Information for Regulating Action in Sport: Metastability and Emergence of Tactical Solutions under Ecological Constraints

Chapter · April 2009

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In: Perspectives on Cognition and Action in Sport
Editors: D. Araujo, H. Ripoll, M. Raab, pp. -
ISBN: 978-1-60692-390-0

Chapter 4

INFORMATION FOR REGULATING ACTION IN SPORT: METASTABILITY AND EMERGENCE OF TACTICAL SOLUTIONS UNDER ECOLOGICAL CONSTRAINTS

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ABSTRACT

The aims of this chapter are twofold. First, we show how experiments related to nonlinear dynamical systems theory can bring about insights on the interconnectedness of different information sources for action. These include the amount of information as emphasized in conventional models of cognition and action in sport and the nature of perceptual information typically emphasized in the ecological approach. The second aim was to show how, through examining the interconnectedness of these information sources, one can study the emergence of novel tactical solutions in sport; and design experiments where tactical/decisional creativity can be observed. Within this approach it is proposed that perceptual and affective information can be manipulated during practice so that the athlete's cognitive and action systems can be transposed to a meta-stable dynamical performance region where the creation of novel action information may reside.

INTRODUCTION

Some of the basic issues in research on cognition and action in sport are related to problems on the nature and use of information by athletes. Key questions concern the meaningful information that athletes perceive to organize their solutions to a tactical problem or the relation between the *amount* of information present in the performance environment and the decision-making behavior of athletes. In some investigations it has been proposed that environmental information is available in advance to performers. In many experiments information has usually been held constant over trials so that the athletes have to merely make a decision and respond accordingly. For example, in traditional cognitive science approaches to the study of reaction time (RT) (e.g., Schmidt and Wrisberg, 2004) the main emphasis has been on the relation between the *amount* of unpredictability (i.e. information content) of environmental events and RT measures of athletes treated as a decision-making performance variable. From this perspective a challenging question has been: How is this information created in sport contexts? A particular concern has been that the amount of information designed into these experiments had to be introduced in an *ad hoc* manner by experimenters, and was not a constituent derived from explanatory models of cognition and action in sport.

In contrast to this approach, some empirical effort has been directed towards unraveling understanding of the *nature* of the information used to support actions. For example, in the ecological approach it is assumed that a rich informative structure in the optical array already exists waiting to be picked up by the athlete's perception systems while moving within the performance environment (e.g., Davids, Savelsbergh, Bennett and Van der Kamp, 2002). The skill of picking up the relevant informational variables sometimes needs a prolonged period of time to educate the attention of learners (Jacobs and Michaels, 2002). Hence, within the ecological approach to cognition and action, it is proposed that the exploratory movements of athletes can maintain or change the nature and amount of meaningful information sources needed for successful decision making and action by their movements. Meaningful informational variables are obtained by perceiving affordances or invitations for action. These variables are meaningful to athletes by supplying them with information from which an action is afforded for a particular behavioral goal. In this respect interesting research relates to the early pick-up of information from the preparatory actions of opponents by performers (e.g., Abernethy, 1993; Ward, Williams and Bennett, 2002). These studies showed how preparatory movement kinematics from the movements of an opponent may contain information invariants, which can be used for action anticipation. Thus, perceptual information for action is not internalized as in the conventional information-processing approach but is distributed inside and outside the athlete and bridges the gap between the athlete and the properties of the environment. In this sense a further basic question arises: How can these separate parameters of cognition and action in sport (i.e. the *nature* and *amount* of information available in a performance context) be unified in a theoretical framework that will enable them to be studied as interdependent qualities?

One way to achieve this aim is by extending principles and concepts of nonlinear dynamical systems theory to the study of information for action in sport. In the last two decades insights from the nonlinear dynamical systems theory have provided an alternative theoretical rationale for explaining how processes of perception, cognition, decision making and action underpin intentional behaviors in complex, self organizing neurobiological systems functioning in dynamic environments (e.g., van Orden, Holden and Turvey, 2003; Turvey and Shaw, 1995, 1999). Within this theory, or more precisely its *synergetics* variant (see Haken, 1983), there are two types of parameters that can constrain action. The first type involves non-specific parameters whose change constrains the stability of ongoing actions. Candidate variables for modifying ongoing actions include perceptions, especially affordances (i.e. invitations for actions), emotions, intentional aims not directly focused on the specific action structure itself, ideas and morphological and physiological properties of the body. In other words non-specific parameters are those which do not specifically constitute the mode of action itself, but which form an influential background performance context for action. The second type includes order parameters (i.e. collective variables), which do define the mode of action. Inherent degeneracy of neurobiological systems and the nonlinear interactions between system components enable the existence of more than one stable solution to a particular task, termed *multistability* (see Kelso, 1995; Edelman and Gally, 2001; Araújo, Davids and Hristovski, 2006). Multistable systems can also exhibit a property known as *meta-stability*. Meta-stability in movement systems always arises when modes of action are weakly stable or weakly unstable (i.e. close to an instability point) and manifests itself in the switching between two or more modes of action (see Fingelkurts and Fingelkurts, 2004; Kelso, 2002). This framework proposes that the most relevant information for producing tactical solutions and controlling action in dynamic environments is emergent during performer-environment interactions (see Araújo et al., 2006; van Orden et al., 2003; Passos, Araújo, Davids, Gouveia, Milho, Serpa, Chapter 3). From this viewpoint, cognitive and action systems of athletes exhibit purposive behavior based on the spontaneous patterns of interactions between system components.

This rationale for explaining cognition, perception and action proposes that order parameters guide the emergent collective cooperative behavior of the athlete's system components (degrees of freedom) and serve two roles. First, order parameters inform the relevant components of the athlete's movement system (e.g. an attacker in the martial arts) how to behave cooperatively. Second, they inform other perceivers (e.g. the defender in a martial arts dyad) about the mode of action of an attacker. Through skilled observation of the collective behavior of an opponent's movement system, an individual can pick up meaningful information, which can be used to regulate ongoing action. Order parameters of an opponent's action can act as relevant essential information that athletes use for anticipating opponents' actions. It is no coincidence that order parameters or collective variables have been termed an "*informator*" (Haken, 1999). In previous work, by adopting concepts from the ecological approach to cognition and action we have attempted to connect these two informational variables. We identified affordances, which, once picked up, could inform athletes about alternatives for action. Other work has investigated order parameters of action modes that express information about the macroscopic behavior of an athlete. In this chapter we describe experimental findings that exemplify how the change and emergence of novel information in tactical solutions are dependent on changing ecological constraints of practice (non-specific parameters of dynamics), specifically perceptual and emotional constraints on individual athletes that influence the emergent dynamics of their actions (see Hristovski, Davids and Araújo, 2006a; Hristovski, Davids and Araújo, 2006b; Hristovski, Davids, Araújo and Button 2006; Hristovski, Davids and Araújo, 2007; Chow, Davids, Button, Rein, Hristovski & Koh, M., 2009).

EMERGENCE OF NOVEL TACTICAL INFORMATION IN A HEAVY – BAG PUNCHING TRAINING TASK

One of the most fundamental functions of complex cognitive systems in sport is to coordinate responses such as defensive or offensive behavior with environmental events (see also Vereijken, Chapter 6). Recent work (e.g., Hristovski, Davids and Araújo, 2006a) has provided insights into perception-action dynamics of cognitive and action systems in athletes characterized as dynamic pattern-forming entities. For example, in one study, 8 novice boxers, unfamiliar with a heavy-bag punching task, were asked to strike a heavy bag 60 times from various distances scaled to their arm lengths. The angle of fist-target collision was treated as an order parameter (i.e. as an informator about the boxer – target coordination state in Haken's sense). The manipulated control parameter was the boxers' perception of scaled distance to the target. It was observed that the perception - action system of boxers was highly sensitive to small changes of scaled distance from the heavy-bag. These small perceptual alterations induced continuous and abrupt changes (i.e. bifurcations)[1] in the set of possible actions as the control parameter was continuously varied (see figure 1). Also, the whole dynamical landscape of actions changed with small variations in the perceptual control parameter, which led to continuous and abrupt changes of action unpredictability and diversity as captured by entropy (H) values depicted on figure 3. For example, the emergence of a novel action influenced future system behavior by changing the probability of occurrence of the whole set of remaining actions. The continuous switching between modes of action suggests that under the constraints of the training task, the dynamical landscape of the boxers was highly meta-stable. Small variations in the perceptual control parameter led to emergence of new affordances (i.e. invitations for action) manifested in new action modes and sharp increases in entropy measures, that is, sharp increases in the information content of the athletes' actions. This finding demonstrated the inextricable link between an individual's perceptual and action systems. The amount of information present in an athlete's actions (i.e. the number of action choices and associated probabilities) was dynamically created by changes in the perceptual systems responsible for detecting the 'strike-ability' affordance. The maximum of the entropy value H (i.e. amount of the information content of striking actions) around the scaled distance D = 0.6 signified a minimal coupling, that is, tendency towards decoupling, between each pair of striking actions and a transition from a predominant use of straight arm jabs to exclusively 'arced' actions (i.e. hooks and uppercuts). This context dependent creation and change of the information content of actions is depicted on figure 3.

Results showed that boxers were able to discover new modes of tactical solutions for the task goal through intentional changes of the scaled distance parameter D. These decisions led to increased exploratory activity and changes in the perceptual context, with boxers consequently altering, sometimes drastically, the informational content of their actions.

This characteristic was also apparent when we analyzed the dynamics of sequential actions (Hristovski, Davids and Araújo, 2006b). The coupling between the left and right arm

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[1] Abrupt changes of the behavior of the system are called bifurcations (i.e. branchings), since typically they signify change of the number of possible action modes of the system.

modes of action, as assessed by the conditional probabilities,[2] was also highly sensitive to small perceived changes in the scaled boxer - target distance. Analogously, this effect produced continuous and abrupt changes in the amount of conditional informational content of temporally juxtaposed actions.

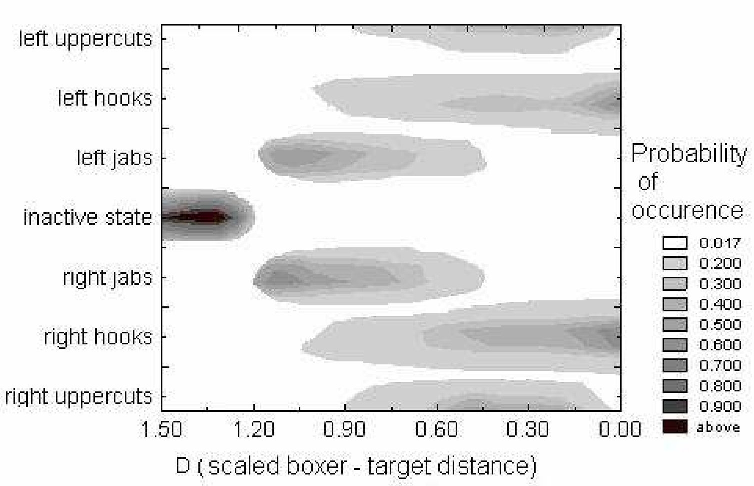

Figure 1. Continuous and abrupt changes (bifurcations) of the occurrence probability of action modes in boxers as a function of the scaled boxer - target distance D (with kind permission from the journal *Nonlinear Dynamics, Psychology and Life Sciences)*.

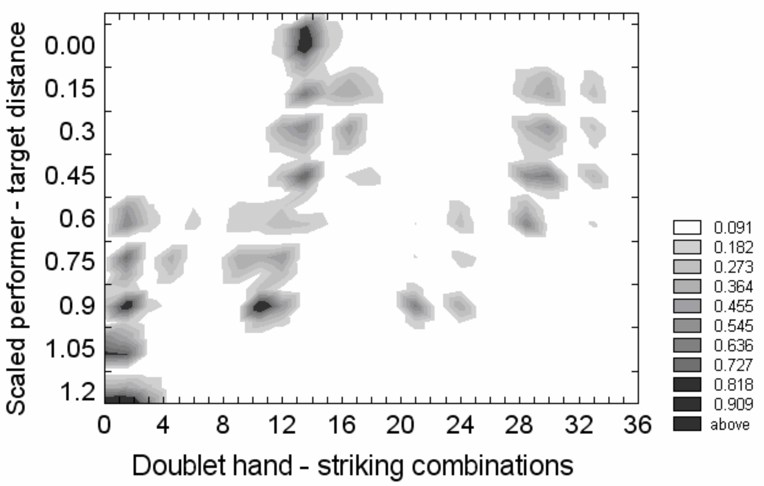

Figure 2. The conditional probability landscape of the hand-striking combinations as a function of the scaled boxer - target distance D. (with kind permission from the journal *Nonlinear Dynamics, Psychology and Life Sciences)*

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[2] Conditional probabilities tell the probabilities of the rest of the actions given one already performed. For example: If a left jab is already performed what are the probabilities of the other actions? These probabilities can be considered as coupling strength. Larger conditional probability means larger coupling strength and vice versa.

In figure 2 one can observe the existence of islands of highly coupled and less coupled actions immersed in a sea of undiscovered sequential combinations spreading between them. This graphic illustrates how the evolutionary stabilized action combinations (such as left-right hand strikes) dominated over the other combinations, reducing the degree of flexibility in sequential behavior, and the amount of information content, in novice boxers. It is apparent how perceptual information induces metastability as a generic dynamical mechanism for producing diversity of actions and the discovery of new action modes and the extinction of others, which leads to changes in the nature and the amount of action information content in the practice task.

On the level of inter-personal coupling, the intra-personal action information content H (see figure 3) has another role (Hristovski, Davids, Araújo and Button 2006). In figure 3 it can be seen that the space (i.e. scaled boxer-boxer distance) is split into two metastable action regimes (the minimal values of the H curve). These areas are metastable because for the time scale of one observation (1 round for example) the inter-personal dynamics will switch many times between those regimes.

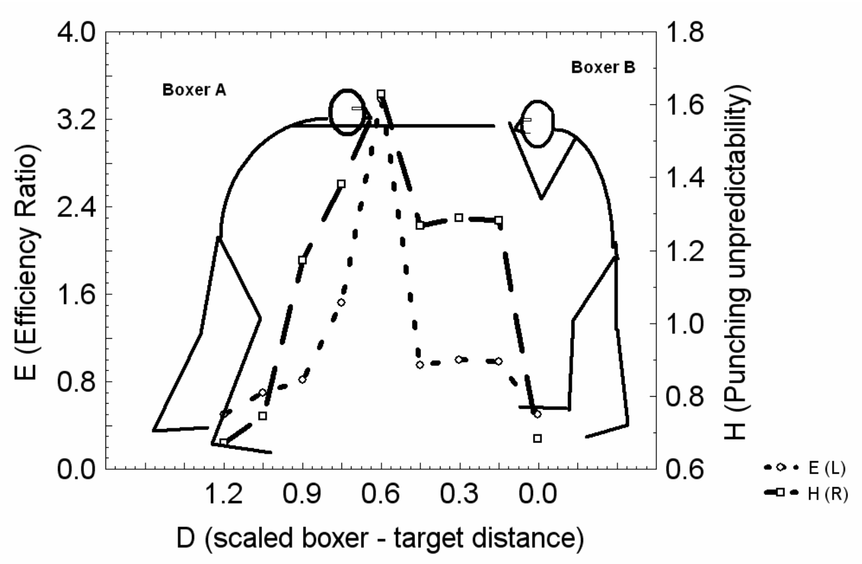

Figure 3. Boxer – boxer coordination (i.e. sparring) spontaneously emerges. The amount of punching information content *(H)* (dashed line) and efficiency ratio *(E)* (dotted line) minima, located around *D* =1.2 and *D* = 0 are the attractive states, and their maxima located around *D* = 0.6 are the unstable states of the coordination. The global minimum is located around *D* =1.2 and represents the optimal strategic position area in which boxers continually spend the most of time since it minimizes the unpredictability, efficiency ratio and consequently the global efficiency of the opponents punching actions (with kind permission from the Journal of Sport Science and Medicine).

The first regime (the location of boxer A) closely matches the distance of the arm length away from the target (i.e. boxer B) and the other is the clenched position where opponent boxers lean against one another, for example when boxer A moves to the position D = 0). In both cases the unpredictability of actions (the H function) is at a minimum because of the paucity of actions possible from those distances, as demonstrated in the experiment. The maximum of the information content (maximum unpredictability peak located at the scaled boxer - target distance = 0.6) is an unstable region for inter-personal dynamics since it is a location in which boxers spend very short periods of time. It is a region of maximal uncertainty in anticipating the type of action that might be used by an opponent (all actions are almost equally possible). In this way, the behavior of boxers is dynamically guided by the information landscape depicted on figure 3. In other words the amount of information (the H function) present has a dynamical role in constraining action. Whereas on the level of intra-personal dynamics scaled distance D has a role as a perceptual control parameter (figures 1 and 3), on the level of inter-personal dynamics, due to the nature of the information landscape H, scaled distance D has a role as an order parameter with two metastable states (the minima of H function) and one unstable (the maximum of H function) located at D = 0.6. In other words, interpersonal dynamics in boxing is spontaneously formed in a self-organizing fashion due to the influence of the informational dynamical landscape. This is an elegant example of the interchanging roles that parameters of the system can have: a non-specific perceptual parameter (i.e. scaled distance) can change its nature and become an order parameter (i.e. action informator) and vice versa. This observation is also valid for the information content H: on an intra-personal level it is dynamically created by continuous and particularly abrupt creations of novel modes of action (i.e. bifurcations) and is dependent on the scaled distance D as depicted in figure 1 and 3. On the higher level of inter-personal coupling, however, it plays a dynamical role in spontaneously forming the most probable strategic positioning of boxers (the minima of H), expressed in units of the scaled distance D. To summarise, the significance of these findings: on the one hand information content (H) was dynamically formed as a function of the scaled distance to target D, and on the other it dynamically controlled the strategic scaled distance positioning of boxers.

Metastability as a generic mechanism of varying information content was also present in the sequential hand-striking behavior as revealed by partial autocorrelation analysis (see figure 4).

Negative partial autocorrelation of lag 1 sequences were dominant in the observations of the boxers' actions, corresponding to left-right or right-left striking couplings. However, other short-range memory[3] sequences were also present in the data, including purely random (i.e. memory-less) sequences, up to those with lag 4 (i.e. action sequence motifs). This observation implied that the action system of individual boxers was highly diverse during the production of striking behavior. Changes in the sequence memory length, illustrating the versatility of the strength and length of the temporal couplings between actions, was another characteristic of meta-stable functioning and of the varied amount of information content of perception-action systems in boxers.

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[3] The term *memory* refers to the range of dependence of the current strike on the past strikes. Memory-less sequence means that there is no dependence between the subsequent strikes. The current strike is not influenced by the type of previous strikes. Memory of lag 4 means the current strike is influenced by the type of the past 4 strikes. Partial autocorrelations show the average *net* influence of the past strikes to the current one.

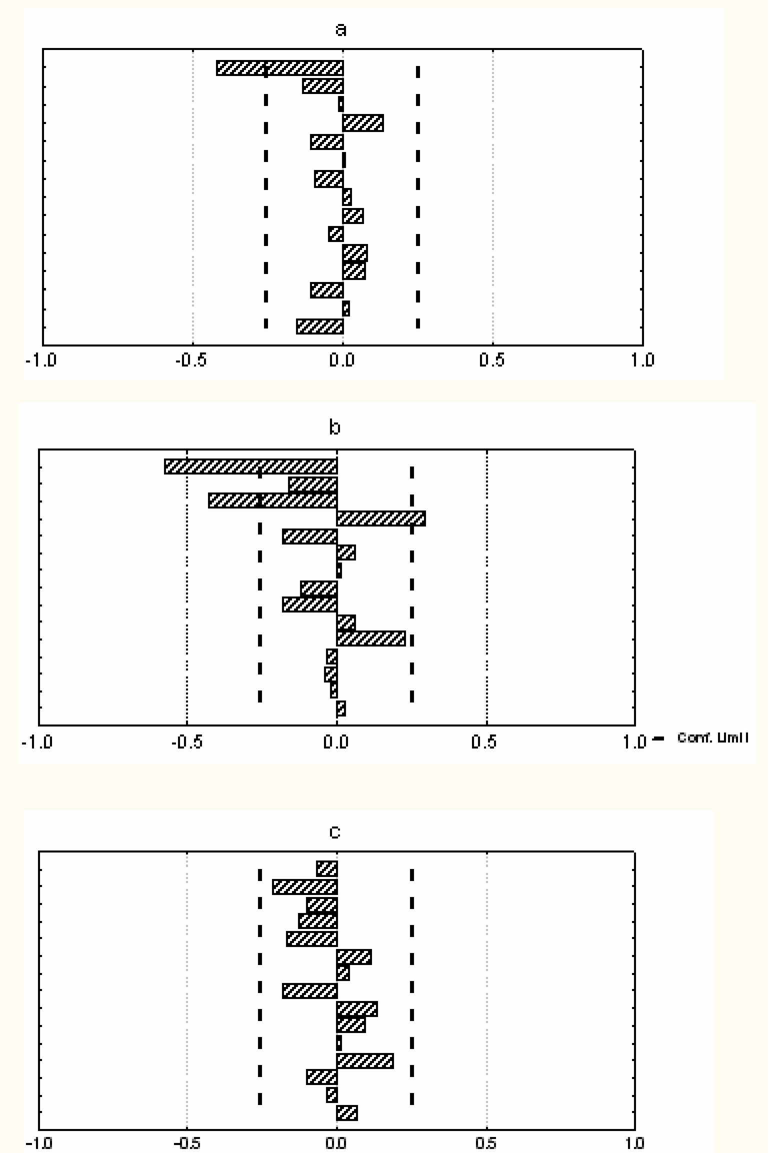


Figure 4. The partial autocorrelation functions for one of the boxers. Production of striking sequences with different memory (information) content is obvious. A. Short range memory of lag 1 corresponds to dominant left ↔ right strikes. B. More elaborate striking motif with memory lasting to lag 4. C. A purely random memory-less punching sequence. The dashed line is the $p = .05$ level of significance.

EMERGENCE OF NOVEL TACTICAL INFORMATION IN ATTACK – DEFENCE DYAD PERFORMING MODIFIED FOCUSERS TRAINING TASK

In another of our experiments six participants formed three attacker-defender dyads. The attackers were asked to increase and decrease their jab striking frequency in time with computer-generated sound signals presented through earphones that they wore. The frequency regimes were divided into 6 frequency groups with a frequency 1 group experiencing the lowest frequencies and a frequency 6 group the highest. Defenders had to try to evade the attackers’ hand strikes with their arms in two modes: (i) under 90 deg. with respect to the direction of attack i.e. left-right-left arm movements in a horizontal plane, and collect points (collecting defensive mode) and (ii) they were allowed to withdraw the hand close to their shoulder (under 0 deg. with respect to the attacking direction) to save the scored points (saving defensive mode). Obviously, this second performance characteristic was a possible alternative *pre-planned* action. The angle of defence was treated as an order parameter (i.e. informator) that contained the information about the dyad collective coordination modes. The 3 tasks were differentiated in the degree of motivation (affective significance) for the defenders to stay untouched, by manipulating a ‘perceived harm constraint’. In the first task there was no motivation for the defenders to stay untouched, since they collected points without regard to whether they were hit or not. In the second task the collected points by the defender, due to successfully evading the attacker’s strikes, were transferred to the attacker if he hit the defender’s arm. In the third task the motivation for staying untouched was made extreme by asking the defenders to imagine that the attacker was attempting to strike them with a sharp object. The defenders had to express behaviorally their defensive decision. The ‘perceived harm constraint’ was introduced as a non-specific control parameter and was scaled by the athletes on a scale 0 – 5 (0 = no harm and 5 = extreme harm). Perceived harm was treated as affective information, and in coalition with the striking – evading frequency control parameter, as a source of perceptual information it was expected to produce different dynamical effects in the three experimental tasks.

In task 1, since all boxers assessed the harm variable as h = 0, the only action observed was the collecting mode of action (see figure 5).

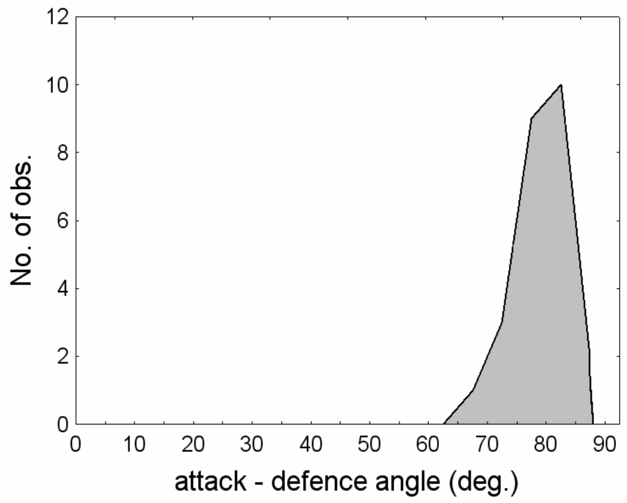


Figure 5. For task 1 coalition of constraints (h = 0) the only stable mode was the collecting one. The probability of actions condensed close to the 90 deg. defensive mode. This is a case of intra-mode variability with informational content arising solely from the non-zero dispersion around the mean.

For all increasing and decreasing striking frequencies the dyadic interaction stabilized the evading actions at approximately 90 deg. with respect to the attacking line. The intra-mode variability of actions produced almost a constant information amount for all frequency groups (see figure 8). Under the task 3 constraints, which contained high perceived harm values, the only stable behavior was the saving mode as depicted in figure 6. The information content of the actions was lowest under these task constraints (see figure 8).

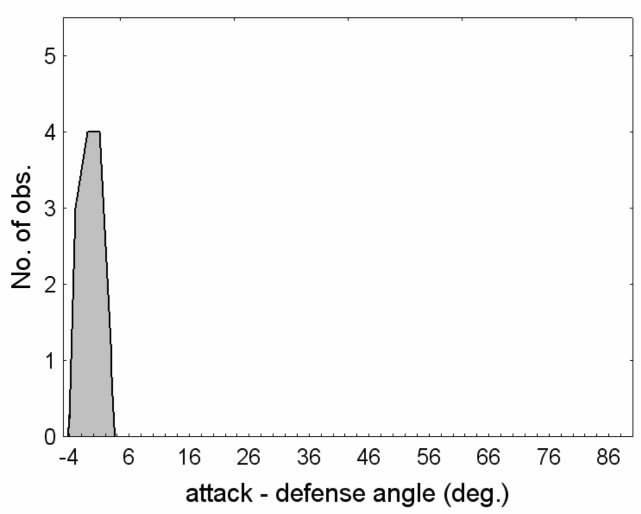
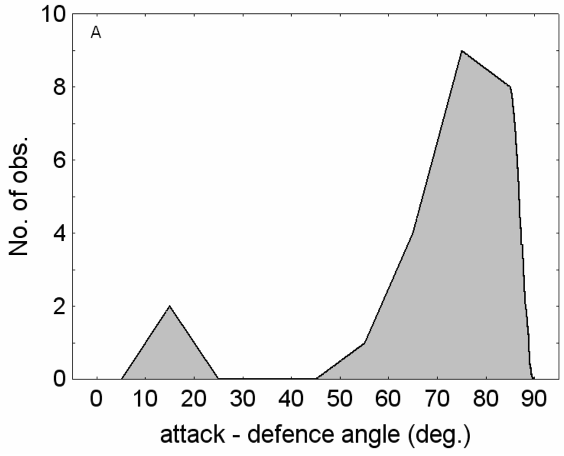


Figure 6. For task 3 coalition of constraints (h = 4 and 5) the only observed action mode was the saving mode. The low variability (i.e. dispersion) around the mean point to the high stability of this mode of action. A case of low intra-mode variability and low information content.

The dyadic interaction produced much more versatile behavior for harm values h = 1 and 2 present under task constraints 2 (see figure 7). For lower striking frequencies of the attacker the more probable state of defense was the collecting mode. For medium striking frequencies the probability of observing the defender's collecting or saving mode was approximately equal and for high striking frequencies the predominantly observed mode was the saving one (see figure 7 under A, B and C respectively).



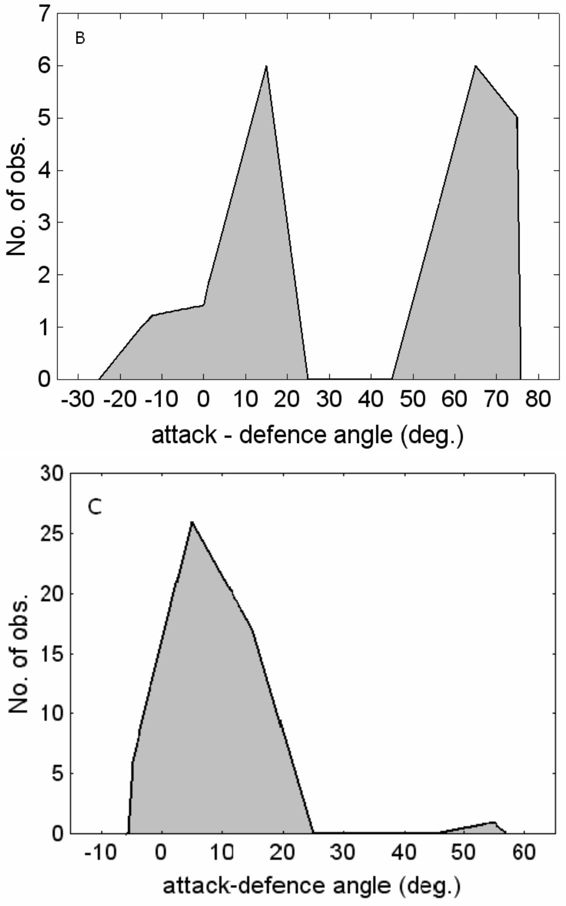


Figure 7. For task 2 coalition of constraints (h = 1 and 2) a meta-stable dynamics occurred (i.e. switching from the collecting to saving mode and vice versa). The probability condensed around two modes of action forming a bi-modal distribution. The minimum between the two peaks corresponds to an unstable (rarely visited or unvisited) region of attacker – defender coordination. This is a case of high intra and inter-mode variability (i.e. diversity) of actions with high information content. As the striking frequency increases the probability of observing one of the actions changes. A. striking frequency group 1. B. group 3; C. group 5.

For task 2 the information content of actions was highest and there was a maximum for medium attacking striking frequencies. The maximization of entropy through producing a meta-stable state is a hallmark of phase transitions of the first kind (Kondratyev and Romanov, 1992). Meta-stability arose as a consequence of the increase in probability of the decoupling between the attacker's and defender's actions. Although not instructionally imposed by experimenters as a prescribed task solution, the constant switching between the collecting and saving modes was a robust observation. That is, defenders discovered a new mode of action, i.e. a combination of collecting and saving actions, to satisfy the interacting perceptual, affective and goal constraints. It is important to note that this new mode of action combination emerged as a *novel* solution to the tactical problem (i.e. task goal) of collecting more points and winning. Whereas during the first and third task constraints the perception – action system of the performers was trapped into stable extremes, under Task 2 constraints the perception – action system was most creative and diverse (as indexed by the entropy measure) around the transition regions where meta-stability resided (i.e. between the two extremes). Intermittently combined actions of collecting and saving points induced a high amount of information from actions, that is, greater diversity and unpredictability in the tactical actions of the defender (see figure 8).

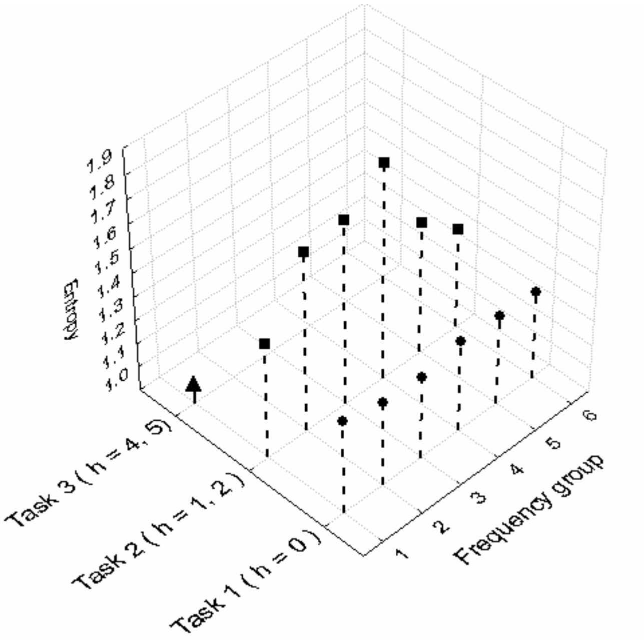


Figure 8. The change of the entropy (amount of information content of actions) as a function of the striking frequency group and degree of harm (h) of attacker's actions.

The pre-planned intention (i.e. the saving mode of action) introduced multi-stability as a necessary condition for spontaneous change of actions in dynamic performance environments. Although the saving mode of action was a pre-planned alternative, instructionally imposed as a possible mode of behavior in all three tasks, it emerged (i.e. contributed to the action information amount) only under the task 2 and 3 coalition of constraints. This observation signified that the pre-planned intention was immersed in the overall dynamical decision-action landscape and was shaped by the ongoing interactions of the manipulated constraints. In task 2 it was stabilized, that is, it became a sole tactical solution, emerging only above a specific range of striking frequencies (see figure 7 and 8) after the system passed through a meta-stable 'collect-save' regime and was intimated by the maximum of the entropy value (i.e. information amount). In other words, it appears that consciously-imposed, pre-planned intentions and the spontaneity of their execution may not be irreconcilable concepts, as intuitively believed (see Davids, Chapter 1). The final stabilization of the intended alternative pattern (i.e. saving mode) spontaneously arose, driven by systematic changes in the non-specific affective and perceptual parameters. Thus, organizational states in athletes, created by intending and decision making, can be construed as various phases of the global intentional aim spread over time. Within the framework of this research program, intentions, even when consciously imposed, emerged as decisions and were non-specifically (emotionally and environmentally) driven events. Both, the specific (i.e.

conscious) and the non-specific (i.e. emotional and environmental) constraints cooperated to create the change from the ongoing collecting to the intended alternative withdrawal (saving) decision-action complex. Specific constraints (intentions) introduced virtual instabilities in the decision landscape, while non-specific parametric influences enhanced them and enabled spontaneous transitions among the collecting and saving tactical decisions as a novel combined form of action.

CONCLUSION

In this chapter, we discussed how perceptual and affective information sources can create and change, sometimes abruptly, through creation of new action modes, the information contained in the order parameter (i.e. the informator) that shapes emergent movement patterns. We showed how ecological information and information entropy influence each other and are interdependent. These findings can be considered under a unified theoretical framework offered by nonlinear dynamics. Empirical work demonstrated how information sources have biological meaning in performance contexts like sport precisely because they are able to provide the basis for creating new, more adaptive, modes of action with respect to emerging task and goal constraints of athletes. Experiments demonstrated that practice task constraints (i.e. instructional, emotional and perceptual context) can be organised in a way that enables maximization of dynamic metastability affording athletes maximal ease and flexibility of discovering and switching between novel action combinations. These action modes were not instructionally imposed on athletes but simultaneously increased the intra- and inter-mode variability of their movements. Therefore, putting the athlete's perceptual, cognitive and action systems in the metastable (i.e. weakly stable or weakly unstable) region by adjusting the instructional, affective and perceptual constraints could be a natural way to amplify the stochastic perturbations and movement variability needed to enhance the diversity of actions and exploratory behavior in athletes (see the Schöllhorn, Michelbrink, Welminski, Davids, Chapter 5). Context dependent metastability of the perceptual, cognitive and action systems is a viable generic dynamical mechanism of creativity in sport.

Another important observation was that pre-planned intentions became stable and emerged as decisions only under a well defined coalition of constraints. Inter alia this observation signifies that coaches should be aware of the moment when athletes simply do not act as prescribed. Pre-planned intentions emerging from externally- or internally-imposed instructions become relevant only when task (including the goal), personal and environmental constraints afford the emergence of that intention. The coach's third person perspective and the athlete's first person perspective might not match, especially during competition, and putting too much emphasis on prescribing individual tactical solutions might be somewhat counterproductive.

Moreover, while the amount of action information content may be dynamically formed by changes in some non-specific control parameter (i.e. perceptions of scaled distances, affective influences or striking frequency of the attacker), on another level it may create the dynamics of that parameter. This is a hallmark of the circular causality that operates on different levels in complex systems. The empirical observations discussed in this chapter showed how the *amount* of information and the *nature* of information interact and can bring about a self-organization of strategic interactions between athletes without instructional intervention. One research direction that should persist in future should be ascertain answers to issues such as: when and why instructional constraints are required and when and why athletes should be released to follow her/his self-organizing capacities (Savelsbergh and van der Kamp, Chapter 2).

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