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Characterization of lower-limbs inter-segment coordination during the take-off extension in ski jumping

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ABSTRACT

Take-off, the most important phase in ski jumping, has been primarily studied in terms of spatio-temporal parameters; little is known about its motor control aspects. This study aims to assess the inter-segment coordination of the shank-thigh and thigh-sacrum pairs using the continuous relative phase (CRP). In total 87 jumps were recorded from 33 athletes with an inertial sensor-based system. The CRP curves indicated that the thighs lead the shanks during the first part of take-off extension and that the shanks rotated faster at the take-off extension end. The thighs and sacrum first rotated synchronously, with the sacrum then taking lead, with finally the thighs rotating faster. Five characteristic features were extracted from the CRP and their relationship with jump length was tested. Three features of the shank-thigh pair and one of the thigh-sacrum pair reported a significant association with jump length. It was observed that athletes who achieved longer jumps had their thighs leading their shanks during a longer time, with these athletes also having a more symmetric movement between thighs and sacrum. This study shows that inter-segment coordination during the take-off extension is related to performance and further studies are necessary to contrast its importance with other ski jumping aspects.

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1. Introduction

Ski jumping is a complex movement composed of five phases: in-run, take-off, early-flight, stable flight, and landing (Schwameder, 2008). Take-off, which consists of a rapid body posture extension (about 300 ms long) at the beginning of the ski jumping table, is considered to be the most important phase in relation to performance mainly because it sets the initial flight conditions (Arndt, Bruggemann, Virmavirta, & Komi, 1995; Baumann, 1979; Schwameder et al., 2005; Virmavirta et al., 2005). From a biomechanical point of view, the goal of the take-off movement is to raise the center of mass and create a quick forward angular momentum (Komi & Virmavirta, 2008; Schwameder, 2008). To better understand this process and its relationship with performance, the body segment kinematics has been investigated in several studies (Schwameder, 2008). For example, the knee angular velocity during take-off has been shown to be correlated to the length of the jump, the primary outcome parameter of ski jumping performance (Arndt et al., 1995; Virmavirta et al., 2009). The somersault angle was also reported to influence the amount of forward angular momentum produced during take-off (Arndt et al., 1995). While many studies were conducted on the take-off, this movement has primarily been analyzed in terms of spatio-temporal parameters and little is known about the neuromuscular and motor control during this movement (Komi & Virmavirta, 2008).

The inter-segmental coordination, which is one aspect of the motor coordination (Kurz & Stergiou, 2004), is poorly documented during take-off although it could be a central element in a successful jump. Therefore, there is a need for a description of the inter-segment coordination (i.e., the relative behavior of one segment with respect to another) during the take-off extension and for an analysis of its relationship with the performance. One study by Sasaki, Tsunoda, Hoshino, and Ono (1997) compared the power production of the knee and hip joint and reported different strategies between athletes. The authors reported that some athletes produce power around the knee and hip joints simultaneously, while other athletes create power around the hip joint first and then around the knee joint. This study is interesting as it analyzed the relationship between two joints and identified different strategies. However, the analysis did not include the movements between lower-limb or trunk segments which are crucial during take-off. In another study (Virmavirta et al., 2009), two main take-off strategies were reported based on an angular description of the shanks, thighs, and trunk movement: (i) the athletes rotating their thighs and trunk, and keeping their shanks more or less static, and (ii) the athletes rotating their thighs and shanks while maintaining a low trunk position. Nevertheless, in this last study the analysis is primarily qualitative. One issue with quantitative analysis of inter-segment coordination is the large number of degrees of freedom of the system (e.g., the angle and angular velocity of two segments) that need to be analyzed simultaneously.

The continuous relative phase (CRP) is a common tool to characterize the inter-segment coordination based on angular measurements (Kurz & Stergiou, 2004) and it has been widely used in clinical and sport applications such as gait, running, and swimming (Heiderscheit, Hamill, & van Emmerik, 1999; Lu et al., 2009; Seifert, Leblanc, Chollet, & Delignières, 2010). The CRP reduces the number of degrees of freedom from four (i.e., distal and proximal angles and angular velocities) to one.

The primary objective of this study is to characterize the inter-segment coordination of the shank-thigh and thigh-sacrum pairs during the take-off in ski jumping using the continuous relative phase (CRP). This study also aims to describe the relationship between the inter-segment coordination of the lower-limbs and the performance assessed by the jump length.

2. Methods

2.1. Experimental setup

2.1.1. Measurement system

Five small inertial measurement units (Physilog®, BioAGM, CH) weighting approximately 100 g each were attached bilaterally to the thigh and shank segments, and to the sacrum using an underwear suit (Fig. 1). Each unit included a three-dimensional gyroscope (±1200°/s), a three-dimensional accelerometer (±10 g), and an embedded datalogger. The procedure in Ferraris, Grimaldi, and Parvis

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