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Estimating center of mass kinematics from an instrumented athletic track: a preliminary study for long jump analysis

Remy Roinson^{a, b}, Jean-Philippe Boucher^b, Nicolas Vignais^{a*}

^a M2S Laboratory, Rennes 2 University, École Normale Supérieure de Rennes, Bruz, France

^b Phyling, Palaiseau, France

* Corresponding author: nicolas.vignais@univ-rennes2.fr

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1. Introduction

Performance in long jump may be approached by describing a succession of three complementary phases: approach, take-off and aerial phases. Among the performance indicators listed in the literature, kinematics of the center of mass (CoM) is particularly of interest during the two first phases because of its correlation with jumped distance (Hay & Nohara, 1990). In the approach phase, lowering the CoM during last few steps enhances the pivot effect on take-off phase and improves take-off speed (Graham-Smith & Lees, 2005). Although several methods have been proposed for estimating the displacement of the CoM, two methods are widely regarded as the gold standards: the Double Integration (DI) method and the kinematic method (Lafond et al., 2004). The DI method, initialised by Cavagna (1975), is based on the double integration of ground reaction forces. This method is used as a reference for standard task as walking (Whittle, 1997), jumping (Conceição, et al., 2022) and running (Girard et al., 2011). However, it has not yet been applied on non-cycling movements like long jump. The kinematic method relies on a segmental modeling from kinematics tools such as optoelectronic system. Mass and position of each segment therefore allow to estimate displacement of CoM. This method is mostly employed through laboratory settings for analyzing both standard and complex tasks.

However, both of these methods have limitations regarding ecological conditions, measurement space, and

setup costs. This has resulted in very few studies directly investigating the CoM during in *situ* sport practice. An instrumented track with force sensors could open new insights on this way by enabling the DI method to be used directly in the field without space limitations. The objective of this experiment is to assess the reliability of the DI method based on a track instrumented with force sensors to estimate CoM kinematics.

2. Methods

2.1 Subjects

Five men participated to this preliminary study (mean \pm SD: age, $23,8 \pm 1.64$ years; height, 1.76 ± 0.04 m). Inclusion criteria were based on the absence of pathology or contraindication to sports. Participants were provided with written informed consent detailing the experimental procedure before participating in the study.

2.2 Materials

The track was equipped with 18 mono-axial vertical force sensors (Phyling, France) recording resulting vertical ground reaction forces (vGRF) at a frequency of 1000 Hz, covering an area of 330 cm x 109 cm. An inertial measurement unit (IMU) system (Xsens MVN, Movella, Enschede, Netherlands) was employed as a “on field” comparison system for the kinematic method (Germanotta et al., 2021), operating at a frequency of 100 Hz. The ‘lower body’ configuration was used, and the CoM displacement estimation was directly calculated by the IMU software.

2.3 Procedure

Each participant was instructed to perform two tasks: running and simulated long jumping. For each task, the participant began in standing position on the instrumented track to obtain body mass. Then he was asked to run naturally on the track with no limitation of speed or cadence. Due to spatial limitations, the long jump task was approached by running on the track with a vertical jump at the end. Each participant completed five trials for each task.

2.4 Data analysis

Data analysis was conducted on Python (3.9). Kinetic data were filtered using a second-order Butterworth low-pass digital filter. The beginning of each step was defined as the moment when the measured force exceeded 50 N (Girard et al., 2011). Kinematic and kinetic data were resampled at 200 Hz. Because of the standing start and variability of subject to perform tasks, only the last three steps were studied. DI method was applied to vGRFs to obtain vertical displacement of CoM. Both of CoM displacements obtained by kinematic and kinetic data were synchronized from the first peak.

Statistical analysis based on intraclass correlation coefficients ($ICC_{3,1}$) was conducted to find the agreement of correlation between the methods. Minimums and maximums values for each step were compared based on Bland-Altman plots.

3. Results and discussion

Intraclass correlations between the two methods and results from the Bland-Altman analysis are shown in **Table 1**. All data from DI and kinematic methods were significantly correlated ($p < 0.01$), as well as results from DI-adjusted (DIA, see below) and kinematic methods ($p < 0.01$).

Compared to other studies related to these two methods, current results showed good accuracy and reliability in CoM estimation for standard tasks like running (Conceição et al., 2022). However, results for simulated long jump task show less accuracy. According to Cavagna (1975), DI method is valid only on cycles where mean vertical speed is equal to zero, which is not the case for the final cycle in a long jump. Therefore, we adjusted the DI method (DIA) to the analysis of the long jump task by not considering the final jump. As shown in **Table 1**, DIA method was more accurate than

DI method in estimating CoM during the simulated long jump. Nonetheless, despite the bias being close to zero, limits of agreement reveal high variability for minimum values, indicating that this method should be used carefully.

Table 1 : Intra-class correlation and mean difference between methods for running and long jump tasks.

| | ICC _(3,1) - CI95% | Mean dif. (cm) [LOA] |
|----------------------|---------------------------------|-------------------------|
| DI-Kinematic | | |
| Running | | |
| Minimum | 0.9* [0.83, 0.94] | 0.72 [-2.20, 3.64] |
| Maximum | 0.79* [0.65, 0.87] | -0.4 [-3.84, 3.04] |
| Long Jump | | |
| Minimum | 0.73* [0.54, 0.85] | 9.04 [-2.59, 20.67] |
| Maximum | 0.64* [0.41, 0.79] | 8.49 [1.27, 15.72] |
| DIA-Kinematic | | |
| Long Jump | | |
| Minimum | 0.85* [0.74, 0.92] | 0.95 [-5.42, 7.31] |
| Maximum | 0.89* [0.81, 0.94] | -0.22 [-4.63, 2.30] |

Intraclass correlation coefficients with 95 % Confidence interval ($ICC_{(3,1)} - CI95\%$); Mean difference with Limits of Agreements (Mean dif. (LOA) in cm) from Bland Altman plots.

In our study, Xsens MVN system was used as comparison system but it cannot be considered as reference due to its accuracy limitations (Pavei et al., 2020). This might explain differences of accuracy and variability between both methods. An optoelectronic system could yield more accurate comparisons in future research.

4. Conclusions

The DI method derived from the instrumented track may be considered accurate for estimating the vertical displacement of the CoM while running. Moreover, this method may be optimized (DIA) for estimating the displacement of the CoM during complex tasks such as the long jump.

Conflict of Interest Statement

The authors declare no conflicts of interests.

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