COMBAT SPORTS

Kerstin Witte

OTTO-VON-GUERICKE-UNIVERSITY MAGDEBURG, GERMANY

Summary

The beginning of this chapter gives an overview of the structures and disciplines of combat sports, as well as samples of combat-specific performance requirements. In contrast to many other sports, only a few authors have focused on performance analysis in combat sports. Known methods and results of several topics of performance analysis (analysis of techniques, modelling and investigation of stress, energy cost, match analysis, and anticipation) will be presented for karate, judo, taekwondo, boxing, and others. The potential to apply these topics to the other combat sports, as well as required modifications, will also be discussed.

Introduction – structure, disciplines of combat sports and performance requirements

Combat sports, specifically martial arts, are characterized by a great manifoldness and have a long history. Their geographical roots can be found in the Asiatic countries: Japan (aikido, judo, ju-jitsu, kendo, iaido, karate, and sumo), China (hung kuen, praying mantis, tai chi chuan, shaolin, jeet kune do, and wing tsun), Korea (taekwondo, hap-ki-do, and taek-kyon), Thailand (muay thai), and others. Many of their sports and arts are practised in Europe and are modified in relation to European tradition and sports rules. One has to distinguish two types: duel (two combatants fight against each other using certain rules of engagement, e.g. kumite in karate) and kata (term referring to a pattern of defence and attack). Further classifications in reference to techniques are: striking (boxing, kick-boxing, full-contact karate, taekwondo), grappling (judo, Brazilian jiu-jitsu, many forms of wrestling), hybrid (shoot boxing, mixed martial arts), and weapons (fencing, kendo, wushu). The focus of this chapter will be on the modern competitive combat sports.

Success in combat sports is influenced by the following factors: coordination, especially exactness and speed of techniques, condition, tactics, and mental load capacity. Many authors focus on condition; McGuigan et al. (2006) found that wrestling is a unique combative sport that places high metabolic demands on the body. For instance, isometric strength is a determinant for successful and less successful athletes. An example of a particular requirement for training methods is the execution of techniques with and without contact. Neto et al. (2007) and Neto et al. (2009) detected differences in the muscle activity by means of surface EMG, which is also a special method in performance analysis. A higher muscle activity could be found...
in strikes with contact, which is justified by a greater psychological motivation and the need for stabilization of the joints during the impact. Another result showed lower electromyography median frequencies for strikes with impact compared to ones without impact. For strikes without impact, this can be an indication of a better synchronization of the motor units.

But systematic studies have not been undertaken for all factors influencing performance in combat sport. In this chapter, a survey of special research studies for single combat sports and some of the author’s own results are presented. In the conclusion, possible knowledge transfer to other combat sports is discussed.

General and specific methods of performance analysis in combat sports

Although it is well-known that mental strength is an important factor influencing the decision on the winner (e.g. a study on kick-boxing by Devonport, 2006, and a study on wushu by Kuan and Roy, 2007), psychological test procedures have generally not been applied. In contrast, measurements of muscle strength are widespread. On the basis of their research, Roschel et al. (2009) concluded that international-level karate players’ kumite match performance is influenced by upper- and lower-limb power. The hand-grip strength of judo athletes can be determined by a static and dynamic judogi strength test (Franchini et al., 2011). In particular, dynamic grip strength endurance seems to be a discriminating variable between judo athletes.

Franchini et al. (2009) and Boguszewska et al. (2010) recommended the inclusion of the following items for an optimal training control: biomechanical measurements, physical fitness tests, and special fitness tests for each discipline. The results of an examination with judo athletes showed a significant correlation between the index of special judo fitness test and the absolute and relative power output and velocity in the maximal cyclometer test. The load index is defined by the quotient of the sum of the final heart rate and the heart rate after one minute of the test, divided by the number of throws (ippon seoi nage). Similar sport-specific tests were proposed by Sterkowicz and Franchini (2009) for karate and by Sterkowicz-Przybycien (2009) for ju-jitsu.

Analysis of technique

Movement coordination is an important factor for effective execution of attacks and defence. Several methods have been established to analyse these techniques. Imamura et al. (2006) accomplished a three-dimensional kinematical analysis and determined the impulses and momentum of three judo throws: harai-goshi, seoi-nage, and osoto-gari. Based on this, it is possible to gather information about the effectiveness of the behaviour between uke (the person who ‘receives’ a technique) and tori (meaning ‘to take’, ‘to pick up’, or ‘to choose’) in relation to the phases (kuzushi, tsukuri, kake). However, these imprecise results were produced by the use of only two cameras, with a sample rate of 60 Hz, as well as manually determined position of the joints. Of special interest are the differences between body mass velocities in the temporal course of both judokas in comparison with training and competition (Imamura et al., 2007).

The use of motion-capture systems with automatic recognition of markers (e.g. the Vicon system, Vicon, Centennial, Colorado) allows the analysis of fast and complex movements. In order to examine the effectiveness of two executions, Camomilla et al. (2009) analysed the jump of the karate kata ‘unsu’ additionally with surface EMG.

Kinematical investigations are supplemented by measurements of force and acceleration. Examples are analyses of kicks in taekwondo and yongmudo (O’Sullivan et al., 2009) and
estimation of effectiveness of several attacks from kung fu using load cell, accelerometers, and high-speed video (Bolander et al., 2009). In this way, Bolander et al. (2009) discovered relationships between acceleration and force under different striking conditions (strike distance, type of strike, and height of target).

The most often used in-flight kick is the roundhouse kick. Wasik (2010) characterized the kinetics of a roundhouse kick in taekwondo by means of three-dimensional motion capture. The first stage contains the rotation of the torso, which accelerates the leg. In the second stage, the knee joint is straightened until it reaches the target. Wasik (2010) detected that the dynamics of the kick depends on the velocity of the foot and the rotation moment of the arms, whereas the speed and acceleration of the jump influence the duration of the kick. Emmermacher et al. (2007) analysed the foot trajectories of different variations of the roundhouse kick ‘mawashi-geri’ in karate. From the statistical results, it was concluded that the foot trajectory is shorter when the technique is executed by the front leg than by the rear leg. A higher velocity of the ankle is found for the variant with the kicked rear leg. The purpose of the study by Witte et al. (2007) was to identify similarities and differences of various roundhouse kicking techniques in karate in terms of kinematic characteristics. On the basis of the ankle velocity–time-courses of the supporting leg and the kicking leg, an objective phase structuring was given (see Figure 33.1). The subject executed variations of the mawashi-geri and the ura-mawashi-geri. General and individual distinctions were found in relation to the temporal structures of the movements. A characteristic of mawashi-geri (front leg) is the appearance of two maximum values of the ankle (kicking leg) velocity, whereas the relation between them is dependent on the subject. The shortest movement times were found for the mawashi-geri with front leg for all three analysed subjects.

Because kicks and other techniques in combat sports are very complex, many biomechanical parameters are necessary to estimate the similarities between these movements. To consider the whole movement, a possibility is to use nonlinear procedures. Unfortunately, there is no relation to the single biomechanical parameters given. Hence, Witte et al. (2010) presented a procedure of visualized movement patterns, which allows a subjective impression of the total movement coordination (see Figure 33.2), and in addition further analyses, by means of statisti-

---

**Figure 33.1** Velocity–time-courses of the ankles of mawashi-geri with the front leg. The time points \( (t_1-t_5) \) represent essential movement points: \( t_1-t'_1 \): preparatory or introductory phase by supporting leg, \( t_2-t_3 \): start-up phase of the thigh of the kicking leg, \( t_3-t_4 \): snapping phase of the lower leg, \( t_4-t_5 \): returning to a balanced stance (source: Witte et al., 2007)
K. Witte

cal tools, confirmed similarities and variability between the movements. Based on this, advice for training optimization can be given.

Modelling and investigations of stress

Baker and Davies (2006) established that the maximum performance on a bicycle ergometer for international karate practitioners depends more on fat-free mass than on body mass index. A simple variant to observe overstress in joints uses a high-speed video. Witte and Emmermacher (2009) discovered an overstretching of the elbow joint and wrist of elite karatekas. A method to estimate the joint stress is biomechanical modelling. Simulations can be used, based on the biomechanical model, in order to find the optimal movement exercise. Witte and Jackstien (2008) modelled the karate kick mae-geri and stepping movements. The full-body human model was created using the ADAMS software package (Multibody Dynamics Simulation) with its LifeMOD plug-in using the Plug-in-gait marker set. To determine the input data and control parameters, extensive investigations were necessary (cf. Witte and Jackstien, 2008). For mae-geri, it is necessary to distinguish between the supporting leg and the kicking leg. While the supporting leg is loaded by the body weight, the kicking leg is loaded by the acceleration and deceleration during movement and the demanded inertia force. Figure 33.3 shows the calculated forces of the knee for both legs. It can be seen that, for the knee of the supporting leg, the greatest values occur at the beginning of the movement; that means in the phase of raising the leg. However, for the kicking leg, we find the greatest stress in the stretching phase, when the foot reaches the target.

Table 33.1 shows the simulated forces and torques (maximum values) of the ankles for uniform and non-uniform step-movements which are common in karate-kumite competition for one karate fighter. As expected, the highest joint loads occur for the non-uniform steps in relation to the transverse component.
It can be assumed that there is a relationship between energy cost and the execution of combat sport techniques, for example, in judo. Franchini et al. (2005) established that blood lactate after general (arm Wingate test) and specific (Special Judo Fitness Test) tests correlated with blood lactate after combat, indicating the similarity of metabolic demands in these events. Lech et al. (2010) proposed that the level of anaerobic capacity plays a specific role in the course of the fight between judo athletes. Individual functional abilities of judo competitors should be taken into consideration during technical and tactical training. In general, elite judo athletes presented higher upper body anaerobic power and capacity than non–elite athletes. Although aerobic power and capacity are crucial for judo performance, the available data do not reveal differences between judo athletes of different competitive levels (Emerson et al., 2011). Typical maximal oxygen uptake values for male athletes are around 50–55 ml.kg$^{-1}$.min$^{-1}$, and 40–45 ml.kg$^{-1}$.min$^{-1}$ for female judo athletes (Emerson et al., 2011). Santos et al. (2010) designed a specific,
simple and non-invasive field test to determine the individual aerobic–anaerobic transition zone in judokas. In this test, which is as close as possible to a real judo combat, the judoka has to perform a determined judo technique in a certain time while a portable gas analyser records spirometric data. Santos et al. (2011) checked the validity of the test in relation to a laboratory test. However, Almansba et al. (2010) warned against overstating the importance of \( \text{VO}_2\text{max} \) because this parameter can vary in between individual training periods and hence cannot be considered a physiological indicator determining the competition level of each judoka.

Blood lactate measurements and spirometrical research have also been carried out in taekwondo (Matsushigue et al., 2009) and wrestling (Karminčić et al., 2009). Beekley et al. (2006) compared the maximum oxygen uptake of several sports with sumo wrestling. They found that sumo wrestlers have a lower \( \text{VO}_2\text{max} \) than athletes from other sports. One reason may be the large fat mass of these athletes.

Nunan (2006) developed an aerobic fitness assessment test for competitive karate practitioners, wearing a portable spirometrical device. A protocol simulating common attack strikes used in competitive karate sparring was developed from video analysis. In addition, a specific sequence of strikes and timings for the test was created out by means of a pilot study. Anecdotal reports revealed that the new test accurately simulates the actions which are used in competitive karate (Nunan, 2006). Witte and Emmermacher (2011) determined spirometrical data during karate-kumite competition under training conditions. The results of the three calculated energy balance components revealed that 60 to 80 per cent of aerobic capacity was used. This agrees with the results of Beneke et al. (2004) and Doria et al. (2009) and should be taken into account during the training process. Based on video and synchronous recording of applied techniques, the coach can conclude energetic reserves of the workout of the athlete.

**Match analysis**

Today, video-based equipment is often used for analysing sport activities. During a judo competition, special forms give information about the executed attacks or actions and their efficiency (Adam et al., 2011). Silva et al. (2011) analysed the time structure of muay thai and kick-boxing, focusing on three levels of effort: observation, preparation, and interaction. Ashker (2011) researched technical and tactical aspects that differentiate between winning and losing performances in boxing. He found that winners were more highly developed than losers in performing offensive skills directed to the head or body, total, lead and rear hand punches, boxing combinations, defensive skills, and technical performance effectiveness.

Marcon et al. (2010) performed a video analysis by means of the self-developed judo analysis software Saats™ (Structural Analysis of Action and Time in Sports), which computes the precise duration of actions, allowing analysis of the following actions: break, grip, technique, fall, and groundwork. It was concluded that the use of this computer software for notational analysis in judo greatly assists in detailing the actions performed by athletes.

In summary, it can be concluded that no systematic match analysis software exists. One example of a video-based software package for karate-kumite has been described by Emmermacher et al. (2010). After loading a video sequence into the program, the user can select the frame and the point of time of the actual event (attack or others) by a key press. A statistical analysis and the creation of a database of the athlete are parts of the match analysis. In the first feasibility study, 16 fights from the under 63 kg weight division for youth (male), 15 fights from the under 52 kg (male), and 11 fights from the open class (male) were analysed to find out which techniques are the most often used in each respective weight class. The results showed that hand techniques, especially gyaku-zuki, are most often used for attacks (up to 60 per cent).
Boguszewski (2011) defined and determined the effectiveness of defensive actions applied in judo. All actions, including attacks, counter-attacks and defence without counter-attack, were recorded and their effectiveness, preparatory actions, breaks, and the referees’ decisions were evaluated. Boguszewski (2011) defined 12 different types of defence without counter-attack. For each technique, he determined the frequency of application and the effectiveness.

In the research study by Del Vecchio et al. (2011), performance analysis quantified the effort–pause ratio (EP) and classified effort segments of stand-up or groundwork to identify the number of actions performed per round in mixed martial art (MMA) matches. In consideration of the duration of the match, they found only one significant difference between rounds: time spent in groundwork at a low intensity was longer in the second round compared to the third round. Another result was the decrease of EP ratio (between high-intensity effort to low-intensity effort plus pauses) from 1:2 to 1:4 in accordance with other combat sports (judo, wrestling, karate, and taekwondo).

**Anticipation and perception**

Hristovski et al. (2006) used a nonlinear dynamical approach for decisions to punch a target. This theory shows that the behaviour of the fighter is influenced by many factors, including environmental, task, and individual constraints. This study focused on the importance of the distance between the boxer and the bag. A study by Wasik (2009) found that an attack (punch in taekwondo) with a duration of 0.1 s could not be prevented because of the reaction time of 0.2 s. So the anticipation of the attack is very important for the competitor. To determine the ability of anticipation and to improve the skill of observing movements, video-based test equipment was developed by Witte and Emmermacher (2010). This protocol contains a practical test and two PC tests in real time and slow motion. The protocol includes the following steps: video selection, creation of a subject database, single tests with analysis, a video database of athletes, several tests and analysis routines, and reports for the coach (see Figure 33.4). The results of

![Figure 33.4 Screenshot of the trainer mode to evaluate the practice test (source: Witte and Emmermacher, 2010)](image)
a pilot study showed that the gyaku-zuki and its variants, as well as combinations with other techniques, were the least anticipated techniques (Witte and Emmermacher, 2010).

To enhance a near-to-reality reaction of the athlete using a three-dimensional attacker, virtual reality technology has been developed using a measuring station. This is advantageous over a two-dimensional presentation of an attacker on a video screen or monitor (Witte et al., 2011). In this study, a virtual environment for karate was developed by means of a CAVE (Cave Automatic Virtual Environment). The results of a comparison between reality, video projection, and virtual reality based on participants’ reaction times to karate attacks showed shorter reaction times in the virtual environment than with the video projection. It was concluded that the virtual environment is more similar to reality than video projection and hence induces more realistic reactions in the athletes.

**Concluding remarks**

There is great diversity in performance analysis in combat sports. The reason for this is that each martial art has its own techniques and rules, meaning generalization is complicated. Nevertheless, the following conclusions can be drawn:

- Modern motion-capture systems allow three-dimensional analyses of techniques and should be used for their optimization.
- High-speed video allows the detection of faults in technique.
- It is worth considering whether nonlinear methods are suitable for analysing techniques of combat sport.
- Biomechanical analysis of joint loads can be carried out and the effectiveness of techniques can be estimated.
- Methods for determining energy balance are necessary for optimal training. The tests should be done while performing under near-to-competition conditions.
- Special software is necessary to simplify the work of the coach for match analysis and to populate a statistical database for each athlete.
- To improve anticipation, special measurement stations are necessary which allow the study of cues from attacks which are used for anticipation.

**References**


Combat sports


