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Network dynamics-based tactic of combat for Taekwondo to identify keys patterns

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Abstract

Aim: Our method of network dynamics-based stratification of combat integrates alterations at multiple levels and is independent of category and athlete type. Specifically, different fighters are described by differentially wired networks with distinct network topology resulting from their tactical action

Methods: Network dynamics of the tactical actions are analyzed by considering its attractor landscape, which consists of trajectories from all possible initial network states of the beginning combat to its attractor states and proves different situations where one or multiple tactics are inhibited. We focus on the set of attractor states that different tactics eventually reach, which correspond to specific steady states of inevitable tactics

Results: The main objective was to measure the attractors for the network by using dynamic systems and show two principal attractors meaning dodge and direct attack are the most important techniques.

Conclusion: Our results not only enable stratification of tactic combat into distinct response groups but also reveal the most important tactic for the network.

Keywords
Taekwondo,
Discrete Dynamic System,
Attraction basins,

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INTRODUCTION

Martial arts and combat sports efficiency can be analyzed from different perspectives, such as increasing coordination allows more techniques in MMA (Bolotin *et al*., 2011), but in combat like taekwondo be able analyze the efficiency of response from a tactical perspective (Menescardi *et al.,* 2019). Based on the abovementioned choosing a correct action to make a tactical decision during the competition and identifying the tactical response to predict the response to the action must have knowledge of the different tactical options (Son *et al*., 2020).

The performed investigations have shown a tactical scheme to face different situations or different beginnings of combat to make a good choice using specific tactical actions (Gréhaigne *et al*., 1995). Taekwondo is the martial art and sport combat in which quick decisions are made in response to stimulus such as the opponent 's direct attack or opening (Gréhaigne *et al*., 1995).

Taekwondo is an Olympic sport in which studies have been carried out to estimate tactical actions in young people (Casolino *et al*., 2012) or subdivide responses actions like attack, counter attack, defenses (Menescardi et al., 2015). There is a need to investigate combat dynamics and how they unfold and try to predict combat patterns (Menescardi *et al*., 2019). Currently fencing reviews has been published showing a pressure action pattern was followed by preparation and attack, while the counterattack actions were performed by the opponent (Tarragó *et al*., 2017). Meanwhile the observed patterns were, attack to the front, to the right, back and to the left and the sequences ended in the base work, a moment of pause or the end of the combat (Miarka *et al*., 2012).

Mathematical modeling systems help researchers and coaches understand the behavior of athletes in competition (Ozcinar *et al*., 2013). Even to describe patterns of play (Barnett et al., 2011, Goldner 2012). Models in the relationships between the actions carried out by competitors have an increasing interest (Menescardi *et al*., 2015).

Based on experimental data, a model can be created that depends on the previous state that would be the action performed by an athlete and can predict the next action (Gottman *et al*., 1990). Recently investigations have been using mathematics tools in Taekwondo like Markov chains (Menescardi *et al*.,

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2019) describing a sequence of possible events in which the probability of each event depends solely on the state reached in the previous event (McGarry *et al.,* 1994, Castellano et al., 2007). For this reason, results of combats work of (Menescardi *et al*., 2019) could be consider a promising dynamic system like a network and this can be analyzed with use of discrete dynamic systems, as well as generating disturbances in the network that will simulate combats in which a specific tactic is not carried out to characterize and stratify the subtypes of combats that can be carried out and thus know which tactics are essential. A dynamic depends only on the previous state and the model takes several decisions until converge in a fixed state. It means that if a combat started by a specific sequence converges into a state "i" and when analyzing different combats with different beginnings and these converge in the same decision "i" this would be an attractor of the system since different beginnings converge in the same final decision (Luna *et al*., 2008).

METHOD

Participants

Based on the work published by the Menescardi group (Menescardi *et al*., 2019) in which they collected data from the London 2012 Olympic games considering the men's and women's branches, they present a network of all the actions that were carried out in 151 bouts. In this work, based on these results, the network of tactical decisions of the fighting was recreated and an analysis of discrete dynamic systems was carried out to know the attractors of the system.

To code the athlete's behaviour, the TKD observational tool, validated by (Menescardi *et al*., 2017) was used. This tool contains seven exhaustive category systems (criteria): Opening (OPE), Direct attack (DIA), Indirect attack (INA), Anticipated counterattack (ACA), Tactical action Simultaneous counterattack (SCA), Posterior counterattack (PCA), Block (BLO) , Cut (CUT), Dodge (DOD)

Statistical analysis

Discrete Dynamic Systems: The way model the activity of the network of interactions between nodes as a dynamic system is a follow: We consider a finite set A of $N \in \boldsymbol{N}$, nodes. Each node represents a technique in the network, which can have only two states, active or inactive {0,1} or more precisely execution or not. That is, our space of possible configurations has 2^N different possible configurations. The state of a node changes under the influence of other nodes (usually a subset of the network). The state change rule is synchronous for all nodes. And the total state of the network at the same time $t \in \boldsymbol{N}$ is a vector of N inputs, which we will denote as X_t. Being a discrete system, the network is updated for each t according to the rule. In a slightly more general way, other biological systems such as neural networks can contemplate the existence of multiple activities and these can be described through different states {0,1,2,...}

Two states were defined for each of the nodes of this network. The state (1) represents some activity, which could be, direct or initiate an action of combat in the opponent. On the other state (0) represents the inactivity of the function of said node.

Dynamics Model

Dynamics starts in an initial state $X_0 = \{x_1(0),\ x_2(0),\ x_3(0), \dots, x_N(0)\}$ where $x_i(t)$, for $i = 1, \dots, N$, represent the activity of each of the nodes at the same time t. The state X_0 is updated with Boolean functions $f(X)$ according to the activity of each of the nodes, as seen in the following equation.

$$X_{t+1} = f(X_t) \tag{1}$$

Since for when applying f to each state of the network X a single exit state is obtained we can say that

$$X_t = f^t(X_0) \tag{2}$$

That is, a fixed point of f is that state of the network, such that

$$f(X^*) = X^* \tag{3}$$

That is to say that state that under f remains invariant. Now, if it happens that when applying f of a X_0 and exist a i and a k such that $f^{i+k}(X_0) = X_i$, we say that the state corresponding to X_i is a point k period of f and each X_j in the orbit of X_i is periodic of the same period k, so that

$$f^k(X_{i+j}) = X_{i+j} \tag{4}$$

An attractor in this context is defined as a state to which a nonempty set of initial conditions converges. Given a set $\{{X_0}^j\}$, X^* is an attractor for the whole $\{{X_0}^j\}$ if for each j, exist $t \in \boldsymbol{N}$ such that $f^t({X_0}^j) =$

$X^*$and furthermore, X^* is a fixed point or a periodic point, once the attractors are found, they are stored and compared looking for similarities.

Once the attractors that appear repeatedly were located, their attraction basins were identified and characterized. Means if for an attractor X^*a set of initial conditions that form the set $\Omega\ (X^*) = \{X_0|\exists\ \ t \in \boldsymbol{N}$ tal que $f^{t+k}(X_0) = X^*\forall f^{t+k}(X) = X^*\forall \geq 1\}$This set is the basins of a fixed point and the shape is similar for the limit cycle.

RESULTS

Tactical stratification by attractor landscape analysis.

Our method of network dynamics-based stratification of combat integrates alterations at multiple levels and is independent of category and athlete type. Specifically, different fighters are described by differentially wired networks with distinct network topology resulting from their tactical and technique actions.

Network dynamics of the tactical actions are analyzed by considering its attractor landscape, which consists of trajectories from all possible initial network states of the beginning combat to its attractor states. We focus on the set of attractor states that different tactics eventually reach, which correspond to specific steady states of inevitable tactic.

Systematic computational approach relies on two steps: 1.- constructing tactic action network models by mapping the functional into the interaction network; and 2.- stratifying tactic action based on the network response profile to perturbations (cannot used one tactic) that can change the network dynamics. The functional alterations that we selected include tactical actions that athletes do not use, such as against attacks, blocks, cut, direct attack, indirect attack, dodge, subsequently analyze disturbances in which no more than action can be performed such as no counterattack, block and cut or direct attacks and indirect.

Mapping genomic alterations to network modifications. Combat tactical actions stratification by dynamic systems looking at the attractor state. Our method of analysis network-based stratification of tactical actions of combat reported for the group of Menescardi (Menescardi *et al.*, 2019) for Olympic games 2012 athletes, see figure 1.

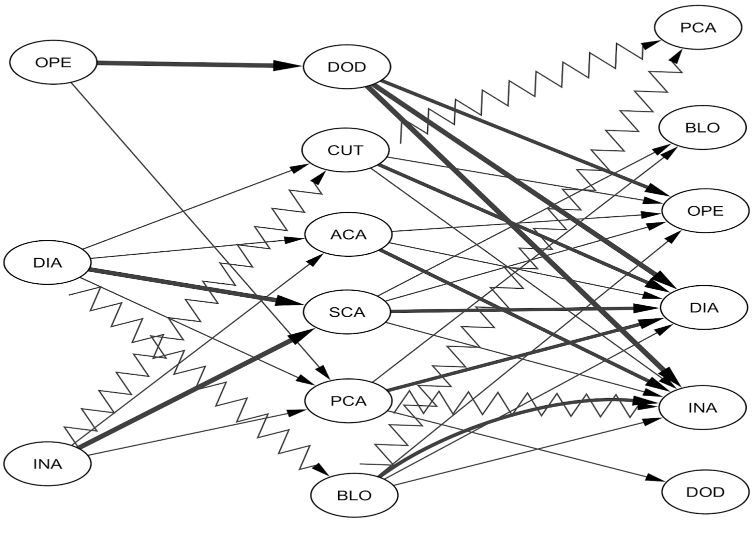
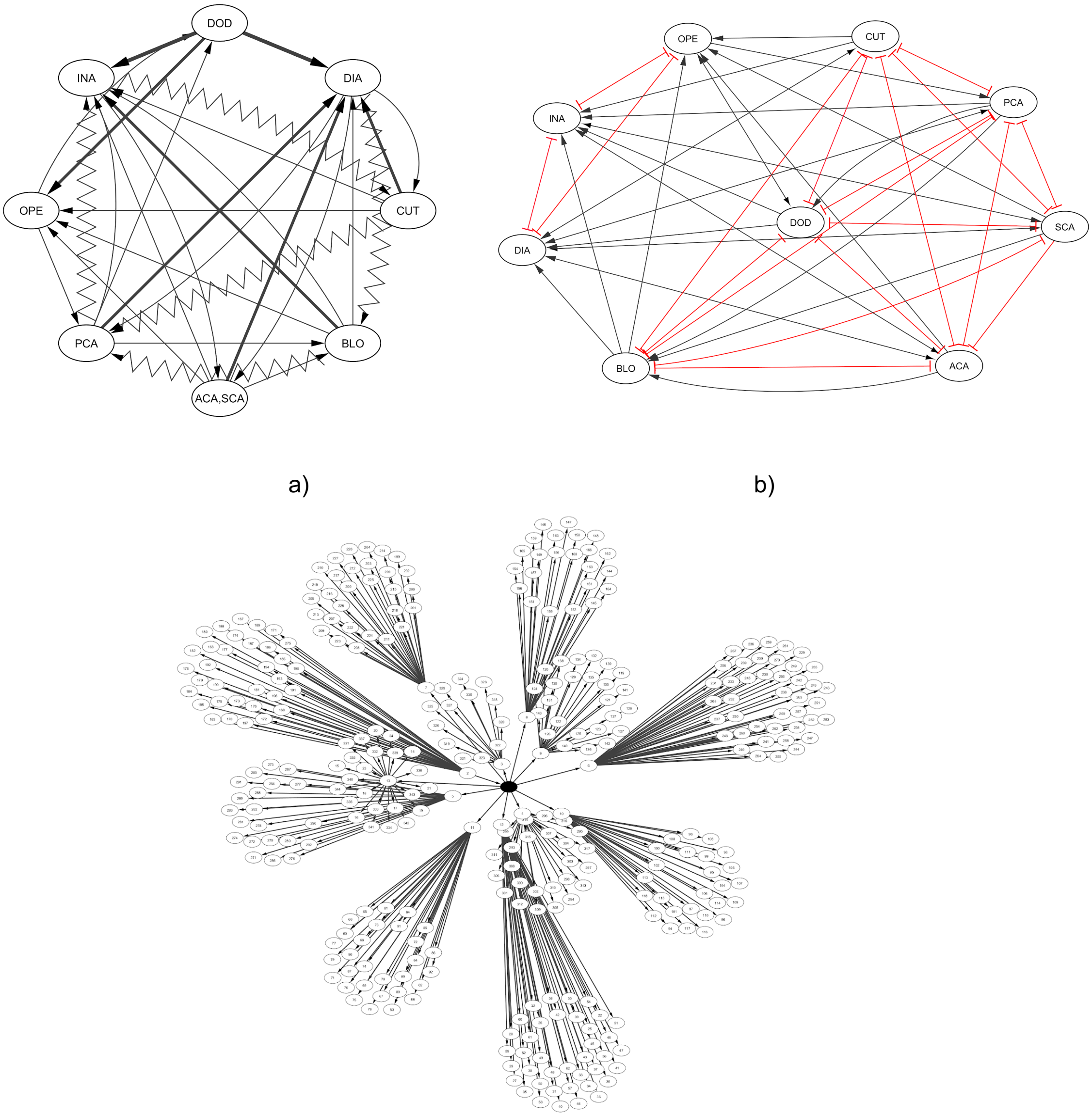


Figure 1. Shows tactical actions based on reported Menescardi (14). The 3 principal actions were OPE, DIA, or INA for athlete A, and athlete B responds with DOD, CUT, ACA, SCA, PCA, BLO, and then athlete A response with PCA, BLO, OPE, DIA, INA, or DOD.

The network integrates all tactics used for men and women in those games and is independent of category. Network of sequences based on Menescardi (Menescardi *et al.*, 2019) show in figure 1 site right, the zigzags were actions for women in the Olympic games that are not used for men. Ticker lines are the actions more frequently in the sequences performed. The left side of figure 2 shows the network used for analysis with a dynamic system, black lines indicate the opponent's next action node j if you performed the action of node i, and the red lines indicate inactivation represent that j action cannot be performed at the same time.



a) b)

c)

Figure 2. Network of stratification tactical actions. Graph right a) shows the sequences of different tactical actions. Graph left b) shows the dynamic of the network. black lines indicate the opponent's next action if you performed the action of node *i*, and the red lines indicate that this action cannot be performed at the same time as node i. In down graph c) it is shown the space face of all initial conditions and converge to one attractor of the system.

We analyzed its state transition dynamics for various perturbations that simulate athletes who cannot do a tactical action by changing either node activity or interaction type figure 3. There were 512 combats simulated in 13 different cases, giving a total of 6656 combat simulations with a total average of 26,624 movements performed. The analysis showed that the network from all possible initial combinations, which we call initial conditions. When converging in a single point so that the network when making a certain number of decisions and executing them reaches a singular point which we call the attractor, this will repeat the same number of decisions and the same decision will be made reaching the same point.

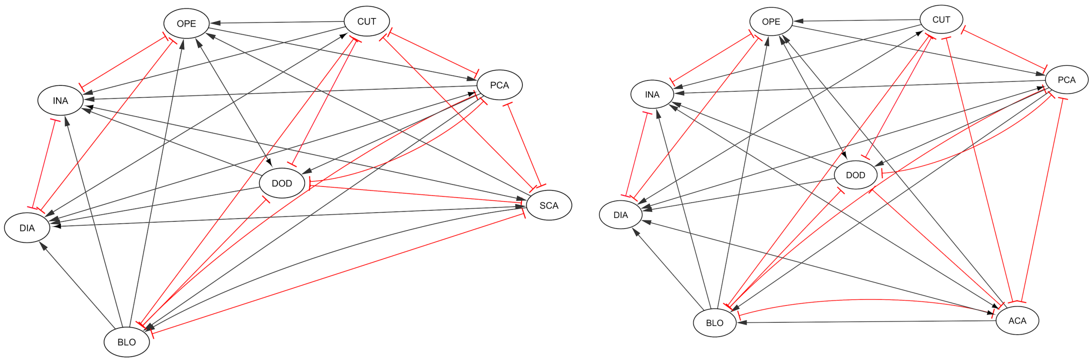


Figure 3. It is shown the network when inactive with one tactical action.

Under normal conditions and in all disturbances carried out that are equivalent to the fact that in the fighting they cannot perform any of the tactics, there is a strong attractor that is repeated with a higher percentage, being highly significant. Said attractor was DOD, previously it was mentioned that from the DOD node the next action can be OPE, DIA and INA based on (Menescardi *et al.*, 2019).

Network dynamics-based analysis all tactics: When analyzing the dynamics of the network where all the tactics are used, it was shown that 68% ($p<0.001$) of the initial conditions converge in the DOD state, this being the only asset. Therefore, the last movement would be DOD, the network converges to this node in 4 steps and it was found that 7 different initial combinations can be answered by 330 possible answers and these in turn can be answered in 13 ways, but in the end the decision converges on DOD, this being the attractor (figure 1, imagen c). For last 0.58% ($p<0.001$) of the initial conditions converge in the BLO and INA nodes, implying that the last movement for those initial conditions implies that one athlete performs INA and the other responds with a BLO. The BLO node its next action can also be OPE, DIA and INA, like the DOD node. The remaining percentage of initial conditions 30.93% ($p<0.001$) converge in a limit cycle that repeats periodically.

Alterations to network modification: The alterations were analyzed in a binary fashion, such that an altered tactic (DOD, DIA, INA, ...) was either constantly inactivated.

CUT was a first alteration such that any combat can use it. This analysis converges in 69 % of all actions that reach DOD status and 0.58 % converge on INA and BLO. The decision and steps number to reach the attractor were the same as in the normal network (1 ← 13 ← 333 ← 7). The second alteration was BLO, as this action could not be performed, 70% of the initial conditions converge on DOD, el 0.19 % respectively converged on the following nodes: {INA, SCA}, {INA, ACA}, {SCA, DIA}, {ACA, DIA}, {CUT, DIA}, the initial conditions, the number of steps and the decisions were almost equal to the case of the normal network (1 ← 13 ← 339 ← 7). The third alteration was SCA, 68.55% converge on the same DOD, 0.58% {INA, BLO}, and respectively 0.19% for {INA, ACA}, {ACA, DIA}, {DIA, CUT}, and the steps to get to the attractor were (1 ← 13 ← 330 ← 7). The fifth ACA disturbance, where 69.33% reaches DOD, 0.58 % {BLO, INA}, 0.19 % {DIA, CUT}, but the number of steps is still 4 steps

(1 ← 13 ← 334 ← 7). The eighth disturbance in INA reached 70.5 % to the same attractor in the same number of steps (1 ← 14 ← 339 ← 7), and 0.19 % for {ACA, DIA}, 0.19 % {DIA, CUT}, table 2. There were three alterations with less usual responses that were: fourth (PCA), sixth (DIA) and eighth (DOD). The fourth disturbance PCA 68.55 % reaches the same DOD attractor, 0.58 % to {BLO, INA}, 0.19m%, {INA, ACA}, {ACA, DIA}, {DIA, CUT} 0.19% to each one respectively but in this case, the number of the steps to reach the DOD attractor is less, it is reached in 3 steps (1 ← 19 ← 331). The sixth DIA disturbance, 97.65% reaches the same attractor but the number of steps increases to 6 (1 ← 15 ← 437 ← 10 ← 22 ← 15), 1.95 % {INA, BLO}, {INA, ACA} 0.19%, in this all cycles disappear. The eighth DOD alteration showed, 66.40% converges to nothing, everything is inhibited as if the network stopped indicating that it is a crucial node, KO. In protein networks, it would be equivalent to a knockout protein, which indicates that without it the cell cannot live, Table 1.

Multiples alterations network: The defenses that imply receiving contact were inhibited {BLO, CUT}, when doing so the network showed that 70.89 % converge in BLO, 0.19 % in {SCA, OPE}, {ACA, SCA}, {DIA, OPE}, {DIA, HERE}. No significant change was shown with respect to the individual alterations or to the normal network, however, the second general attractor obviously disappeared. This indicates that for the network the CUT and BLO tactics, since they are not used, do not modify decision-making 1 ← 13 ← 342 ← 7.

Finally, all the anti-attacks {PCA, ACA, SCA} were inhibited, showing that 69.33% converges on the DOD attractor, while 0.58% {INA, BLO}, 0.19% {DIA, CUT}. This alteration of 3 nodes showed the appearance of a new attractor {BLO}. 1 ← 19 ← 335, show in table 2.

Table 1. The percentages of all initial conditions that converge on the following attractors are shown. The first row indicates the attractors found in the analysis for individual disturbances, the first column indicates the node that was inhibited to simulate the disturbance of not using this tactic. It is shown that the attractor that converges in DOD is robust for all disturbances, making it a central node in the dynamics of the network.

Attractors *vs.* conditions	**DOD**	**INA, BLO**	**DIA, CUT**	**ACA, DIA**	**ACA, INA**	**DIA, ACA**	**SCA, INA**	**DIA, PCA**	**Cycle**	**Significance set for the study**
Normal	68%	0.5%	0.1%		0.1%	0.1%			30%	p<0.001
CUT	69%	0.5%			0.1%	0.1%			30%	p<0.001
BLO	70%			0.1%	0.1%		0.1%		30%	p<0.001
SCA	68%	0.5%	0.1%	0.1%	0.1%				30%	p<0.001
PCA	68%	0.5%	0.1%		0.1%	0.1%			30%	p<0.001
ACA	69%	0.5%	0.1%						30%	p<0.001
DIA	98%	2%								p<0.001
INA	70%		0.1%	0.1%					30%	p<0.001
DOD	X	0.5%	0.1%	0.1%	0.1%	X	X	0.1%	35%	p<0.001

Table 2.- When disturbing multiple nodes, row one corresponds to inhibiting CUT and BLO. Row two corresponds to inhibiting the PCA, SCA and ACA node.

	DOD	**INA, BLO**	**DIA, CUT**	**ACA, DIA**	**ACA, INA**	**SCA, INA**	**SCA, DIA**	**Cycle**	**Significance set for the study**
CUT, BLO	70%			0.1%	0.1%	0.1%	0.1%	30%	p<0.001
ACA, PCA, SCA	69%	0.5%	0.1%					30%	p<0.001

It is shown that for the normal network, with single disturbances or with multiple disturbances, 2 strong attractors appear since most of them converge on these {DOD}, {INA, BLO}. The other attractors that appeared with less than 1% convergence were: {INA, SCA}, {DIA, SCA}, {DIA, CUT}, {DIA, ACA}, {INA, ACA}, and {DIA, PCA}.

The rest of the initial conditions of all disturbances, (30 %) of all disturbances and 35 % for the eighth disturbance converge on the same limit cycle.

Limit cycle or attractor with period k.: Our analysis showed for the network without alterations and with any single or multiple alteration (approximately 30 %) of the initial conditions converge in a limit cycle of period two. Which indicates that this action is repeated periodically in the same order figure 4. The initial conditions converge through decisions in this cycle, in which one athlete starts with DIA, the second responds with one of the following options (DOD, CUT, ACA, PCA, SCA) and athlete one responds again with DIA, giving restart the cycle. In the case of alterations by inhibiting any of the possible actions that would be the response of athlete two, the network can automatically choose any of the remaining nodes and athlete 1 responds with DIA.

DISCUSSION

The network has a property known as robustness, dynamic biological systems tend to be very stable and resistant to alterations, for example genetic networks (Benítez *et al.*, 2008, Espinosa et al., 2011) they can withstand many alterations and the responses or attractors to which genetic networks converge are constant. In this case, this network shows to maintain the same attractors even with modifications, indicating its similarity with biological networks and indicating that it is a stable network.

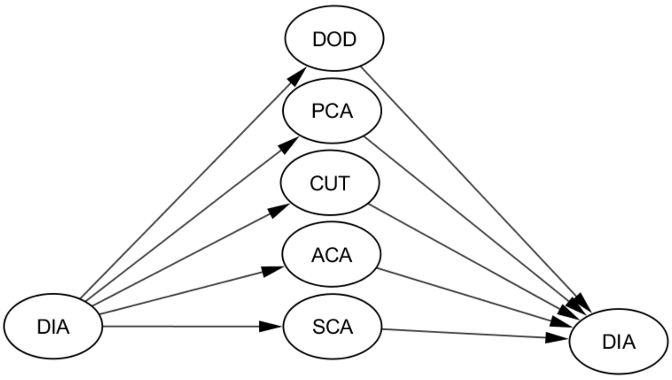


Figure 4.- Shows the attractor with period 2, or limit cycle.

Two main attractors were found for the analysis of the network without alterations, with singular table 1, and multiple alterations table 2. The two main attractors 70 and 30 percent of the initial conditions respectively, where one is stationary and the other is a limit cycle, remains invariant in the face of alterations, indicating that these DOD "dodge" and DIA "direct attack" tactics are crucial for the dynamics. of the network and therefore the dynamics of a high-level combat.

The DOD attractor of the dodge is something unavoidable on the network and it is a decision that the network will make under 70 % of the stimuli. There are several works indicating that this should be a very dominated tactic for those who practice martial arts or contact sports, since by not avoiding a blow even if it is blocked or shortening the distance the impact is received. These works talk about the consequences or injuries that appear when practicing this type of sports as in (Petrisor *et al*., 2019), in which when analyzing a subject who had been practicing mixed martial arts, it was revealed that he had difficulties with the short-term memory and processing speed, as well as difficulties organizing and multitasking. The occurrence of brain injuries resulting from head trauma is a major concern in MMA (Follmer *et al*., 2019). Injuries such as sprains in wrestling, concussions in boxing, and fractures in wrestling, boxing, and martial arts are reported (Pappas *et al*., 2007). In a study in 2014, the main injuries in taekwondo athletes regardless of gender are: elbow (21.3%), foot (17.0 %), ankle (12.2 %), contusions (29.3 %) (Altarriba *et al*., 2014). Recently in taekwondo athletes the injuries were in the lower extremities (74.11 %), followed by the upper extremities (17.87 %) and the head and trunk (7.75 %). Common injury mechanisms include contact with another player (50.89%) (Son *et al*., 2020). In this way evading is a highly relevant tactic. In the case of the limit cycle or attractor of period 2. For the alteration of DIA, the appearance of cycles was affected, this because the DIA node is crucial for the cycle. This indicates that for the analysis of the network presented, the DIA tactic is crucial even when in the simulation of battles where some tactic is inactivated, the cycle remains present.

In the analysis of individual alterations when inactivating CUT and BLO converge in the same attractor and in the same number of steps and decisions as the normal network without any changes, Menescardi's group (Menescardi *et al*., 2019) mentioned that women performed these tactics in little percentage and the network by not using these tactics is not affected in decision making or in the number of steps to reach the attractor. This may indicate that these two tactics may not be used in combat. The other nodes that appear (initial conditions < 0.5) as attractors {INA, SCA}, {DIA, SCA}, are mentioned within the 5 most used sequences (Menescardi *et al*., 2019), {DIA, CUT} and {BLO, INA} in the same work it is mentioned that making a cut after a direct attack or a block followed by an indirect attack can serve to cut the rhythm of the other player.

Likewise, it will be proposed to increase the variables in the network, such as kick laterality, the number of rounds, which increases the possible states and improves the analysis to later become a predictive model. It is also suggested to carry out this analysis by creating networks at different levels, such as universities, national and local tournaments.

PRACTICAL APPLICATION

Our model is an innovative analysis that when studying this network resulted in a stable and robust dynamic system similar to networks of biological behavior. In addition, it is presented that the two unavoidable and most important tactics in the dynamics of the network were DOD and DIA. Being these tactics the ones that athletes would be suggested to have more dominated.

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