Data Acquisition and Analysis in Biomechanics Ergonomics and Sports

A 2D Video Gait Analysis using passive markers at different walking speed

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ABSTRACT

The purpose of this study was to perform a 2-dimensional video analysis of the human gait from the sagittal plane. Data collection was performed in the university laboratory using provided equipment (treadmill, video camera, special light, tripods, passive markers, computer, needed software). The camera was positioned perpendicularly to the treadmill walking band so that it was possible to record the walk of the participant in 2 stages: slow walk and accelerated walk.

Based on the recorded video, and the analysis performed in MATLAB, an analysis of the respective participant gait was done. Therefore, using 2D video analysis it is possible to study if the knee and the ankle perform a healthy movement or there are some abnormalities.

The studied participant's knee and ankle performed a normal movement during 2 walking stages concluding that no abnormalities were discovered during this study.

The knee angle is not influenced that much by the variety of the velocity, what cannot be said about the ankle which is more flexible regarding the velocity. Also, depending on the velocity of the gait, the share of the standing phase and the wing phase vary.

1. Introduction

Walking on two legs is a key characteristic of the human being and is required for many daily and social activities. However, many things can alter the normal gait. The human gait cycle is a complex process, that requires the coordination of different joints, muscles, and bones; therefore, any disfunction in any of those components can result in discomfort, pain, or even injury. Studying that phenomenon provides a better understanding of the human gait cycle, helps to understand the functioning of the human body, and is useful for the diagnosis in case of a gait problem (Whittle 1996, Baker et al. 2016). Also, many reasons can lead to a gait abnormality, such as an injury, an amputation, a neuromuscular or brain disorder. (Baker et al. 2016, Schlachetzki et al. 2017, Malanga & DeLiza 1998). Gait analysis is also used to improve the performances of high-level athletes (Malanga & DeLiza, 1998).

This study will focus on analyzing the influence of gait velocity on kinematics. In order to do this, a 2D video analysis of the sagittal plane will be performed, which is an inexpensive and efficient way to study the human gait cycle.

2. Methods

A 2D video analysis, of one subject, during a walking on a treadmill at different velocities was performed to evaluate the influence of the walking speed on the knee angle and ankle kinematics, using the *Kinovea* software. The subject in study was a female (21 years old, 1.65m, 54kg) healthy with no sports background, dressed in black tights clothes.

2.1. Data Collection

To capture the videos a regular camera was placed perpendicularly to the plane of motion. Furthermore, the camera was pointing to the knee joint, which was the middle point of the ipsilateral leg.

Reflective markers on the lateral malleolus, lateral femoral condyle and on the major trochanter of the subject's left leg were used, as it can be seen in *Figure 1*.

Since the markers were passive, a light was used to allow them to reflect it. This light was close to the camera, to avoid shadows and to make sure that the reflection would be a circle.

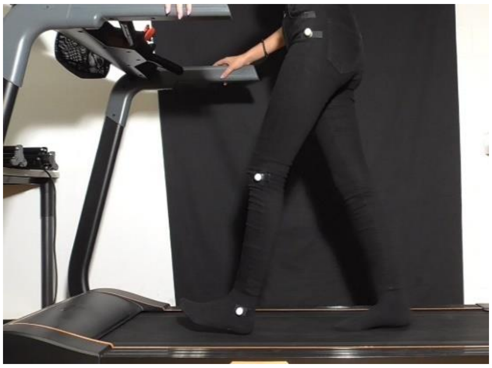

Figure 1. Ipsilateral leg of the study subject, with the markers placed on the lateral malleolus, lateral femoral condyle and on the major trochanter

Before the recording of the subject has started, some camera settings were adjusted:

1. Focus – it was manually set to the plane of motion.
2. Zoom – the camera was placed to cover the full area of motion, and no zoom was required.
3. Recording Frequency – it was 50 frames/sec on the progressive mode.

Lastly, a reference video of a standing object with known dimensions was recorded, to perform conversion from pixel to meter, as it can be seen in Figure 2.

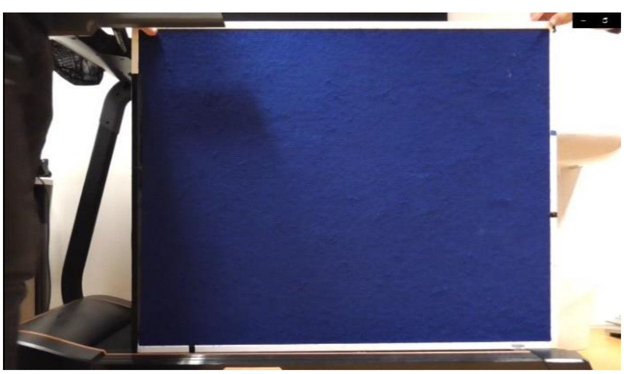

Figure 2. Reference object to calibrate. It was measured the blue part heigh and length, with a measuring tape to find the dimension in centimetres, and with the Kinovea software to find it in pixels

The study subject performed one type of walk at two different velocities (2.5 km/h and 5.0 km/h). After the subject became comfortable with the treadmill and the walking velocity, it was recorded for 30 seconds.

2.2. Data Analysis

As being said before, the first thing to do was to evaluate the coordinates of the scaling points of the reference object. To do that the calibration video was opened on *Kinovea*, the corners of the blue area were marked with the option "cross marker" and then right click to select the option "display coordinates", as can be seen on Figure 3. Once this position was obtained is easy to calculate the length of each side of the board, and to establish a relationship between pixels and centimeters.

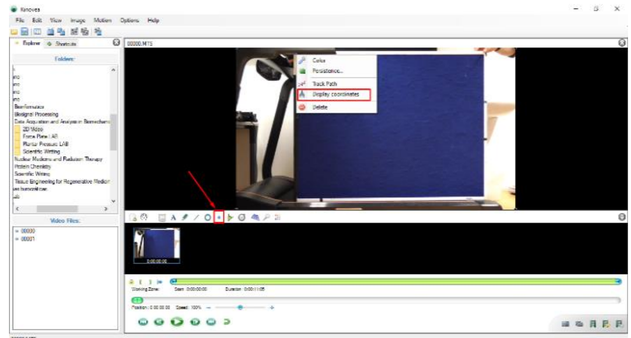

Figure 3. Screenshot of Kinovea software, with the indication of the "cross marker" and "display coordinates" options, that allows the visualization of each point coordinates

To analyze the actual videos that were being studied the markers were marked, like in the reference object (with the "cross marker" option). Then was selected the option "track path" like is shown in Figure 4, once again right clicking the "configurations" window was open when each marker was named and the searching area for the next frame was adjusted. After that, the video was played, and if some marker was lost it was fixed manually in the last good frame.

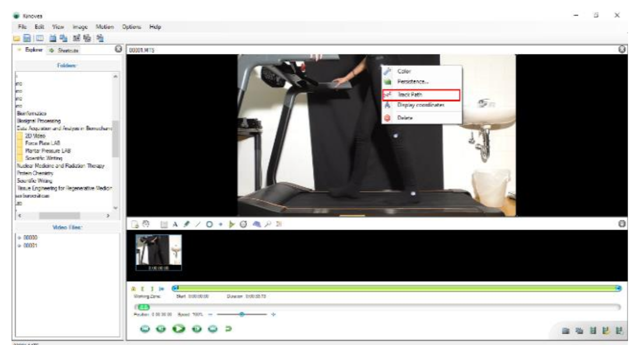

Figure 4. Screenshot of Kinovea software, with the indication of the "track path" option

After 10 gait cycles the data were exported to a .csv file, clicking on tools and then linear kinematics, and choosing the parameter that was wanted to be saved (horizontal movement and vertical movement). This procedure was made for each velocity. To facilitate the further work, the frame where each cycle starts, and end was noted.

The analysis of data was done using MATLAB.

2.3. Equations

The board that was used to calibrate was the size of 15.5 × 86.5 cm which converted into pixels is 1280.12 × 955.55 px, this means that $1\,px = 0.09\,cm$.

To study the kinematics of the ankle it is necessary to calculate the velocity of the movement, and the acceleration of it. Using the equation (1) is possible to determinate the velocity, v, of a point that moves from position s_1 to s_2 between the instants t_1 and t_2. Or, in a general form between the positions s_n and s_{n-1}.

$$v = \frac{ds}{dt} = \frac{s_2 - s_1}{t_2 - t_1} = \frac{s_n - s_{n-1}}{t_n - t_{n-1}} \tag{1}$$

Knowing that the acceleration a, is the derivative of the velocity in order of the time, the above equation can be rewritten as the equation (2) that is analogous to the (1).

$$a = \frac{dv}{dt} \tag{2}$$

As for the angle, φ, on the knee joint, is known that the cosine of an angle formed by two vectors, $\vec{a}$ and $\vec{b}$, is given by the equation (3).

$$\cos(\varphi) = \frac{\vec{a} \cdot \vec{b}}{|\vec{a}||\vec{b}|} \tag{3}$$

3. Results

In order to understand the influence of the velocity and acceleration on human gait, the knee angle and the ankle kinematics were analyzed at 0.7m/s (slow walk) and 1.4 m/s (fast walk). All figures in this section are in order of the time in percentage of one full gait cycle (% GC). As can be seen in *Figure 5* the continuous lines correspond to the mean values of 10 gait cycles, while the dashed curves correspond to the standard deviations. The red lines represent the values when the study subject was performing a slow walk, and the blue ones when the subject was performing a fast walking.

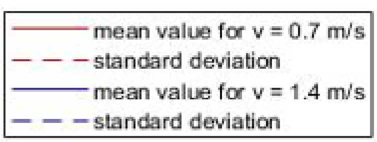

Figure 5. Legend of the following graphics present in this section

In *Figure 6* is possible to see that the knee angle does not vary significantly even if the velocity changes. Assuming that the straight leg corresponds to an angle of 180º the knee angle during the slow walking is slightly smaller (between 160º and 175º). Furthermore, as can be seen in *Table 1* the range of motion (ROM) of the knee angle is also smaller during a slow walking (47.80º ± 5.00º) than during a fast walking (50.72º ± 3.59º).

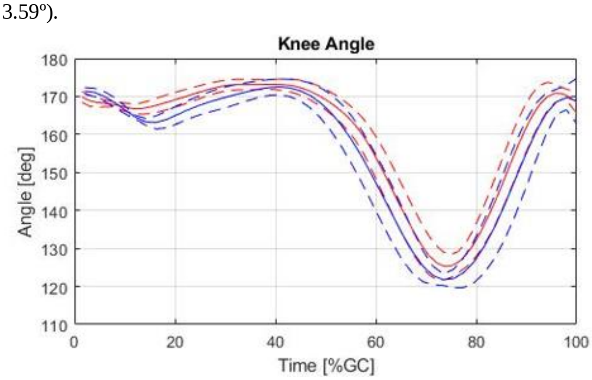

Figure 6. Knee angle in degrees in order of the time in %GC for slow walking (red) and fast walking (blue). Representation of the mean value (full line) and the standard deviation (dotted line) for 10 GC.

Regarding the ankle kinematics, the velocity (v) and the acceleration (a) of the ankle were studied.

It is possible to observe in *Figure 7* that the velocity of the ankle is considerably higher during a fast walking. Besides, in *Table 1* is possible to see that the maximum velocity (Max v) while walking at 1.4 m/s is about 2.65 ± 0.14 m/s and it is twice as big as while walking at 0.7 m/s, approximately 1.85 ± 0.08 m/s.

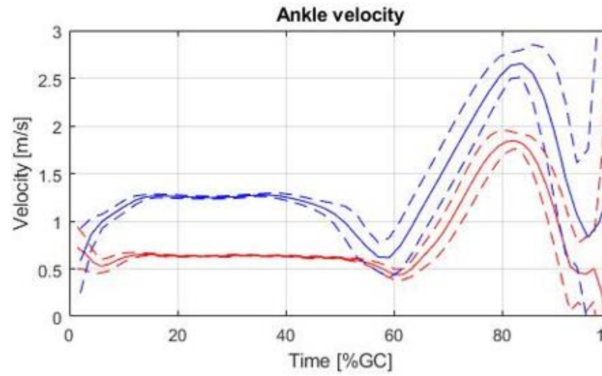

Figure 7. Ankle velocity in m/s in order of the time in %GC for slow walking (red) and fast walking (blue). Representation of the mean value (full line) and the standard deviation (dashed line) for 10 GC

As the velocity, the acceleration in most of the gait cycle is considerably higher while walking fast, just when the whole foot is supported in the treadmill it is 0 m/s^2 in both cases, what is a direct consequence of the constant velocity in that part [see *Figure 8*]. Once more, as it can be seen in *Table 1*, the maximum value of acceleration (Max a) while fast walking is about 30.61 ± 4.68 m/s^2, and it is almost twice as much as the one while walking slower (17.38 ± 2.79 m/s^2).

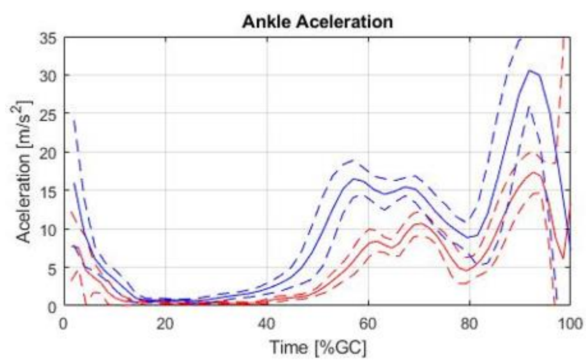

Figure 8. Ankle acceleration in m/s2 in order of the time in %GC for slow walking (red) and fast walking (blue). Representation of the mean value (full line) and the standard deviation (dashed line) for 10 GC

Table 1. Values of ROM, max v and max a during slow and fast walking. Values represented in the format mean value ± standard deviation for 10 GC.

	ROM [º]	Max v [m/s]	Max a [m/s^2]
Slow walking	47.80 ± 5.00	1.85 ± 0.08	17.38 ± 2.79
Fast walking	50.72 ± 3.59	2.65 ± 0.14	30.61 ± 4.68

To complete the analysis – the gait cycles characteristics, as gait cycle duration, percentage of standing phase (StP) and percentage of swing phase (SwP) were calculated and are presented in *Table 2*.

Table 2. Characteristics of the gait cycle (duration, StP and SwP). As in table 1 the values are represented in the format mean value ± standard deviation for 10 GC.

	GC [s]	StP [% GC]	SwP [% GC]
Slow walking	1.36 ± 0.05	62.03 ± 3.59	37.97 ± 3.59
Fast walking	0.98 ± 0.08	51.76 ± 7.14	48.24 7.14

One gait cycle lasts more while slow walking (1.36 ± 0.05s) than while fast walking (0.98 ± 0.08s). Furthermore, the standing phase 62.03% ± 3.59% and 51.76% ± 7.14%, respectively for slow and fast walking lasts longer than the swing phase in both cases, however when the subject walks slower this difference between the phases is higher.

4. Discussion

The validity of Kinovea has already been proved by scientists such as Hisham, Nazri, Madete, Herawati & Mahmud (2017), and this software is especially reliable when the camera is set at a 90° angle, which is the case in this study. (Puig-Divi et al., 2019).

When analyzing the *Figure 6*, it appears that the knee angle is not very affected by the change of speed. However, a slightly more important flexion appears during the mid-stance, this result effect can also be observed in other works, (Robert-Lachaine et al., 2020) (Cooper et al., 2009).

Concerning the ankle velocity, an important difference of velocity can be noticed. Indeed, a more important walking speed results in a globally more important ankle velocity, which makes sense as the same length has to be travelled during a shorter amount of time, 1.4 meters per second instead of 0.7 m/s. Also, when the whole foot is in contact with the treadmill (mid-stance phase), the ankle velocity is equal to the movement's velocity (0.7m/s and 1.4m/s respectively).

Finally, the ankle acceleration also is globally more important when the walking speed is greater. There is an exception corresponding to the mid-stance phase during which the acceleration is zero, this makes sense as the velocity is constant during that same time period, and as the velocity is the derivative of the acceleration. The results concerning the ankle (velocity and acceleration) were expected, but no literature was found in order to compare the results.

An important standard deviation can be noticed for both the ankle velocity and the ankle acceleration, during the beginning and the end of the gait cycle. There can be several explanations to this phenomenon, the most important one is that the acceleration represented is not constant, therefore it is calculated from speeds which are themselves not constant. This results in an important error when the studied point brutally changes speed, which is the case during the initial strike as well as the terminal swing. Indeed, touching or leaving the floor results in a brutal acceleration or deceleration. Easy ways to reduce this standard deviation consist in having a greater sampling frequency, or walking slower, which would have the same effect: more samples for each gait cycle, and therefore make both the acceleration and the speed closer to the instantaneous values.

5. Conclusion

This study was designed to analyze a recorded video, from the sagittal plane, during 2 stages of walking in order to discover if there are deviations from the normality of a human gait. As it is shown and explained in the results and discussion, the behavior of the knee angle and ankle is according to the normality.

Overall, it is possible to conclude that once the velocity is higher – the acceleration is higher too, meaning that these 2 variables are positively correlated. If the velocity and acceleration are positively correlated, the time of a gait cycle is negatively correlated to the velocity, meaning that once the velocity is increased, the gait cycle lasts shorter.

This study is very useful to perform in order to check whether the gait is performed in a normal/recommended way or there are some deviations from the recommendation. As soon the abnormalities are discovered, as soon a rehabilitation strategy can be developed and the process of getting back to a normal gait will last shorter, costless, and painless.

Of course, an analysis of a 2D video recording of gait can not be compared with the information provided by an analysis of a 3D video but comparing the costs of such an analysis and the knowledge needed to perform one, it does not make sense for a simple study.

6. References

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