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Research Article

KINEMATICS ANALYSIS OF SELECTED RHYTMIC GYMNASTIC LEAPS

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ABSTRACT

Very few studies exist on biomechanics of rhythmic gymnastic. Four leaps of an experienced high level (national competition) rhythmic gymnast athlete (16yo, 175 cm height, 50 kg weight) were analyzed in order to provide firsts descriptive data of these movements, to compare different behaviour in similar jumps and to study its variability. The subject performed 10 trials for each of the four movements, for a total of 40 trials, barefoot on a laboratory with a rubber floor. A total of 40 trials were analyzed for grand jetè, kosak jump, kosak jump with half turn, turn scissor jump. The four movements were split into four phases: last stride length (LS), distance between toe off and heel contact of last stride, knee loading angle previous to jump (KL), defined as maximum loading angle at the knee, push time (PD), defined as the time of push off, and flight time (FT). The lower variability, was observed in flight times of all four leaps (2.24-2,92 %), suggesting a strategy to maintain constant this variable among the 10 trials, despite the kind of jump being performed. Last stride lengths, knee loading angles previous to jump, push times and flight times were computed by means of a Vicon 460 motion analysis system. The lowest variability was shown by flight times, and the highest by last stride lengths. All jumps showed similar flight time, despite the different movements being performed during the flight phase. All variables shows to be normally distributed except last stride length of the grand jete (r=0,753; p=0,009) and flight time of cosak jump with half turn (r=0,749; p=0,008). Correlations between all leaps kinematics variables show the influence of push times (r= -0,685; p=0,000) and of the last stride length (r=0,533; p=0,001) on flight times. Flight times were kept constant in all jumps, despite the high (3,90-10,59%) variability in push time and in last stride length.

Key words: biomechanics, rhythmic gymnastic, jumps, variability

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INTRODUCTION

Rhythmic gymnastic is a high leap demanding sport (Hutchinson M., et al. 1998). During flight phase, technical figures are performed by the athletes. In spite of the growth of popularity of this discipline, there is a lack of biomechanical analysis in literature regarding the techniques of rhythmic gymnastic. Hutchinson M., et al. (1998) measured the floor reaction time, explosive leg power and average jump height in elite level gymnasts for leap training evaluation purposes, but they did not perform any kinematics evaluation.

On the other side, understanding through descriptive analysis the kinematics of a sport movement is fundamental to structure training. Up to date in biomechanical literature does not exist any study on the kinematics of rhythmic gymnastic.

Purpose of this case study is to provide first descriptive data of four rhythmic gymnastic leaps in an experienced athlete analyze reasons for different behaviours shown by the athlete in two similar kind of leaps: cosak jump and cosak jump with half turn. As a secondary purpose, we attempt a theoretical modelling of the cosak jump, which required combined movements (leap and leg recovery) to explain the segmental contribution of lower limb, jump using the single subject approach (Bates, 1996; Lees, 1999; Mullineaux, Bartlett & Bennett, 2001; Dapena, 2004; Hiley & Yeadon , 2005) . This allows to study variability in performance in a single subject, and provide to the athlete and the coach a feedback for training improvement, identifying weakness in performance.

MATERIAL AND METHODS

Participants

A highly experienced female rhythmic gymnastic athlete, taking part in competitions at national level (16 year old, weight 50 kg, height 173 cm) was analyzed while performing four exercises of rhythmic gymnastic: "grand jetè", "kosak jump", "kosak jump with half turn" and "turn scissor jump". Informed consent was obtained from the athlete and her trainer.

Instruments

A 6 cameras automatic motion analysis system (Vicon 460, Oxford Metrics UK) with a sampling rate of 100 Hz was employed for the data collection (Figure 1). The markers set configuration was those proposed by Davies (Figure 2)

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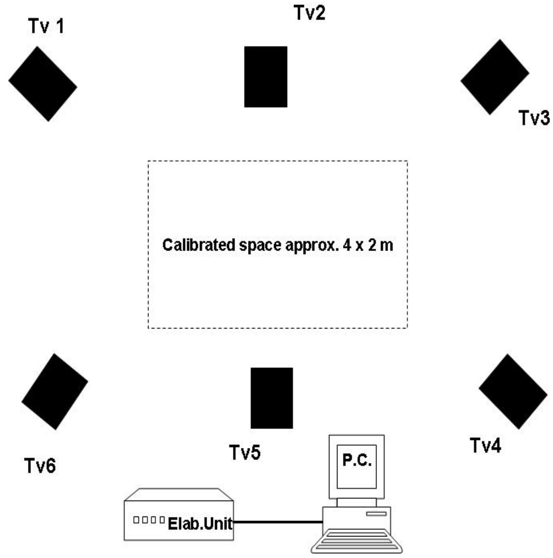


Figure 1. *Camera set-up*

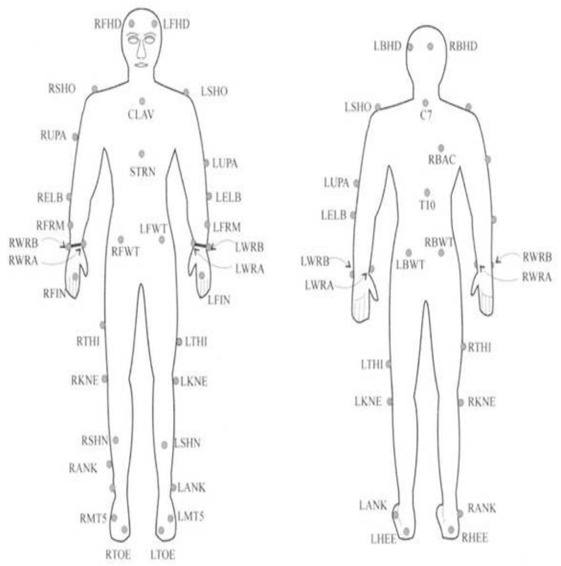
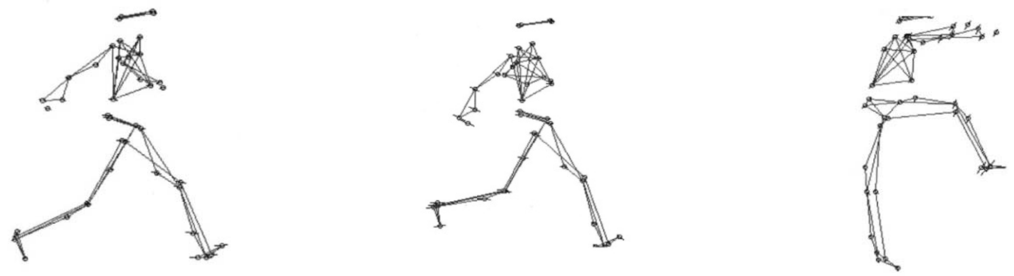


***Figure 2**. Marker set*

The 37 markers utilized had a diameter of 15 mm and were fixed to the reference points with rubber adhesive straps. The motions of the markers were tracked automatically with manual intervention with the software Vicon Workstation v.4.1 (Oxford Metrics, Oxford UK), after automatic 3D reconstruction of the body model. Stick figure were obtained (Figure 3), with internal joint centers being computed from the software on the basis of body joints diameter and segments length measurement taken on the subject prior the motion analysis sessions.



Phase 1: Right foot take off   Phase 2: Left foot impact   Phase 3: Left foot take off

Phase 4: Jump   Phase 5: Right foot impact

***Figure 3**. Stick figure of the grand jetè leap, with phases.*

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Procedures

The subject performed 10 trials for each of the four movements, for a total of 40 trials, barefoot on a laboratory with a rubber floor. Anthropometric measures of the subject were inserted in the software and segmental and whole body centres of mass were computed by the software using regression equations (Winter, 1979). Anatomical coordinate system were computed by the software Vicon Workstation v 4.1, during the calibration phase with the subject standing in a reference position, taking into account the anthropometric measure of the subject. The lower limb angles was defined according to Winter (Figure 8).

The four movements were split into four phases: last stride length (LS), distance between toe off and heel contact of last stride, knee loading angle previous to jump (KL), defined as maximum loading angle at the knee, push time (PD), defined as the time of push off, and flight time (FT). The variables were computed on the animated stick figure obtained with the software embedded in the system (Polygon, Oxford Metrics, UK). The definition of the temporal phases was ascertained on the stick figure created by the Vicon Workstation program and considering the vertical displacement and velocity of the toe marker. The point of take-off was considered to occur when 'Z' score of the right/left toe increases at an exponential rate. The point of landing (FL) was considered to occur when the 'Z' score of the right/left toe ceases to decrease at a significant level and remains relatively constant.

RESULTS

A set of 16 variables was obtained and is presented in table 1.

Table 1. *Variables computed and ordered by ascending rank of the coefficient of variability. Each value is the mean of 10 trials.*

Variability	Variable	Coeff. Variability (%)	Means	St.Dev.
1	Flight Time Grand Jetè (ms)	2,24	765,00	17,15
2	Flight Time Turn Scissor Jump (ms)	2,27	750,00	16,99
3	Flight Time Cosak Jump (ms)	2,46	865,55	21,27
4	Flight Time Cosak Jump with Half Turn (ms)	2,93	765,55	22,42
5	Push Time Scissor Jump (ms)	3,15	468,00	14,75
6	Knee Angle Loading Cosak Jump witht Half Turn (deg)	3,90	46,40	1,81
7	Push Time Grand Jetè (ms)	4,49	339,00	15,23
8	Knee Angle Loading Cosak Jump (deg)	5,94	38,20	2,27
9	Knee Angle at Loading Turn Scissor Jump (deg)	9,77	47,20	4,61
10	Push Time Cosak Jump (deg)	10,00	300,00	30,00
11	Knee Angle Loading Grand Jetè (deg)	10,59	34,00	3,60
12	Push Time Cosak Jump Half Turn (ms)	12,27	448,89	55,10
13	Last Stride Length Cosak Jump (cm)	17,40	161,11	28,03
14	Last Stride Length Grand Jetè (cm)	18,92	101,00	19,11
15	Last Stride Length Turn Scissor Jump (cm)	19,34	117,00	22,63
16	Last Stride Length Cosak Jump with Half Turn (cm)	30,21	138,88	41,96

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Coefficient of variability is a reliable index of the variability in movement kinematics (Mullineaux , Bartlett & Bennett, 2001). The lower variability (coefficient of variation), was observed in flight times of all four leaps (2.24-2,92%), suggesting a strategy to maintain constant this variable among the 10 trials, despite the kind of jump being performed. The variables were analyzed with the Shapiro - Wilks normality test with the software SPSS v.14 (as proposed by Bates, 2004) in order to select the appropriate statistic procedure. All variables show to be normally distributed except Last stride distance of grand jete (r=0,753; p=0,009) and Flight time of cosak jump with half turn (r=0,749; p=0,008). Thus t test for independent samples was applied (SPSS v.14). Flight time in cosak jump was statistically significant longer than in grand jete (t=-17,2; p=0,000) and turn scissor jump (t=16,6; p=0,000). This suggests that the strategy used by the athlete was to shorten the duration of each movement performed during the flight phase. A possible explanation is the inertial contribution of limb flexion on the hip during flight (Figure 4). This movement increases the force acting on the center of mass, thus increasing the flight time. This flexion is less powerful in cosak jump with half turn (Figure 5), due to the need to combine two movements (cosak jump and turn).

Figure 4. *Cosak jump.*

Figure 5. *Cosak jump with half turn.*

In Figure 6 and 7 are represented the hip-knee phase plane plots during knee flexion and extension in the flight phase. Phase plane-plot was proposed as summary plots, useful for immediate understanding of behaviour of body segments in movement (Lees A., 1999).

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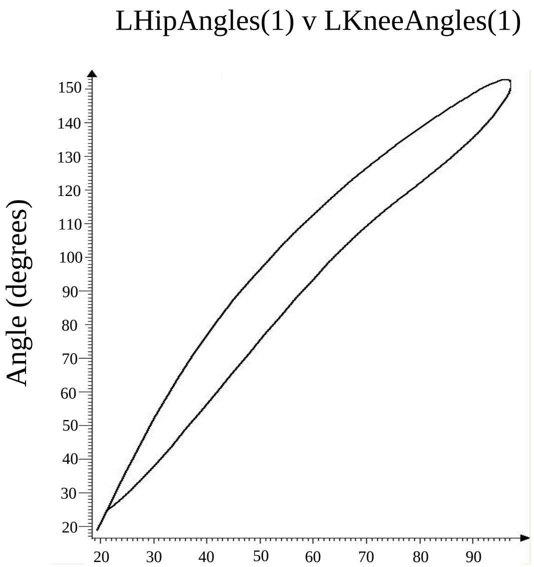

Figure 6. *Hip-knee angle cosak jump.*

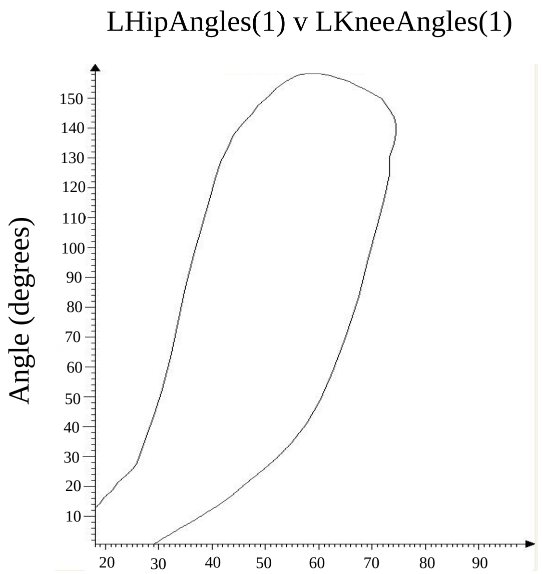

Figure 7. *Hip-knee angle cosak jump with half turn.*

Figure 6 shows hip-knee phase plot for cosak jump and Figure 7 hip-knee phase plot for cosak jump with half turn. The plot for cosak jump shows the closer angle achieved as a results of the most powerful flexion moment. Flight time difference between cosak jump and cosak jump with half turn amount to 100 ms. Inertial contribution of the flexion of the lower limb on the hip during cosak jump (Figure 8) can be estimated as follows:

1) (Leg weight + flexion force – weight of the rest of the body) x duration of the flexion in flight.

If total body mass=1, thus Femur=0,1–Tibia 0,0465–Foot 0,0145 (Winter, 1980).
Flexion force can be assumed to be.

2) Leg mass x acceleration=80,05Nx12 m/sec2=960

Weight of the rest of the body=500-80,5=419,5 and duration of the flexion in flight= 0,2 sec.

Thus (80,05+960– 419,5)x0,2=124,23N, inertial contribution.

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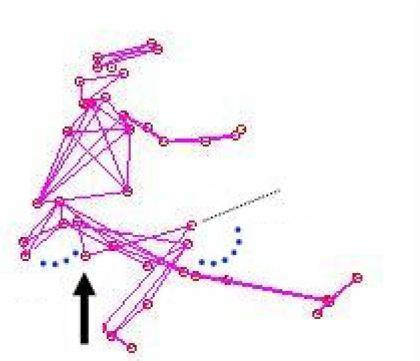

***Figure 8**. Inertial contribution of lower limb on the hip.*

Correlations between all leaps kinematics variables show the influence of push times (r=-0,685; p=0,000) and of the last stride length (r=0,533; p=0,001) on flight times. Flight times were kept constant in all jumps, despite the high (3,90-10,59%) variability in push time and in last stride length. These findings further support the hypothesis that in-flight strategies are important for the performance outcome as proposed by Hutchinson (1998).

DISCUSSION

A method for the kinematics study of leaps in rhythmic gymnastic was presented based on the single subject approach.

Four leaps of rhythmic gymnastic were described on an individual athlete. Descriptive data of the movements were presented for kinematics variables. Stability and outliers of the performance could be a useful index for athletes and coaches in order to identify weakness in performance (Bates, 1996). In our athletes, last stride length was identified as the less stable variable and flight time as the most stable. Comparison between two similar leaps, cosak jump and cosak jump with half turn, was analyzed, in order to study the causes for the differences in flight times observed between this two leaps. Inertial properties of lower limb flexion during flight seems to be the majors determinants of longer flight times observed in movement with high inertial mass and velocity of displacement (cosak jump). A theoretical model for inertial contribution estimation is presented.

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