Estimation of human height from surveillance camera footage - a reliability study.

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Sammanfattning

Mål: Målet var att utvärdera en metod som används vid längdmätning i bilder och att undersöka hur kroppshållning påverkar kroppslängden i stående, gående och springande.

Metod: Tio friska män filmades simultant med en 2D web-kamera och ett 3D rörelseanalyssystem. De utförde sex försök, tre ståpositioner och tre under gång och springning. Den vertikala längden mättes med längdmätningsmetoden och i Qualisys Track Manager och resultaten jämfördes för utvärdering. Den vertikala längden i de olika kroppshållningarna jämfördes med verklig längd.

Resultat: Mätningarna gjorda med längdmätningsmetoden var signifikant högre än mätningarna gjorda med Qualisys Track Manager ($p<0.001$). Den vertikala längden i de båda ståpositionerna var signifikant lägre än den verkliga längden ($p<0.05$). Den vertikala längden i midstance var signifikant lägre än den verkliga längden ($p<0.05$). Ingen signifikant skillnad hittades mellan maximal vertikal längd och verklig längd vid springning ($p>0.05$).

Slutsats: Längdmätningsmetoden mätte vertikala längder med ett medelfel på +2.30 cm. Kroppshållning påverkar vertikal kroppslängd. Vid gång är midstance positionen då vertikal längd stämmer bäst överens med verklig längd, vid springning var det ickestödfasen.

Nyckelord: Kroppslängd; Längdmätning; Kroppshållning.

Abstract

Aim: The aim was to evaluate height measurements made with the single view metrology method and to investigate the influence of standing position and different phases of gait and running on vertical height.

Method: Ten healthy men were recorded simultaneously by a 2D web camera and a 3D motion analysis system. They performed six trials, three standing and three during gait and running. The vertical height was measured with the single view metrology method and in Qualisys Track Manager. The results were compared for evaluation. The vertical height in the different postures was compared to the actual height.

Results: The measurements made with the single view metrology method were significantly higher than the measurements made with Qualisys Track Manager ($p<0.001$). The vertical height in the two standing positions was significantly lower than the actual height ($p<0.05$). The vertical height in midstance was significantly lower than actual height in the walking trials ($p<0.05$). No significant difference was found between maximum vertical height and actual height during running ($p>0.05$).

Conclusion: The single view metrology method measured vertical heights with a mean error of +2.30 cm. Posture influence vertical body height. Midstance in walking is the position where vertical height corresponds best with actual height, in running it is the non-support phase.

Keywords: Body height estimation; Single view metrology method; Posture.

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1. Introduction

Body height is an important factor when identifying a criminal from surveillance camera footage. The definition of body height is the vertical height from the floor to the top of the head when a person is in an upright position with feet together and knees extended. This position seldom occurs in our natural movement pattern. Due to different postures, individual variations in standing and gait, and loss of information when the 3D reality is captured in a 2D picture, body height estimation from surveillance camera images is difficult [1].

The number of surveillance cameras is increasing every day, both in private and in public premises [2,3]. Even though the quantity of cameras is increasing, the quality of the video footage still is too poor to identify the perpetrator in many cases [2,4]. In this study, focus will be on body height estimation of a person from a video recording. After a suspect has been caught on video in Sweden, the footage is sent to the Swedish National Laboratory of Forensic Science (SKL) in Linköping for analysis. If the circumstances are too poor for facial recognition, the perpetrator's vertical height is calculated in the image to make an estimation of his actual body height, no consideration is taken to the perpetrators posture. The variation of the vertical height and the influence of posture is investigated in this paper in two different standing positions and in the phases of the gait and running cycle.

2. Background

There are several methods to estimate height from images; this study will evaluate a single view metrology method, in the rest of the paper referred to as the SVM method, performed in a program written by the SKL.

2.1 Literature review

The SVM method has recently been internally investigated and evaluated by Brolund and Bergström [3]. Their result coincided with their expected result, i.e. the measured height was lower than the actual height, due to the posture of the subjects. The subjects in their study were recorded in lifelike surveillance situations, and an image with the subject in the straightest position possible was chosen for measurements. Some variation in the uncertainty bound (± 3 SD) could be seen depending on which camera view the subjects were measured in. The uncertainty bound was reduced when calculating the vanishing line using the vertical reference heights. This method is to be preferred when possible, on the condition that the position of the surveillance camera does not change from the time of the crime to the time for the measurements [3].

As mentioned earlier, the presence of surveillance camera systems is increasing. This is done to prevent crimes and to facilitate identification of those who commit them [2,4]. Still, facial recognition in 2D images is a difficult task and the risk of error is well known, such as differences between operators in setting landmarks etcetera. [5]. The quality of the video footage is often too poor for facial recognition due to poor lighting, large distances, disguised perpetrators and insufficient camera resolution [2,4]. A way to exclude a suspect as the perpetrator is to estimate body height in images from surveillance cameras [2,4,6]. Height can also be used as evidence to separate two perpetrators from each other, e.g. if one of them is armed. The best condition for measuring the actual body height is when the subject is in an upright, stretched position. During the gait cycle, midstance is the position forensic operators prefer to use for height measurement in images [2,7]. It must also be noted that there are other factors than the variation in height in the gait cycle that influence the measured height, such as standing pose, presence of head and footwear, lens distortion of the camera and location of the perpetrator, among others [8].

The validity and reliability of motion capture systems has been examined, and Qualisys ProReflex system was found to be an accurate system when measuring e.g. distances [9]. Stated in the same study, the accuracy of Qualisys Track Manager (QTM) is 0.6 mm within a 3 m field of view according to the manufacturers' specifications, which validates the use of QTM in this study.

2.2 Single view metrology method

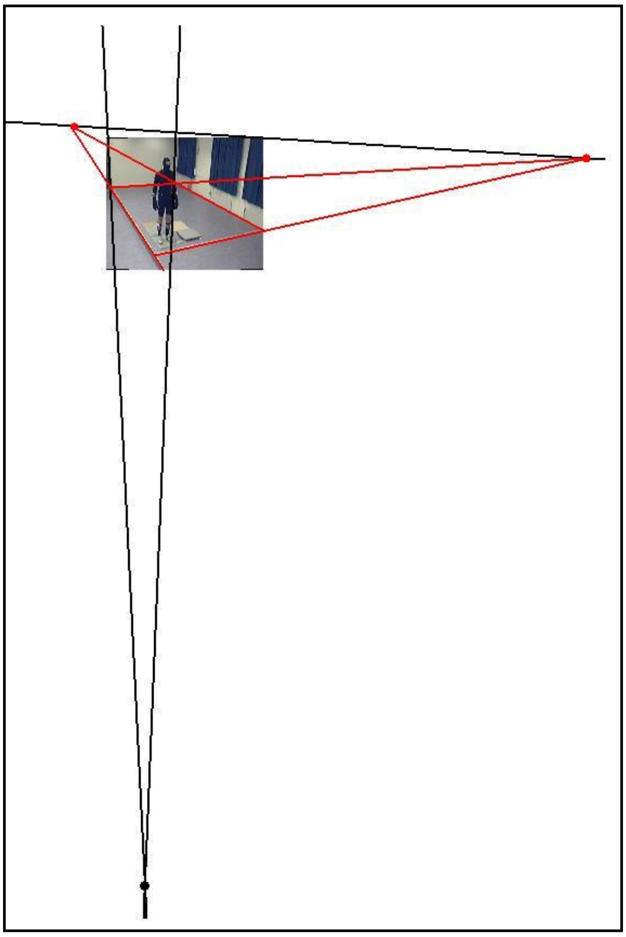
There are several methods to estimate height from video images, and most of them require the policemen to visit the crime scene with a calibrated object of known height to use as a reference [2,3]. They have the surveillance camera take pictures of a standardised range pole in as many different positions as possible spread throughout the scene (figure 1). This is used as reference heights and as a tool to give information about the relation between the 2D picture and the 3D reality.

Corrections are made in the image for lens distortion; this means that the lines that are supposed to be straight in reality also are straight in the picture. There needs to be enough lines to create the perspective in the image, and the vanishing point and vanishing line can be calculated using algorithms. The vanishing point is the point where the vertical parallel lines intersect, and the vanishing line is the line where the horizontal parallel lines intersect (figure

2). The vanishing line can also be calculated from at least three vertical reference heights, and this can lead to a more correct result (figure 3).

The range pole gives vertical reference heights that make height measurement in images possible. To calculate the uncertainty bound (±3 standard deviations) an uncertainty analysis is done. This means that the likelihood that the true value can be found within the calculated range is 99.73% [1,3,10].

From surveillance camera footage, images are chosen where the person is as upright as possible e.g. midstance.



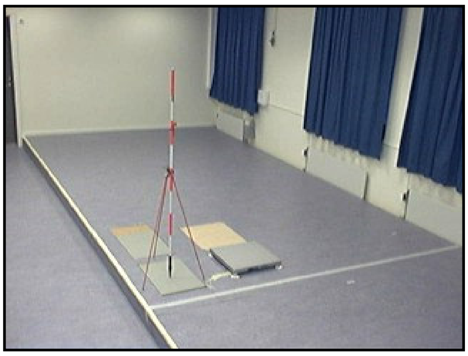


Figure 1. The standardised range pole.

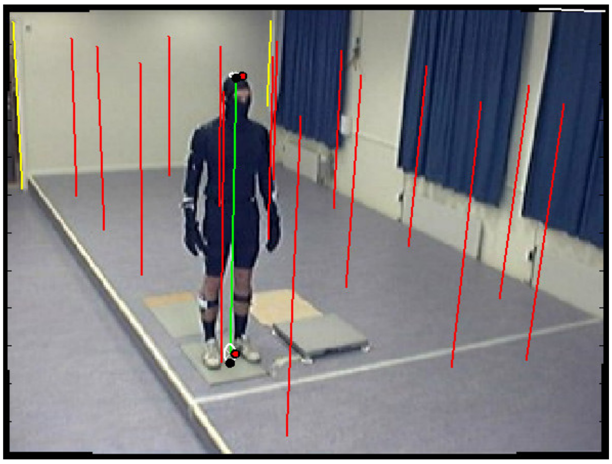


Figure 2. The vanishing point and line calculated from the horizontal and vertical parallel lines.

Figure 3. Reference heights placed in the picture.

3. Aim and hypotheses

The aim of this study is to evaluate height measurements made by SKL with the SVM method and to investigate the influence of standing position and different phases of gait and running on vertical height.

The questions to be answered in this study were:

- How accurate is the SVM method in estimating body height from images?
- How much does the posture influence the vertical height compared to the actual body height, in standing, gait and running?
- Which position in the gait and running cycle corresponds best with the actual height?

The hypotheses for the method evaluation were stated as follows:

- H0: There is no significant difference between the two measurement methods.
- H1: There is a significant difference between the methods.

The hypotheses for the comparison between body height and the different postures were stated as follows:

- H0: There is no significant difference between the postures and the actual height.
- H1: There is a significant difference between the postures and the actual height.

4. Method

The data collection in this study was conducted in a gait laboratory at the School of Health Sciences at Jönköping University.

4.1 Subjects

Ten healthy men without any known gait pathologies were recruited from the School of Health Sciences. The number of subjects was based on a request by the SKL statistician (Brolund P 2008, oral communication, 9th April). Furthermore, the sample was specified to contain only men between 15-30 years of age, since this is the predominant group of suspects in criminal investigations [11]. The mean age of the subjects in this study was 25.6 years (SD 3.95), their mean height was 180.7 cm (SD 8.66) and their mean BMI 23.43 (SD 1.99) (table 1).

Table 1. The height is the actual height of the subjects measured with QTM.

Subject	Height (cm)	Weight (kg)	BMI	Age
1	176.2	68.0	21.90	21
2	164.5	66.5	24.57	28
3	186.6	85.5	24.55	21
4	185.9	82.0	23.72	27
5	185.0	84.9	24.82	25
6	175.4	67.3	21.87	21
7	189.7	70.9	19.71	33
8	168.0	62.7	22.22	28
9	182.7	83.5	25.01	24
10	172.0	75.7	25.60	28

4.2 Ethical considerations

The subjects were informed that they could withdraw from the study at any time and provided written informed consent before participating in the study. An ethics evaluation was performed according to the standards of the School of Health Sciences at Jönköping University.

4.3 Data collection

The subjects wore the same black clothes, gloves and ski-mask to make them look as much alike as possible (figure 4). Each subject wore his own pair of sneakers so an unfamiliar gait pattern would not appear. The variation in height due to footwear is difficult to estimate when measuring height in images and the perpetrators are generally wearing shoes [1,8], and usually height measurements are made with shoes on [1]. Due to this, the data collection and height measurements in this study was made with shoes on. No consideration was taken to the variation in heel height, because each subject wore the same pair of shoes for all of the recordings.

Figure 4. Disguised subject.

Six different positions were performed by the subjects, three standing and three when in motion, as explained in table 2. These positions were chosen because they are often seen on surveillance camera footage, and therefore they are interesting to investigate. The three standing positions were performed during one recording, in numerological order starting at position 1, which is referred to as the actual height in this study. The walking and running trials were recorded separately. All of the trials were recorded at least two times, and recordings containing at least two strides for the walking files and one stride for the running files were chosen for data processing.

Table 2. The positions recorded by the 9 cameras in consecutive order.

	Positions	
1.	Stand_straight	Standing in a straight position with feet 5 cm apart - actual height.
2.	Stand_relaxed	Standing relaxed with feet further apart and weight on both feet.
3.	Stand_oneleg	Standing relaxed with weight on one leg.
4.	Walk_slow	Walk slow in a self selected speed.
5.	Walk_fast	Walk fast in a self selected speed.
6.	Run	Run in a slow running speed.

Motion data was collected with an 8-camera 3D system at 60 Hz (Qualisys AB, Göteborg, Sweden) calibrated according to the manufacturer’s manual. For the data collection a full body marker set of 41 reflective markers was attached to each subject according to Qualisys recommendations for passive markers [12]. The same investigator placed the markers on all the subjects to minimise variation in placement.

During the data collection, video samples with a room overview were captured with a web camera (Logitech QuickCam Pro 4000) at 30 Hz with a resolution of 320x240 pixels. The camera position had been chosen on site in collaboration with a representative from SKL, and was fixed in the exact same position for all of the recordings. The webcamera was controlled from QTM to start recording simultaneously with the 3D data capture.

The reference object used in the SVM method was a standardised range pole supplied by SKL and of the same type used in their measurements of crime scenes (figure 1). It had a known height of 180 cm and was placed in 15 different positions, evenly spread throughout the measurement area, and was recorded by the web camera (figure 3).

4.4 Data processing

There are six files for each of the ten subjects, three standing files and three dynamic files; this resulted in a total of 60 still images and 60 QTM-files.

Due to sampling frequency differences between the motion analysis system and the web camera, the picture frame numbers from the two systems did not correspond. To find the two corresponding frames, the frames that were captured at the exact same point in each systems time line were used for analysis.

One frame for each standing position from the video recording was sent to SKL for height measurement. For each movement data file, one frame was chosen for height measurement and six parts of the gait cycle were chosen as the positions of option (table 3). The chosen positions were randomised. The vertical height was determined by plotting the position of the top head marker in the z-axis in QTM. Since the system measures the distance from the floor to the centre of the marker, that has a radius of 8 mm, and the subjects wore a ski-mask that added on average 5 mm from the skull bone to the marker, 13 mm was withdrawn from all of the height measurements made in QTM.

Table 3. The six phases of the gait cycle according to Whittle [13]

	Gait cycle positions
1.	Initial contact
2.	Foot flat
3.	Midstance
4.	Heel rise
5.	Toe off
6.	Midswing

The still images were renamed and their order randomised by the supervisor of this project in order to blind SKL to the identity of the subjects. Likewise, the corresponding QTM-files

were renamed in the same order as the still images to the authors to minimise the risk of a possible bias regarding reported height, and to facilitate future analysis of the results.
The vertical height is measured with the SVM method in each one of the 60 pictures and their results were compared to the results from the motion analysis system.
To determine which position in gait that correlates best with the actual body height the vertical maximum and minimum height is measured in the walking and running files, the maximum height is then compared to the subjects height when in an upright stretched position (position 1 in table 2).
The first maximum and minimum value of the top head marker's movement in the sagittal plane, when the subject had passed the first force plate, was chosen as maximum and minimum height in the dynamic files.

4.5 Statistics

For the statistical tests and diagrams, SPSS 14.0 for Windows (Rel. 14.0.2.2006. Chicago:SPSS Inc.) and MedCalc for Windows, version 9.5.2.0 (MedCalc Software, Mariakerke, Belgium) were used.
The collected data is normally distributed and to test the hypotheses, 2-tailed paired t-tests were done.

5. Results

5.1 Evaluation of the SVM method

The t-test showed a significant difference between the two height measurement methods ($p<0.001$). The mean value of the SVM method measurements was 176.7 cm and the mean value of QTM measurements was 174.4 cm. In 57 of the 60 measurements SKL measure a higher body length than QTM, the mean error was 2.30 cm. The differences between SVM measurements and QTM measurements are presented in figure 5.
There was a strong correlation between the two methods ($r = 0.988$**), but as seen in figure 6 the regression line lie above the $y = x$ line, which again shows that the SVM measurements were too high.
In 7 of the 60 cases the measurements made in QTM did not fall within the calculated uncertainty bound (± 3 SD).

A Bland-Altman plot was made to display the correspondence between the two measurement methods (figure 7). The SVM method is more consistent when measuring taller subjects, because the values above 180 cm in the plot, is less scattered around the mean difference.

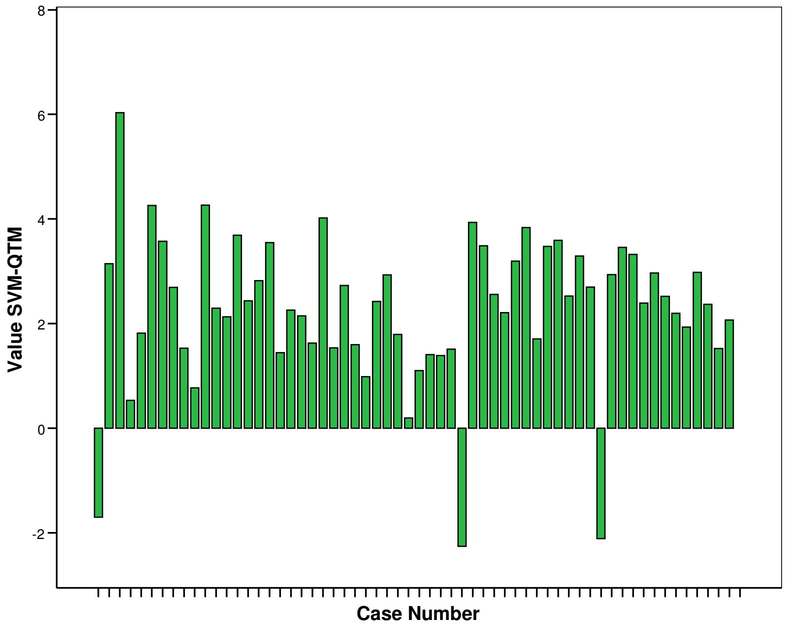


Figure 5. The bars represent the differences between the SVM measurements and the QTM measurements (SVM-QTM).

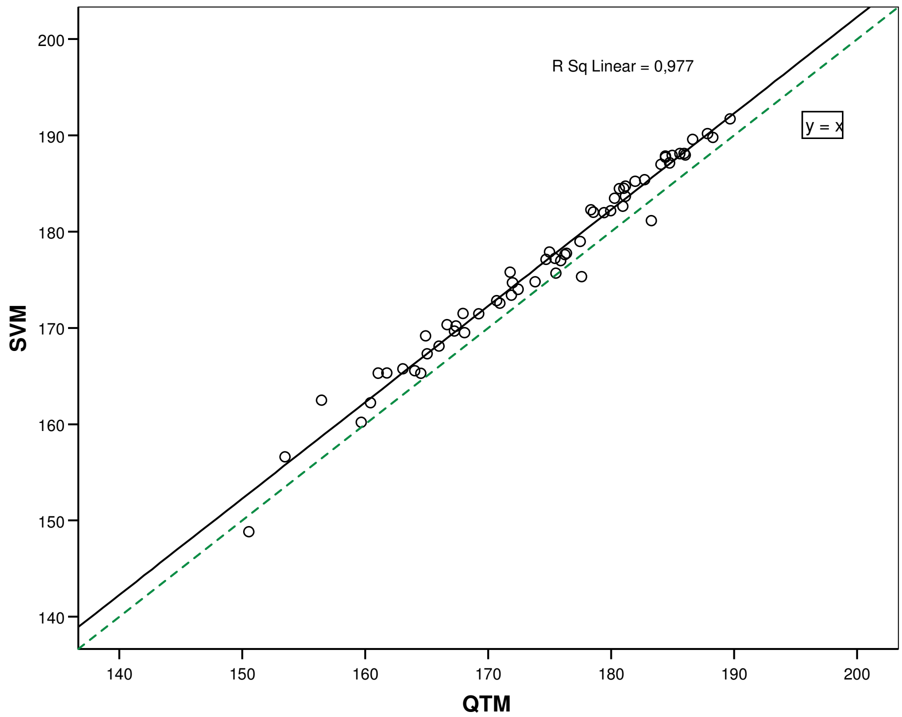


Figure 6. The solid line is the regression line, the dotted line is the line where y = x.

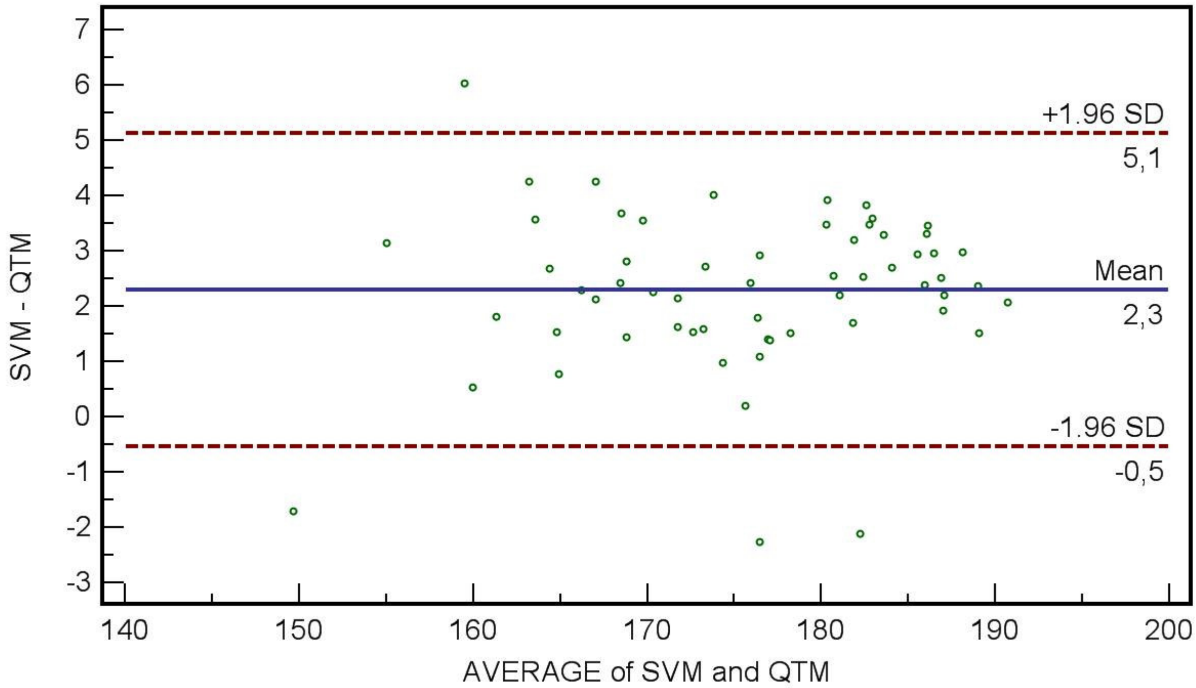


Figure 7. A Bland-Altman plot that shows the correspondence between the SVM method and the measurements made in QTM. On the y-axis the difference between SVM and QTM is plotted and on the x-axis the average height between the measurement pairs is plotted.

5.2 The influence of posture on vertical height

In figure 8 the difference between actual height, relaxed and with weight on one leg is shown, in 9 of the 10 subjects the vertical height decreases from actual height to standing relaxed and from standing relaxed to standing with weight on one leg. The two standing positions were significantly lower than the actual height ($p<0.05$). The mean of the subjects relaxed vertical height is 99.2% of the mean value of the subjects actual height, and the mean vertical height when standing with weight on one leg is 98.4% of their actual height (table 4). The vertical height when standing with weight on one leg was significantly lower than the relaxed height ($p<0.05$). These results imply that standing in a relaxed position gives a vertical height more like actual body height than when standing with weight on one leg, although the vertical height is less than the actual height in both of the positions.

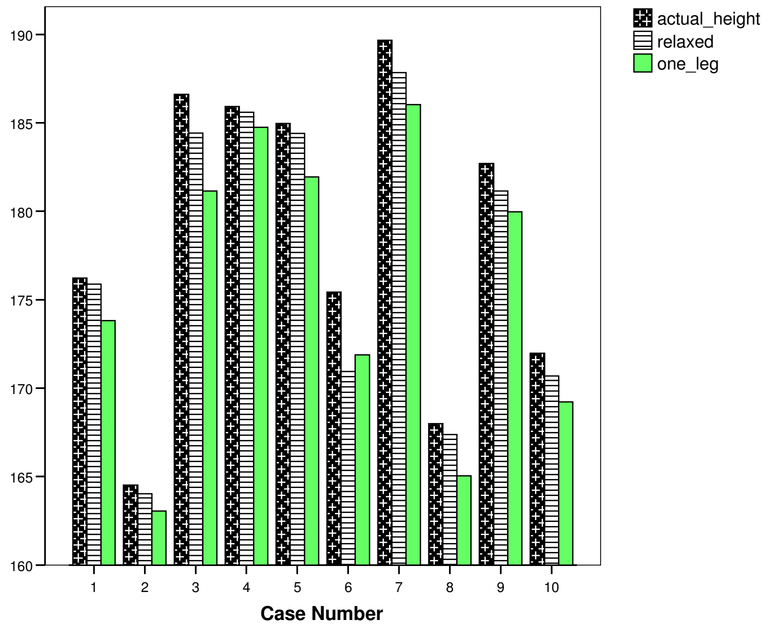


Figure 8. The figure shows the actual height compared to the vertical height when standing relaxed and when standing with weight on one leg.

Table 4. The left column shows how many percentages the vertical height is of actual height when the subject is standing relaxed, the right column is for when the subject is standing with weight on one leg.

Subject	% of actual height (relaxed standing)	% of actual height (weight on one leg)
1	99.8	98.6
2	99.7	99.1
3	98.8	97.1
4	99.8	99.4
5	99.7	98.4
6	97.4	98.0
7	99.0	98.1
8	99.6	98.2
9	99.2	98.5
10	99.2	98.4
Mean	**99.2**	**98.4**

In the walk_slow (WS) and walk_fast (WF) trials the maximum vertical height (slow_max, fast_max) occurred in midstance for all of the subjects, the minimum vertical height (slow_min, fast_min) occurred in double support.
In both of the walking trials, midstance was found to be the position when the vertical height corresponds best to the actual height of the subjects (figure 9 and 10), although there were significant differences between actual height and midstance in both of the walking trials ($p<0.05$). The mean vertical height in midstance is 99.3% and 99.0% of the actual height in WS and in WF respectively (table 5).

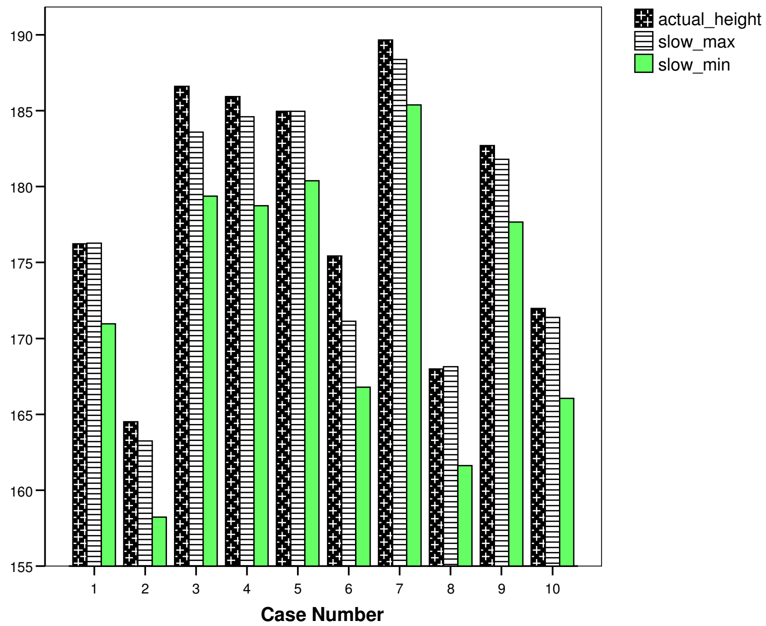


Figure 9. The figure shows the maximum and minimum vertical height in the walkslow trial compared to the actual height in cm.

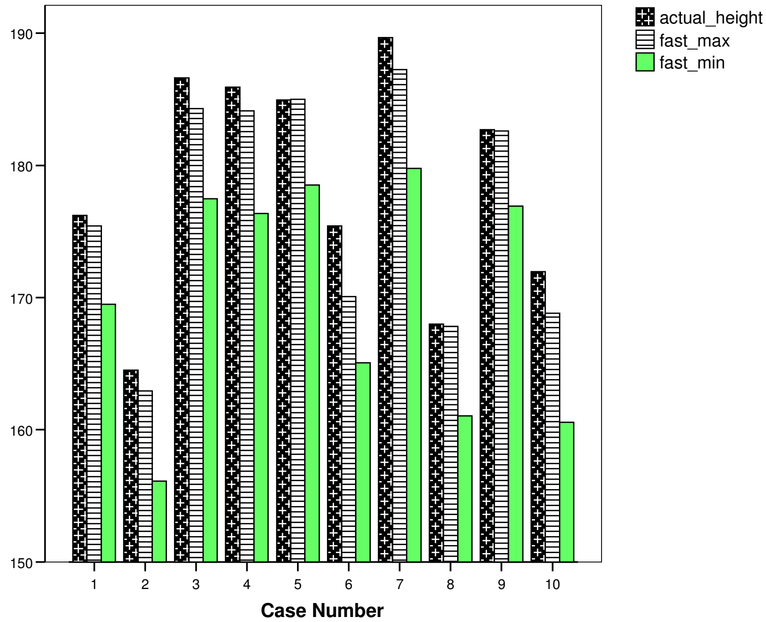


Figure 10. The figure shows the maximum and minimum vertical height in the walkfast trial compared to the actual height in cm.

Table 5. The left column shows how many percentages the maximum vertical height is of the actual height in the walkslow trial, the middle column is for the walkfast trial and the right column is for the running trial.

Subject	% of actual height (walkslow max)	% of actual height (walkfast max)	% of actual height (run max)
1	100.0	99.6	98.3
2	99.2	99.0	98.8
3	98.4	98.8	97.0
4	99.3	99.0	98.3
5	100.0	100.0	100.8
6	97.6	96.9	86.5
7	99.3	98.7	97.8
8	100.1	99.9	100.8
9	99.5	99.9	100.2
10	99.7	98.2	94.1
Mean	**99.3**	**99.0**	**97.4**

The maximum vertical height (run_max) during the running trials occurred when the subjects were in the non-support phase [13], and the minimum vertical height (run_min) when the subjects were in midstance. The mean maximum vertical height was 97.4% of their mean actual height (table 5). In figure 11 the subjects running vertical heights is shown compared to their actual height, and as seen before the vertical maximum is the height that correlates best with the actual height of the subjects, and no significant difference was found ($p > 0.05$).

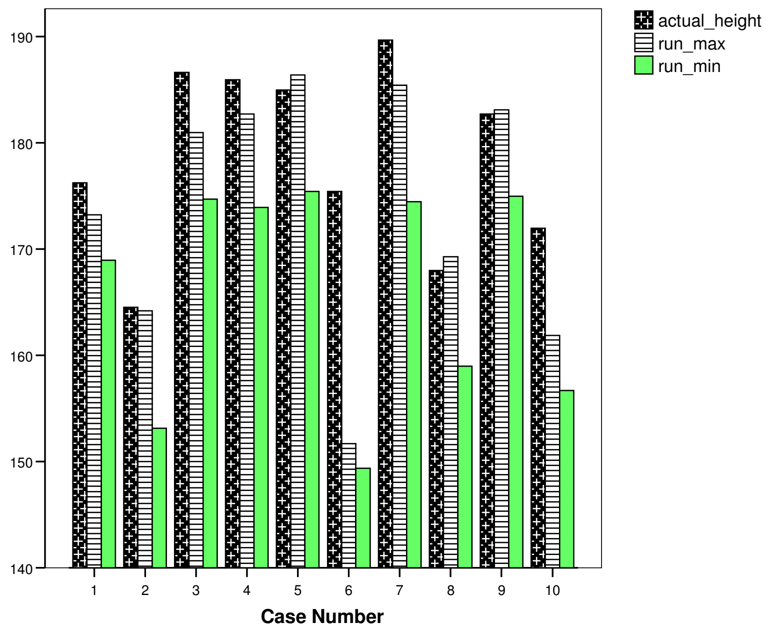


Figure 11. The figure shows the maximum and minimum vertical height in the running trial compared to the actual height in cm.

5.3 Height variation in walking and running

Figure 12 shows the top head markers movement in the sagittal plane when subject 5 is walking slow, fast and when he is running. As seen in the figures the head moves generally in a sinusoidal pattern and the amplitude increases with velocity.

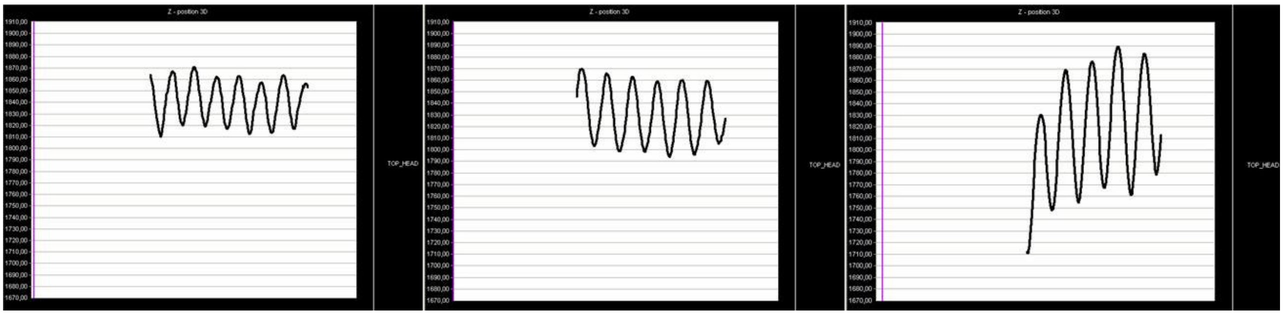


Figure 12. The curves represent the top head markers movement in the sagittal plane for subject 5. To the left: walkslow, in the middle: walkfast and to the right: run. The scale of the y-axis is the same for all the graphs.

6. Discussion

In 57 of the 60 measurements the vertical height measured with the SVM method were significantly higher than the vertical height measured with QTM (figure 5), and only 53 of the 60 measurement errors fell within the uncertainty bound. This could be because it is difficult to place the end points for the measurements at the head and feet of the subjects in the images. The resolution of the images was lower than what the operator is used to. The subjects also wore a ski-mask and a marker on the head, which makes it even more difficult to define the top of the head. Even though the operator was aware of the marker on the top of the head, the low resolution could have made it difficult for him to place the top end point. Another reason why the SVM measurements were too high could be a systematic error because of a possible error when calculating the vanishing point or line. When all the subjects were recorded in the same scene the same vanishing point and line were used for all of the 60 pictures, this means that a possible systematic error will influence all measurements.

An additional reason for the measuring values being too high and in some cases falling outside the uncertainty bound is that the base point of the reference pole was inaccurately defined in the images by the operator. Because of the narrow tip of the reference pole the absolute tip of the pole is not captured in the images. SKL has recently improved their calibration procedure by placing a circular pattern under the reference pole so that the base point can be more accurately defined in the images (figure 13). Also, the resolution of the images sent to the operator for height measurement was 320x240 pixels, which is lower than normal, but the mean uncertainty bound calculated in this study was 3.80 cm compared to 7.5 cm in the previous study done internally on SKL, where the resolution was 720x576 and

384x288 pixels. This means that the operator at SKL could measure the vertical heights in the images with a greater accuracy than in the previous study in spite of the low resolution. Also the error of the SVM method in this study is never larger than 6.03 cm which is a reasonable error given the circumstances. This could be due to the fact that other conditions were better than in real life situations, such as the subject was placed in the centre of the image and there was nothing to obscure him or the straight lines that the operator uses to calculate the proportions of the image. The reference object was placed in more places and they were more spread throughout the scene than in the previous investigation by Brolund [3].

To compare two measurement methods a Bland-Altman plot gives more correct information than correlation because correlation only gives an idea of how well the two measurements lie on a straight line, not if they measure the same thing [14]. The Bland-Altman plot shows how well the two methods relate to each other. The values below 180 cm in the Bland-Altman plot is more scattered around the mean difference than the values above. Those are less scattered around, and most of them lie above, the mean difference (figure 7). This implies that the operator is more consistent when measuring taller subjects, even if he still measure too high.

The sinusoidal pattern made by the marker on the top of the head discovered in this study is seen in several previous studies [2,7,15]. Our results show that the amplitude of the top head markers curve increased with velocity, but the maximum height is practically the same for all the velocities. This could be because when you move with a higher velocity you take longer steps, and the legs are stretched further apart with the result of a lower centre of mass [15], and a shorter vertical height in double support (figure 14 and 15).

Our results show that midstance in walking and the non-support phase in running is the highest and therefore the most appropriate phase to look at when measuring vertical height in images. Those are the positions where the vertical height agrees bests with actual body height, but a person who is running is seldom used for height measurement. The vertical height in these positions is approximately 99% of the actual body height in both of the walking trials and approximately 97% of the actual height in running. This concludes that the vertical height of a person in an image agrees less with the actual body height when the person is running than when he is walking. One thing that is the same for all of the trials is that the vertical height of the subjects is less than the actual body height and in the investigation done by Brolund and Bergström the result was the same [3].

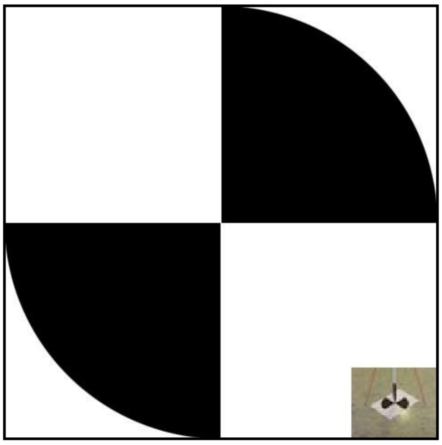


Figure 13. The circular pattern placed below the range pole.

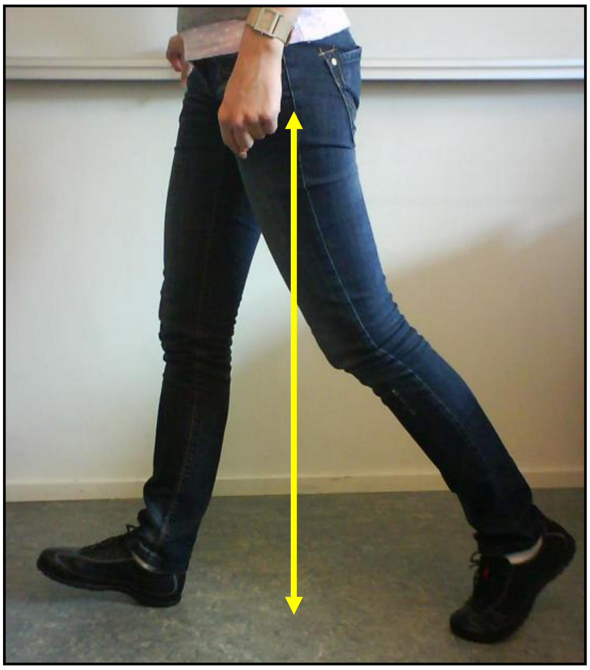


Figure 14. The yellow arrow is the vertical height from the floor to the greater trochanter during slow walking.

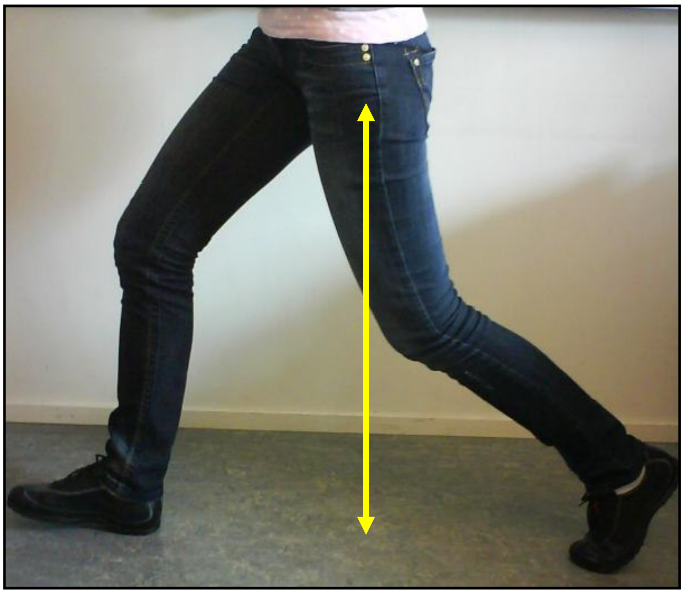


Figure 15. The yellow arrow is the vertical height from the floor to the greater trochanter during fast walking.

6.1 Limitations

One limitation of this study is the number of subjects included. To control the validity of the results of the variation in vertical height compared to actual height in this study, more than ten subjects is recommended for future studies.
Another limitation is the resolution of the camera images, which was lower in this study than the resolution of ordinary surveillance cameras. In future studies a camera more like real surveillance cameras should be used.
One limitation with the setup of the motion analysis system is that a marker has to be placed on the top of the head of the subjects, and the height is measured from the marker to the floor. Due to the movements of the head the marker is not always the highest point, which is the point where the operator places the top end point in the SVM method.

7. Conclusion

The measurements made with the SVM method were significantly larger than the same measurements made in QTM, and only 53 of 60 measurements fell within the uncertainty bound calculated by SKL. The mean difference between the two methods was 2.30 cm and the largest error was 6.03 cm. A Bland-Altman plot showed that the SVM method is more consistent when measuring heights above 180 cm.
The vertical height was less than the actual height of the subjects, both when standing relaxed and when standing with weight on one leg. The vertical height when standing relaxed was 99.2% of the actual height, and 98.4% when standing with weight on one leg.
For the slow and fast walking trial midstance was found to be the position when vertical height agrees best with actual height. During running it was the non-support phase.

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