DEVELOPMENT OF A REAL-TIME BIOFEEDBACK TOOL FOR MARTIAL ARTS COACHING PRACTICE

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Power and neural response are two vital elements in martial arts striking. Currently, there are no practical methods exist to present these aspects to practitioners in a training environment. Our study has developed one. Our method consisted of an optical signal system, EMG and 3D motion capture. The feedback provided was generated by a self-developed dynamic calculation programs using kinematics and EMG data as input. The results showed that our system provided both total power and its components (i.e. linear & angular) of a striking as well as the related response time. Since the method offers feedback of power intensity, attack accuracy, central and peripheral reaction time to practitioners in a quasi-training environment, it has great potential to become a real-time biofeedback tool in practice for increasing training efficiency and effectiveness.

KEY WORDS: Quantification, linear and angular power, attack accuracy, central and peripheral reaction time.

INTRODUCTION: Two fundamental principles of striking in many martial arts are power and speed. These two themes permeate one of the most famous martial artists – Bruce Lee. He stated that “power isn’t generated by your contractile muscles but from the impetus and speed of your arm or foot” and linked this to successful combat, saying that “All the strength or power you have developed... is wasted if you are slow and can’t make contact. Power and speed go hand in hand. A fighter needs both to be successful” (Lee & Uyehara, 1976). Such anecdotal evidence shows that power, speed and reaction time are clearly linked to the qualities of a martial artist.
These concepts have been investigated scientifically through various indirect and direct means (Cavanagh & Landa, 1976; Cesari & Bertucco, 2008; Filimonov et al, 1986; McGill et al, 2010; Pedzich, Mastalerz & Urbanik, 2006; Zehr, Sale & Dowling, 1997). Unfortunately previous studies provide partial perspectives on martial arts techniques due to some limitations that exist in various research approaches. The main limitations are lab-based and/or unwanted constrains induced by measurement technologies (i.e. quantification in a non-training enviroment). As such, there is a great need for real/quasi real life applications and measurement of motor skills similar to reality as desired by practitioners and athletes. The current authors propose to introduce such a method. The quantification was based on the strike timing, EMG measurement, 3D kinematic characteristics of the punching bag and striking limbs analyzed with self-developed programs. Reaction time was investigated by synchronizing the motion capture system with electromyography and a self-developed optical signal system. This allows for the breakdown of total reaction time into central or neural reaction and peripheral or muscular reaction. The whole setting has neglectible influence on athletes‘ performance. Our goal was to supply real-time feedbacks, such as punching and kicking power as well as related reaction for coaches and athletes in a quasi-training environment.

METHODS: When testing sport specific techniques, it is important that the environment closely resembles the real-life situations that the sport will encounter. The method used in this experiment employed an environment that would closely represent a typical training environment for a martial artist in order to allow for more ecologically valid, sport-specific biofeedback. The set-up consisted of a 3D motion capture system with 12 cameras (200 f/s 4x4 m^2 capture area, Fig.1), synchronized with wireless EMG measurement (1000 Hz) and a self-developed optical signal system. The EMG optical systems were used to determine the muscle response throughout the course of the movements. As such the set-up aimed to provide real-time biofeedback for the athlete and for the coach, in order to maximize the training effects of each session.

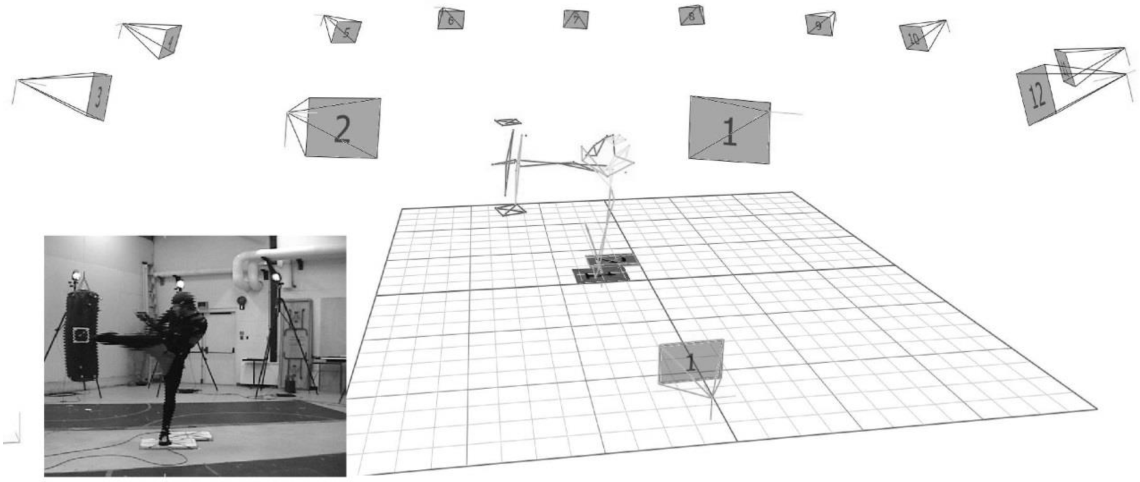

Figure 1: The set-up of synchronized 3D data collection.

Using retro-reflective 42 markers, a full body biomechanical model with 15 segments was built (Shan & Westerhoff, 2005), to determine kinematics of an athlete such as segmental angles and joint angles during a punch or kick. The fifteen segments in the biomechanical model were the head and neck, upper trunk, lower trunk, two upper arms, two lower arms, two hands, two thighs, two shanks and two feet. In addition, a standard punching bag (60 Lb or 27.3 kg) was fitted with 15 markers; eight of which were located on the top and bottom of the bag to provide the framework for the bag, and another seven markers, three vertical left markers, three vertical right markers and one front marker whose height was equivalent with the highest markers on the sides. The eight markers that provided the frame of the bag were used specifically to take the measurements required to determine the punching and kicking power of the athlete. The seven side markers corresponded to the targets of the most common strikes: left jab (left straight punch) and right straight punch to the head, hooks to the head and body as well as left and right kicks to the legs, body or head. They were used to test athletes' reaction by indicating to them the level of attack; high, middle or low through the optical signal system.

These target markers, combined with carefully placed striking markers on the middle knuckle of the glove and lower shin, allowed for the investigation of accuracy. The shin marker was placed at the lower third of the shank and then adjusted based on the subjects' preferred contact area. The height of the bag was standardized by hanging the bag so that the middle or body targets were at the same height as the subject's lowest lateral rib. The high/head and low/leg targets were placed at 20% of body height away from the midpoint marker, which was already located at the middle of the bag. The optical signal system consisting of three LED lights was initiated by a remote trigger controlled by the researcher. These lights were used to initiate the time of strike as well as to indicate to the subject the location of (or style of) strike. This data was integrated (synchronized) with the entire system. The lights were placed at the top of the bag at eye level without interfering with the targets. This allows for random selection of the strike within the chosen style and when combined with EMG and motion data allows for a thorough investigation of reaction time.

The 3D kinematics of the bag was also used to determine the linear power and the angular power, as well as the total power of a striking ($P_T = P_L + P_A$). The linear power is calculated by using $P_L = \vec{F} \cdot \vec{v} = F_1 v_1 + F_2 v_2 + F_3 v_3$, where $\vec{F}$ is the force vector applied on the punching bag and $\vec{v}$ is the velocity of the centre of the bag. $\vec{F}$ can be mathematically determined by the mass of the punching bag and the acceleration of the centre of the bag. Since the velocity and acceleration of the centre of the bag can be derived from the 3D motion capture data of the bag, the linear power of a strike can be obtained using the proposed set-up. Similarly, the angular power is determined by using $P_A = \overrightarrow{M} \cdot \vec{\omega} = M_1\omega_1 + M_2\omega_2 + M_3\omega_3$ where $\overrightarrow{M}$ is the moment applied on the punching bag and $\vec{\omega}$ is the angular velocity of the bag. $\overrightarrow{M}$ applied to the bag can be obtained by applying Euler equations below:

$$\begin{cases} M_1 = I_1\dot{\omega}_1 + (I_3 - I_2)\omega_2\omega_3 \\ M_2 = I_2\dot{\omega}_2 + (I_1 - I_3)\omega_3\omega_1 \\ M_3 = I_3\dot{\omega}_3 + (I_2 - I_1)\omega_1\omega_2 \end{cases}$$

Where, I_1, I_2 and I_3 are the moments of inertia of the bag (calculable) related to each axis respectively. ω_1, ω_2, and ω_3 represent the angular velocities, and $\dot{\omega}_1$, $\dot{\omega}_2$ and $\dot{\omega}_3$ represent the angular accelerations of the bag. These 6 variables can be derived from the 3D motion capture data of the bag. A program written in MATLAB was used to help determine the linear, angular and total power.

Using the synchronized measurement of EMG, optical system and 3D motion capture, we were able to break down the measured reaction time into two segments; central nervous system (CNS) response time and peripheral nervous system (PNS) response time. We found the CNS response time by measuring the time elapsed from the start of the stimulus (optical signal) until the beginning of the PNS response, which was measured using the EMG system to indicate the time where the initial muscle response occurred. We calculated this initiation of the muscle using the EMG envelope. The PNS response time was measured from the initiation of the muscle response until the point of initial contact of the distal end of a limb with the punching bag, which was captured using the 3-D motion capture system.

RESULTS: A sample of reaction time characterization using our method is shown in Figure 2. The figure shows that the subject measured has a longer CNS reaction time (CNSRT) than the PNS reaction time (PNSRT). His preparation for a hook (CNSRT) takes about two third of total reaction time (TRT).

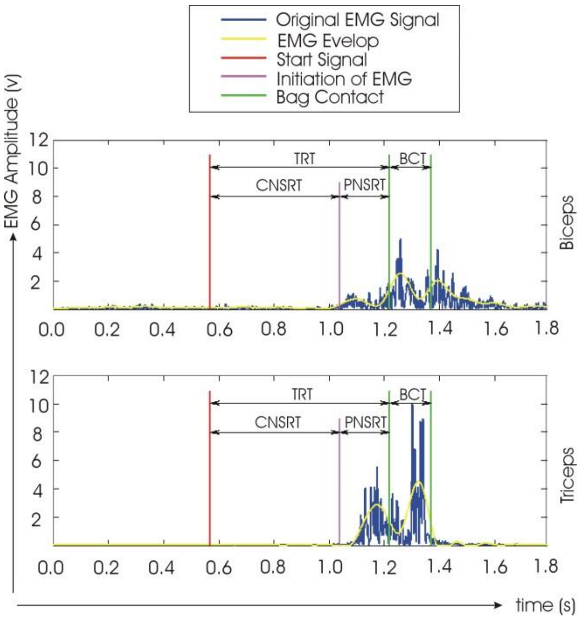

Figure 2: Quantification of reaction time using our synchronized device and EMG collection.

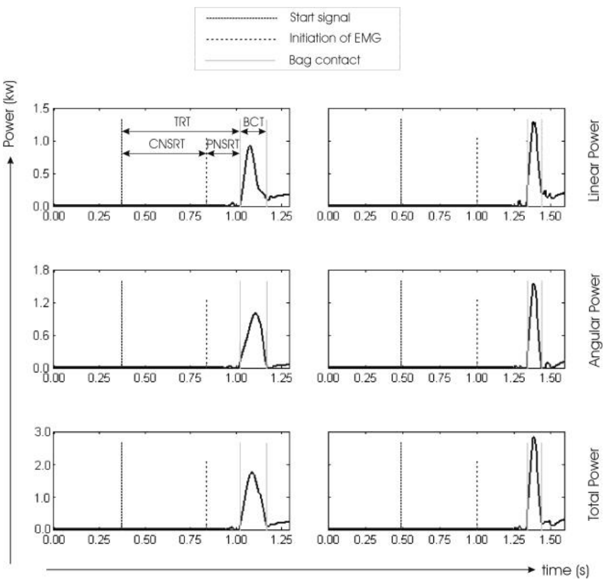

Figure 3. Typical power generation of an 84 kg athlete during a punch (right) and a hook (left).

A sample of power determination (both linear and angular power) using our method is shown in Figure 3. The figure contrasts the differences between a straight and a hook. As expected, a hook technique generated higher maximal power than a punch one, while a punch technique had longer bag contact time (BCT) than a hook one.

DISCUSSION: The sum of CNR and PNR of the response gives the overall reaction time to a given stimulus. As discussed previously, two factors that give a fighter the advantage in a fight are power and fast hands, or in other words, a quick reaction time. If a fighter can train to reduce his reaction time he will have an advantage in a fight. By separating this reaction time into two components; CNS reaction and PNS reaction, a fighter is able to concentrate his training to improve the component of his reaction time that needs the most work. A coach can be provided with real-time biofeedback on the fighter's strengths and weaknesses and is then able to set up a training program that would help the fighter to minimize his reaction time, but it also allows the coach to set up a fighting strategy that can maximize the strengths of the fighter.

When the developed method is applied in a real-time biofeedback environment, it can help practice in the following aspects. During such training, quick feedback of power generation, attack accuracy, central and peripheral reaction time on various offensive techniques could: 1) motivate athletes as their perspective of punching power and reaction time is simultaneously supplied, 2) improve athletes' perception system in order to develop competition strategies (e.g. avoid slower techniques if opponent has fast reactions), and 3) evaluate effect of various training methods or technique variances for training or skill optimization.

CONCLUSION: This study introduced an innovative method for quantifying power and neural response of martial arts striking in order to develop a real-time biofeedback training approach for practitioners. Such an approach provides quantifications of both total power and power components (i.e. linear & angular) of striking and the related response processes/time. The results demonstrated its great potential to become a biofeedback tool in practice.

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