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Perceptual-cognitive expertise in combat sports: a narrative review and a model of perception-action

Habilidades perceptivo-cognitivas en deportes de combate: una revisión narrativa y un modelo de percepción-acción

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Abstract

Despite the many studies on physical and physiological features of combat sport athletes, there has been considerably less consideration of psychological factors. Here, we present a narrative review of literature related to perceptual-cognitive skill in combat sports that require the athlete to score points by hitting or touching the opponent's body with the hands, feet or weapon: boxing, French boxing, fencing, kung fu (wushu), karate, taekwondo and other martial arts. Based on a thorough search of literature, we synthesised findings from empirical studies on Reaction Time, Anticipation, Visual Search and Information Pick-up. Contrary to the belief of coaches, there was no clear consensus regarding Reaction Time being a good predictor of success in combat sports. However, consistent with findings from other sports, expert combat sport athletes better anticipate the opponent's actions based on information perceived before and during the attack. This is likely facilitated by experts using a gaze fixation strategy (i.e., visual pivot) that facilitates information pick-up. In the final section, we present a model that describes how the evolving perception-action relationship between the attacking athlete and opponent depends on distance, attack progression and opponent reaction. Suggestions are provided for training and for future research in combat sports.

Key words: reaction time; anticipation; visual behaviour; decision making; martial arts.

Resumen

Las investigaciones sobre las características físicas y fisiológicas de los atletas en deportes de combate son abundantes. Sin embargo, los factores psicológicos han recibido menos atención. En este artículo presentamos una revisión narrativa que aglutina los principales estudios sobre habilidades perceptivo-cognitivas en aquellos deportes de combate en los cuales se puntúa golpeando o tocando el cuerpo del adversario con las manos, los pies o el arma: boxeo, boxeo francés, esgrima, kung fu (wushu), karate, taekwondo y otras artes marciales. Tras una exhaustiva búsqueda bibliográfica, sintetizamos los principales hallazgos de estudios empíricos sobre tiempos de reacción, anticipación, búsqueda visual y captura de la información. En contra de las creencias de los entrenadores, no hay un consenso claro respecto a que el tiempo de reacción sirva para predecir el rendimiento en los deportes de combate. Sin embargo, en línea con lo investigado en otros deportes, los expertos en deportes de combate anticipan mejor las acciones del oponente, usando la información percibida antes y durante el ataque. Esta capacidad está posiblemente beneficiada por la estrategia de búsqueda visual de los expertos (por ejemplo, los pivotes visuales) que optimiza la captura de la información clave. En la sección final, presentamos un modelo que describe cómo evoluciona la relación percepción-acción entre el atacante y su adversario en función de la distancia, la progresión del ataque y la reacción del oponente. También se aportan sugerencias para el entrenamiento y para futuras investigaciones en los deportes de combate.

Palabras clave: tiempo de reacción; anticipación; búsqueda visual; toma de decisiones; artes marciales.

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Introduction

Combat sports are fast-moving and involve dynamic situations where athletes have to respond to an opponent's movement (i.e., externally-imposed temporal constraint). The physical and physiological features of combat sport athletes have been widely studied in boxing (Chaabene et al., 2015), fencing (Stewart, Peredo, & Williams, 1977), karate (Chaabène, Hachana, Franchini, Mkaouer, & Chamari, 2012), and taekwondo (Bridge, Ferreira da Silva Santos, Chaabene, Pieter, & Franchini, 2014), with the findings often informing athletes training regimes (Arseneau, Mekary, & Léger, 2011), as well as the process of athlete selection (Casolino et al., 2012). However, there has been relatively less consideration of psychological factors involved in combat sports, which may explain why there is still debate regarding those that play a critical role in determining success (Chaabène et al., 2012). Here, we present a narrative review that synthesizes the literature related to perceptual-cognitive skill in combat sports. We performed a thorough search of literature on combat sports, with our criteria guided by previous work on perceptual-cognitive skill in sports such as football, tennis and cricket (Mann, Williams, Ward & Janelle, 2007). These sports require accurate and rapid responses to movements of an opponent and/or object, and thus have some similarities with combat sports that involve a physical separation between opponents (e.g., boxing, fencing, French boxing, karate, kendo, kung fu [wushu] and taekwondo). Unlike other combat sports such as judo or wrestling, the primary goal is to score points by hitting or touching the opponent's body with the hands, feet or weapon, with vision playing a key role in providing information necessary for accurate and rapid responses.

The first topic reviewed is reaction time (RT), which has been examined in a large number of studies, most likely because combat sports are fast-moving and require rapid responses. However, the required time to make a response is often shorter than the available time, which means the athlete should ideally anticipate the upcoming opponent movement based on advance information. The second topic of this review will be anticipation in combat sports. Determining the process that enables expert athletes to anticipate has often involved the study of visual search behaviour, and is thus the third topic covered in this review. Given that the aim of visual search is to orient eye gaze in order to extract the most relevant visual information to facilitate anticipation, the fourth topic will consider information pick-up. Based on this review of the extant scientific research, in the closing sections we introduce a model to aid understanding of perception-action in combat sports, and thereby provide some direction for training and future research.

Reaction Time

It seems remarkable given the high speed and short duration of attacking movements in combat sports (i.e., karate punch = 242 ms in VencesBrito, Rodrigues Ferreira, Cortes, Fernandes & Pezarat-Correia, 2011) that it is possible to make an effective defense. Intuitively, it is tempting to assume that compared to sedentary people or even athletes of lower level, high-level athletes would react earlier to an attack (i.e., shorter elapsed time between the stimulus and the onset of response) and/or move their limbs faster when making the response. Such reasoning likely accounts for why RT was historically a major concern to trainers, psychologists and sport scientists (Layton, 1993). Table 1 summarises the most relevant research on this topic (i.e., 1956 to 2018) and shows RT (mean ± standard deviation) of combat sports athletes, including the main features of measurement: stimulus (non-sport-specific or sport-specific); response (non-specific button/key or sport movements); RT type (simple reaction time [SRT], choice reaction time [CRT], go-no-go [GNG], total response time [TRespT], premotor simple reaction time [PSRT], simple reaction time with later amendment [SRTA]); number of participants (N); attributes of combat sport participants.

Table 1: Reaction time of combat sports athletes.

Authors (Year)	Stimulus	Response	RT type	N	Attributes	RT mean ± SD
Pierson (1956)	Non-specific	Button press	SRT	25	Varsity fencers	217
Rasch & Pierson (1963)	Non-specific	Button release	SRT	12	Karateka	240 ± 26
Nougier et al. (1990)	Non-specific	Fencing attack	SRT	6	Expert fencers (French team)	255 ± 35
Harmenberg et al. (1991)	Non-specific	Fencing attack	SRT	10	World class fencers (11,7 years of practice)	391 ± 46
Layton (1993)	Non-specific	Straight-punch left	TRespT	27	Karateka (4,6 years of practice)	415 ± 3
Heller et al. (1998)	Non-specific	Upper limb movement	SRT	11	Czech taekwondo national team (male)	196 ± 16.4
Lee et al. (1999)	Non-specific	Finger extension	SRT	9	Kendo athletes (9,0 years of practice)	143 ± 12
Williams et al. (2000)	Non-specific	Movement of foil	SRTA	3	New Zealand fencing national team	333 ± 128
Mouelhi Guizani et al. (2006)	Non-specific	Button press	SRT	12	Profesional fencers	253 ± 27,3
Mouelhi Guizani et al. (2006)	Non-specific	Button press	SRT	10	National boxers	274 ± 36
Fontani et al. (2006)	Non-specific	Key press	SRT	9	Karateka high experience (13 years of practice)	204 ± 16
Di Russo et al. (2006)	Non-specific	Button press	SRT	12	Fencers (more than 4 years of practice)	204
O'Donovan et al. (2006)	Non-specific	Button release	SRT	13	Practitioners of hard-style martial arts	210.9 ± 3.7
Vieten et al. (2007)	Non-specific	Kick (first hip movement)	SRT	9	Taekwondo athletes (females below 18 years)	220 ± 20
Del Percio et al. (2007)	Specific	Key press	CRT	14	Elite fencers (8 females)	418 ± 22
Bianco et al. (2008)	Non-specific	Key press	SRT	27	Profesional boxers (14,8 years of practice)	249 ± 7
Martínez de Quel et al. (2008)	Non-specific	Button press	CRT	16	Spanish fencing national team (male)	356 ± 38
Borysiuk (2008)	Non-specific	Button press	PSRT	12	Advanced fencers (8,3 years of practice)	149 ± 28
Chan et al. (2011)	Non-specific	Key press	SRT	15	High-fit fencers	300 ± 37
VencesBrito et al. (2011b)	Non-specific	Key press	SRT	37	Karateka (24,9 years of practice)	295 ± 32
Gutiérrez-Dávila et al. (2011)	Non-specific	Fencing attack	SRT	13	Elite fencers (11,9 years of practice)	220 ± 32
Martínez de Quel et al. (2011)	Non-specific	Fencing attack	SRT	18	Spanish fencing national team	229 ± 30
Chung et al. (2012)	Specific	Button press	GNG	20	Professional taekwondo athletes (5 female)	296 ± 44.8
Gutiérrez-Dávila et al. (2013)	Non-specific	Fencing attack	SRT	30	International and national fencers	188 ± 22
Martínez de Quel & Bennett (2014)	Non-specific	Karate reverse-punch	SRT	15	Karateka (15,2 years of practice, male)	266 ± 52
Gutiérrez-Dávila et al. (2014)	Non-specific	Fencing attack	SRT	18	Fencers (+5 years of practice, 4 female)	174 ± 16
Coşkun et al. (2014)	Non-specific	Manual movement	SRT	43	Karateka 18 years and older	130 ± 32
Sanchez-Lopez et al. (2016)	Non-specific	Button press	GNG	11	Martial artists (more than 5 years practice)	409 ± 48
Gutiérrez-Dávila et al. (2017)	Non-specific	Fencing attack	SRT	25	Spanish fencing national team (10 female)	169 ± 21
Badau et al. (2018)	Non-specific	Button press	SRT	46	National and international boxers	215 ± 20

Close scrutiny of table 1 shows that the results of many so-called RT studies in combat sports are equally as diverse as the methods. This is an important consideration because it is well known that RT differs depending on the tasks and measurement methods, with the same person performing poorly in one task and yet much better in another (Badau, Baydil & Badau, 2018; Chung & Ng, 2012). One should therefore be careful when comparing results among studies, and particularly if the RT task and experimental apparatus differ. A key factor that seems to return mixed results for RT is experience of combat sports. Some studies found that combat sport athletes had shorter RT than non-athletes (Del Percio et al., 2007; Lee et al., 1999; Yotani et al., 2013), whereas other studies reported no differences between both groups (Chan, Wong, Liu, Yu & Yan, 2011; Mouelhi-Guizani, Bouzaouach, Tenenbaum & Kheder, 2006; O'Donovan, Cheung, Catley, McGregor & Strutton, 2006; Pierson, 1956). Much of this equivocality can be explained by differences in complexity and specificity of the RT task studied. In particular, athletes exhibit shorter RT than non-athletes (Di Russo, Taddei, Apnile & Spinelli, 2006; Martínez de Quel & Bennett, 2014; Mori, Ohtani & Imanaka, 2002; Rossi, Zani, Taddei & Pesce, 1992) in tasks that introduce additional factors related to perceptual-cognitive skill (see sections below).

To determine whether RT could be more important in one sport than another, comparisons have been made between athletes of different sports using non-specific RT tasks. Rasch and Pierson (1963) found that karateka had faster RT than wrestlers, whereas Martínez de Quel, Saucedo, Lopez & Sillero (2008) found male athletes had faster RT in fencing than karate. Female athletes in the latter study exhibited similar RT. In a study that compared athletes of boxing, gymnastics, judo, karate, taekwondo and wrestling, Badau et al. (2018) found boxers were the best in simple RT but weaker in other RT tasks. Some other studies have even attempted to establish an order (faster to slower) between sports (Mouelhi Guizani, Tenenbaum, Bouzaouach & Kheder, 2006) with fencers ranked first, followed by tennis players, boxers and finally table tennis players.

There have also been attempts to determine if RT is related to success (i.e., does RT predict the athletes level) within a particular sport. Typically, this has involved comparisons of experts and novices or athletes of varying levels. Some studies found that higher level athletes had faster RT (Borysiuk, 2008; Fontani, Lodi, Felici, Migliorini & Corradeschi, 2006; Lee et al., 1999; Vieten, Scholz, Kilani & Kohloeffel, 2007; Williams & Walmsley, 2000), whereas other studies found no difference (Gutiérrez-Dávila, Rojas, Antonio & Navarro, 2011; Martínez de Quel, Bennett, López, Zapico & Saucedo, 2015; Mouelhi-Guizani et al., 2006; Sanchez-Lopez, Silva-Pereyra & Fernandez, 2016) or even the opposite effect (Bianco et al., 2008; VencesBrito, Silva, Cid, Ferreira & Marques, 2011). Furthermore, results were mixed when several RT tasks were used within the same study. Together, these studies lead to the conclusion that RT is only related to sport performance in certain tasks (Coşkun, Koçak & Saritaş, 2014; Nougier, Stein & Azemar, 1990), or certain tasks in males but not females (Heller et al., 1998). The differences between experts and novices are sometimes more apparent in complex and specific tasks, with experts achieving a shorter RT (Harmenberg, Ceci, Barvestad, Hjerpe & Nyström, 1991; Mori et al., 2002), or more accurate responses with fewer mistakes while maintaining the same RT (Ripoll, Kerlirzin, Stein & Reine, 1995). The latter can be explained by the so-called "wait-and-see" strategy of experts (Williams & Ward, 2007; see also Navia, Avilés, López & Ruiz, 2018), which results in longer RT due to the involvement of additional processes such as decision making.

In conclusion, it would seem that after years of research there is no clear consensus about whether there are differences in RT between and within groups of combat athletes. RT per se does not appear to be a variable that can reliably predict combat sport performance or potential for success. That said, research intended to examine RT has proved useful in highlighting the influence of other perceptual-cognitive processes, which may offer more insight into how best to orientate learning and training procedures.

Anticipation

If we compare some of the fastest RTs reported in work on combat athletes (e.g., 204 ms in fencers reacting to a visual stimulus on a screen by pressing a button in Di Russo et al., 2006) to movement times exhibited when performing an attack (e.g., 228 ms in novice fencers in Williams & Walmsley, 2000), it is clear that the defending fencer would not have enough time to complete the processes involved in making a response (i.e., perceive the opponent's movement, understand where the attack is directed, make a decision about the optimal response and then execute the defensive move; see also Fernando, Vicente, Prudente, Lopes, & Fernando, 2015). Combat sports athletes typically cannot wait until an attack is performed and instead should ideally anticipate the upcoming attack based on prior information available from the opponent's preparatory movements or the situation. Therefore, it has been suggested that experts achieve better response accuracy based on the use of relevant information or cues that predict subsequent attacks (Williams & Elliott, 1999).

The most used experimental technique to study anticipation in combat sport has been temporal occlusion. In this technique, a participant's view of the stimulus is occluded at different times, thus enabling a comparison of behavior based on only a part vs. the entire stimulus sequence (see Williams & Ward, 2007). Temporal occlusion can be achieved using video frame editing (Hagemann, Schorer, Canal-Bruland, Lotz, & Strauss, 2010; Mori et al., 2002; Yoshitomi & Mori, 2007) or with liquid crystal glasses that switch from a transparent to opaque state (Rosalie & Muller, 2013). In research on combat sports athletes, video stimuli in anticipation studies typically show attacking moves from an opponent's point of view. Comparisons can then be made between different levels of temporal occlusion that enable the participant to view parts of the attack progression: i) on-guard position; ii) on-guard to first moment of approach; iii) on-guard to the beginning of attacking limb extension; iv) on-guard to completion of attack. After seeing this partial video sequence, participants are asked to estimate where the attack was directed by giving a non-specific verbal response or button press, or by performing a defense that is more specific and maintains coupling between perception and action (Scott, Williams, & Davids, 1993). In the case of liquid crystal glasses, their use has enabled studies in behavioural settings where a real opponent performs an attack and the participant is asked to defend under conditions that occlude vision at different moments of the sequence (Rosalie & Muller, 2013). This method of temporal occlusion maintains the coupling between perception and action, as well as the fidelity of perceptual information (e.g., binocular cues to motion in depth). It allows the researcher to investigate expert performance under representative conditions (Avilés, Navia, Ruiz & Martínez de Quel, 2019). Probably for these reasons, temporal occlusion with liquid crystal glasses tends to show bigger differences between experts and novices, although the method is less convenient for the experimenter because it is difficult to generate reproducible stimuli during each attack.

Temporal occlusion studies have generally shown that more accurate responses are given when the participant is able to view more of the attack (Hagemann et al., 2010; Rosalie & Muller, 2013; Yoshitomi & Mori, 2007). This is because the quantity and the quality of information about the upcoming attack increase with the attack progression. For a given presentation time, Mori et al. (2002) showed that karate athletes make better prediction than non-athletes about where the attack was directed. Similarly, Hagemann et al. (2010) found that experts and advanced fencers predict the attack direction better than novices when provided with all or only part of the attack sequence. In a comparison of karate athletes, Rosalie & Muller (2013) found that experts exhibited superior anticipation at all levels of temporal occlusion than near-experts and novices. Notably, while near-experts need to view at least the preparatory movement and the initiation of the attack motion to anticipate above chance, experts were able to predict the attack better than chance by viewing only the on guard position prior to the opponent's attack. Thus, it is generally well accepted that experts are better able to perceive the relevant information, in a temporally restricted situation, that is needed to identify the subsequent attack and choose an appropriate response.

Temporal occlusion has also been combined with a spatial occlusion technique whereby the video image is represented by a point-light display (PLD) that shows motion of selected joints. In a study by Yoshitomi & Mori (2007), participants had to make a decision about an attack (i.e., punch/kick, upper/middle, right/left) when viewing PLDs that had six different viewing times. It was found that prediction at half viewing time was better for kicks than for punches but the opposite effect was found when viewing time was longer. Thus, the amount of information needed from the sequence to make a correct response would appear to be dependent on the type of attack: for the same effect in fencing attacks see Hagemann et al. (2010). In addition, it has been shown that accuracy of decision making is dependent on the type of response required. Torrontegui, Martínez de Quel & Lopez (2013) asked taekwondo experts to perform 4 types of response that provided more time in which to make the decision: a) anticipated counterattack where participants had to kick before the end of the opponent kick, b) simultaneous counterattack where they had to kick at the same time, c) posterior counterattack where they went backwards to avoid the opponent kick and after that they performed their kick, d) free counterattack which combined the others. It was shown that providing athletes with a longer time to make their decision resulted in a more accurate response.

Summing up, combat sport experts are able to anticipate the opponent's actions based on several sources of information that occur before the actual attack. The accuracy of response is related to expertise but also to the kind of attack and response (i.e. defense, counterattack), as well as the time available to make the decision and perform the response. In the following section, we describe visual search strategies that lead to more efficient and effective pick-up of the relevant information.

Visual search behavior

In combat sports, visual search behavior has been measured while reacting to attacks by real opponents (Milazzo, Farrow & Fournier, 2016) or video recordings projected in near life-size (Ripoll et al., 1995; Ruiz, Peñaloza, Navia & Rioja, 2013; Williams & Elliott, 1999) or on a computer screen (Hagemann et al., 2010). Results have shown some consistent findings. French boxing experts direct their eye gaze mainly to the head and trunk of the opponent, while less experienced boxers looked to the opponent's fist and arms (Ripoll et al., 1995). Similarly, eye gaze in karate athletes is directed to the head and the chest (Milazzo et al., 2016; Williams & Elliott, 1999). Research in fencing shows that the lower trunk and opponent's weapon are the most viewed areas (50% of the viewing time). Moreover, experts direct their gaze more to the upper trunk, while novices look more to the upper legs (Hagemann et al., 2010). Experts in taekwondo have been shown to direct gaze mostly on the trunk and the head, while less experienced athletes look mainly to the legs (Lee, Kim & Song, 2010; Ruiz et al., 2013). The gaze behavior of combat sports experts is illustrated in figure 1. Experts in each of these sports have something in common. That is, they tend to fix their gaze on a central and relatively still part of the opponent's body (i.e. head and trunk) for the majority of time and not the more distal limbs that tend to produce the largest amplitude movements (i.e. arms and legs). Moreover, experts show a particular scan path as gaze moves from one fixation point to another. Ripoll et al. (1995) found that French boxing experts move eye gaze from the head to the trunk and peripheral areas, later returning to the head. Williams & Elliot (1999) found that karate athletes shift gaze vertically between the head and chest. In taekwondo athletes, Lee et al. (2010) found gaze was oriented from chest to head or abdominals, whereas Ruiz et al. (2013) found that experts move their gaze mainly from chest to head and legs. Thus, expert combat athletes tend to orient gaze in accord with a vertical scan path in the vertical central line of the opponent's body.

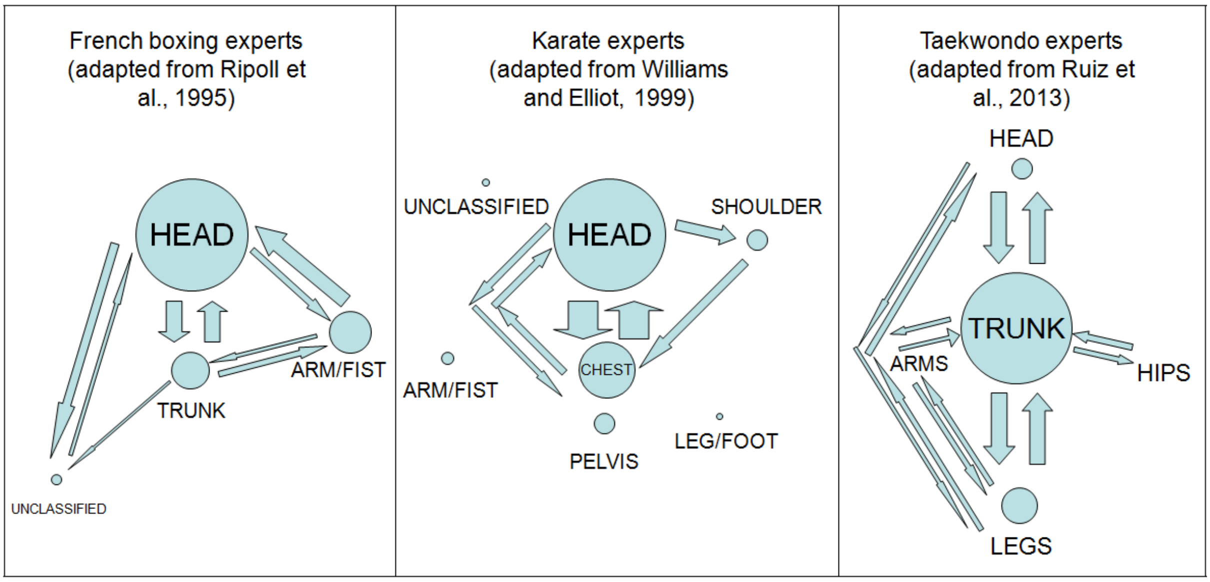

Figure 1. Pattern of visual search behavior of French boxing, karate and taekwondo experts. Circle size shows fixation time in each area and arrow thickness indicates frequency of saccadic between two areas.

Differences in visual search behavior between combat sports could be explained by the different trajectories of frequent attacks, which depends on the limbs used (i.e., fists, feet, weapons) and the target of an attack (i.e., head, trunk, arms, legs). Compared to French boxing and karate where punching and kicking are very common, taekwondo is focused predominantly on kicking techniques. Accordingly, taekwondo athletes direct gaze lower and more toward the trunk (Lee et al., 2010; Ruiz et al., 2013), whereas French boxers and karateka direct gaze at higher locations and more to the head (Ripoll et al., 1995; Williams & Elliot, 1999). The épée fencers studied by Hagemann et al. (2010) direct their gaze toward the lower trunk and the opponent's weapon, which is consistent with the common on-guard position where the hand/weapon is maintained at lower trunk height and attacks can be directed to any part of the opponent's body (right hand, right arm, body, right leg, and right foot in the experiment).

The finding that expert athletes predominantly direct gaze to a relatively static location such as the center of the opponent's body (head or trunk) is consistent with the visual pivot explanation and information chunking (Vickers, 2007). A visual pivot is a point in the visual field where gaze is directed for a period of time, thus allowing information capture from central and peripheral vision; chunking refers to the mechanism that groups several pieces of related information to facilitate better processing (i.e. synthetic perception). Directing gaze to more distal elements such as the arms or legs, which are the weapons that the opponent will use during the attack, would not appear to be advantageous for expert combat athletes. Instead, by directing gaze to the center of the body, expert athletes are able to make good use of both central and peripheral vision. By maintaining gaze on the relatively stationary head and trunk for longer periods, an athlete would also make fewer saccades and could thus benefit from fewer periods of saccadic suppression. In combat sports, there is some evidence that experts do indeed make fewer and longer duration gaze fixations than novices or less experienced athletes (Lee et al., 2010; Ripoll et al., 1995; Ruiz et al., 2013). However, an expert-novice difference in the pattern of eye movements is not always found (Hagemann et al., 2010; Williams & Elliott, 1999), and seems to be dependent on task specific demands such as the type of sport, research protocol, and stimulus presentation modality (Mann et al., 2007).

Although there is some discrepancy about how experts direct their gaze for the purpose of perceiving relevant information to support accurate decision making, there are some points of consensus. That is, experts tend to fixate on a relative stationary and central part of the opponent's body, from where they move gaze mainly in a vertical line of the opponent's body. Having shown that experts orient gaze at different locations than novices, the question remains how they use the available relevant information to produce an accurate response?

Information pick-up

It is important to recognize that there is a distinction between "looking" and "seeing", or "fixation" and "information extraction" (Henderson, 2017; Williams & Ericsson, 2005). As suggested in several studies, gaze behavior does not necessarily represent information pick-up (Hagemann et al., 2010). To understand what information facilitates expert anticipation and decision making, researchers have used the spatial occlusion technique where participants respond to a video or point-light display in which a section of the display is masked. The principle is that if occlusion of a certain area is associated with poor performance, this area must in part be responsible for providing task-relevant information. Research using spatial occlusion in combat sports is relatively sparse but there are some interesting results. Hagemann et al. (2010) found that expert fencers' performance was negatively affected when the opponent's trunk/attacking arm area was occluded, while novices were not affected by any spatial occlusion. Contrary findings were reported in a spatial occlusion study that maintained a better coupling between perception and action by asking taekwondo athletes to perform a real counterattack (Torrontegui et al., 2013). Specifically, performance did not differ between conditions in which experts saw the entire video or a video with part of the opponent's body occluded. The implication is that the expert taekwondo athletes did not need to see all the connected body segments to be accurate at predicting the actions of a real-life opponent. Consistent with spatial occlusion findings from other experts athletes (Huys et al., 2009), performance might be maintained during spatial occlusion by using information from other non-occluded areas. According to global perception theories, expert perception might not depend on perceiving every detail of an image because the human perceptual system can integrate information from several regions based on past experience and expectation (Williams & Ericsson, 2005; Huys et al., 2009). More recently, Petri, Bandow, Salb & Witte (2018) reported a variation of the spatial occlusion technique whereby they masked the attacker's face in karate. Their results indicated better attack recognition and response behaviour when the attacker's facial expressions could not be seen, thus indicating that important anticipatory information was extracted mainly from the attacker's movements.

The cueing technique has also been used to study the relevant information in combat sports. Cueing orientates participant attention toward a certain region of the visual field in an effort to help athletes, or at least novices, to improve performance (Hagemann, Strauss & Cañal-Bruland, 2006). In combat sports, this technique has been found to have adverse effects. Hagemann et al. (2010) found that performance of expert, advanced and novice fencers deteriorated when attention was oriented to a specific part of the opponent's body (head, trunk, upper legs, lower legs). It was suggested that directing attention had distracting effects. These results could support the practical recommendation about not advising athletes to search for a particular feature (Kibele, 2006), which they may be unable to identify under time pressure, since the stimuli are perceived sub-consciously. Instead, it is suggested that perception should be trained by extensive trial and error learning in which the athlete discovers the areas where the relevant movement feature configurations are located. Furthermore, it is important to recognize that the pick-up of visual information, and subsequent response decision, will be influenced by situational probability (Alain & Proteau, 1980). In brief, the probability of a stimulus or event occurring is a function of the situation, and therefore provides additional information to that currently available via the perceptual system. During combat sport, situational probabilities include the score, time to the end of the match and the habitual techniques of the opponent. For example, there is often an increased probability that an athlete behind on points will perform an attack in the last seconds of the combat. If the athlete ahead on points has sufficient task-specific experience, they will use this situational probability information to anticipate the need to prepare a defensive response. Although studied quite extensively in other sports as tennis (Farrow & Reid, 2012), situational probabilities have received less attention in combat sports. To our knowledge there are only two studies, one with fencers (Schubert, 1981) and the other with karate experts (Milazzo, Farrow, Ruffault & Fournier, 2016), that have reported earlier responses when situational probabilities facilitated correct prediction of the upcoming attack. From a practical perspective, there could be a benefit when preparing for a match to analyze an opponent's performance and identifying habitual techniques (Causer & Williams, 2013).

A model of perception-action in combat sports

From the evidence reported in the previous sections, it is clear that perceptual-cognitive expertise is key to success in combat sports. However, rather than simply informing athletes and coaches about key concepts such as anticipation and the visual pivot, it is instructive to consider these factors in the context of perception-action coupling in combat sports. Below we have formulated a model that describes the progression of the attack sequence in combat sports. The model considers the evolving relationship between the attacking athlete and opponent, and thus the opportunities afforded for action.

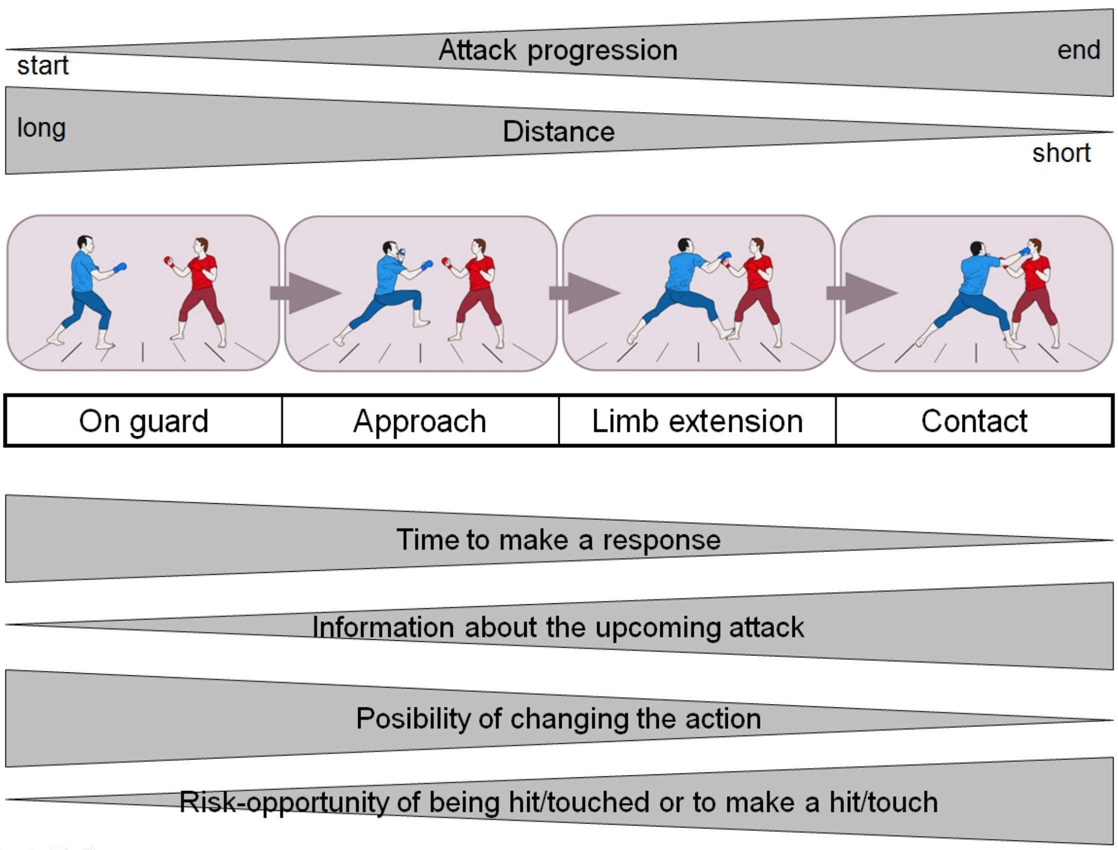

Figure 2. A model for perception and action on combat sports based on distance, attack progression and opponent reaction.

A key concept in the model is distance between the fighters, which in combat sports is more than purely a question of metrics. Distance in combat sports influences when and how an attack progresses (Petri et al., 2016), and is related to factors including timing, tactics and techniques, anthropometrics, and movement speed. The result is that at one specific distance, a particular athlete has opportunities for actions that might not be afforded for another athlete. For instance, Hristovski, Davids, Araújo, and Button (2006) showed how boxers decided upon their punching action depending on the scaled, boxer-target distance. This feature of the performer-environment interaction depends on the distance to the punching bag and the boxer arm length, and thus emerges in a unique way for each boxer. Petri et al. (2016) also showed that karate fighters adjust their distance before initiating an attack, and that the magnitude of the adjustment depends on the chosen attacking technique (e.g., jabbing punch, reverse punch or roundhouse kick). Furthermore, Falco et al. (2009) found that taekwondo experts could maintain impact force of their kick from shorter to longer distances but novices kick weaker as the distance increases. This provides an advantage to the expert who can attack from either distance, and thus in advance of the novice who has to move closer to complete a forceful attack. Together with better anticipation and an ability to make faster movements (Martínez de Quel & Bennett, 2014), this can help explain why there is no consensus about the relevance of RT per se to combat success (Gutiérrez-Dávila, Rojas, Gutiérrez-Cruz & Navarro, 2017).

In our model, the time to make a response (i.e. to perceive, decide and move) decreases as the attack progresses and the distance becomes shorter. When the two athletes are located a long distance apart they have more time to make an accurate response, whereas at a short distance the available time can be less than a simple reaction time. For this reason, trainers usually advise their athletes not to wait or feint at short distances but rather to directly hit/touch their opponent. In addition, it is necessary to account of the fact that some movements are faster than others. For example, a small and quick arm movement can be used as a defensive move at the end of the opponent's attack, while a step backward is slower and should be initiated at longer distances. Based on many years of practice, experts in combats sports will likely have developed domain-specific knowledge structures that enable them to generate a more suitable response than novices (Klein, Wolf, Militello & Zsambok, 1995).

Both the quantity and quality of information about the upcoming attack increases as the attack progress and the distance is shorter (Rosalie & Muller, 2013). At the beginning, the opponent does not have reliable information from the opponent's posture about the upcoming attack, resulting in a high degree of uncertainty since the opponent could perform various attacking moves to different locations of the body. Uncertainty can be reduced by knowledge of situational probabilities, which experts use to make faster and more accurate responses (Milazzo, Farrow, Ruffault, et al., 2016). As the attacker-opponent distance decreases, the attacking move becomes more certain as the perceptual degrees of freedom are reduced. For example, in a kick, when the attacker lifts his/her leg from the floor and the knee is rising, the defender has information about the attacking leg but not where it will be directed. Later, during the leg extension, the defender knows the side of the body where the kick is being directed (right/left) because the kinematics of movement resemble those of a roundhouse kick. In the last moment of the extension, the defender knows if the kick is directed to the head or the trunk. Training that facilitates the build-up of task-specific knowledge that underpins anticipation and situation probabilities can help experts to pick-up and use relevant information perceived earlier during the attack to decide how to respond appropriately. Anticipation could be helped by maintaining gaze most of the time around the central part of the opponent's body (head/trunk), thus providing a visual pivot from where relevant information can be picked-up for making the appropriate response (Ripoll et al., 1995; Ruiz et al., 2013; Williams & Elliott, 1999). One implication is that coaches and trainers should be encouraged to design tasks and instructions to achieve this visual behavior on their athletes (Broadbent, Causer, Williams & Ford, 2015).

As the attack progresses, the possibility of changing the action by both the attacker and defender decreases. Following the previous example, the direction of a kick can be easily changed from the trunk to the head, or transformed into a feint, at the beginning of the attack. However, this would be not possible just before the contact. Similarly, while the defender can change the defensive move easily at the beginning, this becomes increasingly difficult as the attack unfolds. Thus, perception and action of both attacker and defender are intrinsically linked. The possibility of changing the action is related to the speed of movement (Gutiérrez-Dávila, Rojas, Caletti, Antonio & Navarro, 2013). Gutiérrez-Dávila, Zingsem, Gutiérrez-Cruz, Giles & Rojas (2014) studied how a fencing attack can be slowed during execution in order to be transformed into a defensive move. They found that an attack was faster in the situation without uncertainty (i.e. performer had to touch a projected black circle when it appeared on the plastron) than in the situation with uncertainty (i.e. similar than the other condition but performer had to change the attack into a defensive move if the circle disappeared during the action). The risk of being hit/touched, as well the opportunity to make a hit/touch, increases as the attacker-opponent distance decreases (Falco et al., 2009). Combatants can feel safe when the distance is long and can use this as an opportunity to have a short physical or mental rest, or to let the clock to count down in the knowledge that the score will be preserved. On the other hand, the athlete who needs to score has to accept the increased risk at short attacker-opponent distances, and thus appreciate the cost-benefit ratio.

In summary, it is clear from the above model that the decision regarding when and how to act in combat sports evolves in conjunction with the changing perceptual information. Distance between the attacker and opponent is key to the action possibilities. It is therefore important for the combat athlete, and coach, to design training tasks that seek to preserve perception-action coupling while at the same minimizing the risk of injury faced during combat.

Conclusions

Having reviewed a large body of research related to perception, cognition and action in combat sports, it is now more apparent that RT per se is not a good predictor of success. As has been suggested for several other sports, there is a consensus that experts have better anticipation than novices of the opponent’s attack. The expert’s ability to anticipate from the initial part of the attack sequence is facilitated by gaze fixation on a central pivot (head and trunk), and then scanning mainly in a vertical path on the central part of the opponent’s body. Importantly, the decision when and how to act evolves based on the current perceptual information and situational probabilities. To inform practice and the development of perceptual-cognitive expertise, we propose a model in which distance between the attacker and opponent has a key role in perception-action coupling in combat sports.

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