

Quantification of motor abilities during the execution of judo techniques

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Purpose: Quantitative performance analysis is of great importance, especially to increase personalized training and to reduce injuries. The use of inertial sensors has given many possibilities and has been largely used in analysing technical capabilities of athletes. With respect to combat sports, judo has many issues resulting from the great number of variables involved in the techniques and due to the critical measurement environment. The aim of this study was to propose a method for measuring and quantifying motor abilities objectively. *Methods:* Four inertial sensors were fixed to the lower limbs and one on the sternum of five male and five female elite judo athletes. Accelerations and angular velocities of the lower limbs were measured in 480 judo techniques. Regression lines of accelerations and angular velocities have been analysed to obtain 5 single technique indices and 1 overall technique index representing the motor abilities connected, respectively to force expressions and coordination capabilities. *Results:* Correlations of motor abilities (force expression and coordination capabilities) and athletes' weight and height were found in only 6.7% of pairs. Results of force expression and coordination capabilities for most of the athletes are in line with their level of technical and combat experience. *Conclusions:* This method allowed to "photograph" athlete's technical level and to compare it in time through subsequent trials. With this innovative way, motor abilities could become evaluable and measurable, highlighting the importance of their objective quantification in order to evaluate effectiveness and efficiency of the sport technique.

Key words: inertial measurement unit (IMU), sport performance, judo, martial art, motor abilities, motor capabilities

1. Introduction

Quantitative sport performance analysis is an important emerging trend at all levels, affecting both training techniques and competition evaluation [2]. This is associated with increase of sports popularity and availability of sensors embedded in daily usage devices [5], [7], [10]. In high level athletes, sport performance analysis is focused to increase performance by having customized training and to reduce injuries caused by wrong workout [7].

The most important part of performance analysis is done based on experience of the trainer. Some researchers have begun to quantify sport perform-

ance collecting kinematic and kinetic variables by means of different techniques: video analysis, inertial sensors, force platforms, and force sensors [17], [18]. In combat sports, performance analysis was done only using video analysis [13], [14] and force platform [16]. Performance analysis in combat sport is complex because motion of athletes is not forecastable and, thus, it is hard to use an autonomous video processing method. Measurements on athletes are limited by the need of having free movements during the techniques. Other than these main issues, combat sports quantitative analysis is challenging since different elements need to be considered. As far as physical performance is concerned, such elements are coordination, force, and speed, whereas

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specifically for sport and competition management the most important are technical skills, psychological attitude, and strategical capability [22].

Sport analysis

Motor performance and consequently sport performance start from the movement and its technique. Technique is the combination of movements that adapt athlete's motor behaviour to the characteristics of equipment, materials, environment, and especially of team members and opponents. This motor behaviour adaptation is done in order to achieve the best performance in a given specific competitive situation, taking regulations, abilities, motor capabilities, anthropometric and psychological characteristics of the individual and/or team into account [3]. Among all the parameters that influence sports technique, the ones that mainly characterize it are related to motor capabilities and motor abilities (Fig. 1).

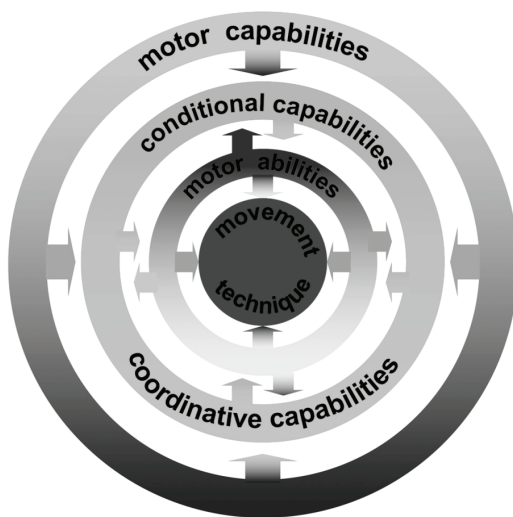


Fig. 1. Relation between movement, techniques, and basic abilities and capabilities

Motor capabilities are the most basic elements that influence movements and athlete technique. They are the set of physical or sport characteristics of individuals, which enable them learning and execution of various motor actions. These capabilities are specific to each individual and are partly linked to heredity and genetics, and can be modified with training. Motor capabilities are divided into: (i) conditional capabilities – related to the physical condition and then to the energetic aspects of a movement (quantitative aspect of movement); and (ii) coordinative capabilities – connected to the central nervous system's ability to start and control a movement (qualitative aspect of movement).

Conditional and coordinative capabilities influence the motor abilities (MAs). MAs are classified depending on the organization of movement's mode, on the importance of motor or cognitive elements, and according to the degree of predictability of the environment in which a movement is executed. MAs represent the concept of efficiency of movement, which consists in being able to achieve the final goal with maximum safety and the least energy expenditure [11]. Furthermore, the MAs being a biomechanical "movement optimization" tool, are linked to the concept of effectiveness. Therefore, MAs are the capacity to efficiently use strength expressions and coordination skills in order to increase the effectiveness of the motor performance [8]. An example of MAs in situational sports, such as judo, is the ability to be at the right time, in the right position, to optimize attack or defense action strategies, and improving the effectiveness of the adopted tactical scheme. This anticipation ability, which consists in perceiving the evolution of the gameplay or of the combat, together with the correct "decision-making" and right "timing" (what to do and when to do), builds a synergy that increases the effectiveness of the various actions. The relationship between MAs and conditional/coordinative capabilities is characterized by a mutual dualism: each capability is influenced by the number and quality of the ability possessed and the increased capability favours, in turn, learning new abilities [3]. As a result, development of motor capabilities goes along different methodological roads which also include various stages of learning and increase in motor abilities. MAs learning, development and consolidation is influenced by the initial level of the motor coordination capabilities, by previous experiences made in the motor area and by the individual predisposition towards maturity. To date, during field motor and sport activities, MAs can be observed but not measured. Observation implies an estimation process based on interpretation and judgement of the examined abilities through not strict benchmarks in different situations, while measurement means a repeatable quantification of the ability.

Biomechanical description of judo techniques

Judo is an individual combat sport. Athletes are divided by gender and weight categories, therefore constitutional preconditions strongly influence sport performance. Membership of a specific cluster determines individual's performance path. Since judo is a situational sport, a sequence of actions is driven by environmental situation that inherently changes dynamically during a match and from match to match. Attack

and defense actions and tactics are generally subordinate to opponent's actions and reactions. It is a sport based on unpredictability of the moment, due to the presence of an opponent trying through feints and deceptive movements not to reveal what the next move will be [9].

In biomechanical terms, sports can be classified according to technical and sporting gesture. In judo, gestures and movements that characterize a fighting technique and struggle phases consist in countless variations. The biomechanical analysis of techniques results in a generalization of movements and their classification into two main groups [19]. The first group of technique is the one in which the Tori (athlete who performs the throw) makes use of physical levers (TLF) to throw Uke's (partner/opponent who undergoes the throw) body using his/her own body segments (arm, hip, leg, foot) as a fulcrum. In this type of technique, it is essential to apply all three stages of execution: Kuzushi (imbalance), Tsukuri (preparation), Kake (throw). The Kuzushi phase is required to apply a favourable physic lever principle, with force applied distant from the fulcrum. For this reason, a stopping time, albeit very short, is needed to allow its completion. The second group of techniques is the one in which the Tori applies two forces in opposite directions (TCF) to throw Uke: sweeping away the legs and simultaneously pulling or pushing Uke's body in the opposite direction. If Tsukuri is performed with the right timing, the phase of Kuzushi is not essential and can even not be executed. This means that only the Tsukuri and Kake stages are necessary, while the Kuzushi stage, although helpful for the throw, is not required. The biomechanical classification of the two groups of techniques can be done accordingly to the force-velocity graph reported in [12]. Involving three stages, TLF techniques are, biomechanically speaking, more complex. They require more time for their execution and use of a greater force. In contrast, TCF techniques can be more rapid because they only require two rather than three stages to be carried out.

In this article, we propose a method for measuring and quantifying MAs objectively. Since performance of situational sports (such as judo) is complex, it is difficult to isolate and observe MAs that each athlete expresses during a combat and until now, only eyes of a very experienced trainer can observe them. Furthermore, judo has a number of critical issues, including continuously changing position (in a 3D environment), contact between athletes, friction and impacts deriving from it, and moisture linked to sweating, which, in general, makes the use of measuring instruments prob-

lematic. Such unfavourable environmental conditions require the use of innovative tools in order to measure MAs expressed in judo techniques performance and during different stages of a combat. A technique based on inertial measurement units was applied to judo performance analysis for high-level athletes [6]. Acceleration and angular velocity of TLF and TCF judo techniques were analysed in order to get two performance indexes related to the force expression and the coordination capabilities respectively. Our hypothesis is to quantify the motor ability through the coordination capabilities and force expressions necessary for the execution of the judo techniques and of some phases of judo combat, through the performance indices obtained.

2. Materials and methods

Participants

Ten athletes, five males and five females, took part in tests for analysis of judo technical performance. Athletes' anthropometric and personal data are reported in Table 1.

Table 1. Athletes' anthropometric and personal data

Athlete	M1	M2	M3	M4	M5	F1	F2	F3	F4	F5
Category [kg]	60	66	73	81	+100	52	57	57	63	78
Weight [kg]	62	68	75	86	116	56	59	63	65	77
Height [cm]	165	170	172	180	175	160	163	169	160	180
Age [year]	27	26	27	23	21	26	22	23	21	21

They are all elite athletes and amongst them there is an Olympic gold and bronze medalist. The others count medals at the World or Continental Category Championships or Grand Prix tournaments included in the valid world circuit for Olympic qualification.

Test description

The struggle situations in judo combat consist of two stages: standing fight stages and ground fight stages that alternate continuously throughout a match duration. In standing fight stages, one athlete tries to throw the opponent to the ground, knocking him to the floor with his back. In ground fight stage, one tries to pin the opponent by blocking him with his back to the ground for 20 s, or to force him to surrender with a strangling or joint lock. The choice of trials for the quantification of the MAs was designed in order to concentrate the largest number of technical situations that occur dur-

ing the standing stages of combat. The choice of pick up technical situation from the standing stage was due to a clear predominance, in terms of time during the competitions, of standing fight stages, compared to those on the ground. The trials involved in performance quantification were grouped according to the classification of judo biomechanics (TLF and TCF). These are:

- (1) Physical Lever Technique – Static (TLF-S): a technique called “seoi nage” or one of its variants, belonging to the TLF group, was performed from a standing start.
- (2) Forces Couple Technique – Static (TCF-S): a technique called “o sotogari” or its variants, always belonging to the TCF group, was performed from a standing start.
- (3) Physical Lever Technique – Dynamic (TLF-D): a technique called “seoi nage” or its variants, always belonging to the TLF group, was performed while athletes were moving. The technique, which had previously been performed with the pair of athletes who started from a static situation, was repeated when moving.
- (4) Forces Couple Technique – Dynamic (TCF-D): the technique called “o sotogari” or its variants, always belonging to the TCF group, was performed while athletes were moving. Even in this case, the same technical type previously performed was repeated, with the only difference that athletes were in a dynamic situation.
- (5) Kumi Kata and/or Randori at 50–100% (KK-R): consists of one minute of combat training simulation. Fight grappling technique stages (Kumi Kata) were performed at near-maximal intensity, while throw stages were performed at average intensity. KK-R was also used to monitor performance decay due to progressive fatigue.

TLF-S and TCF-S are not included in dynamic technical combat, however they were added to experimental protocol for two reasons: to have a base to which compare measurements taken during dynamics situations and because they constitute an important training workout used with continuity by the judokas at all levels. TLF-D and TCF-D are part of technical fundamentals of standing fight. KK-R, being the simulation of a combat, was included to identify the MAs involved in all preparatory movements of technical execution, called General Action Invariants (GAI) [17], and, in particular, those of the Inferior Specific Action Invariants (ISAI), which include all the movements performed with the lower limbs [17]. In fact, in the first two dynamic trials (TLF-D and TCF-D) the partner made no resistance, while in the KK-R combat simulation, the partner, being an oppo-

nent, had a chance to attack, defend and counterattack. The comparison between the trials has made it possible to isolate and analyze the MA used in the GAI and the ISAI.

Inertial Measurement Units

Inertial Measurement Units (IMUs) were used to monitor motions [1], [10]. IMUs allowed to drastically reduce criticality of an unconventional experimental environment such as the “tatami” (carpet where judo workouts are held) and the good wearability allowed athletes to move without constraints.

Five sensor units (TSDN121, ATR Promotions) were fixed to the athlete by Velcro straps; 4 IMUs were fixed to the lower limbs and 1 was fixed on the sternum by medical tape (Fig. 2). IMUs were placed on the trunk (on the sternum), right thigh (on *Vastus Lateralis*, equidistant between greater trochanter and lateral femoral condyle), left thigh (opposite to the right thigh), right shank (on the tibial plateau, at the proximal third of the distance between lateral malleolus and head of the fibula), left shank (opposite to the right leg). During the acquisitions, sampling rate was fixed to 200 Hz, acceleration range – to ± 16 g and angular velocity – to ± 1000 dps.

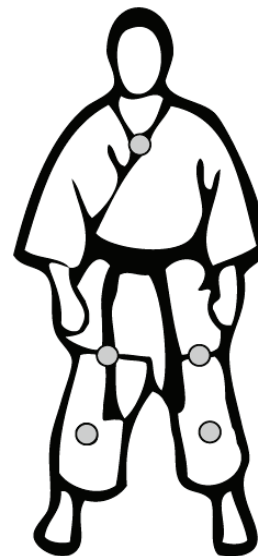


Fig. 2. Qualitative inertial sensors positions

Each IMU consists of a triaxial accelerometer, gyroscope, and magnetometer (size: 37 mm \times 46 mm \times 12 mm, weight: 22 g). The accelerometer and the gyroscope sensors are incorporated in MEMS (InvenSense MPU-6050). Measured data could be transferred wirelessly (Bluetooth ver.2.0 + EDR) to a laptop computer or could be recorded in a local data storage (512 Mbyte).

Protocol

Each athlete performed five trials in the following order: TLF-S, TCF-S, TLF-D, TCF-D, KK-R. For each of the first four trials (TLF-S, TCF-S, TLF-D, TCF-D), athletes performed three sets of four techniques each, for a total of twelve techniques for each trial done. A total of 480 trials were collected. In the fifth trial (KK-R), each athlete performed a minute combat simulation where the priority of evaluation was given to the execution of technique preparatory movements (GAI). Techniques performed in this test were not counted in the final calculation.

Data acquisition and data analysis

For each trial, the peak of the three components of acceleration and the peak of the three components of angular velocity registered by the single IMUs were calculated. Then, the average value among all the articular segments peaks was evaluated for both acceleration and angular velocity, obtaining one representative value for the acceleration and one representative value for the angular velocity, for each trial.

Motor ability indexes: Expression Force (EF) index and Coordination Capability (CC) index

According to the second law of dynamics, force is directly related to acceleration, therefore the idea was to utilize accelerations as EF index of expression force in judo techniques. In fact, acceleration changes are related to the dis-homogeneity of the movement: the more frequent the re-starts during the execution of a gesture (with relative speed decrease/increase or even stopping instant), the greater the EF necessary to complete it.

Considering angular velocity, speed refers to the entire body velocity, while rapidity indicates the execution of gesture performed by a single body segment [22]. The ability to combine all single body segment rapidity to gain a high speed value is an important coordination aspect. Therefore, if the motor gesture is well-organized, precise and fast [4], it means that body segments used to achieve it are coordinated [21]. In 1960, W. Farfel expressed an important concept [4] which was then furthermore analyzed and extended by Starosta in 1984 [20], on the various levels of motor coordination that are encountered in the execution of a movement. The levels are: spatial precision of the movement based on a model, spatial precision of the movement achieved in the shortest time almost under standard conditions, spatial precision of the movement achieved in the shortest time and under changing con-

ditions. In brief, levels of coordination difficulties are: precision of the movement, precision and speed of movement, precision and speed of movement in changing conditions. Judo, considering all its technical aspects, belongs to the last level of coordination. Hence, the idea was to utilize angular velocity as CC index of coordination aspects in judo techniques.

Our intent was to use the MAs indices in order to quantify technical performance and describe technique of individual athletes. These indices are extremely subjective because they depend on motor and coordination capabilities of each athlete, therefore quantifying performance enable each athlete to perceive variations of his/her technical performance in term of EF and CC. In order to confirm the independence of these motor abilities indices, Spearman correlation ($p < 0.05$) between EF index and weight, EF index and height, CC index and weight, and CC index and height was evaluated for all the executions of the five trials.

Trend lines: a method to quantify the subjective motor abilities used in performing judo techniques

Using EF and CC indices, a method was proposed to highlight strong and weak points of MAs involved in technical executions of individual athletes. This method would allow to quantify changes and variations of technical performance over time, correlating them to increase or decrease in physical and athletic performances or other situations that may elapse during a training cycle (e.g., injuries, decreased motivation, over-training). Judo techniques are strongly bonded to the body and morphological structure of an athlete; thus accelerations and angular velocities were linked to athlete's weight and height using linear regression. Four regression lines were calculated: (a) acceleration–body weight, (b) acceleration–height, (c) angular velocity–body weight, (d) angular velocity–height.

- *Single technique index: regression lines for a specific technique*

For each of the five trials (TLF-S, TCF-S, TLF-D, TCF-D, KK-R) the four regression lines (a, b, c, d) were calculated. For each technique and regression line, the predicted values of acceleration and angular velocity were calculated for all athletes. An example of regression line for TCF-D trial for female athletes is reported in Fig. 3.

Then, for each athlete, a general index was calculated between the real value and the predicted value

(corresponding value on the regression line) as percentage, using the following equation:

$$\text{general index} = \frac{V_{\text{real}} - V_{\text{predicted}}}{V_{\text{predicted}}} \cdot 100.$$

Regression line for TCF-D Single technique index

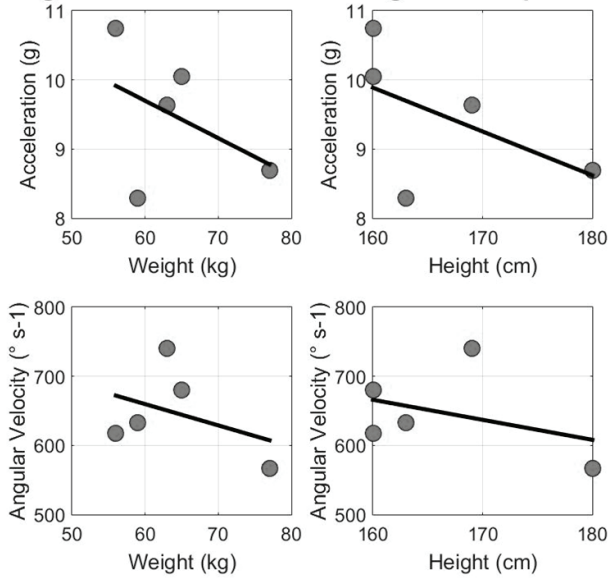


Fig. 3. Example of Single technique index for Forces Couple Technique – Dynamic (TCF-D) technique for female athletes

Finally, for each athlete, the single technique index of force was calculated as the mean value between acceleration–weight and acceleration–height general indexes, whereas the single technique index of coordination was calculated as the mean value between angular velocity–weight and angular velocity–height general indices. Single technique indexes of force and of coordination represent motor abilities expressed in each technique.

- *Overall technique index: overall regression lines*

For each athlete, an average value for acceleration and for angular velocity among all the techniques (TLF-S, TCF-S, TLF-D, TCF-D, KK-R) was calculated. Then, the four regression lines (a, b, c, d), the predicted values, and the general index expressed as percentiles were calculated. The overall regression line for female athletes is reported in Fig. 4.

Finally, for each athlete, the overall technique index of force was calculated as the mean value between the general indices of acceleration–weight and acceleration–height, whereas the overall technique index of coordination was calculated as the mean value between the angular velocity–weight and angular velocity–height general indices. This overall

technique index gave information on general technical level of individual athletes, depending on their weight category. A positive or negative difference between accelerations values allowed quantifying MAs used in carrying out the technical movement by applying a relative value to EF, which represents physical condition and movement energetic aspect. A positive or negative difference between angular velocities values allowed quantifying MAs expressed in the CC used in management and in technical movement organization.

Regression line for Overall technique index

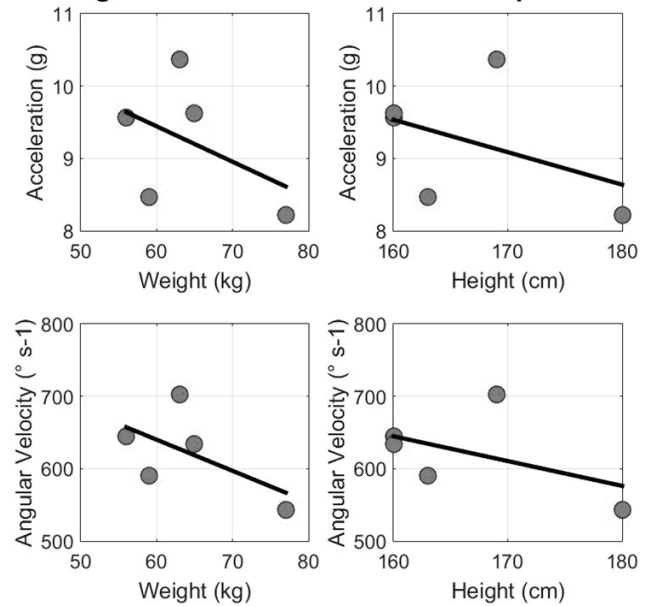


Fig. 4. Overall technique index for female athletes

The two overall technical indices summed (the motor abilities contained in the strength expressions, plus the motor abilities expressed in the coordination capabilities) are a numerical quantification of the motor abilities used in the tested motor (and/or technical) gesture and that consequently represents the effectiveness in the final performance.

3. Results

Results for the data analysis and index evaluation are reported in the following paragraphs.

Trials results

Test results are shown in Table 2. Athletes are divided by gender: female (F_n) and male (M_n). In each trial, acceleration and angular velocity peaks that each participant obtained are reported in Table 2. These values were obtained by averaging peak values recorded for each

Table 2. Real value of acceleration (a) and angular velocity (ω) for the five trials and athletes

Athletes	TLF-S		TCF-S		TLF-D		TCF-D		KK-R	
	a [g]	ω [$^{\circ}$ s $^{-1}$]	a [g]	ω [$^{\circ}$ s $^{-1}$]	a [g]	ω [$^{\circ}$ s $^{-1}$]	a [g]	ω [$^{\circ}$ s $^{-1}$]	a [g]	ω [$^{\circ}$ s $^{-1}$]
M1	9.4	658.2	8.9	676.5	10.4	704.6	9.7	655.6	15.3	638.0
M2	9.1	649.1	8.7	637.0	10.8	622.2	11.3	663.4	13.2	794.4
M3	9.9	568.9	7.4	612.6	7.9	660.9	10.0	757.1	10.4	769.9
M4	6.4	637.9	6.1	458.4	7.4	604.6	7.1	575.2	12.5	729.3
M5	8.7	639.5	7.8	420.9	10.7	705.4	9.3	779.7	10.2	629.6
F1	8.5	634.5	7.8	564.7	8.5	696.4	10.8	617.2	12.2	701.1
F2	8.4	628.0	7.5	597.2	8.6	492.8	8.3	633.3	9.5	601.4
F3	9.7	635.8	11.2	671.0	9.8	714.8	9.6	740.4	11.6	750.5
F4	8.7	675.5	8.2	591.9	9.2	628.6	10.1	679.9	11.9	742.0
F5	6.1	519.2	6.5	476.5	7.5	509.4	8.7	566.5	12.3	643.4

single athlete articular segment. The minutes analyzed in simulated combat situation were twelve because two athletes in women's group repeated this test twice.

Motor ability indexes: EF index and CC index

Correlation between MAs indices and athletes' weight and height showed that only 6.7% of pairs have meaningful relationships, which can be considered completely random. Significant correlations were found only in man athletes, and were found between the following pairs: EF index and height in TCF-S, CC index and height in TCF-S, EF index and weight in KK-R, CC index and weight in KK-R.

Trend lines

Single technique index: regression lines for a specific technique

For each technique, results for the single technique index are reported in Table 3 for male (M1–M5) and

female (F1–F5) athletes. In this table, single technique indices are divided in force expression (EF) and coordination capabilities (CC) for each trial.

Overall index: overall regression lines

Overall indexes results are reported in the last two columns of Table 3 for male (M1–M5) and female (F1–F5) athletes. As for the single technique indexes, also overall technique indexes are divided in force expression (EF) and coordination capabilities (CC).

4. Discussion

Starting from IMUs data collected during the acquisitions, this study aimed to propose a system based on motor ability indices (single technique index and overall technique index) to uniquely identify technical features of tested athletes. Accelerations were linked

Table 3. Motor abilities indexes of each technique (single technique index) and of all techniques together (overall technique indexes). In the table motor abilities indexes are divided according to force expression (EF) and coordination capabilities (CC)

Athletes	Single technique index [%]										Overall technique index [%]	
	TLF-S		TCF-S		TLF-D		TCF-D		KK-R			
	EF [%]	CC [%]	EF [%]	CC [%]	EF [%]	CC [%]	EF [%]	CC [%]	EF [%]	CC [%]	EF [%]	CC [%]
M1	-2.4	3.5	2.6	2.2	3.4	4.8	-8.0	-3.6	9.5	1.5	1.9	1.7
M2	0.3	2.6	6.8	1.9	11.0	-6.3	12.5	-2.2	1.4	0.7	6.4	-0.6
M3	11.3	-11.0	-7.0	0.9	-20.2	0.3	4.0	10.0	-21.6	0.5	-6.2	0.7
M4	-23.7	1.8	-15.3	-19.4	-18.8	-6.6	-22.2	-18.2	9.6	3.2	-10.6	-6.6
M5	6.9	1.7	8.1	9.1	13.3	6.1	5.9	8.6	-5.7	-7.3	5.6	3.9
F1	-7.1	-4.1	-10.8	-9.0	-7.3	6.0	7.8	-8.4	8.7	1.2	-0.3	-2.2
F2	-3.9	-2.4	-12.9	-0.6	-3.8	-29.9	17.3	-4.2	-19.0	-15.8	-11.5	-9.4
F3	-15.0	3.6	26.5	13.9	11.2	13.8	2.1	12.9	0.6	8.4	11.2	10.9
F4	-1.5	5.8	-1.3	0.1	3.8	-0.04	3.9	3.6	4.2	4.2	2.6	3.6
F5	-10.5	4.0	-15.9	-8.4	-6.8	-8.6	-0.2	-7.3	1.3	-3.5	-4.9	-5.7

to the motor ability index of the expressions of force, whereas angular velocities, being represented in the relationship between rapidity and speed [22], were linked to the motor ability index of coordination capabilities. The motor ability indices (single technique index and overall technique index) were calculated assessing the percentage difference between real and predicted value of accelerations and angular velocities collected during technical trials and athletes' physical characteristics (weight and height). Since the regression line was obtained on overall performance among athletes who practice high-level judo, overall technique index is an excellent reference for analysis of technical performances. This method allowed to compare athletes belonging to the same group (or weight class) and athletes belonging to different groups (or different weight classes). These motor ability indices represent the trend deviation of technical performance analysed in relation to height and weight of individual athletes and therefore are attributable to weight classes in which athletes compete. This gives an added value to this data, which "photograph" athlete's technical level and compare it with itself over time through subsequent tests. Overall, by examining values given in the individual tables, it is possible to evaluate the technical details that each athlete has expressed in different techniques and situations proposed.

The single technique index allowed for quantifying motor abilities on the athlete and opened a connection with the other physical aspects, such as force expressions and coordinative capabilities (Fig. 1), in order to find new motory components in the characterization of the technical gesture. As an example, results of the athlete F3, the best one in female group, are summarized in Table 4. This participant presents the 75% of the values on the top in the trend category (marked with "b" superscript in Table 4) and the remaining 25% fall into the average. None of the values is below the trend. The values that refer to technical fundamentals (TLF-S, TCF-S, TLF-D, TCF-D) are the best of

the series among all those acquired during the trials and, as expected, also the values that refers to combat simulation (KK-R) are very high.

Results of athlete M5 (summarized in Table 4) have a different trend. Athlete M5 is the youngest and falls among the least experienced within the male group. For this athlete, only half of the values that relate to the technical progression (TLF-S, TCF-S, TLF-D, TCF-D) are the best of the series. In contrast, between the two values that refers to the combat simulation (KK-R) the expression of force falls into the average, while the coordination capability was the worst of the series. Also in this case, following the logic, if the values that refer to the technical fundamentals are on the top or near the top on the category trend, even the simulated combat performance, being the synthesis of the fundamentals run before, should show a good or very good level; however it did not happened. The motivation is related to the young age and the low experience of this athlete, that being already a high-level athlete in the junior category (he is a former world champion) is able to perform high level fundamental technical (TCF-S, TLF-D), but in combat simulated (KK-R) he still requires an important training job, given his young age and limited experience.

As the last example let us consider results of the athlete M4 (Table 4), certainly one of the most representatives of the group. Among those evaluated, M4 is one of the most experienced and performing in the competitive field. As can be seen from Table 4, almost all the values which relate to technical progression (TLF-S, TCF-S, TLF-D, TCF-D) are the worst of the series, but the value that refers to the combat simulation (KK-R) is absolute the best of all. Normally, if the values that refer to the technical fundamentals are far below the category trend, even the simulated combat performance is expected to show insufficient value. Instead, it was exactly the opposite. Indeed, the athlete was not particularly pleased of being "controlled and measured" during training, did not feeling stimulated to give his best, and expressed his

Table 4. Summary of single and overall technique indices for F3, M4, and M5 athletes for a comparison

		F3		M5		M4	
		EF [%]	CC [%]	EF [%]	CC [%]	EF [%]	CC [%]
Single technique index [%]	TLF-S	-15.0 ^b	3.6	6.9	1.7	-23.7 ^a	1.8
	TCF-S	26.5 ^b	13.9 ^b	8.1 ^b	9.1 ^b	-15.3 ^a	-19.4 ^a
	TLF-D	11.2 ^b	13.8 ^b	13.3 ^b	6.1 ^b	-18.8	-6.6 ^a
	TCF-D	2.1	12.9 ^b	5.9	8.6	-22.2 ^a	-18.2 ^a
	KK-R	0.6	8.4 ^b	-5.7	-7.3 ^a	9.6 ^b	3.2 ^b
Overall technique index [%]		11.2 ^b	10.9 ^b	5.6	3.9 ^b	-10.6 ^a	-6.6 ^a

Notes: ^a the worst value of the series, ^b the best value of the series, all value without superscript fall into the norm.

disappointment engaging the bare minimum in fundamental technical trials, as it was seen from a qualitative analysis of video recorded. Instead, in simulated combat test (KK-R) his competitiveness had the upper hand on his indolence and the indices reported were the best of the series, amongst all the recordings made. Considering only the analysis of the first parameters, we would have categorized this athlete's performance as mediocre, while analysis of the specific performance in a combat brought out the true potential of this athlete.

Judo practiced by these athletes has very special characteristics. Over the years of practice and because of their personal qualities, they have developed a fighting style with marked subjective characteristics. Each of them individually adopts tricks and personal adaptations that allow them to maximize the effectiveness of their techniques. Often these strategies go against the principle of biomechanical optimization and, if analyzed solely from an objective point of view, they lead to the erroneous conclusion on the technical expertise of the user. In these cases, a qualitative analysis taking final effectiveness of technical movements expressed into account helps to give the right value to the performance. Depending on the examples shown, our measurement technique has proven to be able to quantify these individual variations. Naturally it is always advisable to combine a qualitative video analysis to verify data obtained.

Limitations

The values obtained to quantify motor abilities are not independent values, because to be defined they need to be compared with a similar data set. Therefore, a possible limitation is the low number of athletes included in the study. Of course, with the collection of specific databases, relating to the different types of movement to be analysed, this limitation would not only be overcome, but it will become an added value as, by expanding the databases, the data statistical incidence will be strongly improved.

5. Conclusions

Analysis carried out by means of inertial sensors gave us a chance to highlight the performance by a huge number of technical principles. In this way, motor abilities will be both evaluable and measurable, enabling them to have the right importance to assess the effectiveness of the sport technique. It will be finally possible to quantify, with a mathematical process, the

dualistic relationship between abilities and capabilities: where each capability is influenced by the number and quality of the ability possessed and the increased capability favours, in turn, learning new abilities. Surely this will be one of the future evolutions of this first approach to measuring motor abilities and capabilities.

The method seems to have great flexibility and will be able to be applied easily to all types of movements in judo, but also to a great variety of other sports. Obviously, the greater the data gained on the relationship between abilities and motor capabilities, the greater the effectiveness to define their relationship. A right qualitative analysis is the staple in the evaluation of the sport technique and of the motor skills involved. However, technology provides tools that integrate, through objective measures, the qualitative approach [15]. Therefore, it becomes important to learn, know, and use these tools, interpreting and explaining correctly data provided to coaches and athletes. The rhythm of the movement and its "musicality" uniquely identify motor dynamics. Each man or woman has his own, which varies and adapts to the different environmental, emotional, and physical situations. Finding a key that can synthesize a movement like notes represent sounds, by codifying what you can only listen, would allow one to objectify what can only be observed. The acceleration and the angular velocity read and interpreted in the right direction could become descriptors of the physical condition and motor performance. Consequently, accelerometers and gyroscopes fall within the type of tools that Merni [15] wrote about already more than twenty-five years ago. It is just a matter of using them in the most appropriate manner for the measurements one wants to obtain. Then, in the subsequent data processing, the captured information must be "translated" into a language that is understandable by end users, such as athletes or coaches. Only in this way, we will be able to assign the right value and, above all, make a practical use of this type of analyses.

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