpetrator based on CCTV (Closed Circuit Television) material may be used in an investigation or presented as evidence in criminal cases. The measurements often include the height of the person, as measured to the vertex of the head or to the tip of the nose, the eyes or the shoulders and can be a means of comparison between a perpetrator and suspect(s) or as a description of the perpetrator sent out to the public. However, several of the abovementioned height measurements may be difficult to assess as the perpetrators may be disguised by clothes or headwear. The eye height (EH) measurement, on the other hand, is less prone to concealment, simply because the perpetrators need their visual sense. Therefore, the eyes are almost always visible in images from crime scenes unless the perpetrators wear full face motorcycle helmets or similar and thus, the height measured to the eye may be a valid proxy for the full height (stature) of a subject. To further investigate the possibilities of using the EH, we wanted to evaluate how it varies with gait and with head position.

There are two main photogrammetric procedures for estimation of height; the first, called projective geometry, uses so-called vanishing points of parallel lines in the scene, i.e. one set of vertical parallel lines, two sets of horizontal parallel lines in

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different directions and a reference height in the scene [1]. The second method is based on 3D modeling of the scene aided by photogrammetric software [2,3] such as 3ds Max [1] or PhotoModeler Pro® [4]. The model is based on common points on different photos taken at the crime scene that are matched in a procedure called *camera match*. This procedure determines the camera position, rotation and focal length. Once the model is generated, a virtual camera can be placed in the model, viewing the scene from the same perspective as the real surveillance camera at the scene. Edelman et al. [1] found that the projective geometry method produces inaccurate height estimations when the field of view is different from the reconstruction images, as opposed to the 3D model method, which gave accurate estimations. Some studies have also estimated height from the upper body part [5] and the face [6], while others generated body models to estimate height [7,8].

Variation in estimated height originates from either systematic or random variation. Systematic variation can arise from the creation of the 3D model and the camera match, lens distortion, or the location of the person in the image, whereas, random variation can arise from varying head and footwear or the natural variation in interpretation of the head and feet location in the image. However, measurements of a reference object can predict the systematic error in the 3D model of the crime scene.

Several studies have investigated full stature in relation to gait and head position. Criminisi et al. [9] stated that the range between minimum and maximum measured height during steady walking pace was up to 6 cm. The maximum height was found at mid-stance phase and was considered as the most appropriate match of a person's static height, even though it was consistently lower. BenAbdelkader et al. [10] stated that the difference between the maximum height during gait and the static height is typically 1 cm. Ramstrand et al. [11] measured the height of 46 subjects in a variety of activities by plotting a marker on the top of the head in a 3D gait laboratory. They found that the average difference between the standing height measured with a stadiometer and the 3D system was −2.1 cm; the difference in height between standing straight and looking down was 16.2 cm; the average vertical displacement during gait was 4.4 cm and when looking down during gait it was 4.3 cm. There was no significant correlation between the height and the displacement of the head marker. The maximum height during gait was consistently lower than the static height measurement. They also found a correction factor for headwear and shoes of −3.6 cm (1.1 cm for the balaclava and 2.5 cm for the heel height of the shoes).

The purpose of the present study was to investigate: (1) how the eye height varies during the gait cycle, and (2) how the EH changes with head position. The results can be implemented in criminal case work where the height of a person is difficult to determine and where the eyes can be measured in the image, which in turn can be used as a proxy instead of the full height. The measured EH of a perpetrator can be compared with the measured EH of suspect(s). Moreover, the results can provide a 68% and 95% confidence interval (±1SD and ±2SD) of the EH related to the position in the gait cycle and the head position.

2. Materials and methods

2.1. Eye height throughout the gait cycle

Gait data for 16 test subjects were retrieved from a gait database at the Department of Neuroscience and Pharmacology, University of Copenhagen. The included subjects were all healthy males without previous injuries to the lower extremities. The physiognomic details of the test subject group can be seen in Table 1.

Table 1
Physiognomic details of the test subjects for eye height throughout gait cycle.

	Age (years)	Height (cm)	Weight (kg)
Average (SD)	37 (9)	184.8 (8.1)	87.2 (14.0)
Range	24–52	170–200	68–111

The gait of the subjects was captured by two video cameras (Canon MV 600 digital video) while they walked barefooted along a 10 m walkway. The synchronized cameras operated at 50 Hz and were filming from the front from each corner with an angle of approximately 80°. Data were recorded, digitized and processed with the Ariel Performance Analysis System (APAS©, Ariel Dynamics Inc., CA, USA). The test subjects aimed for a gait velocity of 4.5 km/h, which was recorded by two sets of photocells and regulated by oral feedback. They were given unlimited rehearsal trials and when the setting and the speed had been familiarized recording took place. Three trials close to 4.5 km/h were included in the data processing. The gait velocity was kept constant in order to limit the variation caused by difference in velocity.

The eyes were plotted manually in APAS, filtered using a 4th order Butterworth low pass filter with a cut-off frequency of 6 Hz and time normalized. Data from three strain gauge force platforms (Advanced Mechanical Technology, Inc (AMTI OR6-5-1)) were used to locate the two heel strikes which enclosed a complete gait cycle, which was sampled after a few steps. The signal was sampled at 1000 Hz with an analog-to-digital converter (APAS) and subsequently down sampled to 50 Hz to match the data sampled from the video recordings. The normalization was performed with interpolation using the Functional Fourier Transform (FFT) method in MATLAB® (R2010a, The Mathworks, Natick, MA), which evenly spaced out the collected gait data into 100 points for a complete gait cycle. FFT was chosen because it provided the most accurate reconstruction of the signal. The three included trials were corrected for DC offset by subtracting the average amplitude from each sample, which made comparison between trials and test subjects possible.

$$d^{\mathrm{corr}}_{TS,tr}(x) = d_{TS,tr}(x) - \bar{d}_{TS,tr} = D(x)_{TS}$$

where d = dataset, TS = test subject and tr = trial number.

The corrected datasets were averaged for each person.

$$\bar{D}_{TS} = \mathrm{avg}\,(D_{TS,1}(x)), D_{TS,2}(x), D_{TS,3}(x)) = e_{TS}$$

The maximum vertical displacement (VD) was calculated for each test subject and investigated for correlation with the test subject height.

$$\mathrm{VD}_{TS} = \max(e_{TS}) - \min(e_{TS})$$

The average eye height and standard deviation (SD) were calculated for the test subject group, i.e. all the test subjects.

$$E = \mathrm{avg}\,(e_{1-20})$$
$$\mathrm{SD} = \mathrm{std}\,(e_{1-20})$$

The SD was used to calculate the 68% (1SD) and 95% (2SD) confidence intervals (CI).

2.2. Eye height with head tilt

The influence of head tilt on the eye height was investigated in another 20 healthy men. The physiognomic details of the test subject group can be seen in Table 2. Markers were placed on the nose, chin, right and left ear canal, right eyelid and right shoulder. The right eye was chosen as a marker for the EH, as no marked facial asymmetries were assumed for the subjects. The subjects