

MOTOR CONTROL MECHANISMS AND THE PRACTICE OF KRAV MAGA — A NARRATIVE ANALYSIS

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Abstract Krav Maga ('contact combat') is an Israeli hand-to-hand combat discipline that originated in the early 19th century in response to life-threatening conflicts. Today, Krav Maga is a popular self-defense and martial art discipline practiced and taught throughout the world. One of the key features of Krav Maga that distinguishes it from other combat disciplines is its dependence on *reflexive defense* – a natural and immediate defensive reaction. However, the relevant literature has not discussed the motor control mechanisms that underlie reflexive defense in hand-to-hand combat or that account for its temporal characteristics. This introductory study argues that the reflexive defense at the core of Krav Maga is a genuine reflex mediated at the brainstem level. The paper also discusses some aspects of reaction in the context of self-defense and combat sports, and the implications for the debate on whether Krav Maga training should involve more than one combat response to any given threat.

Key words motor control, Krav Maga, reflexive defense, self-defense

Introduction

The term martial arts (MA) is commonly associated with Asian fighting arts, such as karate, kung fu, and taekwondo; however, surprisingly, the term is derived from Mars, the name of the Roman god of war, ergo the name 'Arts of Mars' which was used as early as the 1550s in Europe (Clements, 2006). Today, the term MA may also be used when referring to *combat sports* such as judo and *combat systems* from non-Asian locations such as the French savate (Loudcher, 2007) or the Russian sambo (DeMarco, 2016).

While combat disciplines, combat sports, and MA are varied and have many distinguishing aspects, including their goals, origin, culture, technical characteristics, and philosophy, they also share some similarities because their physical skills "all stem from using the body or weapons for combat purposes" (Johnson, Ha, 2015, p. 65). Accordingly, they all use self-defense techniques to overcome an opponent; thus, reaction time is a significant factor in determining the result of a match or confrontation (Gierczuk, 2017).

Combat systems may also be referred to as 'reality martial arts' or 'reality based fighting' when they focus on real-world situations (i.e. 'the street'), as in the case of the *Keysi Fighting Method* (Bowman, 2014), or are used for army and security purposes, such as *Systema*, which is a Russian combat system (DeMarco, 2016). Krav Maga, which is the scope of this paper, is a combat system originally developed to save lives in real combat situations; however, in recent years, it has also begun to be learned and practiced as an MA (Mor, 2018).

Krav Maga's origins may be traced back to the 1920s, when the current land of Israel was under British mandate and was part of the area known internationally as Palestine (Mor, 2019). Two rival communities shared the land: Jews and Arabs. These two communities were generally hostile to one another and engaged in frequent and violent physical confrontations fueled by cultural, political, and ideological differences. The use of guns and rifles was restricted by the British, so violent exchanges were usually limited to manual combat, knives, swords, stick fighting, and stone throwing (Gross, 2010).

A Jewish paramilitary organization (the Hagana) that was involved in these hostilities sought to develop an effective hand-to-hand combat method to counter these frequent physical threats after known methods such as jujitsu failed to save lives in real combat situations (Mor, 2019). One of Hagana's members, Dr. Moshe Feldenkrais, conducted photographic 'experiments' in which colleagues were subjected to surprise attacks with knives in order to observe their natural reactions. It was found that the combatants' spontaneous reactions were commonly to "substitute an arm for the head, the throat, the back" (Leri et al, 1977) to protect themselves. These responses are known today in Krav Maga terminology as *reflexive defenses* (Netzer, 2020; Vardi, 2020).

The combat system that was developed by Feldenkrais involved the learning and practicing of specific counter-attack routines, each designed to deal with a different type of attack. These routines were executed immediately after the reflexive defense was completed (Cohen-Gil, 2013). The idea of executing an initial unconscious response followed by an *acquired counter-attack routine* (ACAR) was to maintain a shorter reaction time than would be achieved by the initial unconscious reaction alone, while producing a more effective counter to the physical threat. Renden et al. (2017) demonstrated that "Police officers' performance in high-pressure arrest situations improved after reflex-based self-defense training." This improved performance was attributed, among other factors, to the conversion of primary responses into tactical movements. These findings are in line with Feldenkrais' approach of using reflexive defense together with ACARs for achieving tactical advantage in hand-to-hand combat.

The main focus of this paper is the examination of the motor control systems underlying the reflexive defense and the ACAR. In addressing this issue, we also shed light on a major debate that has arisen among instructors of Krav Maga: the question of whether training a single ACAR per threat is more effective than teaching several alternative responses per threat (from which the individual chooses the one that is most appropriate).

Mechanisms in motor control and essential definitions

Before exploring the operation of the motor control mechanisms, it is important to define some of the key terms and concepts:

Motor control refers to the neuromuscular activity responsible for the performance of a motor skill, i.e. the pattern of neural signals that activate and coordinate the muscles and limbs to produce movements (Anderson, 2010; Raiola, 2017). In general, human movements can be purposeful, directed, and coordinated or they can be spontaneous. Furthermore, they can be simple or complex. These movements are controlled by the central nervous system (CNS), which consists of the brain and spinal cord and is made up of three types of neurons: (1) sensory neurons which gather information and send it to the CNS, (2) inter-neurons which are found in the core of the CNS and process the information, and (3) motor neurons, which send neural impulses from the CNS to skeletal muscle fibers that can translate such impulses into movement (Anderson, 2010).

A *motor program* may be defined as a stored neural pattern which is used to control a specific and well-coordinated motor movement (Anderson, 2010). Such stored sequences are quite often compared to a computer

program. *Generalized motor programs* (GMPs) are variants of the movement-specific motor program that consist of an abstract, memory-based representation of the generic features of a class of actions, allowing practitioners to adjust the non-generic features to a changing situation while maintaining short response times (Keslo, 1997).

Motor learning deals with the process of acquiring motor skills, including the behavioral and/or neurological changes that occur while learning, and the variables that influence those changes (Anderson, 2010). Motor learning may be described as a continuous process of repetition and feedback of the same movement in order to create a motor program. However, the learning process may also involve (limited) variations in the patterns of movement, thus enabling the practitioner to optimize the process of learning itself and to develop a GMP for a given movement, rather than repeating precisely the same solution over and over again (Raiola, 2017).

A wide variety of *reflexes* in humans have now been identified. Among these are primitive newborn reflexes, such as the grasp reflex (Futagi, Suzuki, 2010), cranial reflexes (Hall, Chilcott, 2018), and tendon reflexes (Lees, Hurwitz, 2019), as well as other reflexes such as coughing or sneezing. The startle reflex, which causes a defensive response to a sudden or threatening stimulus, is the most relevant for this paper (Ramirez-Moreno, Sejnowski, 2012). While conscious and deliberate actions are processed at the cortical level (Kobesova, Kolar, 2014) and require a longer time to initiate (Valls-Solé, 1999), the neural pathways that subserve reflex responses are shorter and do not reach the cortical level. Instead, they are organized at the spinal and brainstem level (Kobesova, Kolar, 2014). Thus, the startle reflex center is located in the brainstem (Blumenthal, 2015) and has been shown to involve the amygdala, which is central to the perception and processing of emotions and to the response to external threats (including the mediation of defensive responses) (LeDoux, 2003). Humans portray the startle reflex in unconscious flexor defensive movements such as raising and drawing forward the shoulders, abducting the upper arms, or bending the elbows and knees, all executed in response to a sudden or threatening stimuli and potentiated by fear (Hamm, 2015).

Reaction time (RT) may be defined as the interval between the onset of a stimulus and the initiation of a response. *Movement time* (MT) is the interval between the initiation of a movement and its completion, and *response time* (ResT) is the sum of the RT and MT (Baayen, Milin, 2010).

A *simple reaction* happens when a person is required to initiate a single predetermined response to a defined specific stimulus such as light or sound. A *choice reaction* occurs when there are at least two possible stimulus response alternatives and the subject must choose the best response to the presented stimulus (Proctor, Schneider, 2018). Choice reactions entail longer RTs than simple reactions (Baayen, Milin, 2010).

Reaction in combat “is anything but simple” (Hermann, Scholz, Vieten, Kohloeffel, 2008, p. 419); it involves RT, choice reaction, and ResT (Gierczuk, 2018). Research indicates that many factors affect human RT parameters, including “age, sex, ... central versus peripheral vision, practice, fatigue, fasting, breathing cycle, personality types, exercise, and intelligence of the subject” (Jain, Bansal, Kumar, Singh, 2015, p. 124). As for ResT, research suggests that it may be affected by various disruptions, physical exertion (Gierczuk et al., 2018), movement velocity, and agility (Zemková, 2016). Given that reacting quickly is a critical factor which can determine whether one wins (or loses) in combat sports (Gierczuk et al., 2017; Hermann et al., 2008), it is not surprising that understanding the mechanism and the effect of training on both RT and ResT has been of interest for quite some time (Cojocariu, 2011a; Gierczuk et al., 2018; Hermann et al., 2008; Mori, Ohtani, Imanaka, 2002; Petri et al., 2019; Zemková, 2016). The notion that RT and ResT are trainable is supported by papers demonstrating that experienced MA practitioners attain better results in choice reaction tasks than novice or untrained practitioners (Cojocariu, 2011b; Mori et al.,

2002; Zemková, 2016). Even within the same combat sport of karate, when comparing the influence of two different types of training (i.e. kata versus kumite), results show that the latter scored significantly better on choice reaction and agility time (Zemková, 2016).

Analyzing Krav Maga's reflexive defense and acquired counter-attack routine using motor control mechanisms

When a Krav Maga practitioner is attacked by surprise, the appropriate response consists of two elements: The first is a reflexive phase, in which he reacts spontaneously (as Feldenkrais described it); the second is a learned or acquired set of movements by way of a counter-attack (the ACAR). In the following sections we discuss the motor control mechanisms of these elements.

Krav Maga's reflexive defense and the startle reflex

A surprise attack or a surprise physical menace is generally very intimidating and may cause physiological and behavioral responses. The nature of the initial response to the threat or attack is critical in determining whether the attacked person can escape intact or with minimal damage.

In 1927 Ivan Pavlov referred to the reflex of self-defense:

The strong carnivorous animal preys on weaker animals, and these, if they waited to defend themselves until the teeth of the foe were in their flesh, would speedily be exterminated. The case takes on a different aspect when the defense reflex is called into play by the sights and sounds of the enemy's approach. Then the prey has a chance to save itself by hiding or by flight. (Pavlov, 1960)

It seems that what Pavlov referred to as the 'reflex of self-defense' and Feldenkrais identified as 'spontaneous movements' (later termed reflexive defense) are the unconscious flexor defensive movements of the startle reflex. The startle reflex is a response to sudden and extreme stimulation in visual, tactile, or auditory modalities (Blumenthal, 2015). It is represented by a variety of muscular contractions and autonomic responses (Blumenthal, 2015), which may serve to prevent injury (Hamm, 2015) and act to either prepare the body to escape or activate defensive responses (Blumenthal, 2015).

It is believed that the startle reflex is related to the Moro reflex found in newborns, which consists of abduction of the arms in response to sudden sensory stimuli. This response disappears at the age of about four months and is replaced by a generalized contraction of facial and limb muscles (Gómez-Nieto 2020).

Loud acoustic stimuli are commonly used in researching startle reactions. The acoustic startle reflex (ASR) has been shown to involve involuntary muscle contraction with an EMG response latency of about 10 ms. The ASR facilitates a defensive stance that will enable fast movement or escape if required (Gómez-Nieto, 2020). Given the very short latency of the ASR, and similar observations of the startle reflex in anencephalic infants, it is widely accepted that the startle reflex occurs via a subcortical reflex mechanism (Valls-Solé, 1999) and is mediated in the brainstem (Blumenthal, 2015; Gómez-Nieto, 2020).

The startle reflex is dominant in the first stages of the natural defense reaction when attentional factors are in play, and it is restrained in later phases when behavioral factors predominate. It has been shown that the startle reflex is amplified when a person is in an aversive emotional state and constrained when a person is in a positive emotional state (Vial, 2001). This is reflected physiologically in the behavior of the amygdala, which responds to

aversive stimuli by neural transmission to various areas of the hypothalamus, midbrain, and brain stem, which in turn produce expressions of fear, including a potentiated startle response. An intense startle reflex of this kind can be associated with freezing, while escape behavior is associated with inhibition of the startle reflex (Hamm, 2015).

The startle reflex is also affected by other parameters such as the task situation, personality characteristics, clinical conditions, physical conditioning, and situational factors (Blumenthal, 2015).

Speed of response and ACAR

Minimizing ResT is an important factor in many sporting activities, but as mentioned, in the context of combat it may be critical to survival or to the avoidance of injury. However, the reduction of ResT alone may not be sufficient; the generated response must also be relevant to the menace and an effective counter to the threat.

We note that the fastest RTs occur in simple reactions when the subject is presented with only one stimulus and required to make a single, pre-determined response. As the number of alternatives increase, in accordance with Hick's law (Pavão, 2016), RT also increases; this is because discrimination between a number of stimuli and selection of one of a set of response alternatives take time. The increased latency of a choice reaction means that, in the context of self-defense, training combatants to use only one ACAR for a specific menace may serve as a means of reducing RT, due to the decrease in the number of response alternatives.

Alertness and readiness to respond have also been shown to reduce RT. Thus a warning signal that is temporally close to the stimulus requiring action reduces the RT. However, if the interval between the warning and the 'go signal' is too long, the RT increases (Magill, Anderson, 2010).

Training to perform an ACAR in conjunction with the startle reflex may also shorten a process known as the psychological refractory period (PRP). When an action involves two stimulus response chains in sequence, the RT to the second stimulus may be extended due to the operation of the PRP; that is, there may be a delay due to the time required to complete the selection of the first response before selecting the second (Pashler, 1994). This is the situation that presents itself in hand-to-hand combat because a series of stimuli (attacks, movements, noises) must be responded to in rapid succession. It follows that if combatants are given training in generating an ACAR immediately after the startle reflex, as proposed by Feldenkrais, the PRP (after the startle reflex is performed) may be shortened or even eliminated.

Finally, once an ACAR has been successfully coupled with a specific reflex response, and the pairing has been sufficiently practiced, it is possible that the neural mechanisms underlying the movements will enable the creation of a GMP, which will in turn reduce the total ResT.

Discussion

In combat sports, matches are often decided in a split second. Athletes need to quickly identify stimuli, process their significance, and choose the best response which will allow them to gain an advantage and hopefully win the match (Badau, Baydil, Badau, 2018; Pavelka et al., 2020) Thus, provoking instinctive reactions which will allow athletes to react automatically is a major part of training (Mladenovic, Educati, 2015) for athletes and combatants alike. What seems to a bystander to be spontaneous, semi-reflex blocking, attacking, or evasion in combat sports is actually the result of years of accumulated training targeting reaching these specific automated responses (Ericsson, 2014). The importance of accumulated training is evident when comparing combat sport athlete training to police personnel hand-to-hand combat training. The length and magnitude of the latter is limited due to time and

budget constraints. For example, “Dutch police officers train their arrest and self-defense skills only four to six hours per year” (Renden, 2015, p. 1496). In such short periods of training, reaching automatization of reactions without relying on ‘reflex-based training’ is most likely impossible.

As discussed, combat sports and real-life fighting share some similar characteristics as the need for short RT and ResT, practice of block-attack combinations, training for automatization of response and the need for agility. However, there are also some significant differences which should be noted such as: (1) the length of self-defense training is usually much shorter; therefore, creating automated response through numerous repetitions is irrelevant. (2) “attacks on the street differ substantially from the ones confronted with in the training environment” (Staller, 2017, p. 71), simply because in combat sports attacks must follow competition rules. Thus, training and transferring motor skills to the ‘street’ requires adaptations to varied conditions of dissimilar contexts (Collard, 2007). (3) anxiety plays a dominant role in real combat situations and may negatively affect perceptual-motor performance (Renden, 2015). Though combat-sports athletes may also encounter some levels of anxiety, pre and during matches; it is different than the one arises from real violent confrontations where outcomes may be fatal.

It seems that by harnessing the startle reflex to an ACAR, Feldenkrais created a motor pattern which optimizes the tradeoff between the speed of the reaction and the effectiveness of the counter-attack. Since this motor pattern is reflex-based, i.e. based on the startle reflex, it seems that it enables the automatization phase to be reached in a shorter training time than that required for encoding a motor pattern based on repetitions alone. The downside may be that when a single ACAR is practiced and generated automatically as a motor pattern in response to a threatening stimulus, it exposes the combatant to the risk that the acquired routine may not be the best option to counter that specific menace. In contrast, practicing several movement patterns for each specific menace may achieve better relevance but at the cost of an extended RT. Thus, there is a tradeoff between relevance (i.e. effectiveness) and response latency.

The choice between teaching one ACAR or several options is one of the commonly debated issues among Krav Maga instructors. Training in one ACAR is mostly favored by military personnel, whereas teaching several options per threat is preferred by civilian Krav Maga instructors. A commercial factor may be at play here, as it is considerably easier to maintain interest and preserve civilian student numbers over a long period if a variety of techniques is associated with each type of physical threat.

Additional issues for consideration in this context are:

1. The length of training required to embed multiple automated responses. This will be longer than for the single ACAR approach and therefore renders the multiple response model less acceptable when training time is restricted. However, for training civilians, this may not be a constraint.
2. There are benefits arising from the multiple response approach. These include the contribution to practitioner coordination; enhanced interest in and enjoyment of the training process; and enabling the practitioner to choose a response pattern best suited to his or her body type and characteristics.

To summarize this point, while it is clear that teaching a single ACAR response minimizes RT and takes less time to assimilate (which may be crucial for combat professionals), this should be balanced against the benefits of providing multiple-response training for any given threat. These benefits, as set out above, may be more salient for civilians who engage in Krav Maga training as a form of MA.

An additional issue arises from the reciprocal relationship between RT and the timing of the go signal. As noted, if the go signal is unduly delayed, RT will be extended, thus generating a significant disadvantage in

the context of hand-to-hand combat. In such situations we argue that a proactive response might be a better option than waiting for the assailant to initiate an attack. This idea is reflected in one of the basic principles of the Israeli combat discipline dating back to the mid-1940s that initiating attack is preferable to a responsive defense (Unknown). However, initiation of an attack brings with it moral, professional, and legal issues that require additional consideration.

Conclusion

Our analysis demonstrates that key elements of the Krav Maga combat system – the importance of pairing acquired responses with the initial automatic startle reflex, the advantage of anticipatory responses, the impact of training on reducing refractory periods, and the logic behind training one ACAR per given threat - have a rationale grounded in contemporary motor control theory. This provides a retrospective justification for principles that were articulated in the early 20th century, before the physiological mechanisms were fully understood.

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