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Information Flow and the Distinction Between Self-Organized and Top-Down Dynamics in Bicycle Pelotons

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Abstract

Information in bicycle pelotons consists of two main types: displayed information that is perceptible to others; and hidden information available to individual riders about their own physical state. Flow (or transfer) of information in pelotons occurs in two basic ways: 1) between cyclists within a peloton, which riders exploit to adjust tactical objectives ("intra-peloton"); 2) from sources outside a peloton as it is fed to riders via radio communication, or from third parties ("extra-peloton"). A conceptual framework is established for information transfer intra-peloton and extra-peloton. Both kinds of information transfer affect peloton complex dynamics. Pelotons exhibit mixed self-organized and top-down dynamics. These can be isolated and examined independently: self-organized dynamics emerge through local physical rules of interaction, and are distinguishable from the top-down dynamics of human competition, decision-making and information transfer. Both intra and extra-peloton information flow affect individual rider positions and the timing of their positional changes, but neither types of peloton information flow fundamentally alter self-organized structures. In addition to two previously identified peloton resources for which riders compete - energy saved by drafting, and near-front positions - information flow is identified as a third peloton resource. Also, building upon previous work on peloton phase-transitions and self-organized group-sorting, identified here is a transition between a team cluster state in which team-mates ride near each other, and a self-organized "fitness" cluster state in which riders of near equal fitness levels gravitate toward each other.

Introduction

A peloton may be defined as two or more cyclists riding in sufficiently close proximity such that each cyclist is located in one of two basic positions: 1) behind other cyclists, in zones of reduced air pressure, referred to as 'drafting', or 2) leading other cyclists, in zones of highest air pressure, described here alternately as 'riding at the front', 'in the wind', or 'in non-drafting positions'. Drafting cyclists expend less energy than those in non-drafting positions. These zones are located either directly behind or beside other cyclists, depending on wind direction.

Coupling occurs between cyclists when one or more riders seek the energy-saving benefits of drafting. The power required to overcome wind resistance is proportional to the cube of a cyclist's velocity (Burke, ed. 1996). Energy savings is approximately 1 percent per mile an hour when drafting behind a single cyclist, while greater reductions occur by riding in the middle of a larger pack (Hagberg and McCole 1990); below approximately 10mph, drafting benefit is negligible (Swain, 1998). When coupled, weaker riders can maintain the speed of stronger riders. In order to maintain the speed of stronger riders, the reduction in power output due to drafting must be at least equal to the difference in the power output capacity between the stronger and weaker riders, discussed in more detail in earlier work (Trenchard, 2009).

A peloton is a complex dynamical system from which aggregate patterns of behavior emerge that are not predictable from an analysis of the behavior of individual cyclists in isolation from the aggregate (Trenchard, 2005, 2009, 2010). Drafting and collision avoidance are the primary physical principles which underlie these emergent behaviors. Nonetheless, a peloton is a human system, and owes its existence to participants who deliberately apply competitive motivations and who act on rational assessments (usually) of the information available. Cyclists' actions that result from these motives are top-down in nature, and so the question naturally arises whether self-organized dynamics do in fact emerge, or whether peloton dynamics are primarily driven by these top-down influences and are fundamentally not self-organizing. Here “top-down” means centralized control or planning that derives primarily from deliberate human control, while “bottom-up” refers to self-organized dynamics and the patterns or structures that naturally emerge from these processes.

A peloton is thus a mixed top-down/bottom-up complex system. While certain aggregate peloton behaviors are predominantly self-organized and emerge independently of top-down human factors, it is not easy to discriminate between behaviors that are self-organized and those which are not. Here I seek to isolate human volitional factors inherent in the communication of information from the purely physical factors which drive peloton dynamics. Although human factors do have significant bearing on the timing of peloton action and the individual positions of riders, they do not alter certain aggregate emergent structures. In differentiating between these two sets of factors that drive peloton dynamics, I discuss the nature of the information that influences competitors' actions in the peloton. Additionally, I identify where further work may be done to isolate self-organized behavior from human competitive motivations.

Information flow in pelotons

Von Baeyer (2003) defines information as the transfer or communication of form from one medium to another; “form” expresses relationships among parts of a system, spatially, logically, temporally, tonally, energetically, or in terms of color or other media. In mass-start bicycle racing, information transfer occurs through riders' physical senses. Riders evaluate information, frequently in milliseconds, in terms of how it affects their tactical and strategic racing objectives. Once evaluated, riders may, depending upon strategic value, make no response, a delayed response, or an instantaneous response.

Peloton information comprises three main categories: displayed information, hidden information, and hidden information obtained by information systems (subsequently defined).

Displayed information is generally available to all riders, although it is often obscured. Displayed information includes: rider positions and collective configurations, their movement patterns, time-gaps between groups, rider speeds, the course profile and its constraints and obstacles. Displayed information also includes visible properties of each cyclist, such as their body mass and general physical appearance, facial expression, color of uniform, bicycle type, gear selections, riding style, and quantity of liquid in bottles.

Hidden information is available only to each individual rider unless voluntarily shared, or involuntarily expressed through body signals to reveal hunger and thirst, relative strength, degree of suffering, quantity of food in pockets, among other things. Generally riders do not voluntarily share accurate information about fatigue with opponents. However, in certain situations, such as when riders alternate positions in the wind, riders may indicate temporary fatigue by gesturing with their elbow or a flick of one hand, or by simply decelerating and allowing themselves to be passed by fresher riders. Elbow/hand gestures may not accurately indicate rider fatigue, however, since riders may deliberately exhibit inaccurate signals (bluff).

Hidden information obtained by information systems includes radio links between cyclists and team managers (headphones), TV screens in team manager cars, GPS localization for instant measures of gaps between rider, power output monitors and heart rate monitors (Gueguen, 2007). “Information systems” is defined as a set of interrelated components that collect, process, store or distribute information to support decision making and control in an organization (Laudon and Laudon, 2007). Although largely available to the riders directly, this information is often monitored more closely by team managers than by the riders, who are preoccupied with their immediate racing environment. Managers may analyze the information and relay directions back to the riders by radio.

In addition to monitoring time-gaps between riders, power output, etc., managers also use information systems to ask riders for hidden information and to relay that information to other team members. Similarly, team managers use information systems to transmit the following: location of course obstacles, the occurrence of crashes or other mechanical problems, the positions of opponents and their identities, team affiliations, previous results and rider reputations.

Five time winner of the Tour de France, Bernard Hinault (1988), summarized much of the information that riders seek during a race. It is instructive to quote him at length:

> The course and the weather are not the only things to watch. There are also the other riders. First I note which are the “easy” ones by watching the way they ride and react. Then I look at those who are really racing or who have a teammate who is a contender. If you see five or six riders from the same team beginning to move forward in the peloton it means they're cooking up something. You have to move up with them to be sure to be in on whatever happens. If you notice a rider who slips into all the breakaways, it means he's racing to win...It's rare that I don't know exactly who has gone with a breakaway. Since I know the riders well I know how much of a lead I can let them get without jeopardizing my own chances...If you notice that a dangerous opponent is looking tired, and if the terrain is favourable, it might be worthwhile to attack...You have to hide your pain if you are suffering.

Hinault describes both displayed and hidden information; displayed information is the weather and the nature of the course, the configuration of groups of riders, their riding behaviors and movement patterns, and signs of fatigue; hidden information is the actual degree of rider fatigue. Hinault further provides an analysis of that information and predictions of their effects.

Displayed information is frequently obscured to riders. Perceptibility of displayed information depends on course constraints and vantage points from which riders can view the course and the positions of other riders. Riders may share this information with teammates verbally or by other signals, but they may be reluctant to share this information with opponents because it is often tactically advantageous to withhold it.

Displayed information is most obscured when the course is narrow and the peloton is tightly bunched. In this case riders acquire information only about those riders immediately ahead or laterally (Fig 1). As information is locally perceived, information about opposing rider positions is best obtained by advancing to a position nearer the front of the peloton -- but not right at the front facing the wind, so as to remain in a drafting position. From this vantage point, riders may not see what is occurring behind them, but any action behind is minimally threatening until following riders attempt to pass.

The utility of information gathering in given positions is partly a function of the number of riders in the peloton. The larger the peloton, the more important it is to be near the front. This is not only because the energetic cost of advancing to front positions increases the farther a rider is from the front, but also because information about positions of riders ahead is increasingly obscured the farther a rider is from the front.

At the smallest peloton extreme - a two-person peloton - the best information about the opposing rider is obtained in the following position. The following position is doubly advantageous since it also offers the best energy savings and the resulting “slingshot” opportunity heading into the last 50m of a sprint. This is exemplified in two-up track sprinting, in which only two riders compete at a time. With no other riders posing a threat from behind, the two riders jockey for the rear position, and in the process may decelerate to a standstill, or “track-stand” (Fig 4).

At the other extreme, in a peloton of >100 riders, those at the rear of the peloton obtain little if any information about events at the front region of the peloton, unless they are relayed information from other riders or from external sources, which is inevitably poor information.

Degree of information acquisition	
Type	**Description**
Local information only	Riders have view only of riders immediately ahead or laterally and have virtually no information about the peloton as a whole (Fig 1).
Local information and poor partial global information	Riders have reasonably open view of riders ahead and laterally, but have little knowledge of positions of riders behind. Importance of riders’ positions behind decreases as a function of distance: leading riders require frequent updates of close chasing groups, but require less frequent updates if chase groups are too far behind to catch groups ahead (Fig 2).
Local information and good partial global information	Riders have open view of riders ahead and laterally, while positions of riders behind can be inferred and are not threatening (Fig .3).
Complete local and global information	Complete knowledge of all external information; the absolute case occurs only during two-rider races where both are motionless beside each other (track-stand) (Fig.4).

Table 1. Relative degrees of available information to riders, assuming displayed information only and no information via information systems.

Figure 1. Riders with local information only. Each rider sees only those others immediately in front and laterally (note camera view is above the peloton, and does not reflect what the riders actually see).

Figure 2. Local information, poor partial global information. All riders in the chasing group have an unobstructed view ahead and nearly perfect information of each other and the group ahead. Information is lacking about riders behind, who, in a criterium race of this kind are likely very close behind. Information importance is increased when chasing groups are relatively close behind and pose a threat to the positions of the riders ahead. Information may be relayed to these riders, who in this race did not have radios, from external sources.

Figure 3. Local and good partial global information. Downhill, curve and single pace-line structure gives riders at back of peloton a largely unobstructed view of riders ahead, although the length of the peloton reduces the capacity of riders behind to identify specific riders farther ahead. Team uniforms may allow riders behind to identify team organization ahead. In this photo, riders 5 through 10 from the front appear to be team-mates, and information about the organization of this team is available to most of the following riders.

Figure 4. Complete local and global information. In match sprints between two riders on a track, riders complete one kilometre; the first to cross the line wins. There is no advantage to cooperation, but in view of the tactical advantage of drafting, competitors jockey to take the rear drafting position and decelerate until they are locked in a standstill, as shown. The best information in this case is from behind, the reverse of the situation with a larger peloton. Locked at a standstill, both riders have complete local and global information.

Information as a third peloton resource

In previous work, I developed a resource-based conceptual framework for pelotons (Trenchard, 2010). Energy saved by drafting, and near-front positions, are two resources for which cyclists compete. Cyclists undergo continual cost-benefit analyses in seeking to obtain these resources.

Information is a third peloton resource. The value of information varies, measured in terms of the energy riders are willing to expend to obtain it. For example, the energy value of an opponent's position is usually considered to be greater than the energy value of the amount of water in a water bottle. Riders will thus choose to expend comparatively large quantities of energy to learn of others' positions, while not worrying about positioning to replenish water. This situation may be reversed, however, if it is a very hot day and the rider has nothing left to drink.

In races which permit communication by radio between managers and riders, the energy value of positional information may be reduced since managers can save riders considerable energy simply by radioing opponents' positions. Not only are riders saved the energy expense of scouting the peloton, radio communication may also save riders the continuous energy cost of fighting for near-front positions, where riders can see opponents ahead and be satisfied that all those behind are in less threatening positions. That said, managers do not have perfect information about rider positions, which are constantly changing; even in races where race radios are allowed, riders must scout the peloton for positional information. This two-way communication thus has a significant impact in top-down peloton dynamics as compared to those races in which race radios are not allowed, but the impact on basic self-organized structures is not clear. I discuss this further in the following section.

Extra-peloton information

Information fed to riders in the peloton from managers is a form of extra-peloton information. This is distinguished from the directions given by managers to riders to act on this information, which is a top-down dynamic. Extra-peloton information may also be fed to riders from third parties at the roadside, such as race referees, team managers/coaches, or spectators. In velodrome (track) racing, radios are not permitted, but are redundant in any event. This is due to the high quality of information about rider positions available to track riders due to the oval shape and banks of the velodrome: riders can see the positions of other riders almost equally well from all vantage points on the track.

One notable exception to this quasi-omniscience is information regarding the accumulation of points during points-races. In points-races, riders are awarded points at regular lap intervals for their relative placing at the start-finish line. It is difficult for riders to keep track of the number of points accumulated without extra-peloton assistance (Fig 5).

Prior to the late 1990's two-way race radios were not used in road races (Gueguen, 2007). Since the advent of such communication, radio use has arguably altered tactics and reduced riders' motivation and individual volition, thus reducing race aggressiveness (Stokes, 2009).

Gueguen (2007) researched this argument, and analysed the results of several Tours de France, a multi-stage road race, to compare the intervals in arrival times between riders in years before and after the introduction of information systems. Gueguen suggested that more complete information allows cyclists to make rational and effective tactical decisions. The use of developed information systems might therefore logically lead to a reduction of time gaps between riders. Gueguen tested this assumption by counting the number of stages that resulted in finishing bunch sprints of twelve Tours de France in years before and after the introduction of information systems. He then identified statistical differences in the range of finishing times in the data.

While Gueguen's results do indicate a drop in the number of races in which breakaways have been successful since the advent of information systems, he found there was no significant statistical difference for the coefficient of variation in finishing times for the first 30 riders for the same races. He concluded that information systems do not significantly affect race outcomes; and radios, in particular, should not be banned.

This is an important result from a complex systems perspective because it suggests that extra-peloton information does not significantly affect basic collective peloton dynamics. This supports the premise that aggregate peloton dynamics are self-organized in nature.

On the other hand, Gueguen's results do not allow conclusions to be drawn about changes to the timing of riders' movements and the relative effort riders give toward resource seeking at specific times. These priorities may be substantially altered by extra-peloton information that is not otherwise obtainable internally; this may, in turn, alter basic peloton dynamics. Further research is required.

Figure 5. Extra-peloton information in a velodrome points-race. In a points-race, information about the total number of points each rider accumulates is fed to riders from coaches and bystanders. Note that in points-races, as shown here, riders are not permitted to ride as teams.

Distinguishing between self-organized and top-down peloton dynamics

Much of my research to date has been premised on the notion that self-organized peloton dynamics tend to emerge independently from their human competitive dynamics. The question, however, naturally arises as to the degree of influence that individual and team competitive motivations have on the self-organized nature of the dynamics I have identified.

This question can be answered from an information-based perspective because it entails a common underlying conceptual framework for the physical movements of cyclists in both self-organized and top-down dynamical contexts.

It is useful first to isolate basic bottom-up peloton processes from self-organized ones (bottom-up). In previous work, I identified four phases of self-organized peloton dynamics (Trenchard, 2009). These phases emerge from local physical rules. In this model, riders' power output is the adjustable parameter that indicates transition points between phases.

Other self-organized behaviors include: synchronization dynamics (Trenchard, 2005); hysteresis (Trenchard, 2010), which occurs in pelotons through rapid decelerations and corresponding bunching, followed by delayed acceleration from the bunched state, and in other situations; fluid dynamics and sub-group formation (Trenchard, 2010, 2011); others for which there is currently little evidence include power law distributions and punctuated equilibria, wave dynamics, eddies and vortices, and various network structures, among others.

In the simplest case of sub-group formation, subgroups form when individual riders reach a power output threshold in which they can no longer keep the pace of riders ahead. A drafting rider will be unable to keep pace in two basic situations: first, he is weakened such that his output does not equal the power output required even with the drafting advantage; secondly, when he is effectively shifted into a non-drafting position and his output is insufficient to maintain the speed of riders ahead. Peloton divisions occur, and sub-groups may form.

By contrast, in a purely top-down system, aggregate patterns are intentionally imposed, and are not self-organized. In a peloton, when riders execute tactical moves in response to information received from external sources, their actions are top-down because they are volitional and not derived from natural physical rules. Thus managers' directions are one type of top-down peloton direction; the other is the intentional actions of the riders in response to their own tactical evaluations, which is far more significant in its effect on peloton dynamics.

Even so, riders' tactical moves necessarily incorporate physical principles from which purely self-organized aggregate patterns do emerge. Peloton dynamics are thus clearly a mix of bottom-up and top-down processes.

Table 2 contains sets of both self-organized and top-down variables that determine riders' actions. These comprise "survival objectives" and "tactical objectives". "Survival objectives" involve actions by which riders seek to remain part of the peloton system, achieved by sustaining coupled positions (within drafting proximity), and by collision avoidance. Where sub-groups form, riders seek to remain part of the sub-group, and if they are between groups ("no-man's land") they usually seek either to reintegrate one of the two groups. Despite not being directly coupled with any riders in that position, they may still be considered part of the system as a whole because the worst-case for that rider is to drop back to the following group. Once it becomes physiologically impossible for a rider to reintegrate a group ahead or behind, a rider can be said to have failed to achieve the survival objective. Under race rules, arbitrary cut-off times are imposed such that riders outside the cut-off time are eliminated from the race. While riders within the cut-off may be recorded in race results, some may have failed to survive under the definition proposed.

Tactical and strategic objectives reflect top-down factors. They comprise human competitive factors. Although there are more tactical objectives, they are secondary to survival objectives, except at low threshold speeds/power outputs, when it is not energetically necessary for riders to optimize drafting positions.

Human competitive factors

In mass-start bicycle racing, a rider's primary strategic objective is one of the following: to win the race, to place as highly as possible in the standings, or to assist other riders to achieve one of those objectives (Table 2). There are situations in which riders simply race for the sheer enjoyment of the experience, but their numbers are proportionately small, and their presence does not fundamentally alter peloton dynamics.

To further their tactical objectives, riders calculate their moves within the peloton, and in doing so produce top-down dynamics. However, while top-down tactical motives precede riders' *individual* positions, the *timing* of changes in power output, team clustering and information transfer, these motives do not substantially alter fundamental self-organized aggregate peloton behaviors.

This is important because the competitive peloton thus represents an example of the co-existence but independence of top-down and bottom up processes, and suggests that self-organized peloton behaviors can have analogs in other biological and physical systems that may have no top-down influences, despite the presence of top-down factors in pelotons. Further work, however, is required to clearly establish this. Oscillations between team clustering and physiological fitness clustering

One aspect of tactical top-down action is the organization of teams in clusters. Clusters occur when riders within the peloton intentionally maintain near proximity with others. Clusters are distinguished from sub-groups, which form when a peloton divides into smaller pelotons. In the team clustering dynamic - which is not always occurring - riders move toward team-mates, particularly before locations on the course which have high tactical significance, like hills, where there are cross-winds, or the finish.

For example, if a long climb approaches, teams endeavor to ensure their strongest climbers are near the front and near each other. If a pack sprint is approaching, teams endeavor to bring their strongest sprinters forward, who invariably are different riders from the climbers. If it is a multi-stage race, teammates will assist the team leader to remain near the front to avoid crashes and be ready to respond to attacks if necessary. In some situations, however, if strong riders are near the back of the peloton, particularly if the pace is slow and the course is flat and open for a prolonged period, the sense of urgency to bring similarly strong riders forward may be reduced, though it will not be long before the general movement of all the strongest riders is forward toward the front.

The team clustering priority is thus: stay near teammates; stay in the top ten to 15 places, and stay near closest competitors. Physiological fitness clusters ("fitness cluster") form when riders of close athletic ability, either in an absolute sense, or temporarily and according to the condition of the course that best suits certain types of fitness capacities, naturally gravitate toward each other. As the pace increases, weaker riders are generally shifted toward the back of the peloton. The composition of clusters shifts continuously, as do their locations within the peloton.

Further observation and analysis is required to identify the nature of clusters and how they shift positions within the peloton. However, the formation of team clusters is preceded by the transfer of information about the relative positions of other riders in the group, while fitness clusters usually self-organize without information transfer. Fitness clusters can form by top-down processes as riders target specific opponents and seek to be near them, but this usually occurs at lower power outputs and speeds than the power output/speeds that result in self-organized fitness clusters.

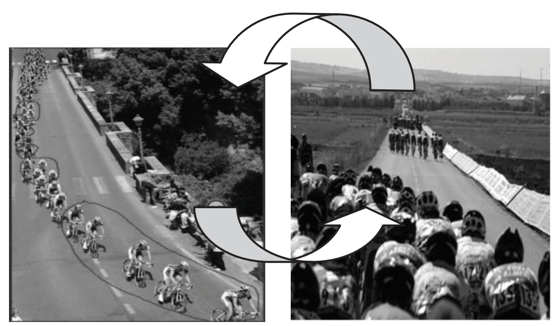
Overall objective: win race; place as high as possible in standings, or assist others to win or place as high as possible	
Solo rider (no team-mates)	**Team rider**

Survival objectives
• Save energy
  o Optimize drafting position
• Avoid collisions
 	
Tactical objectives
• Advance to near-front position
• Watch other opponents
  o Scout positions of opponents
• Cooperate with opponents to bridge or establish breakaways
  o Alternate time in drafting and non-drafting positions with opponents
• Bridge to breakaways
• Attack to establish breakaways
	Survival objectives
	• Save energy
	  o Optimize drafting position
	• Avoid collisions
	
	Tactical/Team objectives
	• Remain near team-mates
	• Cooperate with team-mate(s) to bridge or establish breakaways
	  o Alternate time in drafting and non-drafting positions with team-mates and opponents
	• Bridge to breakaways
	• Attack to establish breakaways
	• Drop back to team cars or roadside for food/water
	• Assist team-mates back to peloton if dropped, crashes or punctures
	• Avoid contributing to chase effort if team-mate in breakaway
	• Advance self and team-mates to front
	  o Advance to nearest position behind chasing team(s) if team-mate is in breakaway

Table 2. Road cyclists race objectives. Elite races are primarily team events, although some races allow individual riders without a team (solo rider).

Prior to top-down cluster formation (team or targeted opponents), riders must identify the riders toward whom they wish to gravitate before they can begin to navigate through the peloton to reach their targets. While doing so, riders must respond to information they receive about the degree of their own fatigue, the location of obstacles or course changes (like corners, cross-winds, or hills), and the length of the peloton and the speed of its members. All of this information allows each rider to calculate the energy required to reach his positional targets; his actions are correspondingly noted by others, establishing an information feedback loop.

Fitness clusters may become sub-groups when riders' power output parameter is collectively increased through a phase transition point (Trenchard 2010, 2011). A peloton division in this instance thus marks clearly the point at which top-down dynamics shift to self-organized dynamics. The peloton oscillates between these two states, as collective power outputs fluctuate (Figs 6a, 6b).



Figures 6a Riders endeavor to remain near team-mates in order to protect leaders from wind or to assist them in changing position through the peloton. This is a top-down organized situation which can undergo a transition to self-organized clustering. **Figure 6b** Team members appear randomly distributed. The state is, however, a phase state in which dynamics may have transitioned from top-down organization, to bottom-up self-organization in which clusters of riders form based on closer average fitness. A peloton oscillates between the two states.

Further work and conclusion

As noted, there is an information acquisition advantage to certain positions, like near front positions for large pelotons, and near the back for small pelotons. It would be useful to correlate specific positions within pelotons to their information gathering importance and relative tactical advantage.

It will also be instructive to gather data which demonstrates the transition from team clusters to fitness-based sub-groups. Longer duration overhead video footage and corresponding trajectory graphs will allow for clearer identification of phases and their transitions.

As examples of peloton trajectory graphs, I plotted rider trajectories (position over time) for 17 second and 8 second videos from the 2010 mens World Championships (Fig 7). Because of their short duration (the maximum possible from the footage used), they are of limited value, but represent a method for further analysis once longer duration footage is acquired. Analysis of such graphs may also reveal the comparative effects of intra and extra-peloton information flow on rider trajectories and general peloton dynamics.

Finally, if a peloton is a mixed self-organized/top-down dynamical system, can the framework outlined here apply to other systems? One system to which this framework may be applied is the human economy, where competitive and rational/irrational decisions mix with physical principles. Further, the peloton model may assist in isolating dynamics that are driven by human motivations from self-organized dynamics. The identified self-organized dynamics of such mixed systems may then be compared with the dynamics of purely self-organizing biological systems for increased understanding of the principles that drive purely self-oganized systems. For example, insight may be obtained about the dynamics of bird flocks, fish schools, penguin huddles, or more complex self-organized systems like ecosystems and insect superorganisms and their evolutionary processes.

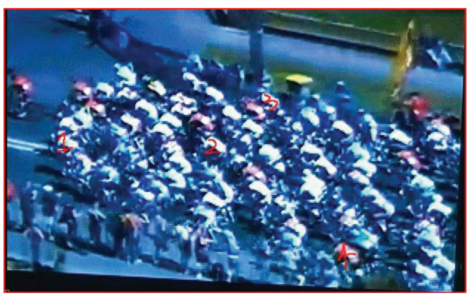
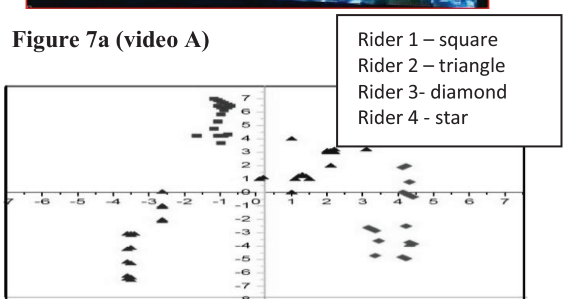


Figure 7a (video A)

Figure 7b (video B)



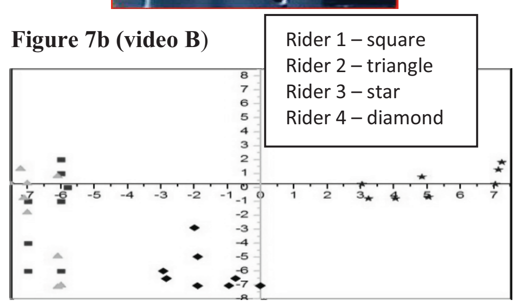


Figure 7c

Figure 7d

Relative positional change (trajectory) tracked by position per second. Video images sectioned into quadrants. In video snapshots Figures 7a, 7b, randomly selected four riders are labeled by red numbers 1-4 (labels may not be visible). As videos progressed, riders in Fig 7a were tracked over 17s, for 18 points on the graph for each rider; Fig 7b, relative rider positions were tracked over 7 seconds, for 8 points on the graph for each rider. Riders were tracked for maximum possible given the video footage available. Relative positional changes were faster in video B (note similar distances travelled in less than half the time), indicating faster positional change (i.e. general peloton rotation is faster in video B than video A).

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