Exploring the giant circle on the high bar with ICT tools

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Daan Knobbe and Nic Nijdam were secondary school students with artistic gymnastics as a hobby. They jointly investigated the mechanics of the gymnastics swing around the high bar. They not only did this to meet the curriculum requirement of a carrying out a large research project, but also to satisfy their curiosity regarding the sports science subject. With a high-speed camera they recorded the motion of a backward giant circle on the high bar. Hereafter they analysed their data both quantitatively and qualitatively. We present the results of the students' research work about the backward giant circle on the high bar, which resembled the practice of sports scientists. We discuss the authenticity of this project, the role of ICT, and potential further exploration at student level. In our opinion, the presented work is a nice illustration of authentic experiences of secondary school students in doing sports science that they will never forget.

Introduction

In the Dutch secondary education system, students must carry out at the end of their school career a research or design project with a study load of 80 hours to demonstrate their ability to apply acquired competencies while pursuing a research question or design goal in some depth. Students are encouraged to choose the topic themselves and they are to some extent free in setting up their work. Normally they work in small teams over a long period parallel to the regular lessons and they deliver a report and a presentation about their results. Ideally, the students do not only see it as a compulsory subject but also enjoy the stimulating aspects of doing their own research or design. Challenging and authentic projects, which are representative for actual research and design work done by practitioners, and projects on subjects to which students can personally relate seem effective in this respect. This is at least the experience of the first author in earlier work with student research projects in the context of human movement (e.g., Heck & Ellermeijer, 2009; Heck & Holleman, 2003; Heck & Van Dongen, 2008). In these projects, the focus was on providing students with opportunities to experience how science is enacted, i.e., with authentic inquiry, and in particular on providing students with ICT tools that allow them to act as 'real' scientists (Heck, 2009).

In this paper we report on a project of two secondary school students who investigated the backward giant circle on the high bar. We present the results of their research work, which resembled the practice of sports scientists, and we discuss the authenticity of this project and the role of ICT. This means that we go into questions like "What did the students actually do in their project and what could they have done more or better?", "How did ICT contribute to the realization and the success of the sports science project of the secondary school students?" and "To what extent did the students' work resemble scientific practice?".

The backward giant circle on a high bar

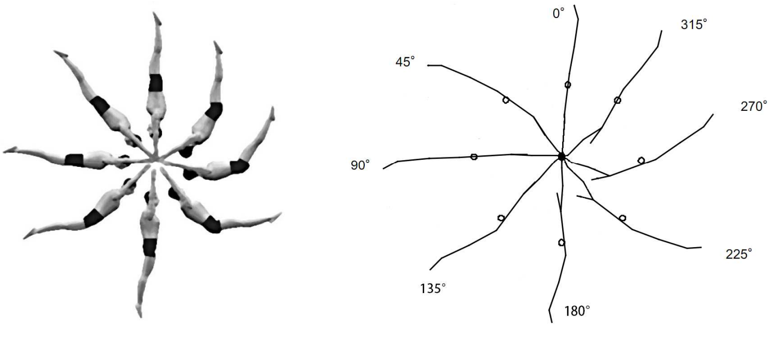

Figure 1. Graphics sequence of the traditional technique of a backward giant circle, in which the gymnast circles backwards (anti-clockwise direction) from a handstand on the high bar through 360° [after (Hiley & Yealdon, 2001) and (Tsuchiya, Murata & Fukunaga, 2004)].

The high bar is one of the six pieces of apparatus used in Men's Artistic Gymnastics competitions. A high bar routine consists of a number of circling skills, flight elements, and a dismount. The backward giant circle is used to link the circling techniques and to provide the required flight and rotation for flight elements and the dismount. It is an artistic gymnastics element in which the gymnast passes through a handstand position above the bar and fully rotates around it, without releasing the bar at any time, without bending arms and knees, and with only smooth changes in hip and shoulder joint angles that have little influence on the aesthetic execution (cf., www.fedintgym.com). This at least is the description of a traditional backward giant circle in which the gymnast extends his body close to the highest point of the circle, maintains it in the downward phase and flexes the shoulder and hip joints during the early upward phase (See Figure 1).

The students teamed up to investigate the mechanics of the backward giant circle on the high bar, triggered by their own hobby and interests. They were given printed copies of relevant literature (e.g., Hiley & Yeadon, 2001) to put them on the way. Their physics teacher and gym teacher advised them during their research. The students formulated the following main purpose of their study: "We investigate the influence of the shoulder and hip joint angles on the angular velocity in a backward giant circle on the high bar and we investigate how a gymnast can optimize these and other factors in his performance in order to achieve the highest possible angular velocity and still perform well in the eyes of the gymnastics jury."

Video analysis of the backward giant circle on the high bar

In this section we present the results of the students' research work about the backward giant circle on a high bar. We discuss in depth their experimental design, data analysis, and use of ICT. In order to get a better impression of the students' performance and to assess their results, we have also redone the video analysis of one giant circle in a more advanced way.

Experimental design

For the purpose of exploring the influence of the shoulder and hip joint angles on the angular velocity in a backward giant circle with both quantitative and qualitative methods, the student researchers designed an experiment in which they could collect position, angle, velocity and time data for a backward giant circle on a high bar through video measurement and in which they could use video tools for analysing video clips of various types of swing motions. In the previous sentence we deliberately wrote, "designed an experiment", because a lot of thinking and preparation went into the set-up of the experiment.

First of all, the students arranged the location of their experiment, namely, the practice room of their gymnastics club where the high bar apparatus could be used on a quiet moment during daytime. A performance of several subsequent giant circles was required for a good analysis of a backward giant circle in which a gymnast just swings about the bar without the goal of increasing or decreasing the angular velocity at the highest point above the bar. In order to be able to make several full swings after another, the students used a training tool for the apparatus that reduced the friction when the gymnast circled about the bar, made it easier to do a full swing, and simplified the control over experimental conditions.

The next thing to watch in the experimental set-up was the type and positioning of the camera(s) with which the movements were recorded. The student researchers used a point-and-shoot high-speed camera operating at a frame rate of 120 fps to get enough data for a quantitative video analysis and to get at the same time a good resolution quality of the video clip. Ideally, the camera for recording the giant circle would have been positioned perpendicular to the plane of motion, at a distance and height that reduce perspective distortions, and with the camera oriented such that the *x*- and *y*-axis are aligned horizontally and vertically, respectively. In reality, these experimental conditions are often difficult to arrange. The student researchers did their best and luckily the video analysis tool of the Coach environment (Heck, Kędzierska & Ellermeijer, 2009) provides a tool to correct perspective distortion afterwards.

Before recording body movements, a researcher must at least have an idea of what (s)he will do with the video clips. The questions that the student researchers asked themselves already give a clue of the type of body segments model of a gymnast performing a backward giant circle that they had in mind. The rigid 3-segments model is shown in Figure 2 (adapted from the students' report). To make it easier to measure positions of wrist, elbow, shoulder, hip, knee and ankle, the students attached markers to the gymnast's skin and shorts over the right body side joints. The markers over elbow en knee joint were attached only to verify whether the arms and legs were kept straight during the giant circle, but were not used in the video measurement and in the biomechanical analysis of the motion. Body orientation was defined as the angle between the vertical and a line from the bar to the body centre of gravity. The body orientation angle, shoulder angle, and hip angle were estimated on the basis of displacement data using the convention illustrated in Figure 2.

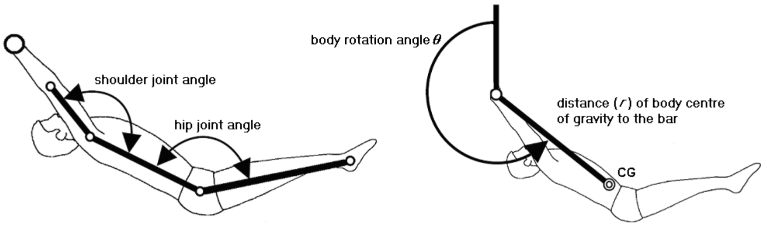

Figure 2. Body segments model of a gymnast performing a backward giant circle. White dots represent the wrist, elbow, shoulder, hip, and ankle markers and the location of the body centre of gravity (CG).

Video analysis of the student researchers

The students used the video tool of the Coach software environment (www.cma-science.nl) to measure the distance of the body centre of gravity and to compute its velocity during the giant circle. They used a fixed position for the body centre of gravity, slightly above the hip joint as shown in Figure 2. To calibrate distance, they used the known gymnast's height and the height of the high bar measured from the bar at rest to the upper face of the landing mat.

The students determined the joint angle–rotation angle graphs in the following way. They utilized the open source video analysis software Kinovea (www.kinovea.org) to collect data about shoulder and hip joint angles for certain predetermined body rotation angles per giant circle. The students decided to do measurements only at body rotation angles 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° for the 6th up to and including the 10th giant circle in a sequence of 14 consecutive giant circles on the high bar. The picture on the right-hand side of Figure 1 gives an impression of a subject's body configuration at these rotation angles.

Using an Excel spread sheet, the students averaged the measurements for the 5 consecutive giant circles in order to deal with small changes between giant circles. In this way, they obtained a data plot of 8 points, in which the shoulder and hip joint angle were plotted against the body rotation angle. In order to get line graphs, they utilized the demo version of the Igor scientific graphing and data analysis program (www.wavemetrics.com) for curve fitting. They used a sinusoidal regression type. Figure 3 shows the graphs obtained by the students.

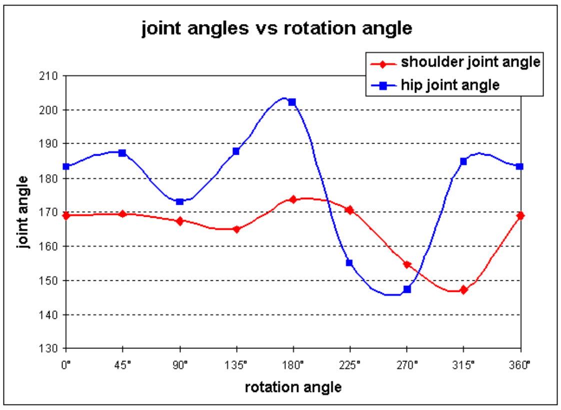

Figure 3. The shoulder and hip joint angle plotted against the rotation angle of the body centre of gravity for a backward giant circle on the high bar.

The students also used the measured shoulder joint angles at the given eight rotation angles per giant circle and the known body segment dimensions to compute the distance of the hip joint to bar at the particular rotation angles. This was a nice application of the cosine rule learned at school to biomechanical problems in a real context.

The students qualitatively analysed their graphs in much the same way as we present in the next subsection. In addition they analysed whether a gymnast can return to handstand when his shoulder joint angle gets small during the movement. They concluded that only a free hip swing to handstand on the high bar is possible, but this is not considered a giant circle.

The motion analysis of the student researchers continued with reflection about other factors that influence the performance of a backward giant circle on the high bar but are not under less control of the individual gymnast. Using qualitative arguments, based on fundamental biomechanical principles about angular motion such as moment of inertia, angular velocity, and angular impulse, and based on formulas for these quantities in simple cases, the students came to the conclusion that gymnasts can swing faster about the high bar when they are less heavy and have a shorter distance between their body centre of gravity and the bar.

The behaviour of the student researchers in their video analysis of the backward giant circle on the high bar resembled the attitude of scientists in that they tried to explain the effects of various factors on the gymnast's performance by scientific reasoning and also by quantitative analysis, if possible. Their data collection, processing and analysis were based on the same methods that sports scientists use in practice and references to research literature were made. The students also reflected on their research design and the obtained results, looked for alternative methods and explanations of phenomena, and made suggestions for further investigations in their detailed research report. This is what professionals do in practice, too. In the choice of ICT, the student researchers had the same attitude as most scientists: they just used whatever tools were available to them and seemed useful for their research aims.

Video analysis based on a computed body centre of gravity

In reality, the body centre of gravity is not always located at the same body point: due to changes in body configuration, the location changes and may even be outside the body (as shown in Figure 4). In a more advanced video analysis one would compute the location of the body centre of gravity during the giant circle from the recorded position of the markers and from anthropometrical data for human body segments. It is more work, but the procedure is standard (e.g., Robertson et al., 2004) and the benefit is an improved quantitative video analysis of the motion. We used the same five-segment model of the gymnast (two upper and low extremities, plus the head and torso as one component) as Townend (1993) and utilized anthropometrical data as presented in (Robertson et al., 2004) to predict the location of the body centre of gravity during the giant circle.

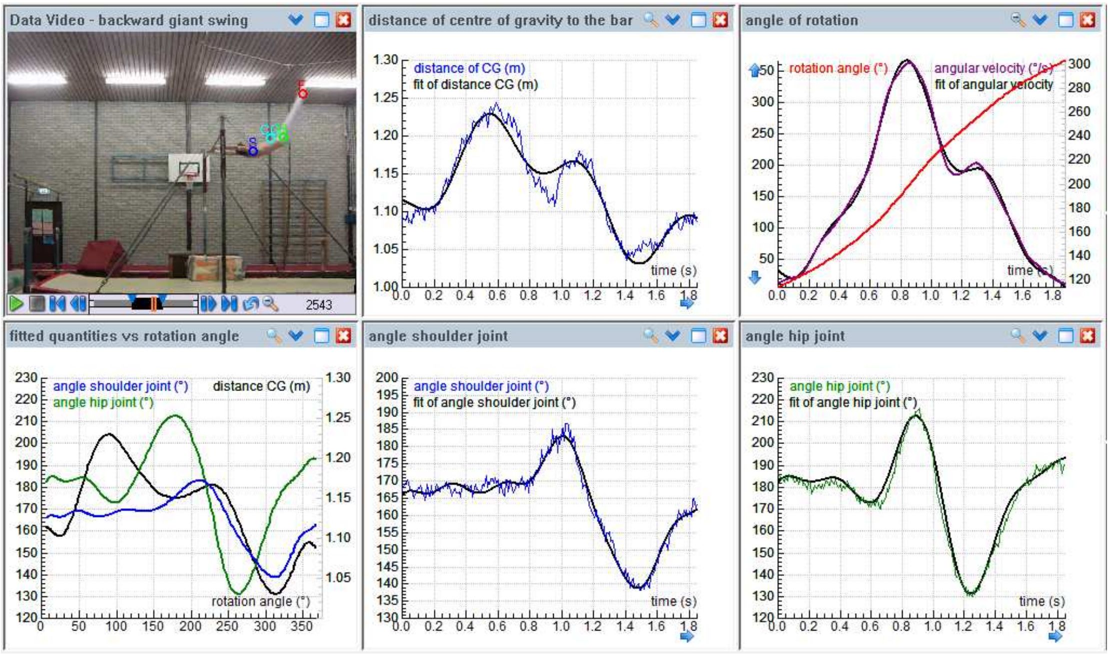

Figure 4. Screen shot of a Coach video analysis activity about one backward giant circle.

Figure 4 is a screen shot of the video analysis of one giant circle (actually the 6th in the uninterrupted sequence of 14 giant circles performed by the gymnast) based on the described methodology. The upper-left window in the above screen shot show a still from the recorded video clip in which the gymnast has bent his shoulder and hip joints in the upswing phase of the giant circle. The points overlaying the video clip are the measured positions of the shoulder, hip and ankle joints and the computed position of the body centre of gravity with respect to the moving reference frame that has the right hand of the gymnast as its origin. Since the video clip in which spatial and time data are collected and mathematical representations like graphs and tables are synchronized in Coach, pointing at a graph automatically shows the corresponding video frame, and selecting a particular frame highlights the corresponding points in diagrams, when scanning mode is on. This makes scrubbing, i.e., manually advancing or reversing a clip, an effective means to identify and mark interesting events in the video clip and to relate them with graphical features. This feature is much used in motion analysis. In the diagrams of Figure 4 are shown sinusoidal regression curves for the data, the formulas of which have been used in computer modelling of the motion (not further discussed in this short paper). Below we describe some diagrams in detail.

Going in clockwise direction through the above screen shot, the first diagram consists of the distance–time graph of the body centre of gravity and a curve obtained by approximating the data with a sum of sine functions. In this particular case, a sum of two sinusoids (plus a constant) gives a remarkably good approximation. The distance–time graph of the body centre of gravity can be understood in the following way. Initially, when the gymnast is in a handstand above the bar, his body is not fully extended and the distance of the body centre of gravity is not maximal. During the first phase of the down phase, this quantity actually increases to a peak value when the body is close to horizontal orientation. Hereafter the distance of the body centre of gravity to the bar decreases to a (local) minimum when the gymnast passes under the bar. His hip joint is maximally hyper-extended at this time. In the first phase of the upswing the gymnast closes his hip joint angle. First his body configuration becomes more extended, with the effect that the distance of the body centre of gravity to the bar increases to a local maximum when his body is close to full extension. But as the upswing phase continues, the gymnast's shoulder and hip joint angles close more, with the effect that the distance of the body centre of gravity to the bar decreases to a minimum when the gymnast is already in the second phase of the upswing and is going to pass the bar soon in handstand. The minimum distance of the body centre of gravity coincides more or less with the minimum of the shoulder joint angle. The gymnast in the last part of the upswing extends the shoulder joint again so that the distance of the body centre of gravity to the bar increases.

The rotation angle–time graph and the angular velocity–time graph are displayed together in the second diagram, in which the left vertical axis is used for the measured rotation angle and the right vertical axis is used for the angular velocity. The time profile of the angular velocity, which was determined via an advanced numerical method for computing smooth derivatives, can be understood in the following way. Angular velocity increases in the downswing as the gymnast falls from the handstand position above the bar and reaches a maximum value shortly before the gymnast passes below the bar when the hip joint is maximally hyper-extended. The angular phase velocity decreases when the gymnast starts moving to a more extended body configuration and progresses to the upswing. If the gymnast were a rigid body swinging about the bar, then his angular would decrease monotonously in the upswing. The angular velocity–time graph reveals that this assumption is not true: the gymnast opens and closes his shoulder and hip joint angles. The changes in body configuration during the upswing result in a second small peak in the graph due to closing of the shoulder and hip joint angles. The local maximum coincides with maximal flexion at the hip joint.

The hip joint angle–time graph and the shoulder joint angle–time graph show clearly when the gymnast flexes and extends his body, and they reveal that the gymnast did not perform optimally: Apparently the gymnast did not deliver the required hip joint torque to avoid opening of the hip angle in the downswing and his shoulder joint was hyper-extended at the beginning of the upswing, which is also considered a weakness in the gymnast's performance.

The relationships between shoulder joint angle, hip joint angle and distance of the body centre of gravity, and certainly the special body configurations during the backward giant circle become more visible when these quantities are plotted against the rotation angle. This has been done in the lower-left diagram of Figure 4. These graphs are in good agreement with the graphs found by the students (Figure 3) and graphs found in the research literature (e.g., Tsuchiya et al, 2004; Sevrez et al., 2009).

Conclusion

The educational issue in the presented students' inquiry work is the ICT-supported interaction between the world of experiments, in which empirical data are obtained, and the world of theories, in which ideas are scientifically developed and further explored. The acquisition and analysis of empirical data is based on methods from mathematics, science and technology. The fact that students must apply their mathematical and scientific knowledge and their experiential knowledge in a meaningful way in a concrete context leads at the same time to consolidation and deepening of this knowledge. The example in this paper shows that affordable technology (both hardware and software) can bring students into contact with the field of biomechanics. In particular, ICT can contribute to the realisation of authentic inquiry and can raise its level by allowing students to (1) gather information about the subject and be in contact with experts (at least in the form of literature and by supervision of knowledgeable teachers); (2) collect real-time data of good quality; (3) process, analyse and visualise data; to do computations that are otherwise impossible; (4) work in much the same way as practitioners do; and (5) report results in a professional way. Besides, students can develop, practise and demonstrate research abilities in such inquiry activities. We consider the student-driven experimental design, the underlying thinking processes, the effective use of ICT, and the improvement of students' mathematical and scientific literacy as more important in the students' work than the obtained results. All the same, it is joyful when experiments, theory, and experiential knowledge are in agreement, as was the case in the presented research project of understanding the biomechanics of the backward giant circle on the high bar.

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