Authors: Rubio-Campillo, Xavier¹; Valdés, Pau²; Ble, Eduard²

Title: Centurions in the Roman Legion: Computer Simulation and Complex Systems

1 – Corresponding author, Barcelona Supercomputing Centre, xavier.rubio@bsc.es

2 – Universitat de Barcelona

Abstract

The Centurion was a key figure of Roman warfare over a span of several centuries. However, their real role in battle is still a matter of discussion. Historical sources suggest that their impact in the efficiency of the Roman battle line was highly disproportionate to their individual actions, considering their low numbers. In the past decades a number of authors have proposed different descriptive models to explain their relevance, highlighting factors such as an improvement on unit cohesion or high levels of aggressiveness, which made them lead the charges against the enemy. However, the lack of a quantitative framework does not allow to compare and test these working hypotheses.

This paper suggests an innovative methodological approach to explore the problem, based on computer simulation. An Agent-Based Model of roman legions is used as a virtual laboratory, where different hypotheses are tested under varying scenarios. Results suggest that the resilience of formations to combat stress increase exponentially if they contain just a small percentage of homogeneously distributed warriors with higher psychological resistance. Additionally, the model also shows how the lethality of the entire formation is reinforced when this selected group is located at the first line of the formation, even if individually they are not more aggressive or skilled than the average. The interpretation of the simulated patterns in terms of Roman warfare suggest that the multiple roles of the centurions observed in the sources were not caused by changes in tactics or values, but can be strictly explained by an increase in their experience and overall combat performance.

Keywords: Centurion, military history, agent-based model, Roman Warfare, complex systems

1 Introduction

The figure of the centurion has always been considered a key factor to understand the Roman combat system. His role seemed to be crucial for the efficiency of the legions, despite the fact that their structure and tactics radically changed over time. During last decades these topics have seen an increasing number of competing yet overlapping hypotheses about the dynamics of these tactics on the battlefield. This includes the exploration of how a charge developed, the importance of ranged weapons or the impact of psychology and self-preservation on the behaviour of soldiers¹.

All these works provide rely on the analysis of classical authors or archaeological evidence to create descriptive models presenting competing hypotheses. Even though it is difficult to assess which of these models is closer to reality, for all these authors the figure of the centurion remains central in these combat dynamics². However, the intricacies of Roman tactics make difficult to understand why centurions were so relevant during the clash of lines in a battlefield. Were they a model followed by the rest of the soldiers? If this is the case, where were they located? How the radical changes of Marius reforms (ca. 100 BC) affected their role?

Descriptive models are difficult to compare and the different hypotheses cannot be tested. A formal model could be used to explore their plausibility, but classical quantitative tools such as equation-based models have difficulties dealing with this type of problems; the diversity of situations portrayed by the sources often provide contradictory versions of similar scenarios, so the homogenization needed to build these models would lose vital components of the system. In particular, any formal model of combat needs to integrate this stochasticity while providing a way to understand how the aggregation of individual behaviours produce large scale dynamics (e.g. collapse of a line, charges and retreats, manoeuvres, etc.).

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- 1 For a general overview of previous works see Sabin, P. (1996) "The mechanics of battle in the Second Punic War." In *The Second Punic War: A reappraisal*, edited by T. Cornell, B. Rankov and P. Sabin, 49–57. University of London: Institute of Classical Studies, School of Advanced Study; Goldsworthy, A. (1996) *The Roman Army at War 100 BC-AD 200*. Oxford Classical Monographs. Oxford: Clarendon Paperbacks; Zhmodikov, A. (2000) "Roman Republican Heavy Infantrymen in Battle (IV-II centuries BC)." *Historia* 49 (1): 67–78.; Sabin, P. (2000) "The Face of Roman Battle." *Journal of Roman Studies* 90: 1–17. S. Koon, *Infantry Combat in Livy's Battle Narratives*, Oxford UP, 2010; Rawlings, L. (2007) "Army and Battle During the Conquest of Italy (350–264 BC)", in: Erdkamp, P. (ed. 2007) *A Companion to the Roman Army*, The Blackwell Companion to the Ancient World. Blackwell Publishing; Hoyos, D. (2007) "The Age of Overseas Expansion (264–146 BC)" in: Erdkamp, op.cit; Cagniat, P. (2007) "The Late Republican Army (146–30 BC)" in: Erdkamp, op.cit.
 - 2 See for example Lendon. (2005) *Soldiers and Ghosts. A history of Battle in Classical Antiquity*. New Haven and London: Yale University Press; Palao Vicente, J.J. (2009) "Virtus Centurionis. La figura del centurión en César." *Gerión* 1: 191–206.

First, the model cannot be deterministic or homogeneous, because similar situations can have different outcomes, and is impossible to predict the exact result of any engagement.

Second, warfare is not a chaotic system; the situations studied by military historians and conflict archaeologists are robust enough to minimal variation on the initial conditions, as they will not produce major changes on the dynamics of the system. Even though some authors suggest the contrary, by its mathematical definition a chaotic system is not a good model of human interactions, because the sensitivity of the system to minimal changes on initial conditions is not as extreme as to be impossible to predict³.

The approach that suits better these characteristics is the complex systems theory⁴. These are systems that portray a situation where the interactions between the components of the model are non-linear. This means that some properties of complex system cannot be detected in any individual part, but emerge from the relation of their components. These emergent properties are difficult to predict, but not chaotic⁵. Focusing on our research field, battle tactics can be understood as rules defined to organize a large sum of individuals in armed conflict against a similar group of humans⁶. Within this theoretical framework we can define the impact of centurions on legionary formation as an emergent behaviour of the system, as micro (individual) actions of a small quantitative part of the system produce a cascade effect, creating macrodynamics far larger than expected.

This corresponds to the basic idea of previous authors: the impact of centurion behaviour on the battle line went far beyond their individual actions, which is a typical assumption of a complex system.

This paper aims to explore the role of the centurions in the roman legions during the transition period of the Civil Wars using an Agent-Based Model (ABM), a technique of computer simulation suited to explore the behavior of complex systems. Next section presents the theoretical

3 For example, a clash between two armies would not have huge changes if one army had 11.001 soldiers instead of 11.000 (which would be the case in chaotic systems). For a different approach (without actually using mathematical models) see Culham, P. (2010) "Chance, command, and chaos in ancient military engagements", *World Futures: The Journal of New Paradigm Research*, 27(2-4), 191-205.

4 Miller, J.H., Page, S.E. (2007) *Complex Adaptive Systems. An Introduction to Computational Models of Social Life*. Princeton University Press, USA, 5.

5 Sawyer, R.K. (2005) *Social emergence. Societies as Complex Systems*. Cambridge University Press, UK, 3.

6 Rubio-Campillo, X. (2014). "An evolutionary approach to military history", In: *Revista Universitaria de Historia Militar*, 4 (2), pp. 255–277.

framework of Roman combat that will be used in the formal model, including battle tactics, the behavior of the centurions and our research questions. The ABM is then presented, with experiment design used to test the working hypotheses. The paper concludes with the interpretation and discussion of the simulation results in the context of roman tactics.

2 A framework of Roman combat

There are several proposals previously published that describe the dynamics of Roman battles. Despite their differences, there is a list of key aspects of that can be aggregated as a general framework of Roman combat. These are the components that need to be present into any formal model. In particular, this work integrates the model proposed by Philip Sabin⁷ with additional hypotheses considering the role of the centurio on these battle dynamics.

2.1 Key components

The key aspects of the framework used to build the model are as follows:

2.1.a Individual experience

Influenced by the major work *The Face of Battle*, by John Keegan⁸, some studies of roman warfare analyzed the soldier experience of battle⁹. The most important author using this approach has been Adrian Goldsworthy, who proposed a descriptive model based mainly on psychological factors¹⁰. The model was based on two key concepts, following the influential work of Marshall¹¹ on the performance of USA soldiers during World War II. The model was based on two key concepts: a) most of legionaries were not aggressive, just tried to survive and

7 Sabin 2000, op.cit.

8 Keegan, J. (1976) *The face of battle. A Study of Agincourt, Waterloo and the Somme*. New York: Viking Press.

9 See MacMullen, R. (1984) "The Legion as a Society." *Historia* 4: 440–56.; Harris, W.V. (2006). "Readings in the Narrative Literature of Roman Courage." In *Representations of War in Ancient Rome*, edited by S. Dillon and K.E. Welch, 300–320. Cambridge: Cambridge University Press, 317.

10 Goldsworthy 1996, op.cit. Additional discussion on this model in Wheeler, E.L. (2001) "Firepower: Missile Weapons and the "Face of Battle"" *Electrum* 5, 170-174; Quesada, F. (2006) "El legionario romano en época de las Guerras Púnicas: Formas de combate individual, táctica de pequeñas unidades e influencias hispanas", *Espacio, Tiempo y Forma* 16, 180-187; Lee, A.D. (2009) "Morale and the Roman Experience of Battle". In: A.B. Lloyd, *Battle in Antiquity*, Classical Press of Wales, 199-218.

11 Marshall, S.L.A. (1947) *Men against fire. The Problem of Battle Command*. Norman, Oklahoma: University of Oklahoma Press. See also Engen, B. (2009) *Canadians Under Fire: Infantry Effectiveness in the Second World War*. Montréal: McGill-Queen's University Press for a critique of this model of combat.

b) fighting was unsustainable for soldiers after 15-20 minutes, due to physical and psychological fatigue.

These two dynamics portrayed a battle without continued combat, as it is closer to a succession of sporadic charges that can potentially end as a melee. Unless there is a breakthrough during the charge, both battle lines withdraw out of the killing zones until another charge develops. This sequence of successive attacks and retreats is not simultaneous in all the line, as they are localized at different locations. However, if one charge succeeds it can create the optimal conditions for a panic chain reaction over the whole line, leading to the total defeat of an army. Casualties would be low until this point, as soldiers would have been more focused on being close to their friends than to attack. During this final phase casualties would increase exponentially as soldiers stop fighting and try to escape from the enemy.

2.1.b Ranged combat

Another component of the model was provided by Zhmodikov. He published a study based on written sources to highlight the role of ranged weapons, previously considered as minor¹². His hypotheses suggest that the majority of casualties portrayed in the written sources were caused by pila or javelins, not hand-to-hand combat. At the same time, he proposed that ranged weapons were not only used in an initial volley, but at a constant rate over the span of the engagement.

2.1.c The figure of the centurio

The final element of the formal model is the centurio itself.; what properties identify this soldier compared to the rest of the legionaries? The traits that define the portrayal of a centurion certainly are different depending on the authors, being Polybius (the first one to describe them) and Caesar the main references to understand their role on battle. The importance they have in transmitting orders and in leading their troops but also to be able to resist while fighting in inferiority or adverse situations (Plb. VI, 24, 9). This portrayal reflects the ideal soldier from an aristocratic perspective¹³. On the other hand, they don't have particular relevance for the narrative of the author, as their appearances are derogatory or merely anecdotal. Lendon highlights that this emphasis of Polybius

¹² Zhmodikov 2000, op.cit.

¹³ Palao Vicente 2009, op.cit. 195–6, 202, 204

in obedience and discipline is influenced by his background and experience¹⁴, as his narrative cannot be disentangled from his context and culture¹⁵.

In contrast, Caesar shows his centurions as the crucial element of the battlefield¹⁶. They are represented displaying valor and heroism under the concept of *virtus*¹⁷ and similar expressions such as *animus* and *fortitudo*¹⁸. This characterization are related to the changes that took place within roman society in 1st BC, where centurions would adopt the role of aristocracy and its conception of *virtus*¹⁹. Its use in the context of Caesar has some variations, such as the relation with experience and training, as aggressiveness alone do not win battles. Within this perspective, centurio are valuable not only by their fighting efficiency, but specially because inspire soldiers by exemplary leadership²⁰.

2.2 Battle dynamics

The majority of these components were combined by Sabin in a general framework of Roman combat, to which we want to add the relevance of centurio in the battle line.

The framework presents close combat as a sequence of isolated events that most soldiers try to avoid. Clashes are isolated events between long periods of tension. During these passive phases the two battle lines are distanced by the killing zones, while maintaining low intensity ranged combat. Projectiles would produce an increase amount of casualties and disruption, while hand-to-hand combat would be responsible of breaking the enemy line, being the decisive aspect of the battle.

The charge itself implied that the side that took the offensive had higher confidence on victory, at least enough to risk their own security. Centurio would have a major role leading these charges by

14 Lendon, J.E. (1999) "The Rhetoric of Combat: Greek Military Theory and Roman Culture in Julius Caesar's Battle." *Classical Antiquity* 18 (2): 282-5.

15 Lendon 1999, op.cit., 274–5, 278.

16 Palao Vicente 2009, op.cit., 193

17 Virtus is a complex concept that is usually linked to activities and qualities of men. It reflects ideal behaviour in warfare but it also has other meanings such as aggressiveness, morality and physical courage. See Bryan-Brown, A.N. editor (1968). "uirtus", *Oxford Latin Dictionary*, p. 2973; McDonnell, M. (2006). *Roman manliness. Virtus and the Roman Republic*. Cambridge University Press, Cambridge, p.32.

18 Palao Vicente 2009, op.cit., 196

19 Lendon 2005, op.cit., 218

20 Brown, R. (2004) "'Virtus consili expers': An Interpretation of the Centurions' Contest in Caesar, De bello Gallico 5, 44." *Hermes* 132 (3): 292–308., 340.

example, and maintaining the cohesion of lines due to their training and *virtus*. If one these attacks was able to break the cohesion of the enemy, the probable outcome would be the panic on enemy ranks, moment at which the clash would transform into slaughter; this final moment would explain the disproportionate balance of casualties between sides.

2.3 Hypotheses

This theoretical framework can be used to explore what happened during the clash of two battle lines. We will use it to analyse what we assume are the main three parameters that explained battle outcomes: a) the number of ranks, b) the position of the centurions and c) the impact of their behavior over the rest of the legion.

2.3.a Number of ranks

There is a general consensus about the number of soldiers that a legion would deploy in battle. In the context of Late republican period a theoretical legion would include 4800 infantrymen, distributed in 10 cohorts of 480, which in turn were composed of six centuries of 80²¹; these figures would translate, in reality, to roughly 3000 soldiers due to different factors²².

However, the deployment of these units into battle formation is still subject to debate based on different sources. In the case of the *centuria*, there are proposals of unit depth ranging from three to 16 ranks. Flavius Josephus and Vegetius describe a system based on 3 and its multiples (Josephus, *Jewish War*, II, 173; V, 131; Vegetius, III, 15), while Arrian and the *Strategikon* of Maurice seem to prefer multiples of 4 (Arrian, *Ectaxis*, IV, 5, 16-17; *Strategikon*, XII, 9-11). There are some outliers to these rules, as the description of the battle of Pharsalus by Frontinus, where Pompey deployed its *centuriae* in 10 ranks (Front., *Stratagems*, II, III, 22).

Goldsworthy used all this data to suggest that Romans would work with multiples of 3 and 4²³. This two would be the most common rank numbers, being raised to 6 or 8 when facing cavalry, fighting in a narrow space or with newly recruited troops. Soon after he stated that the most common

21 Connolly, P. (1981) *Greece and Rome at War*, Frontline Books, 213-217.

22 Cowan, R. (2007) *Roman Battle Tactics 109 BC - AD 313*, Osprey Publishing, 4.

23 Goldsworthy 1996 op.cit., 179-181.

layout would be 6 ranks, even if formations with 3, 4, 8 or 10 ranks were used²⁴. Sabin also thinks that each *centuriae* may have been only 3 or 4 ranks deep but, as there were two in each *manipulus*, they would be aligned one behind the other to give an overall depth of 6 to 8 rank²⁵.

Based on different authors, Connolly and Cowan suggest deeper formations of 8 ranks and 10 files²⁶. In this same line, Wheeler published an alternative based on multiples of 4: 8 ranks as a standard that could increase to 12 or even 16 when fighting against cavalry²⁷.

The underlying question behind this discussion is the function of the ranks in the back of the battle line. In an ideal situation the goal of any army would be to minimize the depth of their units in order to widen the line, thus presenting a greater front to the enemy. On the other hand a thin line would be have less cohesion as a fighting formation. That could be the reason why in a pitched battle, only the most seasoned units could afford to deploy in thin formations, such as the center of the Carthaginian frontline at Cannae or veteran legions of Caesar at Pharsalus. Instead, levies and newly recruited troops tended to have additional ranks.

Given that all of these proposals are equally valid we will explore different deployments (4, 6 and 8 ranks), under the hypothesis that deeper formations are more resilient to combat than thinner deployments.

2.3.b Position of the centurion

A second aspect to explore is the position adopted by the centurion inside the maniples, The only evidence we have for the position of the centurions comes from Polybius, who says only that the senior centurion of the maniple commanded the men in the right-hand *centuria* and the junior centurion the ones in the left-hand (Plb VI, 24, 8). From this statement, it has been suggested that in the manipular legion centurions stood at the extreme right and left of the first rank²⁸.

But how did the cohortal legion worked? Starting with Connolly, most of the academics place the centurion on the first rank at the far right of the *centuria*²⁹. This would be a legacy of Hellenistic

24 Goldsworthy, A. (2000) *Roman Warfare*, Cassell, 98

25 Sabin 2000, op.cit.

26 Connolly 1981, op.cit, 213-217; Cowan 2007, op.cit., 59.

27 Wheeler, E.L. (1979) "The legion as a phalanx", *Chiron* 9, 303-318

28 Cowan (2010), "The *centuria* in battle. Tactical organisation and combat", *Ancient Warfare*, Special Issue 2010, 40.

29 Connolly (1975) *The Roman Army*, Macdonald Educational, 40-41; Connolly 1981, op.cit, 213-217; Cowan (2003),

warfare, being the place of honor in both hoplite and Macedonian phalanx. An alternate hypothesis is to deploy them in the center of the formation³⁰.

In order to understand the importance of the centurion's location, we explore three different positions: a) in the front right, b) in a random position at the front rank and c) in a random location of the *centuria*.

2.3.c The behaviour of the centurion

The role of the centurion is usually discussed based on example or leading behavior. The first idea would translate the centurion into a cohesive reference of the unit, preventing the panic on the ranks. As a leader, the centurion would be an aggressive individual, leading his companions into charges against the enemy.

It is important to note that both roles are not mutually exclusive. In addition, their importance is based on the copy of behavior from centurions (i.e. the model) to the rest of the troops. Therefore, its effectiveness depends on the intrinsic quality of the centurion, expressed in terms of several factors such as training, moral, *virtus* and experience. In the model all these attributes are translated into a general capability for sustaining the stress of combat; a centurion portraying higher values of the traits would be capable of better guiding his soldiers to attack, as well as maintaining the battle line for longer periods of time. Considering his role as model of the rest of legionaries, we will explore what is the impact when the centurio have slightly higher capabilities for sustaining combat than the rest of his teammates, which can be considered a characteristic of an army of the first century BC.

3 The model

Once we have defined the three factors that we want to explore we need to describe the formal model that will be used to perform the experiments. The best tool for these aims is an Agent Based Model (ABM). It will be capable of capturing the importance of heterogeneity amongst the different

Roman Legionary 58 BC-AD 69, Osprey Publishing, 62-63, plate G.

30 Cowan 2007, op.cit., 59. Cowan 2010, op. cit., 40-45.

soldiers, and the emergence of macro dynamics that affect the whole formation from aggregated individual behavior. ABMS are computer simulation defining a system as a set of different entities (individuals or small groups) with particular internal states and decision processes. The simulation is run over a finite number of time steps, where macro dynamics emerge from the interaction of these entities³¹.

ABMs have been extensively used to explore conflict mechanisms, particularly related to modern combat tactics³². The technique has also been applied to link hypotheses on human behavior with archaeological evidence³³, but its use in military history case studies is quite recent³⁴.

In this case, the model will focus on the basic mechanisms that explain the dynamics described on the different sources. First of all it needs to link individual psychological conditions to collective behavior. In addition, the continued exposure to the enemy killing zone would need to degrade the fighting will of the individuals, modeling the increased fatigue suffered by soldiers during the engagement. Finally, as we pointed out these dynamics need to be local, so the situations developing near a soldier (i.e. friendly casualties, increased stress, etc.) will affect his internal state

These behavioral requirements can be summarized as a model capturing (a) collective movements perpendicular to the enemy formation (charges/retreats), (b) the effects of accumulated fatigue in the soldiers and (c) contagion of stress through signals between agents. We continue defining the different concepts that will be used and the different components of the model.

3.1 General description

The model will simulate an engagement between two formations. To test the hypotheses we don't need an entire battle line (i.e. princeps, hastati, triarii), but only the line that is fighting the enemy.

31 Epstein, J.M., Axtell, R.L. (1996). *Growing Artificial Societies: Social Sciences from the Bottom Up*. The MIT Press, USA.

32 Ilachinsky, A. (2004). *Artificial War. Multiagent-Based Simulation of Combat*. Center for Naval Analyses - World Scientific, USA.; Doran, J. (2006). "Modelling a typical guerrilla war". *Distributed Intelligent Systems: Collective Intelligence and Its Applications, DIS 2006*, 285-290.

33 Lake, M.W. (2014). "Trends in Archaeological Simulation". In: *Journal of Archaeological Method and Theory*, 21(2), 258-287.

34 Hill, R. R., Champagne, L. E., Price, J. C. (2004). "Using Agent-based Simulation and Game Theory to Examine the WWII Bay of Biscay U-boat Campaign". *Journal of Defence Modeling and Simulation*, 1(2), pp. 99-109.; Rubio-Campillo, X., Cela, J.M., Hernández, F.X. (2013). "The development of new infantry tactics during the early XVIIIth century: a computer simulation approach to modern military history". In: *Journal of Simulation*, 7, 170-182.

Adding other battle lines would increase complexity without improving the understanding of the underlying mechanism. Spatial scale is suited to the area occupied by an individual capable of fighting (1 squared metre x cell). Temporal scale is related to the movement, so we have chosen a pace of 1 second per time step. Finally, the atomic entity of the model (the agent) is the individual, divided in two different types: Legionaries and Centurions. They both have the same traits and behavior, and belong to a particular side (defined as Blue and Red).

For each time step, each agent will:

1. adjust its internal state based on situation
2. advance, retreat or stay in the same place
3. engage in combat (ranged or hand-to-hand)

3.2 State of the agent

Following the psychological constraints detailed by the authors previously discussed each soldier is defined by a stress value and a threshold, which define the will of the soldier to continue fighting or retreat:

- $S_{i,t}$ - level of stress of a soldier i during time step t .
- T_L, T_C - threshold in which high levels of stress forces a legionary T_L or a centurion T_C to stop fighting and try to retreat.

This threshold is a summary of the factors that affect the efficiency of the individual in the battlefield (e.g. training, experience, morale, etc.); a high T implies that the agent is more resilient to the stress of the battle, and for this reason will be able to continue fighting for longer periods of time.

- F - Fatigue modifier that increase due to friendly casualties.

In addition, any action that an agent performs is modified by fatigue, that increases with any casualty and decrease its general efficiency. Finally, it must be noted that there is no difference between a legionary and a centurion except for different parameter values for T_L and T_C .

The stress of a soldier i at time $t+1$ is computed as the stress in the previous time step increased or decreased by transmitted stress from other legionaries (TS) and generated stress from potential threats (GS):

$$S_{i,t+1} = S_{i,t} + (TS_{i,t+1} + GS_{i,t+1}) \cdot W_{i,t}$$

being W a fatigue weight equal to $F_{i,t}$ if $TS+GS > 0$ and $\frac{1}{F_{i,t}}$ if $TS+GS < 0$.

Transmitted Stress is defined as $TS_{i,t+1} = \frac{S_r}{T_r} \cdot T_i - S_i$, being r a random adjacent friend that i can see (at his front or flank).

Generated Stress is positively correlated with the distance between the legionary and the closest enemy following a logistic function $[-0.05, 0.05]$ as follows:

$$GS_{i,t+1} = \frac{0.1}{e^{(1+12 \cdot D-6)}} - 0.05 \quad \text{being } D \text{ a distance weight} \quad D = \frac{T_i \cdot \text{dist}(i, \text{enemy})}{kz} \quad \square$$

An example of this mechanism is depicted in **Figure 1**.

Figure 1: Values of Generated Stress over distance for a legionary with and enemy. As the legionary closes the distance to the enemy line (x axis) its stress level (y axis) increases exponentially.

The state of an agent is also modified by friendly casualties. Any casualty c increase S and F of adjacent friendly i soldiers depending on an exponential decay following the equation

$$I_{i,t+1} = 0.1 \cdot e^{-0.5 \cdot (dist(i,c)-1)} \text{ as seen in Figure 2.}$$

Figure 2: Increase in the stress (Y axis) of friendly soldiers based on distance (X axis) to a casualty. The impact of the friendly casualty in the stress of a soldier increases exponentially with the inverse of distance.

3.3 Movement dynamics

The movement of the agents is restricted to advance or retreat, and is correlated with $\frac{S_i}{T_i}$ using

a logistic function $M_{i,t+1} = \frac{1}{e^{(1+12 \cdot S_i/T_i - 6)}}$. When M is lesser than 0.1 the agent will advance,

and if it is larger than 0.9 the agent will retreat, as shown in **Figure 3**.

3.4 Combat

If a legionary has enemies inside its kz and still has its pilum it will throw with probability 0.1 (the legionary will throw its pilum during the next 10 seconds). Additionally, if the legionary has adjacent enemies it will attack a randomly picked enemy r amongst its neighbors. In both

cases a uniform random value $U(0,1)$ is compared against lethality (let_r if $pila$, let_{cc} if $close combat$); if the value is lesser than lethality the enemy is a casualty.

Figure 3: Movement of soldiers is modeled as a logistic function receiving the relation between current stress and threshold. If the outcome is close to 0 the agent will try to retreat away from the enemy; if it is close to 1 the agent will try to advance towards the enemy.

3.5 Experiment design

The model will be used to explore our defined research questions in three different experiments. All simulations are defined as an engagement between two roman legions, identified as Blue and Red. The parameters defining the values for one side (Blue) are fixed, while we explore the parameter space for the other side (Red). In this way we reduce the number of possible combinations while analyzing the effects of different parameters in only one side, thus making possible comparison between results.

Our research questions only involve the direct engagement, so the experiments will only focus on the front line of both formations. Each of them is deployed in 10 columns and a varying number of ranks (4, 6, 8), deploying 4 cohorts (24 centuria) in the case of 6 ranks. We are interested on the

effect of the formation's depth, and for this reason the width of the formation remains constant (thus avoiding the factor of flank attacks). This gives a total of 960 soldiers for 4 ranks, 1.440 for 6 ranks and 1920 for 8 ranks.

Every simulation has been executed 1000 time steps, enough time to see the emergence of panic in one of the sides (calibrated based on initial tests). The summary statistic collected from each simulation is the number of soldiers that are still fighting (i.e. still alive, in the battlefield and current stress lower than threshold).

Common parameters for both sides are:

- $kz = 15\text{m}$.
- $let_{cc} = 1\text{‰}$
- $let_r = 3\text{‰}$

In addition Blue side is defined with standard values:

- $T_L = 1$
- $T_C = 1.5$
- $P_c = \text{1st rank right}$
- $ranks = 6$

A parameter exploration is defined for the Red Side following these values:

- $T_c = \text{from 1.0 to 2.0 in 0.1 steps}$
- $P_c = \{\text{random, 1st rank random, 1st rank right}\}$
- $ranks = \{4, 6, 8\}$

These parameters define a number of 99 different combinations; and each one of them has been repeated 100 times for stochasticity. In order to understand the effect of these parameters in the case of uneven armies 3 different scenarios has been explored, varying T_L for the Red Side (

$T_L = \{0.9, 1, \text{and } 1.1\}$ for a total of 29.700 runs.

4 Results and discussion

Each scenario has been classified in 9 sets of 1100 runs, depending on the tuple $(ranks, P_c)$.

Figure 4 shows the results classified by increasing T_C for one of the configurations.

Figure 4: Results for the tuple $(T_L=1, ranks=4, P_c=1\text{st rank right})$. The X axis shows the red T_C for each run; each dot shows the final number of fighting soldiers (Y axis) for Reds or Blues in a single run

Two different patterns are detected in this analysis. On the one hand the cohesion (e.g. soldiers willing to fight) of the red formation increases linearly with the threshold of its centurions. On the other hand the performance of the enemy formation do not decrease in the linear trend, but it follows a sigmoidal curve. This means that, in the model, centurions with average values (1.1 to 1.7) have an increasingly significant effect on the general resilience of the formation during combat, but only experienced centurions (1.8 to 2.0) have the impact needed to degrade the

enemy formation. In other words, only professional centurions ready to charge would be able to attract their legionaries in assaults capable of breaking the enemy line; if this was not the case only a successive chain of attacks and retreats would generate the same effect. Finally, the stochasticity of the system is well captured through the number of runs chosen in the experiment, as the average values (shown with lines) are coherent with the interpretation of the results.

These visual analytics show some interesting trends in the data, but the strong links between the three parameters we want to explore (centurion stress threshold, number of ranks and centurion position) suggest that their interaction is related in a non-linear way. **Figures 5, 6 and 7** shows average bar values for the entire set of experiments.

Figure 5: Experiment results divided by centurion position (rows) and ranks (columns) for Red $T_L=0.9$.

Figure 6: Experiment results divided by centurion position (rows) and ranks (columns) for Red $T_L=1.0$.

Figure 7: Experiment results divided by centurion position (rows) and ranks (columns) for Red $T_L=1.1$.

A visual comparison of the three scenarios shows that variations in Red do not change the dynamics, only the phase transitions where Red performs better than Blue. This is logical, considering that it affects the entire group of soldiers, which are capable of increasing or decreasing their performance on the battlefield. For this reason we focus for the next discussed patterns in the neutral scenario, where $T_L=1.0$:

1. P_C has an important impact in the outcome depending if the centurion is randomly deployed or in the first rank. Results identical for *1st random* and *1st right*). The macro dynamics for the first case are completely different than the rest, as the decisiveness of the engagement is significantly reduced for runs with *random* locations. The centurions of the red formation are able to increase the general cohesion of the line but, at the same time, their limited numbers at the front mean that the Red side has limited charging capabilities compared to the other positions (both in quantity and effectiveness). This supports the hypothesis that the preference for the right end was just a fossilized cultural trait. However, we should keep in mind that this position might also have been beneficial in

other aspects such as the deployment of the *centuria* before the battle or the control of the front-line, issues that are not taken into account in our psychological model.

2. The number of ranks is a significant parameter when centurions have low T_C values. The depth of the formation is extremely useful in these cases, as the intersection points between sides shift to the left when the number of ranks is increased. A formation where centurions have increased T_C (understood as experience, training, etc.) is able to widen its front, even if the soldiers they lead are not experienced; if this is not the case the legion will have to increase its depth in order to maintain the cohesive status of the unit. However, the model focuses on the clash between lines, and we have not taken into account the width of the formation; An increase in the number of ranks could also be a weakness to flanking or encirclement maneuvers, which our model doesn't explore.

3. The model proves that a small number of centurions evenly distributed among the soldiers has, by itself, a critical impact on the general performance of the battle formation. Centurions are only 1 out of 80 soldiers, but a slight increase in their T_C shifts the outcome of the battle in a decisive way. Experienced centurions are so crucial that they outweigh an increase of more than 30% in the number of soldiers of the enemy formation.

These results shows that differences on centurion capabilities for sustaining combat produced diverse roles in the battlefield. On the one hand, the higher their relevance the greater the impact on the charges. On the other hand less experienced or trained centurions would still have a major influence in the cohesion of the troops. This dual emergent property of the system could explain why different classical authors described such radically different of the functions of this type of soldiers.

5 Concluding Remarks

This work provides an innovative quantitative method to improve our understanding of historical sources. The complex system approach allows not only to identify the factors that conditioned the outcome of a battle, but also to establish comparisons between competing hypotheses in different

scenarios.

First, the emergent properties of the system show how the rank depth of the formation and the role of the centurion mutually influenced each other. This link can be also detected on the evolution of the Roman army, and the consensus that these units could only reach its peak of performance after several campaigns³⁵. Republican legionaries had to serve between 6 and 16 years³⁶, while Hircio considered that the XI Legion of Caesar, didn't still reached its efficiency peak after 7 years (Caes. Bel. Gal. 8, 8). Despite the fact that several Republican soldiers had campaign experience, the fact that legions were recreated every year disabled the possibility of increasing the cohesion of the units (except for some cases during the Second Punic War). Even social ties were actively broken during recruitment³⁷; in this context the centurion played a vital role as a model, increasing the cohesion of the unit as a group of individuals with uneven experience.

Second, higher numbers of ranks compensate the lack of resilience of centurions and soldiers, augmenting the cohesion of the unit and preventing the spread of panic over the whole formation. This explains the tendency among Roman generals to deploy in columns recent recruited troops, such the ones described in Cannae (Plb. III, 113, 16 ranks) and Pharsalus (Front., Stratagems, II, III, 22, 10 ranks).

Third, the role of the centurion gradually changed when diverse factors increased their combat performance, particularly training and experience. The model shows low-mid values of T_C highly increase the defensive cohesion of the unit, while only centurions with high T_C are capable of leading charges and have an impact on the enemy. This can be linked with the emphasis that Caesar puts in *virtus*, because his legions would only exploit their higher experience if they took aggressive centurio as models.

To summarize, results suggest that changes in the role of the centurio can be explained strictly as an increase in their experience and overall combat performance. Applying the concept of

35 Goldsworthy, A.K. (1999). "Community under Pressure: The Roman Army at the Siege of Jerusalem". *The Roman army as a community: including papers of a conference held at Birkbeck College, University of London, on 11-12 January 1997, edited by A..K. Goldsworthy and I. Haynes, 197-210. Journal of Roman Archaeology*. Supplementary series 34. Portsmouth: Journal of Roman Archaeology., 201

36 Walbank, F.W. (1970). *A historical commentary on Polybius*. Oxford University Press, Oxford., pp. 698.

37 See Polybius (VI, 20); also Lendon, J.E. (2004). Review: The Roman Army Now. *The Classical Journal*, 99, 441–449.: p.445-446.

parsimony there is no need to elaborate more complex hypotheses such as changes on their training, values or tactics³⁸; there is no need to consider two different roles for the centurion, as they could do both (lead charges and provide cohesion) depending on the particular situation and army.

This ABM is a useful theoretical exploration of the dynamics of Roman combat. As any other model it has several limitations, as it was built to explore the impact of three factors during the clash of two battle lines (ranks, centurion position and centurion performance). Besides, there is currently no data that can be used to test these results. Finally, its assumptions rely on the evidence provided by written sources and the works of different authors.

Despite these limitations, the proposed method is able to compare working hypotheses and test their plausibility, at least in the controlled environment of the virtual simulation. In this context complex systems are a powerful tool that historians can apply to explore a diversity of research questions and develop a quantitative framework to build, compare, and select ideas with the aim of improving our understanding of the past.

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38 See competing hypotheses in Lendon 2005 op.cit.; Palao Vicente 2009, op.cit.

39 Rubio-Campillo, X. (2014). "Pandora: A Versatile Agent-Based Modelling Platform for Social Simulation" In: *Proceedings of SIMUL2014*, 29-34. R Development Core Team. (2008). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from <http://www.R-project.org>