3D KINEMATIC ANALYSIS OF THE FRONT HANDSPRING STEPOUT: A PILOT STUDY

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This study analyzes the 3d kinematics of the front handspring stepout (FHS) performed by three female gymnasts with different levels of expertise. The purpose was to identify the crucial biomechanical components and how they govern the performance of the athletes. An optoelectronics system (with 6 infrared cameras at 100 Hz) was used to record a specific passive marker-set placed on the subjects' bodies. We found that the most important biomechanical parameters were the horizontal components of displacement and velocity.

KEY WORDS: gymnastics, front handspring.

INTRODUCTION: In gymnastics the forward handspring stepout (FHS) is a basic tumbling skill which belongs to the international code of points on 3 different apparatuses: the floor, the balance beam, and the table vault. In this analysis we have studied the FHS on the floor where it would be used as the first element of a tumbling pass to create an efficient and powerful body rotation in the forward direction. The FHS begins with a forward lunge to place the hands on the floor, while the back leg (BL) drives upward and overhead, forcing the back to arch with the legs split as wide as possible. The gymnast, now on her hands, pushes through her shoulders, keeping the back arched and, springs momentarily into the air, until one foot, the "back foot" (BF) reaches the ground. The landing is on one foot. Previous research (Takei et al) has only studied the FHS with a two foot landing on the vault in 2D kinetics and, never before the FHS with a single foot landing on the floor in 3D [see ref]. With this current study we intend to analyze the FHS element in terms of its 3D kinematics to quantify the biomechanical parameters necessary to satisfactorily execute this skill. We also have quantified the degree of opening of the sagittal split which is evaluated as an aesthetic component by judges during competition. Then we have compared the selected variables between gymnasts of 3 different levels of ability.

METHODS:

Subjects: Three Italian female gymnasts aged from 11 to 14, competing for a local club, had voluntarily participated in this study. They belong to different technical levels according to Italian Gymnastics Federation, which ranks gymnasts on a scale of three categories: level A, B, and C, where A is the highest and C the lowest. Subject 1 was a Level A gymnast (1A) and she had competed for Junior Italian National Team, sub 2 was Level B gymnast (2B) and sub 3 was a Level C (3C).

Data Collection: The athletes were evaluated anthropometrically to determine each one's center of mass. Then, following a normal warm-up routine, each athlete performed at least four repetitions of the FHS from a standing position, from which we assembled the best data for each subject and only the resultant compilation of data was analyzed. The video recordings were performed using an optoelectronics system [6-7]. A 3D motion infrared registration system (Vicon 460), with six cameras, recorded the position of 46 light reflecting markers at 100Hz. 36 markers were applied to each subject's body according to the total body Plug-in Gait marker set (from Davis-Kadaba). In addition, another 10 markers were added to create a marker set able to register transversal rotary manoeuvres. [8] In order to obtain an optimal construction of the initial data, it was necessary to perform manual labelling frame by frame of the dynamic registrations. Then the 3D path of each marker was cleared, and the critical body segments (chest and head) were corrected by means of biomechanical modelling software (BodyBuilding). We have broken the FHS movement into four phases which are defined by the succession of specific impact (IMP) and take-off (TKO) instants. The four phases are: 1.Lunge; 2.Tripod support (T-SUPP) which is defined as both H and FF

on the ground simultaneously; 3.Hands support (H-SUPP) which is just both hands on the ground; 4. Flight phase (FL). The lunge phase begins with the static standing position (SSP) instant and ends with the FF-IMP instant. Next, the T-SUPP phase has the H-IMP and the FF-TKO instants. Between these first two phases there is the BF-TKO as a single isolated instant. The third phase, the H-SUPP consists of the H-IMP and the FF-TKO instants. Lastly, the FL phase is made up of a H-TKO and BF-IMP instants.
Data Analysis: The statistical parameters used were mean values (mv), standard deviation (sd) and variability coefficient (vc).

RESULTS:

Spatial-temporal data
The spatial data was analyzed in terms of horizontal movement during three of the phases and normalized based on the difference in height between the gymnasts. The temporal data of the four phases was expressed in percentage and rounded to the nearest whole number, whereas the total time to execute these four phases was expressed in seconds (Tab.1). The missing percentage was the time spent by each athlete to return to the standing position.

Table 1 Horizontal space and time

	SPACE				TIME (%)				TOT
	LUNGE	T-SUPP	FL	TOT	LUNGE	T-SUPP	H-SUPP	FL	(sec)
1A	O,5	0,51	0,54	1,85	35	5	28	8	1,08
2B	0,48	0,34	0,49	1,56	29	2	36	12	0,91
3C	0,56	0,53	0,51	1,88	29	1	31	9	0,95
Mv	0,5	0,5	0,5	1,8	31	3	32	10	1,0
Sd	0,04	0,11	0,03	0,17	4	2	4	2	0,1
Vc	7,64	22,6	5,3	9,8	12	70	14	19	9,1

COM vertical shifting data
Fig. 1 illustrates the COM vertical shifting in three phases of the FHS movement for each subject. The lunge phase was measured from the SSP with arms straight up, to the instant in which the COM was the lowest.The entire H-SUPP phase was evaluated. The FL phase was divided into two segments consisting of the H-TKO to apex and apex to final BF-IMP instant.

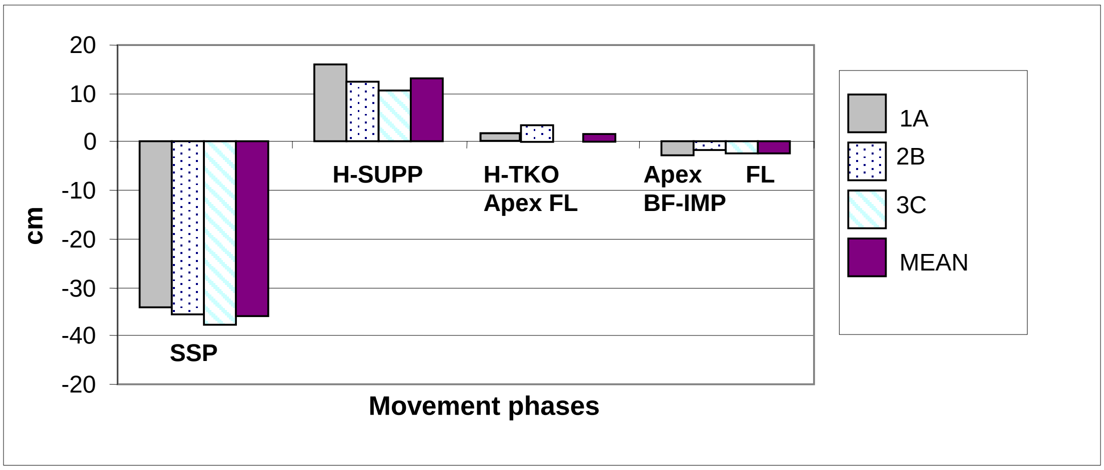

Figure 1 COM vertical shifting

COM velocities data
The COM horizontal and vertical velocities were measured in m/sec in all of the IMP and TKO instants. Only the mean values were reported in Fig. 2 because the variation in data between gymnasts was minor.

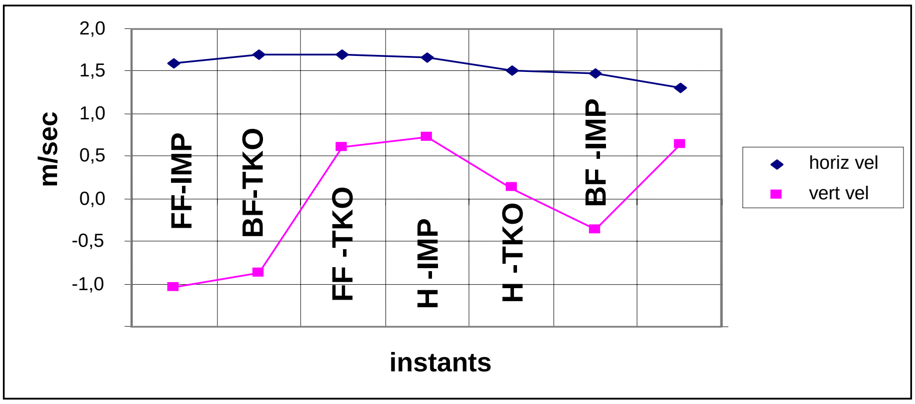

Figure 2 COM mean average horizontal and vertical velocities

Sagittal split angle data

To quantify the split legs' amplitude on the sagittal plane we measured the angle between the front leg and back leg at the coxo-femoral joint at six separate instants during the movement: the BF-TKO, FF-TKO, H-TKO, and BF-IMP. To analyze the split properly we have added two new instants: the maximum split (MAX) and the handstand position (HST). Fig. 3 below shows the results for each gymnast as well as the mean average.

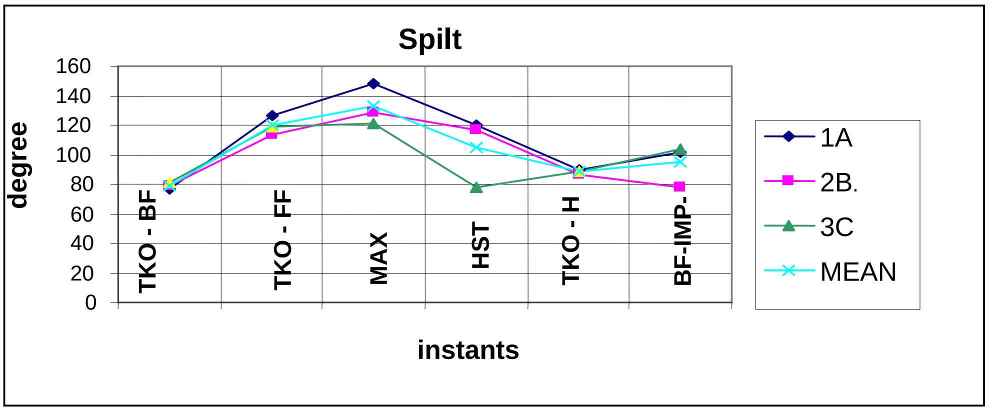

Figure 3 sagittal split angle data

DISCUSSION: From the temporal analysis of the four phases of the FHS, it was possible to notice that there were two long phases (the lunge 31% mv, and the H-SUPP 32% mv) and two short ones (the T-SUPP 3%mv, and the FL 10%mv). The phase of T-SUPP had the most temporal variation between subjects (3% mv; 70 vc) with 5% spent by the expert gymnast (1A) and just 1% by the novice gymnast, 3C.

The normalized horizontal spaces had the same mv (0,5) in all phases measured, however gymnast 2B performed a shorter T-SUPP phase (0, 34) which influenced her total horizontal space of execution where she had the least value of 1, 56 versus 1, 85 and 1,88, for 1A and 3C respectively. Correlating the data of the horizontal displacements with the temporal data in each phase, it was noticed that 1A performed the lunge () and T-SUPP() using more space and longer time. Gymnasts 2B and 3C performed shorter lunges both in space and time. 2B´s T-SUPP was tight() and fast whereas 3C´s was wide and brief. Gymnast 2C had the longest H-SUPP phase. In FL, with similar spatial execution among the subjects, 1A and 3C employed shorter execution times.

From the representation of the COM vertical shifting in Fig. 1 we have studied the downward and upward shift of the COM during the FHS. We found two downward and two upward COM movements. The first two COM shifts, belonging to the lunge and H-SUPP phases had an inverse relation to each other where less downward shift in the lunge resulted in more upward shift during H-SUPP. In the FL phase, the least experienced subject 3C didn't lift her COM so she didn't achieve FL.

From Fig. 2 it was possible to observe that the average horizontal velocity had a constant course in all phases, whereas the average vertical velocity reached its peak values (mv 0,6 m/sec and 0,7 m/sec) only in the crucial instants of FF-TKO and H-IMP thereby creating the opportunity for a good FL phase.

From the analysis of the sagittal split angle data in Fig. 3 it was clear that this parameter was an indicator of coxo-femoral dynamic flexibility as it related to the gymnasts' level of ability. In fact, the most experienced gymnast performed the widest split in all phases of the FHS movement. In each case the gymnasts reached their maximum split before the HST instant.

CONCLUSION: The methodology employed by this study, although requiring a lot of time, was adequate to record the rotary movement of gymnasts. From the linear kinematics data observed it was possible to conclude that the horizontal component was the crucial biomechanical parameter necessary for execution of the FHS. In fact, the horizontal shift (Tab. 1) was greater than the vertical shift (Fig. 1) in all phases. The normalized total horizontal length, with the mean value of 1.8, was quite long, but the vertical COM shift wasn't ever higher than 10 cm. Based on the observation of the collected data we can affirm that the T-SUPP was the most important phase that distinguished a higher level gymnast from a novice, where more time was spent in a large T-SUPP than in lunge and H-SUPP.

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