Examination of Movement in Young Gymnasts

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Abstract: Objectives To improve gymnasts' performance, it is essential to assess their movements and build an effective training plan based on the results. Several aspects were considered in the analysis, including flexibility, dynamics, accuracy, and balance, which are greatly important in gymnastics. We studied the young athletes during the movement analysis, intending to help them achieve a more successful gymnastics career after recording and analysing their data. Design in this study, we analyse the movement analysis of junior gymnasts, which contributes to better competitive performance and personalised training. A movement and gait analysis of Hungarian youth and adolescent national team athletes was carried out, which confirmed that the method and training plan used to design Method Participants appropriately are 14 youth and adolescent national team gymnasts aged 13 to 15 years. Equipment is Goezhe gait Lab video-based computer-assisted motion capture system. Thus, the first measurement position was a smooth gait test. In contrast, the second step was a movement imitating a beam gait, i.e. the subject walked to the end of a one-centimetre line in the middle of the calibrated space. Exams detected and analysed the full-body model at all points, but the knee flexion and extension are the most exciting and essential for ANOVA and Mann Whitney tests. Results of the length of the step cycle increases with training, both on the left and the right side and ordinary and line walking. As a result of training, the range of knee motion increased significantly, and the maximum flexion force increased significantly. Conclusion the presented results showed the efficiency of the classic training methods in strengthening the muscles responsible for correct low extremity posture. The findings suggest a valuable method for posture improvement in young athletes. Further studies with larger sample sizes, age-range and sports backgrounds are required to clarify the efficacy of good training for flexion problems originating from incorrect posture caused by low muscle tone and strength.

Keywords: Biomechanics gymnasts; gait test; balance test; training plan

1 Introduction

The good performance of gymnasts is needed in the athletic race; it is important to assess their movements and build an effective training plan based on the results. [1, 2]

Several aspects were considered in the analysis, including flexibility, dynamics, accuracy, and balance, which are greatly important in gymnastics. We studied the young athletes during the movement analysis, intending to help them achieve a more successful gymnastics career after recording and analysing their data. Therefore, it is worth looking at the history of gymnastics: it was a sport for highly muscular athletes in the past, but now it is clear that this muscle mass is harming the results. The development of muscular strength, acceleration, endurance, and static strength is most effective between the ages of 13 and 15, so we tested flexibility and dynamism in our subjects. We only need to look at the most critical work of the quadriceps hamstring muscle – when kicking off the ground and at the end of exercises, when jumping off the apparatus and in the steadily extended leg posture. [4, 5]

1.1 Literary Research – No Literature

In Hungary, this is the first movement analysis of gymnasts using a movement laboratory, and no similar analysis has been found in the Hungarian or foreign literature. We discovered general musculo-articular and biomechanical descriptions but nothing specific. Gymnastics has numerous elements, so it would have been unrealistic to assess from the point of view of joint movement which joint is working in which position, set, and phase. As no such study has been done, we are starting from ground zero and analysing the gait of junior gymnasts, focusing on joint mobility and the building blocks of the sport: accuracy and flexibility. This data will reveal who is capable of what and how they can improve to perform better in a particular area. As mentioned earlier, 13-15 ages are crucial, so we chose this age group as there is still room to develop the flexibility, dynamism, and acceleration that are considered the basis of explosiveness. [7]

1.2 The Ritual: Sports, Movements, Drugs

Before analysing physical activity, it is worth clarifying the concept of sport, and perhaps most importantly, drawing from the European Charter of Sport: 'sport is defined as any physical activity, whether performed occasionally or in an organised manner, which aims to improve physical well-being and mental fitness, to develop social relationships or to achieve competitive results at various levels'.

There are also two branches of sport, one called participatory or recreational sport and the other spectacular sport. A brief explanation of these is essential because sports can be classified into both categories. In the case of a spectator sport, as the word itself suggests, the spectacle of the sporting event and the emotions that go with it, such as cheering and excitement, are the product to be sold, an experience designed to entertain the athletes themselves, participants. On the other hand, recreational sporting activity is carried out by the amateur competitor himself and is, therefore, a physical activity, with the sport itself as a direct experience. [8]

Furthermore, why does gymnastics fall into both categories? The explanation is simple, on the one hand (recreational sport), there is school physical education and gymnastics played as a hobby, which brings health benefits to the person playing the sport. On the other hand, gymnastics as a professional sport is at the centre, where fans can enjoy the exercises on display, so much so that it has now become the fourth most-watched sport at the Olympics games.

From the perspective of gymnastics, acrobatics is one of the essential starting points, as it is a crucial part of the two fundamental apparatuses, the floor and the vault (the two apparatuses found in both men and women). From a historical point of view, it is interesting to note that archaeological evidence has been found from antiquity that acrobatics had already appeared in Egypt. In the 16^{th} and 17^{th} Centuries, gymnastics originated, and the village fair or circus was considered the forerunner of the competitions. It required an organisation similar to that of a modern-day tournament. Both terms active participants and spectators had a community-building effect. Club gymnastics, like national associations, began to take off in 1800. Unlike today's competitions, there were no judges in the early days. The competitions, combined with other sports and the shows, were a famous festival, with the winners announced by a subjective jury. From a Hungarian point of view, 28 June 1885 is worth highlighting, as gymnastics was then publicly introduced as a sport. A regular and free gymnastics demonstration followed a parade of adults and students in Budapest. The winner had awarded a wreath, and this event became a national holiday. On 29 June, the Hungarian national association MOTESZ, the Hungarian Gymnastics Clubs Association, was formed with 15 clubs. Hungarian athletes had already competed at the 1896 Athens Olympic Games in keeping with historical fidelity. We have 15 gold, 11 silver, and 14 bronze medals in the gymnastics competition at the five Olympic Games. [9]

There are two specific events in today's men's and women's events, floor and vault. In addition, the women have half-bar and beam, while the men have ring, vault, bar, and stretching, so there are four and six events, respectively.

It is an indisputable fact – and all the experts agree that gymnastics is a primary sport that should be part of every young child's life since all sports feed on this movement material and its comprehensive elements help everyone. Several analyses have shown that gymnastics is studied from the point of view of motor

strength, i.e. speed and relative strength, joint mobility, flexibility, balance, and accurate spatial and temporal perception of movement. These are the fundamental skills affected, alongside psychological and aesthetic characteristics.

One of the essential components of gymnastics is the floor exercise. Furthermore, these exercises have been around since before the dawn of time. Modern ground exercises have been calculated since the 1950s – initially, they were called artificial ground exercises. The dimension of the floor is 12 meters by 12 meters and is made from unique materials and layers to provide more bounce, called a spring floor. Ensures that the athletes' joints are not damaged when they land after a jump. Medium where strength, balance, and acrobatic skills count alongside flexibility. Rotation, jumping, handstands, and circling are all part of the routine, along with additional strength elements, and for women, there are dance elements in the routine. The demonstration must be done at a given time, with music for the ladies. The first Hungarian Olympic champion in the event is Ágnes Keleti, who will turn 100 in 2021.

Moreover, what type of training is needed to become a good ground player while constantly practising elements and combinations on the ground and honing techniques? The literature includes natural jumping and static and dynamic balance exercises. In terms of free-form exercises, the focus is on exercises on stools, benches, tools, or racks. Another sport, athletics, also helps develop a good groundworker, whether long jumps from a standing or running position or short sprints.

The beam is exclusive to women's gymnastics and is a unique apparatus, as it is not related to any male apparatus. As early as the 1936 Olympics, competitors were allowed to compete here, but only women. Interestingly, it can also play a role in men's training at a younger age, improving balance, a fundamental skill in gymnastics. It reached its final form in 1950, 10 cm wide, 5 m long, made of wood or plastic. The 10 cm surface acts as a flattened floor, allowing some elements to be performed on it, also used for floor exercises. So that some acrobatic and gymnastic elements are combined in a single exercise, for this reason, the competitors first assemble and prepare their routines on the floor and then adapt them to the beam. Several basic skills are needed to excel in the sport, the main one being balanced, but courage is also important, as are other motor skills typical of gymnastics.

Balance is the ability (vestibular ability) that allows you to keep your body in the desired position or movement while changing postures and movements. The result of multifaceted practice is acquiring a specific balancing skill. The beam itself, by the way, stands on a 20 cm mat. There is also a given time interval, 70-90 seconds. On the floor, Agnes Keleti won the Olympic gold medal in Melbourne in 1956. Among today's gymnasts, the European champion in high bar and vault, Zsófia Kovács, is one of the best, with her first place at the World Cup.

The next event – found in both men and women – is the vault, which has a history stretching back thousands of years. In the old days, the man called the horse vault, as the men performed it in the long jump, while the women performed it on a horse without a crossed cauda equina. They used a buck (a log attached to a stand) as early as the 1800s. However, it was not used in Europe until the second half of the 1900s.

Today's dimensions are 1x1 m surface and exceptional design. We can use different heights for women (1.25 m) and men (1.35 m). The competitor did the run-up for the vault, stepped onto a spring-loaded bumper, then touched the apparatus with both hands, rotated longitudinally and transversely in the air, and landed on the ground with both feet. The gymnast also twists and turns before touching the apparatus in some jumps. We also have an Olympic champion in this event, Henrietta Ónodi, from 1988. The Olympic champion Zsófia Kovács, mentioned above, became the European champion in 2020.

In this case, a good running technique is essential, and this is interesting for our study because the most optimal canter technique is one in which the footrests are parallel to the ground. Motor skills can also be developed with other exercises such as stair-stepping and knee bending. The most necessary for developing specific acceleration power is the serga, with fast kicking from the ankles and knees.

2 Method

In the Ferencváros Gymnastics Hall of Ferencváros, the movements of 14 youth and adolescent national team gymnasts aged 13 to 15 years were the subject of our study, and the measurements were taken before and after the training sessions. As mentioned before, we also examined the balance positions and the gait on the beam for accuracy. There is no coincidence, as a balance position is one of the foundations of gymnastics. Hence, athletes who already boast national championship titles and international results are in great need of developing this skill.

We measured the athletes with the help of the Goethe Gait Lab motion capture laboratory. Our goal was to find a method that is not cumbersome, not expensive, not painful, easy to use, non-invasive, and produces measurable results that can be easily compared. Moreover, that was computer-controlled video-based motion tracking, with visible light as the essential tool to aid optical tracking. Four video cameras recorded the motion sequence under investigation. They are connected online during the test, controlled by a computer. We created an open terrain, as this was the best way to mimic the gymnasts' training and competition conditions, where nothing interferes with them, so we tried to work with as few cables and wires as possible to assess the competitors in a prominent field.

The most important part of the measurement is the calibration, for which a unique body is used, described below. After data acquisition comes transformation, i.e. converting the images from 2D to 3D, finally filtering and denoising the data.

Calibration is all about reducing the longitudinal distortion of the cameras, which is why we need 18 calibration points and an independent fixed point, as our primary goal is to achieve the highest possible accuracy.

We use a particular sphere grid developed by the Goethe Gait Lab, which gives high accuracy, practically less than 1 per cent, which means that we can test deviations in the millimetre range. Similarly, using 18 calibration points, the position of the chambers can be measured.

It is important to note that the fixed point is the absolute zero of the system. A salient point on the calibration body defines the zero point of the Descartes coordinate system concerning which the directions are given. X coordinate is taken as the (sagittal) direction of progress, i.e. the direction of motion. The coordinate is the vertical direction, i.e. the direction in which the foot is lifted, and the z-direction is the lateral direction (horizontal). It was necessary to create this type of coordinate axis with a left-hand twist to be paired with the designations used in medical examinations. It could be presented and interpreted by both trainers and the medical profession. [10, 11]

The basic test is the so-called Dempster's body model, which applies to the whole body and follows the body's movement. Naturally, the anthropometric characteristics of the subjects are measured beforehand, and the model has adapted accordingly. (Fig. 1)

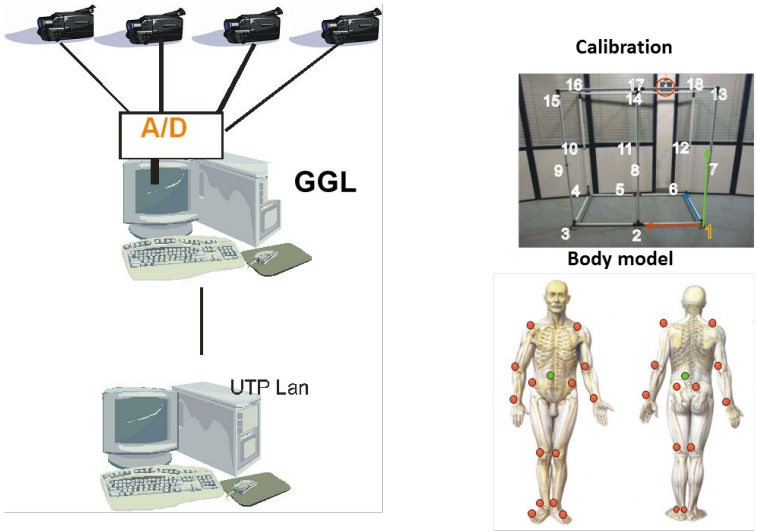

Figure 1
GGL system (hardware, calibration cube, body model: markerset)

The participants in the study wore black clothes, on which we applied reflective markers, i.e. we used the black and white technique. Both passive and active markers are helpful in this system, but we only used the passive ones, mainly because of the fast movements of the gymnasts. These markers need much lighting, and we used special spotlights for this. The markers were placed on the joints of the participants in the study using triangulation, i.e. we tried to determine the anatomical rotation point of the joint by placing three reflective points on each joint. In addition to the measured data, a unique database was used to record any additional data that were specific to the subject.

Two different measurement settings were used in the study. We were looking for a form of movement typical in gymnastics that could easily be compared with other groups' measurements. Thus, the first measurement position was a smooth gait test. In contrast, the second step was a movement from imitating a beam gait, i.e. the subject walked to the end of a one-centimetre line in the middle of the calibrated space.

In sports, movements are based on time outcomes, so the data were often not analysed using the distance-time function in the function analysis. We defined local minima (the start of the stride cycle during the gait) and maxima in the function analysis. They were examined and their relation to each other and their distance. In addition to this, statistical analysis was also carried out, using other methods than the basic statistical methods – ANOVA, Mann – Withney and regression.

In all cases, our null hypothesis was that the results of the two studies were not different (95% threshold set at $p =<0.05$).

3 Results

The results obtained should be highlighted that our motion analysis is based on the step cycle for several reasons. On the one hand, this form of movement can be performed by everyone, regardless of whether they are an athlete or not, and thus the results obtained can be compared with other results in different variations. [12, 13] We have developed a test procedure that focuses on the factors of great importance in gymnastics. [14, 15] In the preparation of training plans, coaches emphasise flexibility and dynamism, so we have designed a training plan-oriented analysis in terms of the usefulness of the results. It will show to what extent this analysis helps trainers in their work and to what extent and how emphasis should be placed on developing these skills. This professional desire should also be taken into account in the approach from the engineering side. In the following is the characteristics of normal, healthy movement and the main parameters of our research. (Fig. 2, Fig. 3)

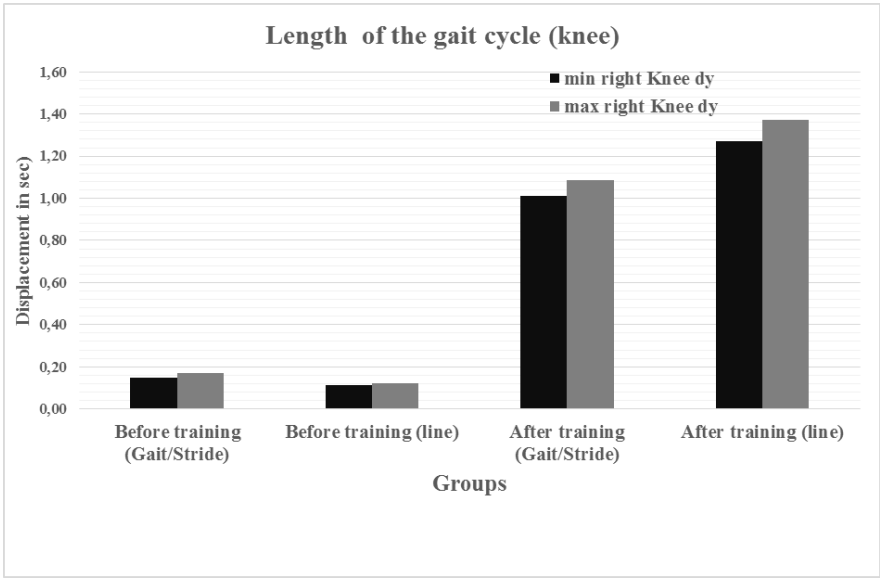

Figure 2
Lengths of the gait cycle (right and left knees in vertical plane)

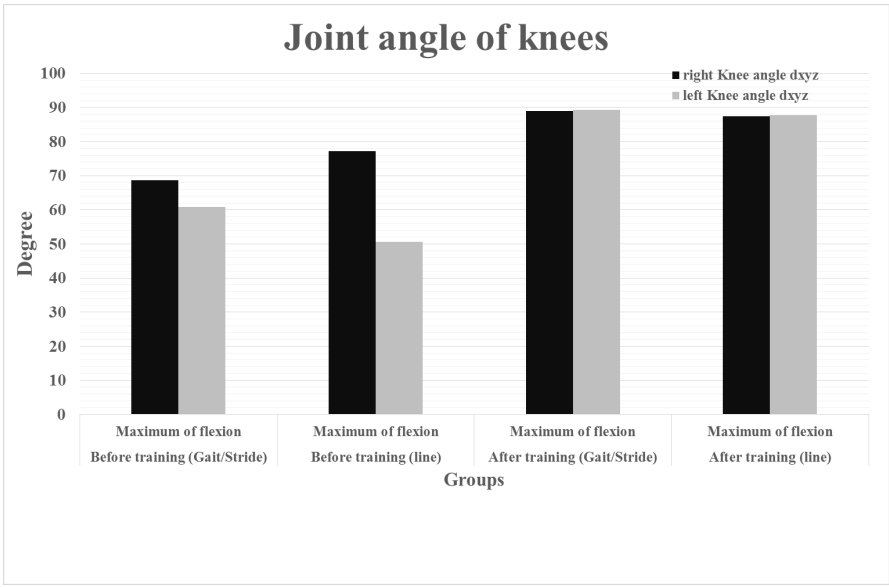

Figure 3
Joint angles of the knees (maximum flexion of right and left knees in 3D)

4 Discussion

The gait cycle is defined in terms of the path-time function, and the length of the step cycle is the distance from the heel strike of a leg to the next heel strike or the time it takes to reach that distance. [16, 17] According to the literature, the gait cycle consists of two phases: the support phase and the swing phase. The support phase is when the foot is on the ground, and the swing phase is when the foot moves forward. In our measurement, the aim is to make the right and left sides separable and accessible. Man has slightly modified the literature of physiotherapists and doctors, which means that we always consider the time and distance from the moment a heel strike is made to the moment the next heel strike is made.

If we consider the stride cycle to be 100 per cent, then in a healthy case, the proportion of the support phase is 60 per cent, and the proportion of the swing phase is 40 per cent. During the stride cycle, the centre of mass is also considered. It is also looked at in a healthy case, in which case it will give a sagittal, or x, angle of 45 degrees in the direction of gait. [18]

In addition to x, we also considered y-directional deflection, which represents explicitly the rate and height at which the heel or ankle rises off the ground. In this case, we can also analyse the movement of the centre of gravity, which shows that the centre of gravity follows the movement very well with its sinusoidal nature.

The z-directional deflection was also mentioned, which is the lateral displacement. In this case, it is shown how the limb follows this movement with lateral displacement.

We have given the step as a form of movement with three directional parameters. We can specify the position of the swing phase and the support phase in each direction and see characteristic deflections on the curve in each direction.

Since we are talking about gymnasts, we consider it extremely important for training planning to have as much information as possible about the dynamics of the movement. For this purpose, we have not only considered the step cycle as a function of time but also analysed the individual stages of the step cycle, i.e. the minimum and maximum of the curves and their distance. Here, too, a uniform system was developed, with the minimum being the ground grip and the maximum the highest point of the step cycle. The distance between the two was not defined in centimetres and time, as this gives an idea of the dynamics of the movement.

When analysing gait, it is essential to consider the movement of the joints. In this case, the movement and angular range of the knee joint is the most important for us. The literature shows that the normal knee angle is 60 degrees when walking horizontally and 80-90 degrees when walking upstairs. Passive knee flexion can reach 130-140 degrees with strong hip extension and 160 degrees with powerful movement. [18, 19, 20]

If we analyse the gymnasts' stride cycle, we first find an asymmetry between the right and left sides, which is also typical of the average population. If a gymnast wants to achieve a good result, this asymmetry must be reduced. Think of a floor exercise or a beam exercise.

It is also observed the following that the length of the step cycle increases with training, both on the left and the right side. ($p< 0.005$) (Fig. 2) This trend is also observed for normal and line walking. The analysis of the phases of the stride cycle continued and at this level proved a significant thesis for gymnastics. By examining the distance between the first (minimum and maximum) and the second (maximum and minimum) phases of the swing phase, it can be concluded that the swing phase is essentially shortened as the minimum-maximum distance increases. The initiating phase becomes more pronounced than before, i.e. the motion becomes more explosive.

Furthermore, explosiveness is a fundamental tenet of gymnastics, which a gymnast needs. It is fascinating that this type of shortening is much more pronounced when walking on the line (imitating a beam). The stride cycles are much shorter, which means that this type of walking will be much easier at the end of the training session. In summary, this is the most effective movement in training, which is particularly beneficial for gymnastics. As we have studied young athletes, it can also be considered very effective, as precision, flexibility and muscular explosiveness are required to perform the exercises in gymnastics.

As indicated above, when looking at joint angles, we are concerned with the knee joint for gymnasts. The angular extent is defined as follows: between the femur and tibia, as a three-dimensional vector. (Fig. 3.)

As a result of training, the range of motion increased significantly, and the maximum flexion force increased significantly. The state of maximum flexion during the step gives the maximum of the path-time function describing the flexion position and angular motion.

Conclusions

From the above results, it is clear that a well-executed training plan or training programme for young athletes increases flexibility and explosiveness and muscle strength. It can be seen from the increase in stride cycle both in natural gait and in line walking. The latter also tests the degree of balance retention by imitating movement on a beam. Robustness and flexibility are also necessary, and this was investigated by determining the maximum knee bending angle value (the fully flexed position). There was a significant increase in MKinden parameters compared to previous data. It indicates to us that the training plan and programme effectively improved the movement of the young athletes.

This research could only provide initial results because of the low number of subjects in the groups and the relatively small test movements. The present study had several limitations. The study consisted of a small sample with a similar

background, limiting the ability to apply the results to the general population. Second, the design of the study is not optimal. A large, double-blind, randomised, controlled trial is required to provide reliable evidence. There should have been a follow-up period after the research to study long-term effects.

The presented results showed the efficiency of the classic training methods in strengthening the muscles responsible for the correct low extremity posture. The findings suggest a valuable method for posture improvement in young athletes. Further studies with larger sample sizes, age-range and sports backgrounds are required to clarify the efficacy of good training for flexion problems originating from incorrect posture caused by low muscle tone and strength.

Our Practical Implications

The study raises many practical applications.

It has shown that there is scientific added value in using movement testing in the design of exercise plans.

The importance of analysing the movements of young athletes using movement analysis software

The results obtained can design better training plans to help athletes achieve their goals.

Movement analysis helps both athletes and coaches work more efficiently and safely in the short and long-term.

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