COMPUTER SIMULATION MODEL OF THE STARTING MOVEMENT IN THE SPORT OF LUGE

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Abstract. *In the sliding winter sports, including the sport of luge, the start performance of an athlete often determines his or her overall result. During the initial phases of the luge start, when a luger is holding to the start handles, athlete's body and the sled are forming a closed kinetic chain. Computer modelling has found vast application in the field of sports biomechanics, and the aim of the present study was to develop and evaluate limitations of a simplified simulation model of two most important start phases in the sport of luge. Various kinematically driven unilateral luger body models were created and tested using computer modelling environment. Model drivers were obtained from motion capture data of elite athletes. Modelling results had shown that in the simplest case the sled and torso movement can be modelled in one plane, however, a minimum required number of torso segments is two. Arm and leg movements of a luger performing the start cannot be limited to one plane, and a three-dimensional model is required. Whereas leg model can include only thigh and shank segments, arm needs to be modelled with all three segments present. Force data can be derived from the created model; however, validation of the obtained results requires installation of force measuring equipment at athletes' training premises.*

Keywords: *biomechanics of sports, motion capture, start performance, closed kinetic chain, winter sports*

1. INTRODUCTION

The sport of luge is one of so-called sliding winter sports (other sliding sports are bobsleigh and skeleton), in which athletes compete sliding on the sleds over the curved iced track, and the objective of the competition is to complete the run in the shortest possible time.

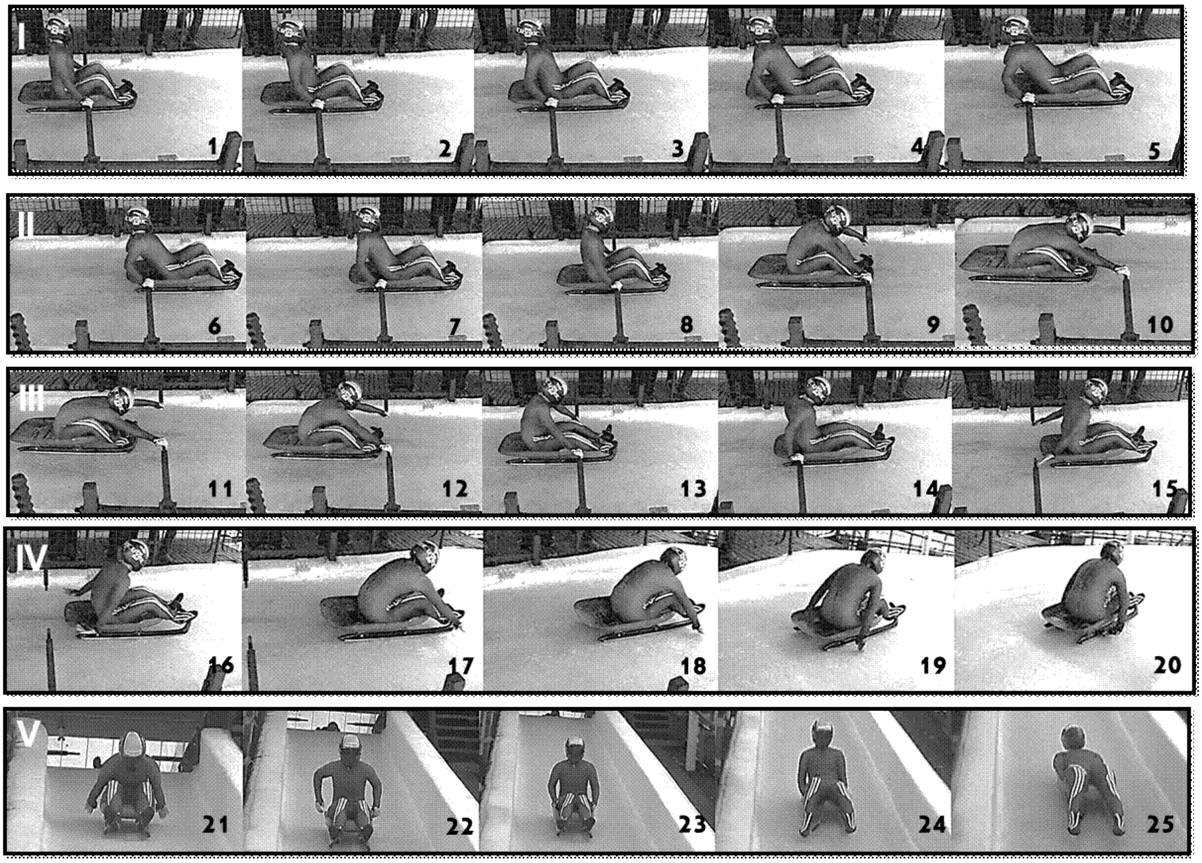


Figure 1. Start phases in the sport of luge

The sport of luge is one of the fastest winter Olympic sports; it attracts attention of vast number of spectators by its breathtaking speeds that sometimes reach 150 km/h. In this sport thousandths of a second often determine a winner, therefore athletes and coaches pay thorough attention to every detail of the performance. It is known that a good start performance plays an essential role for the successful overall outcome of the run (Bruggemann et al., 1997). The start in luging is divided into five phases (Fig. (1)): sliding forward (I), sliding backward (II), the start spurt phase (III), several paddling arm-strokes (IV), and assumption of riding position (V). Phases II and III are considered the most important phases for achieving an outstanding start performance (Lembert et al., 2011; Platzer et al., 2009).

Computer modelling is a powerful research tool, which is often applied in sports biomechanics to simulate and optimize sports movements. In various sports computer simulation models were created to serve as an aid in understanding and improving the performance and enhancing a motor learning (Yeadon and King, 2008). These sports include gymnastics, tennis, swimming and a number of other sports; however no model is known to be created for the starting movements in luging. Considering the importance of the initial start phases for overall performance in the sport of luge, the aim of the present study was to develop and evaluate limitations of a pilot simulation model of the kinetic chain formed by an athlete’s body and the sled. Development of such a model would serve as an important step in creation a more sophisticated and detailed luge simulation model and providing essential feedback information to the athletes.

2. MATERIALS AND METHODS

During the initial phases of the start, when an athlete is holding the start handles (phases I to III), the athlete’s body and the sled are forming a closed kinetic chain – athlete’s hands close the chain through the start handles, and feet are pressed against the sled, closing the chain through the ice surface. Phases II and III of the start were modelled in this study using Simulink SimMechanicsTM (The MathWorks, Inc.) computer modelling environment. The modelled motion begins with the sled’s backward movement instant (beginning of phase II) and lasts until the athlete releases the start handles (end of phase III). The developed unilateral model is kinematically driven, and the necessary drivers were obtained from markerless motion capture data of elite luge athletes (Yeadon and King, 2008). The collected motion capture data were also used as a reference for model evaluation. Motion capture was done with 3 synchronized high-speed cameras at 100 fps using Simi Motion analysis software.

Anthropometric measurements of one athlete were used with an informed consent to imitate segment lengths in the model. Segment inertia parameters were estimated as in works of de Leva (1996) and Zatsiorsky et al. (1990). The following body landmarks were mapped in the video records in order to reconstruct 3D coordinates of the body: vertex (Vert), acromion (Acr), epicondylus lateralis (Cub), processus styloideus ulnae (Man), articulatio coxae (Cox), condylus lateralis (Con), malleolus lateralis (Mal) and vertebra prominens (C7). Kinematics of the sled was described with one additional point SLb at centre of the left runner of the sled. Estimation of model’s degrees of freedom (DOF) was done after the analysis of motion capture data of 8 participants of the study. The models were created in XYZ plane, where X axis is pointing in the direction of horizontal movement of the sled, Z is vertical axis.

3. RESULTS AND DISCUSSION

In first approach a sled-torso model was developed and tested. The analysis of athletes’ movement had shown that kinematics of torso and sled can be modelled in XZ plane, since notable changes in y coordinate of these segments were not registered among the participants of the study. The endpoints of the torso segment are points C7 and Sacrum (Sacr); however, in planar model coordinates of point Sacr coincide with coordinates of point Cox. Firstly it was assumed that at the sled and torso connection point (point Cox) the torso has one DOF – rotation around Y axis. Sled’s DOF were limited to translations along X and Z axes; rotation around Y axis was restricted. Horizontal and vertical velocity of the sled coincided with velocity of point Cox. Kinetic chain of this sled and one-segment torso model is shown at Fig. (2a).

Movement simulation with one-segment torso model had revealed that this model does not imitate athlete’s kinematics during the start precisely enough – the model-predicted coordinates of point C7 significantly differed from motion capture results. Therefore the torso segment was split into two segments at thorax 9 (Th9) point (Fig. (2b)). Torso upper and lower parts have one relative DOF in point Th9 – rotation around Y axis.

Point Th9 of the model was driven using linear generalized coordinates of points Cox and C7 and connecting point C7 to a “virtual ground” with a planar 3DOF massless joint, thus transforming an open kinetic chain into closed. This operation was performed in order to avoid mapping of an additional body landmark in movement video. Movement simulation with two-segment torso model had shown that model with two-segment torso provides a realistic representation of the athlete’s start performance, and this simplified model is appropriate for usage at the initial stages of model development.

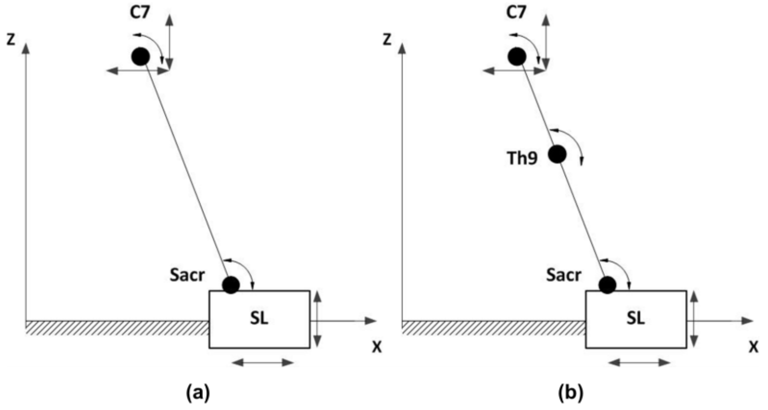


Figure 2. Kinetic chains of one-segment (a) and two-segment (b) torso models

At the next step various arm models were created and tested. During the start phases movements of lugers' arms and legs are essentially three-dimensional, therefore planar models cannot be expected to produce adequate movement simulations, and three-dimensional limb models are required. Testing a two-segment arm model (without a hand segment) showed that it is not suitable for realistic representation of the chosen movement, and a hand segment has to be added to the model. The three-segment arm model consists of an upper arm segment (between points Acr and Cub), a forearm segment (between points Cub and Man) and a hand segment (starting at point Man and connected to the fixed start handle at point Met, at this point rotation is allowed around global Y axis and hand local X axis). Upper arm and forearm segments have one relative DOF: forearm rotation around upper arm local Y axis is allowed. Two hand-forearm models were tested in order to estimate a necessary number of DOF at the wrist joint. The simulations had shown that one DOF at this joint is not enough, and at least two rotations should be allowed: hand segment rotation around forearm local X and Y axes. Figure (3a) shows a kinetic chain of the three-segment arm model that realistically simulates luger's movements during the start phases of interest.

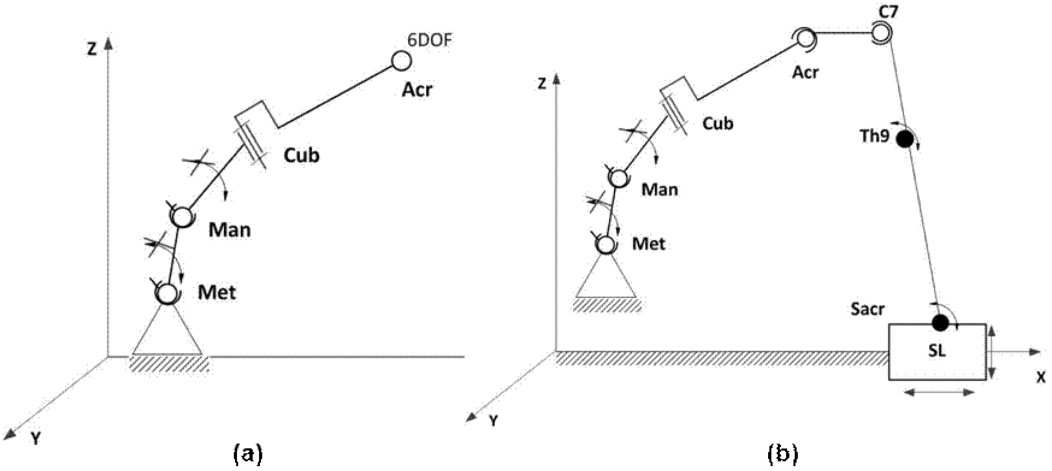
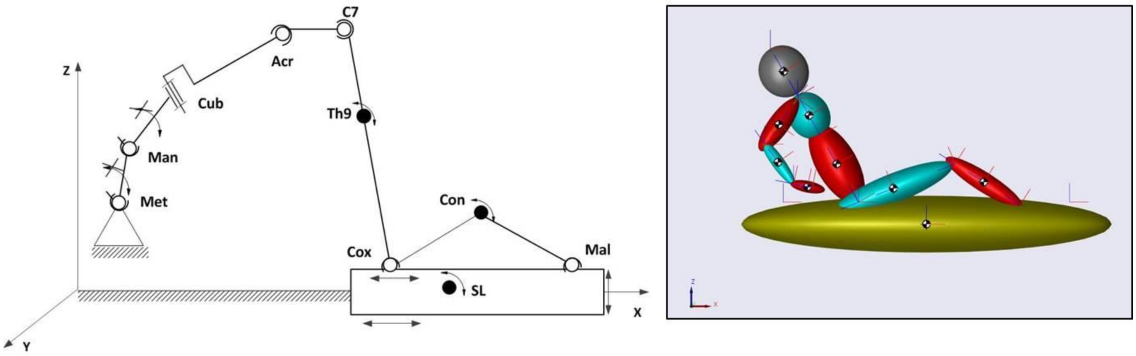


Figure 3. Kinetic chains of arm (a) and upper body (b) models

A simplified unilateral upper body model combines two previously developed models of two-segment torso and three-segment arm. All participants of the study had shown a considerable movement of shoulder point Acr along Y axis when performing the start movement, therefore the joint between the arm and torso models has to imitate a kinematic shoulder segment. This was achieved by inserting a spherical-spherical massless connector as a joining element of two models. The kinetic chain of unilateral simplified upper body model is shown at Fig. (3b). Movement simulation with this model produced coordinates of body landmarks that were very close to the reference motion capture data. The simulation was also visually consistent with realistic athlete's movements.

To obtain a unilateral full-body model the thigh (points Cox-Con) and shank (points Con-Mal) segments were added to the upper body model. Previously restricted DOF were also included into the model: translation of torso along the sled segment local X axis and sled segment rotation around Y axis. The thigh is connected to the torso segment with a spherical joint at point Cox. The shank is allowed to rotate around the thigh local Y axis at knee joint. At the Mal point the shank is connected to the sled with a spherical joint, which restricts all relative translations of the shank at this point.

The foot segment was excluded from the model to simplify the procedure, however, it is known that feet play a certain role at the start performance, therefore to improve the full-body model it is recommended to add the foot segment to it. The kinetic chain and visualization in computer modelling environment of the unilateral full-body model are shown on Fig. (4). Head segment is added to the visualization for aesthetic reasons. Results of computer simulation had shown that the developed model accurately predicts the coordinates of athlete's body landmarks and visually corresponds to the luger's start performance.



(a) (b)

Figure 4. Kinetic chain (a) and visualization in computer modeling environment (b) of unilateral full-body model

The developed models are purely kinematically driven, as no force data were available to use as drivers. The created models allow deriving force data from the movement simulations, however, validation of obtained force results is challenging as long as no reference measurements are available. Force exerted by a luger on the start handles is considered to be one of the important start performance predictors, therefore obtaining force measurements during trainings is highly desirable.

4. CONCLUSIONS

Various computer simulation models of a luger performing the start movements were developed and tested, revealing that a simplified 7-segment athlete's body model can be used to realistically predict body landmark coordinates. The developed pilot model can be used as a starting point for development of more sophisticated models, including more detailed sled segment. Adding force measurement equipment to the athletes' training equipment would allow validation of model-predicted force estimates.

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