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Original Article

Inertial analysis of acceleration, deceleration, and angular speed in the technical of the front tucked somersault in female artistic gymnastics.

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Abstract
The aim of this study is to characterize the physical attributes of specific sports movements such as, those in women's artistic gymnastics, using objective parameters derived from advanced inertial sensors. A key focus of this reaserch is to establishing the validity, reliability, and reproducibility of data, acquired through state-of-the-art inertial instruments such as K-Track (K-Sport, Italy). The study focused on elements defined as performance-determining, such as acceleration, deceleration, and angular speed in the dynamics of the technical gesture, in this case, the "front tucked somersault" in female artistic gymnastic. Aiming to a more detailed study, the technical act in question was broken down into its three constituent phases: the first and third phases (detachment-ascent and descent-landing of the jump) basically related to a brush leap and the second phase (the frontal turn) to a forward flip. The data obtained from the brush leap confirmed what was expected from an early analysis with the naked eye: significant upward and forward acceleration and development of the jump itself in height and length. On the other hand, with regard to the forward flip, i.e., a forward roll around the transverse axis, after a body tuck-up, we detected rotations around the y-axis that were not expected to be observed, at least with the gyroscope-determined performances, concerning a distinct rotation on the longitudinal axis.
Keywoeds: Artistic gymnastics, technical gesture analyze

Introduction

Deconstruction, the analytical breakdown from the biomechanical point of view of the gesture, in our case sports, surely allows an analysis from which important suggestions can be drawn for the improvement of the whole act and the possible correction adapted to the training plan (Hay et al., 1985). Biomechanics clearly finds its applications in greater depth as the technical gesture being investigated become more complex, and artistic gymnastics is unquestionably one of the disciplines that succeed in showcasing the most complex things the human machine can accomplish (Batini, 1988). It seems evident, therefore, that the biomechanical study of the gesture is essential not only for a better understanding of what occurs in the execution of various technical elements but also in applying the most correct form of teaching this discipline (Gaverdovsky et al, 1984). Nowadays, thanks to the introduction of new tools and dedicated software, we are able to study and analyze the technical gesture in a more in-depth, meticulous manner, thus finally being able to produce real and meaningful values of the same, and managing to objectively quantify the act, both from a physical and technical point of view such as, in our case, the times of the flight phase of any specific artistic gymnastics gesture (Bruggemann et al., 2005). It becomes evident that being able to analyze, for example, physical elements during the take-off phase and then the flight phase of a technical gesture allows us to highlight any inaccuracies or errors, thus consequently acting in a more timely manner and indicating the necessary correctives. Therefore, the study focused on elements such as acceleration, deceleration, and angular velocity in the dynamics of the overall technical element of the "front tucked somersault" (Fig.1), using state-of-the-art inertial sensors.

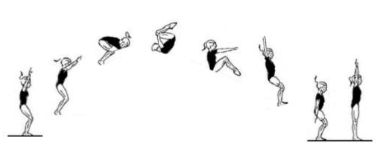

Figure 1: front tucked somersault

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As mentioned above, the technique was broken down into its 3 main phases: the first and third phases (ascent and descent of the jump) related to a vertical jump, i.e., a brush leap (Fig.2), and the second phase (the rotation) to a front somersault (Fig.3). We then analyzed, through the inertial sensors contained in the K-Track instrument (K-Sport, Montelabbate, Ita.), first distinguishing the technical gesture of the brush leap and the front flip, thus finally comparing the outcomes to the execution of the central part of the front tucked somersault.

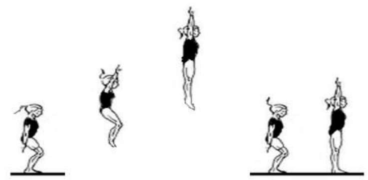


Figure 2: brush leap

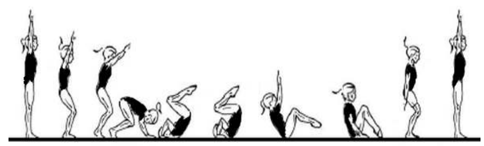


Figure 3: front flip

Despite the considerable and decisive help provided by technology, we also made use of notational analysis, which, in our opinion, still carries a practical value in research, especially in establishing a correlation between the effectiveness of the work suggested, both in a quantitative and qualitative sense, in relation to the results obtained. For this reason, in this paper, we also used the SAM (MAS in original language), Systematic Analytical Monitoring (R. Izzo, 1988 upg. 2018), applied to artistic gymnastics, on which, in a spreadsheet, the exercises presented are noted daily, both under a quantitative and qualitative point of view, in order to always keep in mind the precise proportion and qualification of the training session. The monitoring method (SAM) has only been applied to the basic technical elements, such as the handstand and round-off, as well as to the strength and flexibility required to the body districts concerned (Izzo et al., 2018). The skills needed in the sport being taken into account, for an excellent execution of technical gestures, are (Luppino, 2005):

- Joint mobility. Ability to make optimal use of all body segments maximum range of motion, and especially of the scapulohumeral, coxo-femoral, tibio-tarsal, and intervertebral (flexibility of the spine) joints;
- Motor coordination. Ability to control and rapidly perform the movements, amplitude and direction of gesture, dosage of muscle use and specific electivity of interventions. This ability must be finely honed refined as it is essential for the execution of particularly complex elements such as those typical of gymnastics;
- Thrust and momentum skills, as well as the promptness of action and reaction. Skills that are built over time through practice, as they are crucial to the ability of performing even the simplest element of such discipline.
- Balance. Indispensable not only to beam (an implement in which balance is the most important component to its success) but also to all other equipment in order to maintain and recover body stability when it is lacking;
- Rhythmic ability. A skill that allows harmonizing, refining, and personalizing the movement. This is meant not only to adapt to external rhythms (such as musical ones), but to be able to internalize one's own rhythms.
- General and specific endurance. Defined as the muscular capacity to withstand prolonged exertion, warding off exhaustion. Conditional qualities for the optimized execution of movements.

From the latter, we can see the key importance of studying the technical gesture and all its components aimed at its overall optimization. As important elements of performance, the project design of the work here presented, took into consideration those variables that are considered meaningful in influencing the execution of the technical gesture such as: *Ability to gain height; Ability to rotate; Generating twist; Ability to swing; Ability to land and balance* (Prassas et al., 2013). The entire technical element development is provided by the integration of all the above factors.

Study design

Through inertial sensors (K-Track, K-Sport, Ita.), the study analyzes the technical gesture of the "front tucked somersault". The front tucked somersault is a technical element of medium complexity within the discipline of artistic gymnastics. The jump involves an initial ascent phase in which, following a run-up and an even-footed cue, one tries to obtain as much height as possible in order to best perform the rotation. The second phase of the jump represents the central moment of execution, indeed, this is where the grouping of the body and the rotation around its transverse axis takes place. In order to perform the rotation, it is necessary to actively bend the trunk and at the same time, bring both heels back up into a grouped position. Immediately afterward, there's a body stretching to a tense position to facilitate, after the rotation, an even-footed landing on the ground, maintaining the upright position with the legs open to hip width in order not to incur infringements. There is also some knee bending aimed at cushion the impact and maintain the landing position, counteracting the centrifugal force of the movement performed. The focus of the study is analyzing the rotations and displacements of the above gesture around and along the major axes. In addition, evaluations of the take-off and rotation speeds as well as the acceleration required for a successful jump, were carried on. The 15 gymnasts of average qualitative level which were examined wore a bib (K-Shirt, K-Sport Ita.) with a pocket on the back in which was placed a device (K-Track), needed to collect all data of the movements relevant to the study. Three phases of the "front tucked somersault" were specifically identified: the ascent (rise) phase, rotation phase, and opening/descent phase (Bradshaw et al., 2010). The first phase, the ascent phase, can be compared to a vertical jump, so the gymnasts were made to perform a brush leap (Fig.4) with their arms in the air; the second phase, the forward rotation phase, can be compared to a roll on the ground and, specifically, a forward flip (Fig.5); the third and final phase can be traced back to the second part of the vertical jump (brush leap, Fig.4) in fact, the descent moment, can be related to the open turn-forward jump and subsequent landfall.

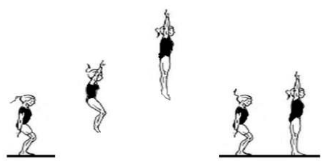


Figure 4: brush leap

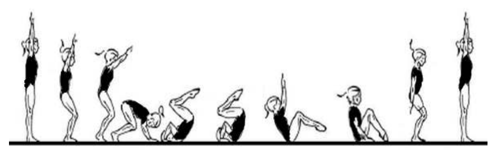


Figure 5: front flip

This helped to identify the key points to be evaluated for the best performance of the entire technique investigated, as further deepened in this article. After the initial analysis, we compared the data on the key points of the front tucked somersault (Fig.6), then identified the overall jump and examined its rotations, displacements, accelerations, and speeds.

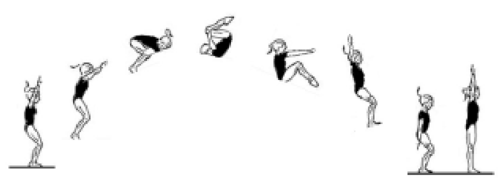


Figure 6: front tucked somersault

In conclusion, the gymnasts were asked to perform a series of front tucked somersaults for a total of 100 jumps in order to test the validity and reproducibility of the results obtained.

Materials and Methods.

To carry out the study, we used the following material: Inertial sensors (K-Track, 3D with the ability to receive up to 4700 Hz, but used at 100 Hz, K-Sport Ita.), Bib with a special pocket to insert the device (K-Shirt, K-Sport Ita.), Laptop (normal composition), Video Camera (25 Hz), Trampoline and Mats. The Sample investigated was of 15 Gymnasts. The 3D inertial sensors, while having a largely higher capacity (4700 Hz) were set to better interface with other technologies at 100 Hz. The device has a built-in battery that allows it to be used for 2 hours and 30 minutes, as well as a memory to record all activities during the operating time (Izzo et al., 2018) On the front side, one can find the power button. By powering up the device a flashing red light signals the sensor's activation. To turn off the sensor a double click is needed, because a single click would lead to accidental shutdowns during the execution of exercises. The device has an internal memory of 4GB, weighs about 25 grams and features a 3D sensor. By placing the device correctly, as explained later, the x-axis is positive toward the left Cartesian quadrant, the y-axis is positive down, and the z-axis is positive back (Simons et al., 2005). When placing the device in the t-shirt, it is important to ensure that the red power-on light is outward and the USB pin is upward so that the axes are well aligned with the software readout. In case it is turned over the reference systems are inverted. As a standard, the IMU features an accelerometer, a gyroscope and a 3D magnetometer. The numerical data are reported in the tables with a decimal comma following the Italian convention adopted by the system. By plugging and opening the USB flash drive into a computer, one will find Excel files and a configuration folder inside, in which the device settings are written. Upon opening the spreadsheet (Excel files), a table will display the values related to time, accelerometer, gyroscope, magnetometer, temperature, and battery. On the top left are reported the basic information about the record that has been carried out: ID (device number), model, ACC SCALE and GYRO SCALE. ACC SCALE and GYRO SCALE can be defined as a full scale, representing the maximum and minimum points the device can record. The higher the full scale, the less accurate the data will be. However, a settings change will be deemed necessary in case of very high accelerations in movement. The *bib/K-shirt* that's being used is designed with a pocket on the back to let the K-Track fit. The device, which is tightly attached to the body so as not to affect data collection, is then worn on the back through T-shirts or bibs with special pockets in which to place the sensor in order to minimize movement and obtain the most accurate data possible. A consistently wide number of devices have been used to catch on tape the performances and to make photos: cameras, SLR cameras, and GoPros. To perform the jump, the equipment used is a mini trampoline for the push phase and mats for the finish. The gymnasts were recruited for the study among middle/high level athletes. The subjects are between 14 and 18 years old and compete in the FGI (Italian Gymnastic Federation) Junior and Senior categories.

Results/Discussion

Before moving on to the analysis of the front tucked somersault in its entirety, we will show the results obtained from the study of PIs (performance Indicators) identified through the decomposition of the jump into its executive phases. Along the y-axis there are vertical displacements; along the x-axis there are lateral displacements, while along the z-axis there are forward and backward displacements. As for rotations around the axes, the right-hand rule applies: once the thumb is positioned facing the direction of the axis, rotations occurring in the direction of the fingers will be positive, while, on the opposite side, negative. Rotations around the x-axis occur on the transverse axis; around the y-axis occur on the longitudinal axis; rotations in the z-axis occur on the sagittal axis. The first analysis was carried out on the brush leap element (vertical jump, fig.7), which can be traced back to the ascent and descent phase of the front tucked somersault.

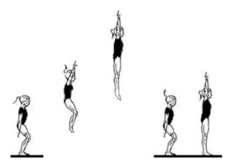


Figure 7: brush leap

The data obtained are listed below (Tab.1):

Version:2.2						
ID:02						
MODE:E						
ACC SCALE:08						
GYRO SCALE:1000						
NAME DEFAULT XYZ						
SAMPLE	ACC X	ACC Y	ACC Z	GYRO X	GYRO Y	GYRO Z
20,7	-0,126	0,018	-0,415	472,9	184,8	-63,8
20,72	-0,121	0,333	-1,216	170,7	-64,1	48,9
20,73	-0,137	0,32	-0,774	164,4	-38,1	8
20,74	-0,212	0,482	-0,809	158,8	57,1	-10,8
20,75	-0,191	0,483	-0,867	160,4	-6,1	-21,8
20,76	-0,165	0,503	-0,622	161,6	-9,5	-17,6
20,78	-0,108	0,431	-0,402	107,5	-74,8	-12,2
20,79	-0,074	0,384	-0,276	72,2	-63,4	-15,9
20,8	0,007	0,376	-0,148	34	-11,5	-37,1
20,81	0,032	0,33	-0,031	44,7	41,4	-48,7
20,82	0,079	0,261	-0,045	85	93,2	-59,8
20,83	0,16	0,187	-0,062	103,2	107,8	-75,3
20,85	0,18	-0,175	0,026	141,1	135,2	-67,9
20,86	0,082	-0,229	0,088	181	102,3	-82,3
20,87	-0,008	-0,144	0,166	230,6	95,8	-87,9

20,88	-0,085	0,053	0,33	325	122,7	-85,9
20,89	-0,072	0,177	0,414	392,9	141,4	-81,3
20,91	-0,024	1,533	1,462	278,7	145,4	-31,6
20,92	0,001	2,737	2,017	-304,3	214,7	-26,3
20,93	-0,083	1,212	0,397	-529,8	-167,8	-7,3
20,94	0,181	0,781	0,577	-456	-170,7	-14,9
20,95	0,503	0,961	1,243	-359,4	67,8	-14,5
20,97	-0,105	0,565	2,974	-412,7	306,2	29,6
20,98	-0,402	0,257	3,86	-211,5	-22,3	-17,3
20,99	-0,036	0,133	3,195	-137,2	-20,7	-28,3
21	0,316	0,055	1,97	-192,6	57,5	-40,3
21,01	0,227	-0,343	1,665	-226,3	62,8	-53,4
21,02	-0,003	-1,257	1,315	-260,7	44,8	-69,3
21,04	-0,167	-2,304	0,679	-241,3	9,4	-71
21,05	-0,154	-2,986	0,445	-200,7	-36,3	-31,4
21,06	-0,199	-4,547	0,153	-148,8	-31,1	7,5
21,07	-0,291	-6,15	0,047	-141,6	-40	17,1
21,08	-0,757	-8	0,655	-191,3	-57	17,7
21,1	-0,329	-6,361	3,438	-151,5	-5,9	25,8
21,11	-0,445	-4,606	3,009	-2,1	31,4	33,7
21,12	-0,679	-4,186	1,65	-33,1	33,6	68,5
21,13	-0,602	-4,026	1,297	-140,2	6,5	61
21,14	-0,449	-3,34	1,216	-221,8	-4,8	60,5
21,15	-0,301	-2,623	1,131	-230,2	6,8	66,6
21,17	0,044	-0,776	0,459	-205,4	-15,1	75,7
21,18	0,105	-0,472	0,301	-227	12,1	52,8
21,19	0,119	-0,422	0,042	-275,8	-6,4	20,5
21,2	0,09	-0,469	-0,004	-296,6	-44	7,4
21,21	0,134	-0,647	0,011	-314,2	-91,6	-2,1
21,23	0,177	-0,599	-0,015	-296,2	-138,2	-44,8
21,24	0,058	-0,649	-0,229	-245,9	-191	-52,1
21,25	-0,235	-0,634	-0,872	-20,1	-356,7	-72,9
21,26	-0,405	-0,671	-0,943	212,9	-331,7	-97,2

Table 1; brush leap data

From such data, it has been derived a chart regarding the accelerometer and the gyroscope (Fig. 8 and Fig. 9).

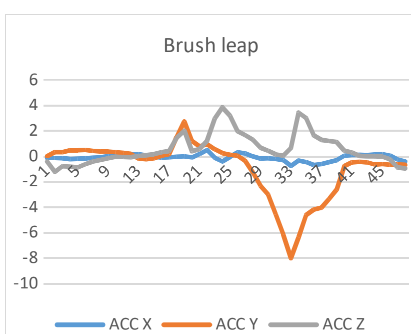


Figure 8: Chart referred to leap brush acceleration

Chart analysis:
- ACC X (blue line): the line is flat, with no significant peaks, as there are no lateral displacements during the performance.
- ACC Y (orange line): the first peak represents the downward displacement for jump loading and the subsequent thrust; the second peak indicates the upward vertical rise.
- ACC Z (gray line): indicates the forward displacements. The first peak, during loading, represents the interruption of the run-up to make the thrust; the second peak indicates the displacement toward the high forward (ascent phase of the jump); while the third peak highlights the slight forward displacement during the descent phase.

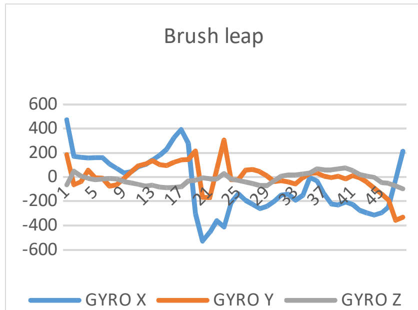


Figure 9: Chart referring to the gyroscope, reporting on the leap brush .

Chart analysis:
- GYRO X (blue line): we notice more pronounced peaks in the take-off phase, indicating a slight closing and consequent opening of the upper body at the moment of loading.
- GYRO Y (orange line): small peaks are also noticeable with regard to rotations in the longitudinal axis.
- GYRO Z (gray line): there are no significant rotations on the sagittal axis.
We then turned to the analysis of the forward flip (Fig. 10), an element that leads back to the rotation of the front tucked somerault.

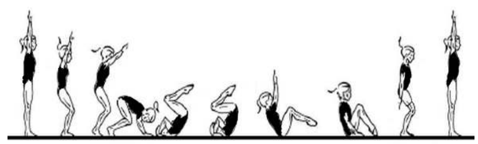


Figure 10: front flip

The data obtained with the K-Track are reported hereunder.

Version:2.2						
ID:02						
MODE:E						
ACC SCALE:08						
GIRO SCALE:1000						
NAME DEFAULT XYZ						
SAMPLE	ACC X	ACC Y	ACC Z	GYRO X	GYRO Y	GYRO Z
12,29	-0,04	0,547	-0,55	313,9	-3	-40,8
12,3	-0,057	0,657	-0,666	333,6	-16,7	-41,2
12,32	-0,05	0,75	-0,737	343,3	-19,8	-42,2
12,33	-0,046	0,757	-0,759	326,8	-18,1	-41,2
12,34	-0,037	0,756	-0,765	309	-13,3	-41,2
12,35	-0,021	0,767	-0,81	283,4	-9,5	-41,9
12,36	0,008	0,767	-0,849	272	-10,7	-42,7
12,38	0,153	0,938	-0,969	256,1	15,5	-34,6
12,39	0,161	1,034	-1,036	243,9	5,1	-26,6
12,4	0,113	0,998	-1,099	221,8	-27	-17,3
12,41	0,051	0,749	-1,088	216,7	-52,5	-13,7
12,42	-0,046	0,406	-1,06	219	-51	-15,6
12,43	-0,114	0,269	-1,103	221,3	-28,4	-18,2
12,45	-0,055	0,471	-1,126	225,9	-49,1	-17,4

12,47	-0,088	0,323	-1,11	237,6	-71,5	-23,6
12,48	-0,108	0,188	-1,135	245,8	-59,7	-28,9
12,49	-1,687	7,999	-2,946	999,9	999,9	-46,8
12,51	0,98	-1,597	-5,384	693,2	-782,4	11,1
12,52	0,631	-1,881	-2,964	574,3	-26,2	-74,8
12,54	0,021	0,418	-3,575	136,2	10,5	-1,4
12,56	0,087	0,17	-1,753	152,3	-2	0,5
12,57	0,029	0,134	-1,093	153,6	-14,7	1,9
12,59	-0,004	0,118	-0,563	142,9	-1,1	0,4
12,62	0,01	0,015	-1,066	180,3	12,6	-0,4
12,63	0,067	-0,134	-2,03	142,8	-17,9	7,1
12,65	-0,027	-0,187	-1,071	21,3	9,8	4,2
12,67	0,028	-0,164	-0,668	-65,3	9,5	-1,5
12,68	0,029	-0,404	-0,757	-20,4	-103,2	29,9
12,7	-0,387	-0,37	-1,853	149,4	-396	-61,7
12,73	-0,292	-2,072	-2,76	999,9	242,5	-123,4
12,74	0,658	-2,617	-5,257	799,8	245,3	6,1
12,76	-0,336	-1,522	-3,359	586,3	-146	51
12,78	-0,002	0,538	-4,095	360,2	22,7	-38,6
12,79	-0,26	-0,192	-3,128	197,2	-58,8	-15,7
12,81	-0,189	-1,049	-1,43	429,2	61	2,2
12,83	0,097	-0,939	-1,437	391,1	-89,6	-2,5
12,85	-0,001	-1,052	-0,685	278,8	1,8	-11,5
12,86	-0,094	-1,4	-0,931	252	-20,2	-7,7
12,88	-0,095	-1,387	-0,972	285,9	-11	-7
12,9	0,038	-1,087	-0,932	336,8	-16,4	-9,1
12,91	0,011	-0,577	-0,876	307,9	-6,3	-8
12,93	0,003	-0,211	-0,864	262,7	-11,1	-5,1
12,95	-0,012	0,421	-0,911	179,3	-34,5	9,3
12,96	-0,102	0,782	-0,502	175,2	-51,9	6,6
12,98	-0,13	0,501	0,082	234,4	-40,8	-10,6
12,99	-0,117	0,579	0,758	244,6	52,1	-31
13,01	0,084	1,897	1,505	-143,3	243,2	-39,9
13,03	0,001	0,121	0,765	-235,8	-161,8	-30,2
13,04	0,087	-0,484	1,214	-90,3	127,7	62,9
13,06	0,043	-1,537	1,228	-238	665,5	1,9
13,07	0,142	-0,83	1,694	125,2	-98,1	-46,2
13,09	0,033	-0,115	0,58	80,2	29,6	-9,4
13,11	-0,092	-1,014	0,841	110,4	-20	-8,1
13,12	-0,127	-1,037	0,844	52,8	23,3	-4
13,14	-0,089	-1,116	0,814	50,7	3,7	-14,4
13,16	-0,079	-1,076	0,958	73,5	14,2	-4

Table 2; Front Flip Data

As done with the brush leap, we derived charts from the data referring to the accelerometer (Fig. 11) and gyroscope (Fig.12).

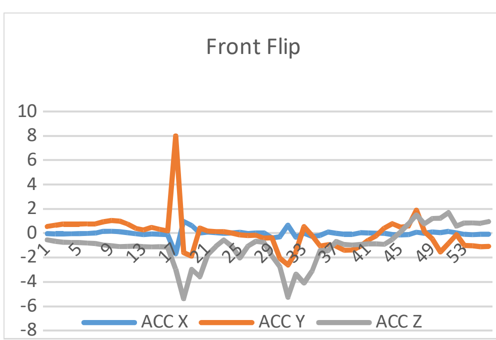


Figure 11: Front Flip accelerometer chart

Chart analysis:
- ACC X (blue line): the line is almost flat. There are no peaks as there are no lateral displacements during the execution of the jump.
- ACC Y (orange line): the first peak represents the downward descent on the way to the ground roll.
- ACC Z (gray line): it indicates the forward displacements during rolling. The first peak, at the downward displacement, represents the beginning of forward rolling; the second peak indicates the displacement to the high forward (the upward phase from rolling).

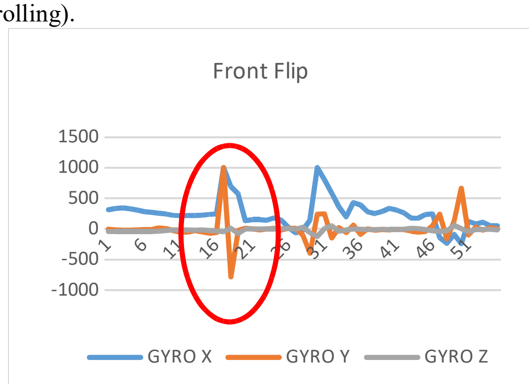


Figure 12: Forward flip gyroscope graph

Chart analysis:
- GYRO X (blue line): two peaks can be seen during forward rolling around the transverse axis.
- GYRO Y (orange line): marked peaks are observed at the first phase of rolling and lower peaks at the upward phase from rolling.
- GYRO Z (gray line): there is no rolling around the sagittal axis.

GYRO Y considerations.
Both to the naked eye and with video camera systems (even in slow motion), rotations around the longitudinal axis during the execution of the forward flip are not noticeable. This element, as can be seen in Figure 13, involves a ground contact moment. For this reason, we hypothesized that the peak on the y-axis regarding the GYRO Y could be due to the ground contact of the device; therefore, we tried to clamp the K-Track with a tight taping to make it as firm as possible to the body and avoid displacement. After doing this, we had the gymnasts perform the forward flip again, and from the subsequent data analysis, the peak in the GYRO Y occurred again (Fig.13).

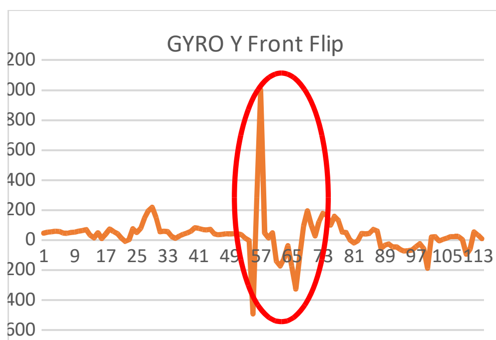


Figura 13:-Referred graph for the forward flip after device fixing.

From the analysis of 100 forward flips performed by 10 different gymnasts of the same level of preparation, we found the peak taken into account on all executions. Specifically in 8 flips the peak was more pronounced (with GYRO SCALE about ±1000); in 13 flips the peak was slightly less pronounced (GYRO SCALE ±1000 and ±800); in 16 flips there was an even slightly less marked peak (GYRO SCALE between ±1000 and ±400); in 11 runs the peak was marginally lower in both directions (GYRO SCALE between ±800 and ±800); in 23 flips the GYRO SCALE is between ±800 and ±400; in 22 repetitions the GYRO SCALE is foundable on a level between ±400 and ±400; and finally there are 3 and 4 forward flips in which the peak is unremarkable (GYRO SCALE between ±0 and ±800 and between ±0 and ±400, respectively).

From these data, and given a large number of forward flips with GYRO SCALE inherent to the very high y-axis, we deduced the occurrence of rotation around the considered axis. Consequently, from the analysis of these two movements, we identified the PIs, namely the points of interest relevant for evaluating the front tucked somersault. In particular, regarding the leap brush , the PIs (Performance Indicators, R.Izzo, 1988) recognized are:

- PIs concerning y-axis acceleration.

Two PIs were identified (blue circles Fig. 14) corresponding to the pushing phase (first peak) as well as the jump's ascent and descent phase (second peak).

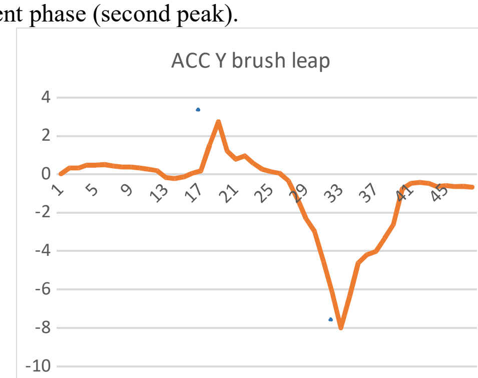


Figure 14: PG covering the y acceleration of the brush leap

- PIs/GDs (Performance Indicators/ Game Determinants) concerning z-axis acceleration.

3 PIs were identified (blue circle Fig.15) that coincide with the 3 peaks. These respectively represent the interruption of the run-up to perform the loading, the forward displacement during the jump execution, and the further forward displacement during the descent phase.

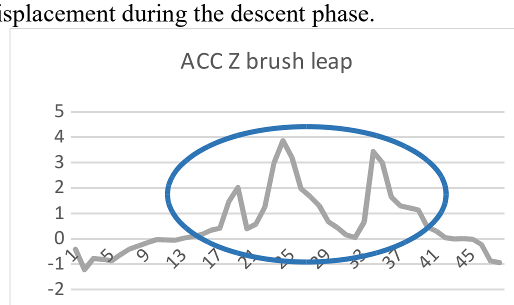


Figure 15: PIs concerning the z acceleration of the brush leap

- There are no PIs on the x-axis.
- PIs inherent in the gyroscope.

There are no points of interest regarding the gyroscope.

Regarding the forward flip, we have identified the following PIs:

- PIs concerning y-acceleration.

There are no significant PIs.

We notice a peak in the descent phase (blue circle in Fig.16), but we did not consider it as PI because, representing the descent phase to the ground, it constitutes a movement that is not part of the execution of the front tucked somersault.

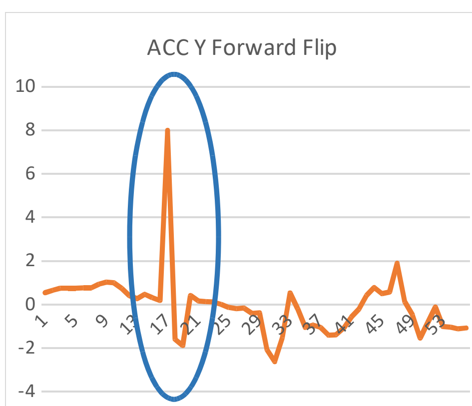


Figure 16: chart referring to the y acceleration of the forward flip

- PIs concerning the z acceleration.

We recognized 2 points of interest (PIs) represented by the two downward waves corresponding to the forward displacement during rolling (red circle, Fig. 17).

An additional PI was identified with the last upward displacement of the line (green circle, Fig. 17), which indicates the interruption of rolling to return to the upright position.

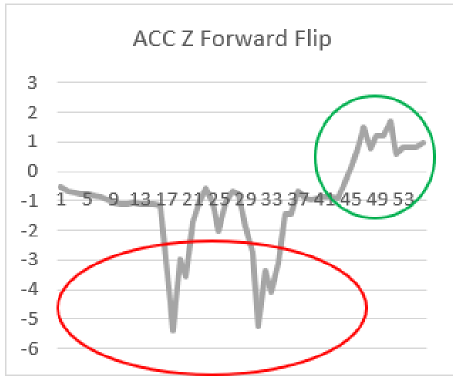


Figure 17: chart referring to the z acceleration of the forward flip

- There are no PIs on the x-axis.

PIs concerning the gyroscope:

- PIs concerning GYRO X.

We have identified 3 PIs.

The first peak (blue circle - Fig. 18) represents the closing of the upper body forward to initial rotation; the second peak (green circle in Fig.18) corresponds to rotation around the transverse axis; and the third peak (yellow circle in Fig.18) refers to the opening of the upper body back to the upright position.

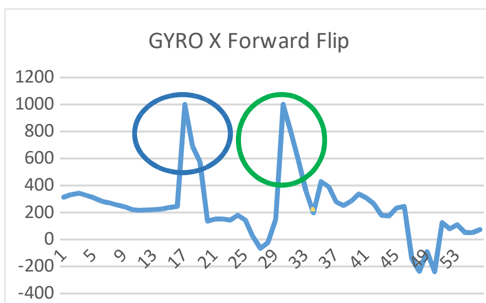


Figure 18: Chart referring to GYRO X of the forward flip.

- PIs related to GYRO Y.

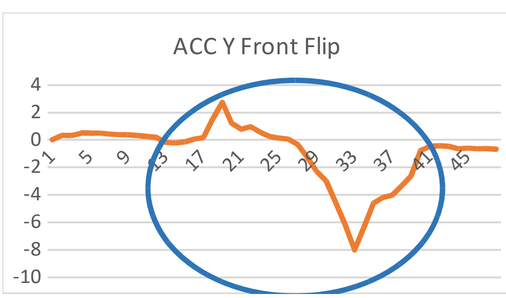
We identified an important point of interest: the peak (blu circle in Figure 16) represents a rotation around the longitudinal axis.

- There are no PIs inherent in GYRO Z.

Finally, we compared the obtained PIs identified in the brush jump and forward flip with the graphs obtained from the device detections concerning the collected forward turn jump.

Starting from the push phase and then from the brush leap, we found the two peaks in Fig. 21, in the y-acceleration chart of the collected forward flip, too (Figs. 19 and 20).

In the following, both the ACC Y chart of the leap brush and the ACC Y chart of the collected forward lap jump are shown and compared.



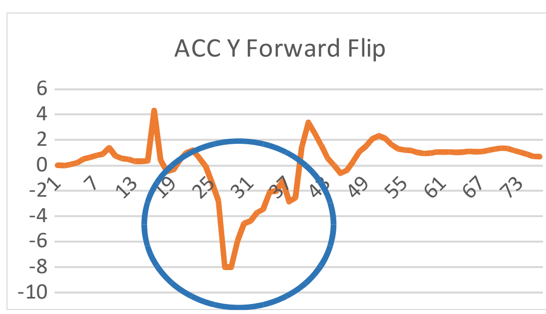
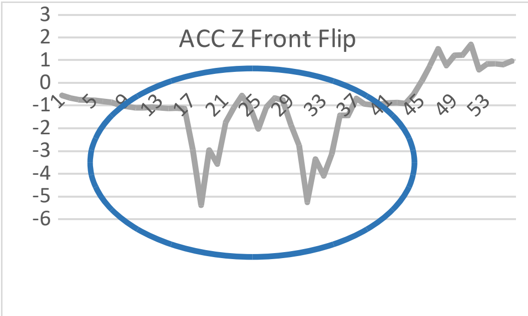


Figure 19 and 20: Graph regarding the y acceleration of the collected Front Flip and Forward Flip



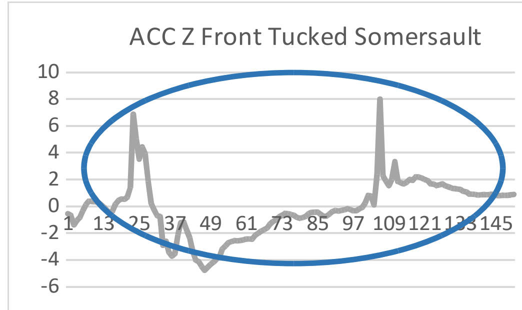
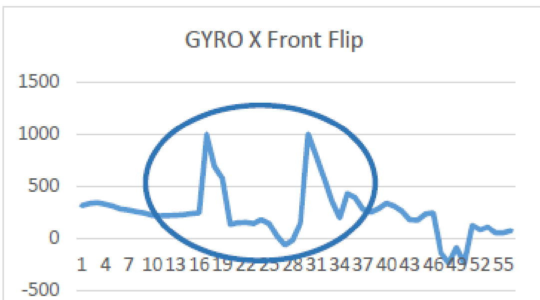


Figure 21 and 22: Chart concerning the z-acceleration of the front tucked somersault.

The peaks, (blue circle in Fig. 22) represent the rising phase before rotation



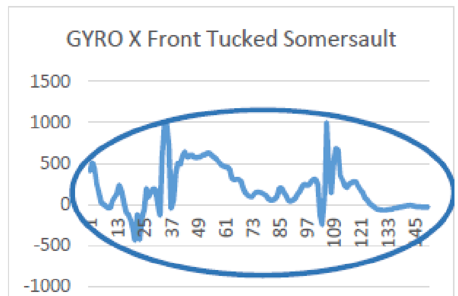


Figure 23: Graph regarding the GYRO X of the Front Flip

Figure 24: Chart referring to the GYRO X of the front tucked somersault

The *2 waves* found in the forward flip are also observed in the front tucked somersault. The only difference is that, in this one, they are pointing upward because the rotation occurs in the air and not on the ground. With regard to x-acceleration, in both the brush leap and the forward flip, we found no points of interest; in fact, even in the front tucked somersault, the x-acceleration line is flat. As we move on to the gyro analysis, we can give a deepened look at the forward flip. What is most interesting in these terms is the rotation phase, which, as mentioned, can be traced back to the forward flip performed on the ground. Relatively to the GYRO Y, the two peaks in Fig. 25, corresponding to the closing of the upper body forward to perform the rotation, are also present in the front tucked somersault

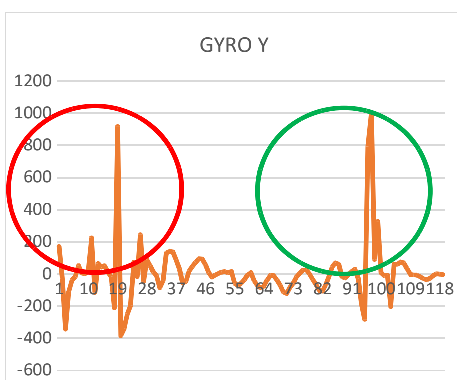


Figura 25 : Gyro Y front tucked somersault

To conclude, let's analyze it in GYRO Y. As a reminder, in the study done on the forward flip and reported earlier, we found rotation around this axis. By examining the front tucked somersault we found the same rotation. In detail, the executions in which the GYRO SCALE exceeded ±400 is 96% of the cases.
Next is a chart referring to the forward tucked somersault showing the rotation on the longitudinal axis in the first phase of collection (red circle in Fig, 25).

From the chart in Fig. 25 we note a marked peak (green circle) at the final phase of the movement as well, that is the end of the rotation, and the start of the landing. There are no significant considerations to be made related to GYRO Z; in fact, the chart obtained from this axis presents a flat line.

Conclusions

In addition to the front tucked somersault, the two movements investigated, which were part of the execution of the technical gesture under consideration, were the brush leap and the ground forward flip. The data obtained from the brush leap confirm what was expected from a first "naked eye" analysis: an upward and forward acceleration (because the leap develops in height and length). As for the forward flip, on the other hand, we have to make some considerations; in fact, we detected rotations around the y-axis that we did not expect to see. The forward flip consists of a forward roll around the transverse axis (x-axis) after a grouping of the body. From the gyroscope data, however, we also detected a marked rotation in the longitudinal axis.

In order to assess the repeatability of rotation around the y-axis, we had the gymnasts perform 100 forward flips, and after individual analysis of each performance, we found a recurrence of this movement in 96% of cases; in calculating this percentage, we did not consider flips with an angular speed between ±0 and ±400.

Specifically, in 8% of the flips, the rotation occurs with an angular speed between ±1000; in 13% of the cases between ±1000 and ±800; in 16% between ±1000 and ±400; in 11% between ±800 and ±800; in 23% between ±800 and ±400; in 22% between ±400 and ±400; and in 3% between ±0 and ±800. Next, to analyze the front tucked somersault, we found the same rotation around the longitudinal axis during the grouping phase of the body, except that we also find this rotation in the opening phase, the moment when the descent, and thus the final phase, are about to start. We believe that the different performances analysis of the components, outlining the investigated gesture, can help technical staffs to establish in a careful and meaningful way the design of workouts, using principles firmly corroborated by mathematical calculation and obtained thanks to the efficient use of the technologies described above, moreover filling a possibly total gap in the specific literature. Furthermore, they will weigh scientifically and not only experiencially on the quality and quantity of workload and way of performing it (Izzo et al, 2018c).

A step due, in our opinion, to technological scientific work approach for a more ethical and correct training proposal in artistic gymnastic and generally in sport.

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Conceptualization: Izzo R., Ubertini S., Cruciani A.
Methodology: Izzo R., Biancalana V., Crudelini E.
Validation: Izzo R., Cejudo A., Hosseini C.
Formal analysis: Biancalana V., Ubertini S., Cruciani A.
Investigation: Ubertini S., Izzo R., Hosseini C.
Data curation: Ubertini S., Izzo R., Biancalana V.
Statistical analysis: Cejudo A., Izzo R., Crudelini E.
Writing, original draft preparation: Izzo R., Ubertini S., Hosseini C.
Writing, review and editing: Izzo R., Crudelini E., Biancalana V.

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Disclosure statement

No potential conflict of interest was reported by the authors.
All authors have read and agreed to the published version of the manuscript.
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