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Neuromuscular onset succession of high level gymnasts during dynamic leg acceleration phases on high bar

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ABSTRACT

In several athletic disciplines there is evidence that for generating the most effective acceleration of a specific body part the transfer of momentum should run in a "whip-like" consecutive succession of body parts towards the segment which shall be accelerated most effectively (e.g. the arm in throwing disciplines). This study investigated the question how this relates to the succession of neuromuscular activation to induce such "whip like" *leg* acceleration in sports like gymnastics with changed conditions concerning the body position and momentary rotational axis of movements (e.g. performing giant swings on high bar). The study demonstrates that during different long hang elements, performed by 12 high level gymnasts, the succession of the neuromuscular activation runs primarily from the bar (punctum fixum) towards the legs (punctum mobile). This demonstrates that the frequently used teaching instruction, *first* to accelerate the legs for a successful realization of such movements, according to a high level *kinematic output*, is contradictory to the *neuromuscular input* patterns, being used in high level athletes, realizing these skills with high efficiency.

Based on these findings new approaches could be developed for more direct and more adequate teaching methods regarding to an earlier optimization and facilitation of fundamental movement requirements.

1. Introduction

Up to now, movement analysis and teaching methodology in technical sports such as gymnastics is mostly based on the analysis of kinematic and kinetic data of top level athletes (e.g. video analyses). These kinds of analyses are valid for investigations of the specific body positions and displacements, but, human movements are more complex. Normally the athlete is instructed in a very specific way about the *kinematic result* that is expected, but not about what to do exactly to *induce* the desired result. This lack of information could lead to ineffective or failing trials of the requested movement. For a better understanding of what athletes are *really* doing during fundamental movement sequences the following study video captured different elements on the high bar, demonstrated by high level gymnasts being additionally equipped with a wireless surface electromyographic system (EMG) for measuring activation timing (e.g. Hug, 2011). The use of EMG is one possible method to get a deeper insight into aspects of intersegmental neuromuscular coordination. However, publications concerning electromyographic measurements are very rare in gymnastics (e.g. Bernasconi et al., 2006; Medved et al., 1995; Frère et al., 2012) and none of them is related to aspects of intersegmental whole body coordination. This is probably caused by earlier technical restrictions of valid electromyographic data capturing during complex multiaxial movements. However, the recent development of reliable *wireless* EMG systems with lightweight data transponders opens new approaches to also establish measurements during highly dynamic and multiaxial whole body movements.

In many athletic disciplines, one of the main objectives is to generate a peak acceleration of a specific body segment to produce the maximum velocity of that segment. This effect seems to be generated most effectively by prior generation of a preload of all body segments for getting a maximum muscular "load effect" in the sense of stretch–shortening cycles (Komi, 2000), as a fundamental basis for an effective "unloading" of the muscular tension, resulting in a "whip-like" torque production of the body segments, running consecutively to the segment, which shall be accelerated (Kearney et al., 1993; Bath and Kearney, 1996). Several authors identified these aspects as being critical to performance (e.g. Bartlett et al., 1989; Bartonietz, 2000; Morriss and Bartlett, 1996).

However, whereas most sports movements require such accelerations for the *upper extremities* while the lower extremities are

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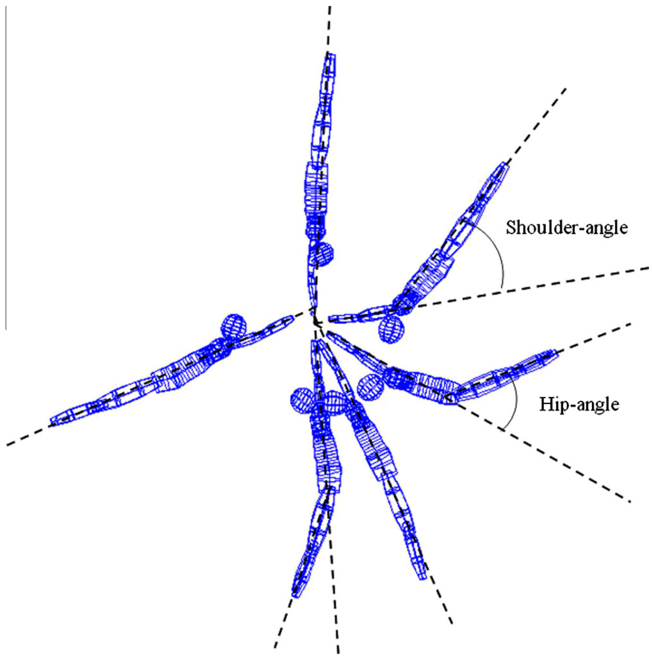

Fig. 1. Lattice model based on the kinematic data of a high level gymnast performing a giant swing.

fixed at the bottom (e.g. throwing movements), in gymnastics lots of movements have to be generated in a position with the *hands fixed* (e.g. on high bar), while the segment of the *lower extremities* has to be accelerated by such a "whip-like" effect for generating the most effective impulse to realize specific elements. So, our idea was that for an *effective* acceleration of the legs during such movements on high bar, the spreading of the neuromuscular activation has to run from the hands (we call it "punctum fixum") to the legs ("punctum mobile").

However, in contrast to this idea training instruction mostly is in an opposite way (*first* to accelerate the legs to be able to close the shoulders), according to the *kinematic* temporal succession of the movement (Fig. 1). Several publications clearly document this inter-segmental temporal succession in giant swings and other long hang elements (e.g. Arampatzis and Brüggemann, 1999, 2001; Irwin and Kerwin, 2007; Yeadon and Hiley, 2000, (p. 154, Fig. 1)), which result in an effective shortening of the "pendulum system" by bringing the center of gravity (COG) closer to the rotational axis and causes a rotational body acceleration (e.g. Arkaev and Suchilin, 2004; Bauer, 1983; Yeadon and Hiley, 2000).

Based on the aforementioned considerations concerning the *spreading of neuromuscular activation* for generating efficient "whip-like" accelerations and based on the first results of a pilot study (von Laßberg et al., 2009), the following general hypothesis was formulated: "For an effective acceleration of the punctum mobile, the neuromuscular activation has to run principally from punctum fixum to punctum mobile" (punctum fixum – punctum mobile hypothesis). In particular, this hypothesis will be considered within this study.

2. Methods

High level male gymnasts were tested by wireless surface EMG during the demonstration of 4 defined long hang elements on high bar, all being marked by a dynamic leg acceleration phase (LAP) for generating the rotational impulse of the body. The focus of the analysis was the *temporal succession of the neuromuscular activation* which generates the impulse for effective leg accelerations. The above mentioned "punctum fixum – punctum mobile hypothesis" should be scrutinized.

2.1. Participants

With regard to the special necessity of this study to recruit expert participants with a high technical level, 12 competitive male gymnasts were recruited from the National Training Centre for Artistic Gymnastics in Stuttgart. They were comprised of a group of 6 A and B Level gymnasts (Ages: 18–28; Training schedule (TS): 23–28 h per week), 2 Ex-C-Level gymnasts, who did not yet reach the B-Level (Ages: 18–19; Training schedule (TS): 18–28 h/week), and 4 D-Level gymnasts (Ages: 15–17, TS: 20–22 h/week). A-Level gymnasts were members of the German national team and were Olympic competitors. In fact, two of the gymnasts were bronze medallists in world championships 2010. Members of the B-Level group represent "second tier" gymnasts that were competing for entry to the A-Level team. The C-Level is defined as the "junior national team". The D-Level group is defined as a selection of the best area, or state junior gymnasts.

2.2. Technical equipment

Surface EMG was captured with a Noraxon wireless EMG system (Telemyo 2400T Noraxon, USA). The transmitter unit was fixed using an elastic belt at the lower spine of the participants. A further transmitter box was used to receive the trigger signal which was visualized on a separate channel in the EMG-recording. Furthermore an elastic body suit was carried to fix the transmitters, electrodes and cables in order to not disturb the subjects' movements. After shaving and fine grinding the skin area with mild sandpaper a pair of gel covered AG/AL disc electrodes (Ambu blue sensor, Denmark; radius: 1 cm) were placed over the muscle belly aligned with the fiber direction with an inter-electrode distance of 2 cm. A reference electrode was attached to the sternum. All electrodes were fixed on the skin with tape to avoid movement artifacts. Electrode skin impedance was accepted at a level of <5 kOhm. The following muscles were plotted: musculus pectoralis major (PEC), musculus rectus abdominis (RecAbd) and musculus rectus femoris (RecFem) as essential parts of the anterior muscle chain. The following standards of EMG detection were given by the manufacturer: Input impedance: >100 MOhm; CMRR: >100 dB, SNR: Baseline noise <1 μV RMS. The raw EMG signals were bandpass filtered (10–500 Hz) and sampled with 1500 Hz, AD-converted (12 bit) and stored for further processing in a PC-System. Using Noraxon Software (Myoresearch, Version 1.06.60; Noraxon, USA) the raw data were full-wave rectified to a maximum amplitude of 1000 μV and smoothed over a constant time window of 25 ms.

Additionally, a 50 Hz video camera (shutter: 350 frames/s) was used for visual control of the elements and for documentation. The camera was synchronized with the EMG by a LED, being placed in the focus of the camera and connected with the trigger signal to ensure a frame based synchronization of the capturing systems. For better movement recognition the participants were additionally fitted by markers over the ankle, knee, hip, pelvis, shoulder [acromion and teres mayor], elbow, wrist, and by 5 head markers, as well. Some elements of the video sequences were processed by a 2-D-videokinemetric system (custom made software: "2D-Mess", developed by the Institute of Applied Training Science, Leipzig) for an intra-individual comparison between neuromuscular and kinematic data. Caused by the facts that the processing of videokinemetry is very time-consuming and the analysis of kinematic data was not the primary aim of the study, only a small part of the demonstrated elements was captured by that procedure by means of some additional single case analyses.