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Investigating optimal technique in a noisy environment: Application to the upstart on uneven bars

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ABSTRACT

The upstart is a fundamental skill in gymnastics where it is used to transfer a gymnast from a swing beneath the bar to a position above the bar. The aim of this study was to optimize the technique in the upstart on the uneven bars in order to determine the underlying control strategy used by gymnasts. A previous attempt based on minimizing joint torque had failed to find a satisfactory solution without forcing the joint angle histories to pass through a "via-point" (Yamasaki, Gotoh, & Xin, 2010). Using a computer simulation model of a gymnast and bar, the technique (joint angle histories) used in the upstart was optimized under three different criteria: minimizing joint torque, minimizing joint torque change and maximizing success in the presence of movement variability. The third optimization introduced "noise" into the joint angle time histories based on measurements of kinematic variability. All three optimizations were started from the technique used by a gymnast competing in an Olympic Games uneven bars final. Root mean squared (RMS) differences between the recorded and optimal joint angle time histories were computed. The two optimizations based on minimizing joint torque diverged from the gymnast's technique. However, the technique based on maximizing the number of successful performances in a noisy environment remained close to the gymnast's technique. It is concluded that the underlying strategy used in the upstart is not based on minimization of joint torque; rather, it is based on ensuring success in the task despite the inherent variability in technique. Gymnasts develop techniques that are able to cope with the level of kinematic variability present in their movements.

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1. Introduction

The upstart is a fundamental skill in artistic gymnastics where it is used to transfer the gymnast from a swing beneath the bar to a position above the bar (Fig. 1). The skill is typically used in women's artistic gymnastics when moving between the uneven bars, and after release and regrasp skills where the gymnast has insufficient amplitude of swing to move directly above the bar. The upstart comprises a swinging phase (Fig. 1A and B) and a "kip" phase (Fig. 1C–E). In order to receive no deductions from the judges (FIG, 2009) all phases should be performed with straight arms and legs (Fig. 1).

Yamasaki et al. (2010) presented a simulation model for swinging on bars and investigated the underlying control strategy of the upstart by optimizing technique under various criteria. The optimal solutions (techniques) were compared to recorded gymnast performances and the criterion that compared most favorably was deemed to be the likely control strategy. The optimization criteria were based on minimizing angle jerk, joint torque change and effort. None of the criteria could reproduce the technique used by the gymnasts without forcing the model through an arbitrary via-point at which the shoulder and hip angles were matched to the recorded gymnast performance. It should be concluded that none of the optimization criteria could account for the techniques used by gymnasts. There must be some other criterion that can explain the gymnasts' technique or some important aspect of human movement that has been overlooked.

In movements where a gymnast must exert near maximal effort to achieve the performance outcome, technique may or may not be based on minimizing joint torque. For example, in the undersomersault to handstand on parallel bars, beginners often adopt a technique similar to that used in the clear circle to handstand on high bar as it is less demanding in terms of strength compared to the more commonly performed stoop stalder technique adopted by senior gymnasts (Davis, 2005). The clear circle technique was predicted by minimizing peak joint torque at the shoulder and hip using a simulation model (Hiley & Yeadon, 2012a). However in order to produce the stoop stalder technique, an optimization criterion based on performance requirements (vertical path of the mass center) was required and resulted in a technique that used close to maximal effort for the gymnasts studied. The underlying control strategy for the stoop stalder undersomersault technique is therefore not based on minimizing joint torque.

Timing the actions (flexions and extensions) at the shoulder and hip can be a critical factor in the successful performance of the upstart, particularly in the early stages of learning. Broderick and Newell (1999) showed that in a task that required precise timing for success, skilled performers demonstrated lower levels of movement variability. When a gymnast performs the same skill a number of times, it might be expected that within each attempt there will be some variability in the technique used, i.e., variability in the timings and angles of the shoulder and hip angle time histories (Newell &

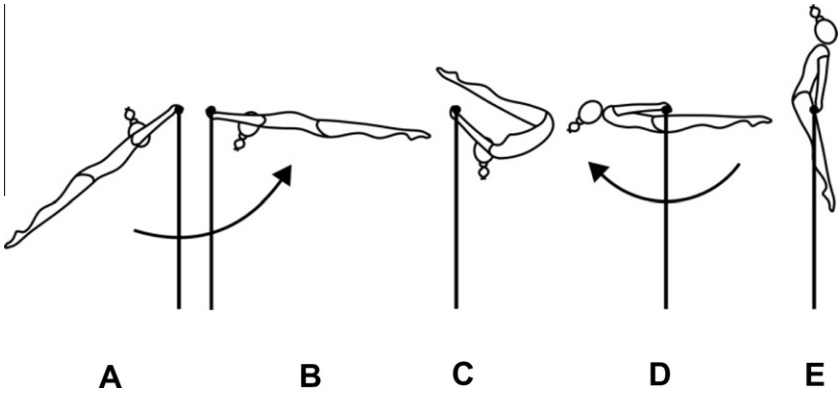

Fig. 1. The upstart (adapted from the FIG Code of Points, 2009).