Kinematic traits of an elite Paralympic karateka: a case study

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Milan, November 22nd, 2019

Dr. Alberto Oliaro

Editor

The Journal of Sports Medicine and Physical Fitness

Dear Dr. Oliaro,

Please find enclosed the revised version of the manuscript J Sports Med Phys Fitness-10141 entitled “Kinematic traits of an elite Paralympic karateka: a case study.”

We thoroughly considered all the comments of the Reviewers, and we revised the current version of the manuscript. In the following, we provide a description of the changes introduced, which are also highlighted in the manuscript.

We would like to thank you and the Reviewers for the time and expertise devoted to improving the quality of our manuscript. I trust that this revised version will be suitable for publication in *The Journal of Sports Medicine and Physical Fitness*.

Best regards,

Chiarella Sforza

Reviewer 1

R1.1 Major corrections (main criticisms)

Here are several major concerns: (1) The participant performed a traditional Shotokan karate – KATA which is a standardized sequence of karate movements. The some parameters from CoM and knee were analyzed. Those parameters are critical factors to KATA? It needs solid evidence-based support.

We would like to thank the Reviewer for his/her precious suggestions.

We thoroughly reconsidered the main passages of the Discussion and Introduction, as marked in the text. As suggested, we added in the Introduction a paragraph containing information about the critical factors for Kata performance, that on a biomechanical perspective include also those mentioned by the Reviewer. These data are supported by previously published studies.

R1.2 (2) Those parameters were analyzed from which karate movement of KATA? which movement phase?

We agree that the data extraction flow was not clear and we thank the Reviewer for the chance to clarify this point. We now added details about the computation of kinematic data in the Procedures section. Moreover, we added in the Discussion some features regarding relevant outcomes for knee kinematics in particular step of the sequence.

R1.3 (3) Kumite and Kata are two types of karate. The scoring requirements and critical factors are very different between Kumite and Kata. However, some literatures on Kumite also cited in the discussion.

The point raised by the Reviewer is correct. However, the studies we included addressed both kata and kumite athletes (references #2 and #5) in order to highlight the relevance of dynamic postural control during the execution karate techniques. In such papers, the importance of the achievement of a adequate technique (also in terms of biomechanical parameters) is addressed, and its role in the obtainment of a high-level performance is discussed.

Reviewer 2

Major corrections (main criticisms)

R2.1 The usage of expressions as “reduced” or “decreased” (see detailed comments) are inappropriate and should be replaced throughout. However, I feel some speculations on practical consequences or specific recommendations would enhance the value for the reader. All the areas where the manuscript needs further improvement have been pointed in the specific comments.

We would like to thank the Reviewer for his/her precious suggestions. We thoroughly checked the manuscript and clarified all the potentially misleading expressions.

As prompted by this suggestion, we also added some practical outcomes and recommendations that could provide useful insights for the reader.

R2.2 Minor corrections (page, paragraph, line where the author must make the corrections)

Page 2, Line 7: replace “study is” with “study was”

Fixed as suggested by the Reviewer.

R2.3 Page 2, Line 16: Please delete “traditional”.

This word was deleted as suggested by the Reviewer.

R2.4 Page 2, Line 16: Please delete “Shotokan” (doubling).

Thank you for noticing the typo. We deleted the doubling.

R2.5 Page 2, Line 20: replace “more” with “longer”

Corrected as suggested by the Reviewer.

R2.5 Page 2, Line 22: replace “decreased” with “lower”

Corrected as suggested by the Reviewer.

R2.6 Page 2, Line 27: replace “reduced” with “lower”

Corrected as suggested by the Reviewer.

R2.7 Page 3, Line 9: change “incoming” into “upcoming”

Changed as suggested by the Reviewer.

R2.8 Page 3, Line 12: change “involving a sequence” into “involving sequences”

Changed as suggested by the Reviewer.

R2.9 Page 3, Lines 28-30: This is also true for the non-paralympic games, I guess.

The point raised by the Reviewer is correct. We focused only on the Paralympic Program to highlight the lack of international recognition for top level competitions of para-karate. However, if the Reviewer believes that adding a reference to able-bodied competitions should clarify the context for the reader, we are open to add more details.

R2.10 Page 3, Line 53: change “Participants” into “Participant”

We made the change as suggested by the Reviewer.

R2.11 Page 4, Lines 14-16: What does “5/6” or “3/4” mean in this context?

The Paralympic karateka trained 5 to 6 times per week before and 3 to 4 times per week after the operations. We agreed that there was a lack of clarity. We clarified this sentence by replacing “/” with “to”.

R2.12 Page 4, Line 29: Which kata was performed?

As stated, the kata was the same of the previous study (reference #14) taken as a comparison with able-bodied athletes. We intentionally didn't report the entire sequence of movements to avoid redundancy. However, if the Reviewer believes that adding the description of the whole sequence of movement should be useful for the reader, we are available to add the details of kata performed.

R2.13 Page 4, Line 37: What does “advancement” means? “in front”? “forwards”?

We acknowledge that passage was not as clear as we intended. We added “forward” before “advancement” to clarify the direction of the movement.

R2.14 Page 5, Line 43: replace “reduced” with “lower”

Replaced as suggested by the Reviewer.

R2.15 Page 6, Line 29: replace “decreased” with “was lower”

Replaced as suggested by the Reviewer.

R2.16 Page 7, Line 13: What does “decreasing” mean in this context?

Thanks for the question. We replaced “decreasing” with a more consistent expression to highlight physical impairments negative effects.

R2.17 Page 9, Lines 19-21: Please correct citation #5.

Thanks for noticing the error. We corrected the citation adding the missing details.

R2.18 Figures 1 and 2: The resolution of the figures should be improved. Why did you report the median instead of the mean with 95% confidence intervals?

We now exported the figures at higher resolution.

Thanks for noticing the typo. We replaced “median” with “mean”.

Kinematic traits of an elite Paralympic karateka: a case study

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ABSTRACT

Karate is a martial art that include striking, kicking and punching techniques, ~~demanding~~ and ~~requires~~ high levels of functional ~~abilities~~ skills. Karate counts millions of practitioners worldwide and it is ~~also spreading~~ in Paralympic competitions, ~~requiring~~: there is a need for accurate categories definition for disabled athletes. The aim of the ~~present current~~ study ~~is was~~ to present kinematic data of an elite Paralympic karateka, in comparison with able-bodied athletes, to promote a better classification within the discipline, based on objective evaluations of physical impairments. A male black belt Paralympic karateka (age: 36 ~~years~~; body weight: 75.5 kg; height: 173 cm) with lower limbs impairments was evaluated. He performed a standardized sequence of movements (kata) from ~~traditional~~ Shotokan karate ~~Shotokan~~. Joints and ~~center-of-mass~~ kinematics were collected with an optoelectronic motion capture system and compared with those obtained in two groups of able-bodied (~~Masters~~ and ~~Practitioners~~) athletes from a previous study. The sequence performed by the karateka lasted ~~more~~ longer than in both able-bodied groups. Center of mass velocity and acceleration ~~decreased~~ lowered in comparison with ~~Masters~~. Knees range of movement and peak angular velocity were similar to ~~Practitioners~~ but lower than ~~Masters~~. ~~We concluded that~~ The physical impairments negatively affected the function of lower limbs in the Paralympic athlete, ~~as fundamental~~ skills in karate elite performance (dynamic balance control and joint angular velocity) were ~~reduced~~ lower.

Keywords: martial arts, adapted physical activity, sport biomechanics, disability, motion capture.

INTRODUCTION

Karate is a Japanese martial art that originated in the island of Okinawa and spread worldwide following World War II. Nowadays the World Karate Federation (WKF) claims that Karate has more than 100 million practitioners in 194 national federations around the world. Moreover, the International Olympic Committee (IOC) has recently included karate competitions as an additional sport in the ~~incoming~~ **upcoming** Tokyo 2020 Olympic Games program.

Karate competition consists of *kumite*, competitive sparring, and *kata*, an exhibition of forms involving ~~a sequence~~ **sequences** of offensive and defensive movements targeting a virtual opponent¹. These movements include mainly striking, kicking and punching techniques and require high levels of functional and motor abilities². During a conventional fight system, conducted within a sustained endurance regimen, the karateka highly increase their ventilation and blood pressure³. Furthermore, continuative karate training improves physical qualities including flexibility, strength, balance and cardiorespiratory fitness⁴⁻⁷.

Recently, consideration for adapted physical activity (APA) for people with physical or cognitive impairments increased, alongside with the inclusion of Paralympic disciplines in national sport federations. In addition, some studies regarding elite Paralympic athletes **have been published**⁸⁻¹².

To date, among oriental martial arts, only Judo and Taekwondo entered the Paralympic Games program. However, WKF has been working since 2006 to create para-karate, with competitions involving athletes with various disabilities. In 2015 WKF has also been recognized as a member by the International Paralympic Committee.

Biomechanical analyses can highlight the residual functional ability of athletes and provide an evidence-based classification in Paralympic sports, showing how physical impairments influence activity and sport performance¹³. **One of the main factor affecting performance in *kata* competition is dynamic postural control, represented by the kinematic analysis of the body Center of Mass (CoM)^{2,5,14,15}. Information about CoM displacement, velocity and acceleration during Karate techniques execution offer a general description of whole-body movements and reflects athletes' ability and experience^{1,15-17}.**

Moreover, some studies identified knee movements as crucial factors for enhancing performance in both punching and kicking *kata* techniques¹⁸⁻²¹.

~~However~~ **Despite the determinants of *kata* performance were extensively discussed in the actual body of literature**, no studies currently reported data regarding the biomechanics of Paralympic karate. In fact, some studies reported differences between elite athletes and practitioners^{13,14},

but to date no one has presented a comparison between high level Paralympic and able-bodied karateka.

Therefore, the purpose of this study was to evaluate body kinematics of an elite Paralympic karateka (national champion), comparing his data to those collected in a previous study conducted on able-bodied karateka¹⁵.

The findings of this work could be useful both for karate coaches and physical therapists in improving their training and rehabilitation strategies for Paralympic athletes.

CASE REPORT

Participants

Kinematic assessment was accomplished on a 36-year-old male black belt Paralympic karateka (body weight: 75.5 kg; height: 173 cm). He was a member of Federazione Italiana Judo Lotta Karate Arti Marziali (FIJLKAM, affiliated to WKF) and national champion of para-karate individual *kata*. Furthermore, he took part in several international competitions of para-karate. His physical disability was caused by complications after surgical operations, due to tendons laxity in his lower limbs. At the moment of evaluation, the main impairment was a complete bilateral gastrocnemius and soleus atrophy, that caused a notable decrease in knee and ankle mobility and force output. The athlete had been performing high level karate for 20 years before the disability took place, with 5 to 6 training sessions per week. After the post-operative rehabilitation, he attended 3 to 4 sessions of para-karate training per week.

The karateka signed an informed written consent; the study was approved by the local Ethics committee and met the current ethical standards in sports and exercise research, according to Helsinki Declaration.

Kinematic parameters were compared to those from obtained in a previous study investigation, conducted with analogous procedures on 10 able-bodied black belt karateka divided in two groups: Masters (elite karateka, members of the Italian national team), and Practitioners (non-elite, amateurs karateka)^{1,15}.

Procedures

The karateka performed seven repetition of the same *kata* performed in of the previous study, defined by an experienced Master of *Shotokan* karate, to allow a comparison with able-bodied athletes. In short, movements composing the sequence of 11 steps were chosen among the fundamental techniques of traditional *Shotokan* karate¹⁵. Before trials, the karateka warmed up with his coach. The sequence was performed at maximum effort; between repetitions, full recovery was conceded.

The 11-steps sequence was performed along three directions (forward advancement, right backward displacement and left advancement) and included advancement and backward positions, blocks, punches, and a circular kick with the left leg.

Twenty-three body markers (diameter: 15 mm) were placed on the skin at the following landmarks: right and left tragon, acromion, olecranon, radius styloid process, anterosuperior iliac spines, great trochanter, femoral lateral epicondyle, lateral malleolus, heel, toe, glabella, spinous process of the 7th cervical vertebra, sacrum. The three-dimensional coordinates of each landmark were recorded at 120 Hz by an optoelectronic motion capture system (BTS Smart-E, Milano, Italy). The markers coordinates were filtered with a 15 Hz, low-pass, 2nd order Butterworth filter. The 11 events linked defining the timing of to each *kata* technique were manually located using the motion capture software. Sequence duration was calculated between the first and the last event.

Knee flexion angles were computed under the simplifying assumption of 1-degree-of-freedom joints. Angular range of motion (RoM) during the sequence and peak angular velocity were obtained to provide a complete joints motion description.

~~body Center of Mass~~ CoM coordinates were estimated using the Segmental Centroid Method²³. CoM height and vertical displacement were computed as the mean of the values over the entire *kata* and normalized to the body height. Horizontal displacement was expressed as the sum of all movements of the CoM projection on the horizontal plane. CoM average velocity was calculated over the whole sequence, as well as CoM acceleration, expressed by the root mean square (rms) of the relative track.

Statistical analysis

Each kinematic parameter regarding the Paralympic karateka was expressed as the mean over trials. Kinematic variables for Masters and Practitioners were presented as group mean together with 95% confidence intervals (CI). To assess differences between Paralympic karateka and able-bodied groups, the one-sample t-tests were performed. The Significance level was set at 5% ($p < 0.05$).

RESULTS

The duration of the *kata* sequence performed by the karateka was significantly longer than those of both Masters and Practitioners (6.51 s vs. 3.33 s, $p < 0.001$ and 3.96 s, $p = 0.012$ respectively). Table 1 lists CoM and knee kinematics data of Paralympic karateka compared with able-bodied groups.

Table 1

Figures 1 and 2 show CoM and knee kinematics results. Masters and Practitioners data are displayed as percentage increment or decrement from the Paralympic karateka mean values, taken as reference, together with 95% CIs.

When compared to elite karateka, CoM average velocity was 73% lower ($p < 0.001$) and acceleration was 21% lower ($p = 0.053$). Additionally, knee RoM and peak angular velocity were significantly ~~reduced~~ lower, except for right knee RoM.

Fig. 1 – Fig. 2

DISCUSSION

To date very few researches have been conducted on the **biomechanical** profile of Paralympic athletes¹³, and none reported quantitative biomechanical data concerning martial arts, despite their global spread. To partially fill this gap, in our study **we evaluated** an elite Paralympic karateka, with serious lower limb impairments, ~~was evaluated~~ and **we compared** his kinematics ~~was compared~~ **features** with those of able-bodied athletes.

CoM kinematics

In *kata*, likewise the correct execution of techniques, balance control represents the main performance factor for athletes' evaluation^{2,5,15}. The karateka's dynamic balance should be maintained during constant and rapid movements.

Dynamic balance has been demonstrated to be strongly related with CoM position and displacement²⁴. In Paralympic karateka, lower limb impairments could influence CoM displacement, velocity and acceleration, **affecting the whole-body postural control**.

The current study revealed that the duration of the sequence performed by the karateka was considerably longer than that of healthy Masters and Practitioners. We ~~can~~ hypothesize that a complex sequence of movement, such as the selected *kata*, requires more time to be executed by a disabled athlete. Indeed, lower limb impairments can modify patterns of movement and decrease the velocity of displacements, consequently increasing the time required to perform the whole sequence.

CoM height and vertical displacement were similar to those of elite athletes: the karateka preserved his ability to control static balance adjustments. On the other hand, CoM average velocity and acceleration ~~decreased~~ **were lower**. Since the angular acceleration is ~~theoretically~~ proportional to the resultant ~~torque~~ **power at the joint**, this trait is probably the consequence of

the ~~powerlessness~~ inability of calf muscular area to express normal ~~moments-of-force~~ levels of power. Therefore, dynamic balance together with the ability of moving the CoM in space with a high-power rate could be negatively affected.

Knee kinematics

In karate, techniques are performed much faster than in ~~any~~ other martial arts³, requiring high levels of speed and agility². A high grade of muscular power is needed during kicking actions. Moreover, elevate joints angular velocities during these movements are essential features for elite karateka²⁵.

Considering that the knee was the joint mainly affected by the disability, notable differences were expected. RoM values for both knees were similar between the Paralympic karateka and Practitioners, also taking the great variability of amateurs' parameters into account. Comparing the same parameters with Masters', a decrease of 12% for both knees occurred. In particular, considering step 4, a transitional phase from a forward punch to a blocking technique using the left limb as a single support, the right knee was considerably less flexed than both in Practitioners and Amateurs. Since the karateka executed the movement during a unipedal stance, it should be reasonable that the knee of the swinging leg was less flexed to maintain the right foot closer to the base of support. This could be a strategy to oppose the loss of control during the single limb stance, probably due to the weakness of the support leg.

~~Analyzing~~ Concerning the peak angular velocity, we can notice the same behavior of RoMs. Besides a high variability, the Paralympic karateka had quite similar results compared to Practitioners, while he showed a clear reduction of his physical performance when a comparison with Masters was done. Bearing in mind the similar exposure to practice (20 vs. 17 years)¹⁵, we can state that the strong reduction of calf muscular tissue had negatively affected the performance, entailing reduction of RoMs and slowness of knee movements.

Knee kinematics is crucial in high level *kata* punching and kicking techniques¹⁸⁻²¹. Thus, a recommended purpose for physical therapists and karate coaches, working with Paralympic athletes, should be to recover, as much as possible, acceptable levels of strength and RoM at the joint. Exercises improving joint mobility, during rehabilitation phase and practices, should allow to increase knee flexion and thus maintain CoM lower during movements, enhancing dynamic balance. Moreover, trainers should aim to retrieve leg extensors muscular strength, preserving at the same time a normal hamstrings-to-quadriceps ratio to avoid injuries and asymmetries²⁶.

The study has some limitations. Firstly, the peculiarity of the athlete's physical impairments has not allowed a collection of data on a larger sample. Moreover, we didn't measure muscular

force output or muscular activation. Finally, to compare the karateka's values with data from the previous study, some joints were excluded from kinematic computations.

CONCLUSION

In this study, whole body kinematics of a Paralympic elite karateka was analyzed and compared to the same parameters of able-bodied athletes. The physical impairments of the assessed athlete negatively affected his of lower limbs function in the karateka, decreasing negatively altering key factors for *kata* performance, like dynamic balance control and knee joints RoMs and angular velocity.

Since Paralympic categorization for karate is already in process, this case report could support a better classification and encourage further biomechanical studies on disabled athletes.

NOTES

Acknowledgements

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Disclosure

The authors have no conflicts of interest to declare.

Authors' contributions

All authors meet the criteria for authorship established by the International Committee of Medical Journal Editors.

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TABLES

Table 1: Paralympic Karateka kinematic values (mean±SD) and statistical significance (one-sample t-test) of differences with able-bodied groups

CoM kinematics		<i>p</i>		Knee kinematics		<i>p</i>	
		Masters	Practitioners			Masters	Practitioners
CoM height (% of body height)	47.13 ± 3.54	0.877	0.007	Right knee RoM (rad)	1.41 ± 0.08	0.075	0.259
CoM horizontal displacement (m)	2.96 ± 0.10	0.009	0.004	Left knee RoM (rad)	1.81 ± 0.13	0.003	0.250
CoM vertical displacement (% of body height)	13.45 ± 0.76	0.489	0.355	Right knee peak angular velocity (rad/s)	10.14 ± 0.64	0.027	0.864
CoM average velocity (m/s)	0.44 ± 0.08	<0.001	0.495	Left knee peak angular velocity (rad/s)	16.12 ± 1.98	0.005	0.303
CoM rms acceleration (m/s ²)	3.63 ± 0.53	0.053	0.053				

Abbreviations: CoM, center of mass; RoM, range of motion; rms, root mean square

TITLES OF FIGURES

Figure 1 Median Mean of Masters (circles) and Practitioners (squares) and 95% Confidence Intervals (bars) relative to the percentage change of CoM kinematic variables, taking the Paralympic karateka values as reference (0%). Negative values express a decrease while positive values express an increase, compared to Paralympic karateka values

Figure 2 Median Mean of Masters (circles) and Practitioners (squares) and 95% Confidence Intervals (bars) relative to the percentage change of knee kinematic variables, taking the Paralympic karateka values as reference (0%). Negative values express a decrease while positive values express an increase, compared to Paralympic karateka values

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ABSTRACT

Karate is a martial art that include striking, kicking and punching techniques, and requires high levels of functional skills. Karate counts millions of practitioners worldwide and it is also spreading in Paralympic competitions: there is a need for accurate categories definition for disabled athletes. The aim of the current study was to present kinematic data of an elite Paralympic karateka, in comparison with able-bodied athletes, to promote a better classification within the discipline, based on objective evaluations of physical impairments. A male black belt Paralympic karateka (age: 36 years; body weight: 75.5 kg; height: 173 cm) with lower limbs impairments was evaluated. He performed a standardized sequence of movements (kata) from *Shotokan* karate. Joints and center-of-mass kinematics were collected with an optoelectronic motion capture system and compared with those obtained in two groups of able-bodied (Masters and Practitioners) athletes from a previous study. The sequence performed by the karateka lasted longer than in both able-bodied groups. Center of mass velocity and acceleration lowered in comparison with Masters. Knees range of movement and peak angular velocity were similar to Practitioners but lower than Masters. We concluded that physical impairments negatively affected the function of lower limbs in the Paralympic athlete, as fundamental skills in karate elite performance (dynamic balance control and joint angular velocity) were lower.

Keywords: martial arts, adapted physical activity, sport biomechanics, disability, motion capture.

INTRODUCTION

Karate is a Japanese martial art that originated in the island of Okinawa and spread worldwide following World War II. Nowadays the World Karate Federation (WKF) claims that Karate has more than 100 million practitioners in 194 national federations around the world. Moreover, the International Olympic Committee (IOC) has recently included karate competitions as an additional sport in the upcoming Tokyo 2020 Olympic Games program.

Karate competition consists of *kumite*, competitive sparring, and *kata*, an exhibition of forms involving sequences of offensive and defensive movements targeting a virtual opponent¹. These movements include mainly striking, kicking and punching techniques and require high levels of functional and motor abilities². During a conventional fight system, conducted within a sustained endurance regimen, the karateka highly increase their ventilation and blood pressure³. Furthermore, continuative karate training improves physical qualities including flexibility, strength, balance and cardiorespiratory fitness⁴⁻⁷.

Recently, consideration for adapted physical activity (APA) for people with physical or cognitive impairments increased, alongside with the inclusion of Paralympic disciplines in national sport federations. In addition, some studies regarding elite Paralympic athletes have been published⁸⁻¹².

To date, among oriental martial arts, only Judo and Taekwondo entered the Paralympic Games program. However, WKF has been working since 2006 to create para-karate, with competitions involving athletes with various disabilities. In 2015 WKF has also been recognized as a member by the International Paralympic Committee.

Biomechanical analyses can highlight the residual functional ability of athletes and provide an evidence-based classification in Paralympic sports, showing how physical impairments influence activity and sport performance¹³. One of the main factor affecting performance in *kata* competition is dynamic postural control, represented by the kinematic analysis of the body Center of Mass (CoM)^{2,5,14,15}. Information about CoM displacement, velocity and acceleration during Karate techniques execution offer a general description of whole-body movements and reflects athletes' ability and experience^{1,15-17}.

Moreover, some studies identified knee movements as crucial factors for enhancing performance in both punching and kicking *kata* techniques¹⁸⁻²¹.

Despite the determinants of kata performance were extensively discussed in the actual body of literature, no studies currently reported data regarding the biomechanics of Paralympic karate. In fact, some studies reported differences between elite athletes and practitioners^{13,14}, but to

date no one has presented a comparison between high level Paralympic and able-bodied karateka.

Therefore, the purpose of this study was to evaluate body kinematics of an elite Paralympic karateka (national champion), comparing his data to those collected in a previous study conducted on able-bodied karateka¹⁵.

The findings of this work could be useful both for karate coaches and physical therapists in improving their training and rehabilitation strategies for Paralympic athletes.

CASE REPORT

Participant

Kinematic assessment was accomplished on a 36-year-old male black belt Paralympic karateka (body weight: 75.5 kg; height: 173 cm). He was a member of Federazione Italiana Judo Lotta Karate Arti Marziali (FIJLKAM, affiliated to WKF) and national champion of para-karate individual *kata*. Furthermore, he took part in several international competitions of para-karate. His physical disability was caused by complications after surgical operations, due to tendons laxity in his lower limbs. At the moment of evaluation, the main impairment was a complete bilateral gastrocnemius and soleus atrophy, that caused a notable decrease in knee and ankle mobility and force output. The athlete had been performing high level karate for 20 years before the disability took place, with 5/ to 6 training sessions per week. After the post-operative rehabilitation, he attended 3/ to 4 sessions of para-karate training per week.

The karateka signed an informed written consent; the study was approved by the local Ethics committee and met the current ethical standards in sports and exercise research, according to Helsinki Declaration.

Kinematic parameters were compared to those obtained in a previous investigation, conducted with analogous procedures on 10 able-bodied black belt karateka divided in two groups: Masters (elite karateka, members of the Italian national team), and Practitioners (non-elite, amateurs karateka)^{1,15}.

Procedures

The karateka performed seven repetition of the same *kata* performed in the previous study, defined by an experienced Master of *Shotokan* karate, to allow a comparison with able-bodied athletes. In short, movements composing the sequence of 11 steps were chosen among the fundamental techniques of traditional *Shotokan* karate¹⁵. Before trials, the karateka warmed up with his coach. The sequence was performed at maximum effort; between repetitions, full recovery was conceded.

The 11-steps sequence was performed along three directions (forward advancement, right backward displacement and left advancement) and included advancement and backward positions, blocks, punches, and a circular kick with the left leg.

Twenty-three body markers (diameter: 15 mm) were placed on the skin at the following landmarks: right and left tragon, acromion, olecranon, radius styloid process, anterosuperior iliac spines, great trochanter, femoral lateral epicondyle, lateral malleolus, heel, toe, glabella, spinous process of the 7th cervical vertebra, sacrum. The three-dimensional coordinates of each landmark were recorded at 120 Hz by an optoelectronic motion capture system (BTS Smart-E, Milano, Italy). The markers coordinates were filtered with a 15 Hz, low-pass, 2nd order Butterworth filter. The 11 events defining the timing of to each *kata* technique were manually located using the motion capture software. Sequence duration was calculated between the first and the last event.

Knee flexion angles were computed under the simplifying assumption of 1-degree-of-freedom joints. Angular range of motion (RoM) during the sequence and peak angular velocity were obtained to provide a complete joints motion description.

CoM coordinates were estimated using the Segmental Centroid Method²³. CoM height and vertical displacement were computed as the mean of the values over the entire *kata* and normalized to the body height. Horizontal displacement was expressed as the sum of all movements of the CoM projection on the horizontal plane. CoM average velocity was calculated over the whole sequence, as well as CoM acceleration, expressed by the root mean square (rms) of the relative track.

Statistical analysis

Each kinematic parameter regarding the Paralympic karateka was expressed as the mean over trials. Kinematic variables for Masters and Practitioners were presented as group mean together with 95% confidence intervals (CI). To assess differences between Paralympic karateka and able-bodied groups, the one-sample t-tests were performed. Significance level was set at 5% ($p < 0.05$).

RESULTS

The duration of the *kata* sequence performed by the karateka was significantly longer than those of both Masters and Practitioners (6.51 s vs. 3.33 s, $p < 0.001$ and 3.96 s, $p = 0.012$ respectively). Table 1 lists CoM and knee kinematics of Paralympic karateka compared with able-bodied groups.

Table 1

Figures 1 and 2 show CoM and knee kinematics results. Masters and Practitioners data are displayed as percentage increment or decrement from the Paralympic karateka mean values, taken as reference, together with 95% CIs.

When compared to elite karateka, CoM average velocity was 73% lower ($p<0.001$) and acceleration was 21% lower ($p=0.053$). Additionally, knee RoM and peak angular velocity were significantly lower, except for right knee RoM.

Fig. 1 – Fig. 2

DISCUSSION

To date very few researches have been conducted on the biomechanical profile of Paralympic athletes¹³, and none reported quantitative biomechanical data concerning martial arts, despite their global spread. To partially fill this gap, in our study we evaluated an elite Paralympic karateka, with serious lower limb impairments, and we compared his kinematics features with those of able-bodied athletes.

CoM kinematics

In *kata*, likewise the correct execution of techniques, balance control represents the main performance factor for athletes' evaluation^{2,5,15}. The karateka's dynamic balance should be maintained during constant and rapid movements.

Dynamic balance has been demonstrated to be strongly related with CoM position and displacement²⁴. In Paralympic karateka, lower limb impairments could influence CoM displacement, velocity and acceleration, affecting the whole-body postural control.

The current study revealed that the duration of the sequence performed by the karateka was considerably longer than that of healthy Masters and Practitioners. We hypothesize that a complex sequence of movement, such as the selected *kata*, requires more time to be executed by a disabled athlete. Indeed, lower limb impairments can modify patterns of movement and decrease the velocity of displacements, consequently increasing the time required to perform the whole sequence.

CoM height and vertical displacement were similar to those of elite athletes: the karateka preserved his ability to control static balance adjustments. On the other hand, CoM average velocity and acceleration were lower. Since the angular acceleration is proportional to the resultant power at the joint, this trait is probably the consequence of the inability of calf

muscular area to express normal levels of power. Therefore, dynamic balance together with the ability of moving the CoM in space with a high-power rate could be negatively affected.

Knee kinematics

In karate, techniques are performed much faster than in other martial arts³, requiring high levels of speed and agility². A high grade of muscular power is needed during kicking actions. Moreover, elevate joints angular velocities during these movements are essential features for elite karateka²⁵.

Considering that the knee was the joint mainly affected by the disability, notable differences were expected. RoM values for both knees were similar between the Paralympic karateka and Practitioners, also taking the great variability of amateurs' parameters into account. Comparing the same parameters with Masters', a decrease of 12% for both knees occurred. In particular, considering step 4, a transitional phase from a forward punch to a blocking technique using the left limb as a single support, the right knee was considerably less flexed than both in Practitioners and Amateurs. Since the karateka executed the movement during a unipedal stance, it should be reasonable that the knee of the swinging leg was less flexed to maintain the right foot closer to the base of support. This could be a strategy to oppose the loss of control during the single limb stance, probably due to the weakness of the support leg.

Concerning the peak angular velocity, we can notice the same behavior of RoMs. Besides a high variability, the Paralympic karateka had quite similar results compared to Practitioners, while he showed a clear reduction of his physical performance when a comparison with Masters was done. Bearing in mind the similar exposure to practice (20 vs. 17 years)¹⁵, we can state that the strong reduction of calf muscular tissue had negatively affected the performance, entailing reduction of RoMs and slowness of knee movements.

Knee kinematics is crucial in high level *kata* punching and kicking techniques¹⁸⁻²¹. Thus, a recommended purpose for physical therapists and karate coaches, working with Paralympic athletes, should be to recover, as much as possible, acceptable levels of strength and RoM at the joint. Exercises improving joint mobility, during rehabilitation phase and practices, should allow to increase knee flexion and thus maintain CoM lower during movements, enhancing dynamic balance. Moreover, trainers should aim to retrieve leg extensors muscular strength, preserving at the same time a normal hamstrings-to-quadriceps ratio to avoid injuries and asymmetries²⁶.

The study has some limitations. Firstly, the peculiarity of the athlete's physical impairments has not allowed a collection of data on a larger sample. Moreover, we didn't measure muscular

force output or muscular activation. Finally, to compare the karateka's values with data from the previous study, some joints were excluded from kinematic computations.

CONCLUSION

In this study, whole body kinematics of a Paralympic elite karateka was analyzed and compared to the same parameters of able-bodied athletes. The physical impairments of the assessed athlete negatively affected his lower limbs function, negatively altering key factors for *kata* performance, like dynamic balance control and knee joints RoMs and angular velocity.

Since Paralympic categorization for karate is already in process, this case report could support a better classification and encourage further biomechanical studies on disabled athletes.

NOTES

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Disclosure

The authors have no conflicts of interest to declare.

Authors' contributions

All authors meet the criteria for authorship established by the International Committee of Medical Journal Editors.

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TABLES

Table 1: Paralympic Karateka kinematic values (mean±SD) and statistical significance (one-sample t-test) of differences with able-bodied groups

CoM kinematics		<i>p</i>		Knee kinematics		<i>p</i>	
		Masters	Practitioners			Masters	Practitioners
CoM height (% of body height)	47.13 ± 3.54	0.877	0.007	Right knee RoM (rad)	1.41 ± 0.08	0.075	0.259
CoM horizontal displacement (m)	2.96 ± 0.10	0.009	0.004	Left knee RoM (rad)	1.81 ± 0.13	0.003	0.250
CoM vertical displacement (% of body height)	13.45 ± 0.76	0.489	0.355	Right knee peak angular velocity (rad/s)	10.14 ± 0.64	0.027	0.864
CoM average velocity (m/s)	0.44 ± 0.08	<0.001	0.495	Left knee peak angular velocity (rad/s)	16.12 ± 1.98	0.005	0.303
CoM rms acceleration (m/s ²)	3.63 ± 0.53	0.053	0.053				

Abbreviations: CoM, center of mass; RoM, range of motion; rms, root mean square

TITLES OF FIGURES

Figure 1 Mean of Masters (circles) and Practitioners (squares) and 95% Confidence Intervals (bars) relative to the percentage change of CoM kinematic variables, taking the Paralympic karateka values as reference (0%). Negative values express a decrease while positive values express an increase, compared to Paralympic karateka values

Figure 2 Mean of Masters (circles) and Practitioners (squares) and 95% Confidence Intervals (bars) relative to the percentage change of knee kinematic variables, taking the Paralympic karateka values as reference (0%). Negative values express a decrease while positive values express an increase, compared to Paralympic karateka values