Using Experience to Promote the Emergence of Leaders and Followers

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1 Introduction

Many animals form large aggregations that have no apparent leader, yet are capable of highly coordinated movements. How this is possible has fascinated biologists for a long time. Which individuals of a group emerge as leaders and why? Often, all individuals of a large group are considered to be equal. But realistically, individuals in a homogeneous group are not all equal and existing differences may affect emerging leadership. Clearly, individuals will differ based on traits like sex, age, and also experience. Of particular interest in this context have been differences in correlated traits, or personalities. Such personalities can arise via complex gene/environment interactions and are often shaped by individual experience.

One very important experience that can influence future behavior is whether or not attempts at leadership are successful or not. Although the effects of personalities and individual experience on leaders and followers is an active area of research [7], we are particularly interested in how individual experience in successful leadership can give rise to leaders and followers when the individuals in a group all share the same personality. There are a variety of systems which can benefit from the improved coordination achieved through effective leadership, such as multi-agent systems, but lack distinct personality types within the group from which leaders and followers naturally emerge. In these artificial systems, it is possible that individual experience can be used to promote the emergence of distinct personality types, which will in turn, lead to the emergence of leaders and followers.

In the work discussed here, we present predictions on the emergence of distinct personality types through experience gained in repeated collective movement simulations. A collective movement model developed through observation of natural systems was extended to use personalities in determining leader and follower roles. After a collective movement attempt, the leader's experience attempt at leadership either increased its tendency to lead future movements or increased its tendency to follow. The simulations predict that this simple model can result in the rapid emergence, or differentiation, of distinct personality types and the improved coordination that effective leadership can provide.

2 Materials and Methods

The model chosen for this experiment was developed through observations of collective movement attempts in a group of ten white-faced capuchin monkeys [3, 8], and was

later confirmed in observations of sheep groups ranging in size from 2–8 members [9]. It uses three interaction rules to govern the decision-making process involved in starting collective movements. The first rule assumes that all individuals within the group can initiate a collective movement attempt. While this assumption may not hold for groups with dominant leaders, studies have shown that it is a viable assumption for egalitarian animal groups, such as the capuchin monkeys used in the model's development.

The second rule describes the rate at which followers join the collective movement attempt. As the number of individuals following the initiator increases, the rate at which individuals join the movement also increases. Note that the model assumes global communication and once an individual initiates a collective movement, the remaining individuals are assumed to have observed the initiation attempt and have the opportunity to follow the initiator.

The third rule describes the fact that not all initiation attempts are successful as initiators often cancel and return to the group. As the number of individuals following the initiator increases, the rate at which the initiator cancels an initiation decreases. Also, simulations of the model include the implicit assumption that a successful collective movement requires all of the members of the group to participate, since there is a non-zero probability of canceling even if all but one member participates. While this is not necessarily the case in nature, cohesive, collective movements are the primary objective of this work and, as such, incomplete movements are considered failures.

2.1 Adaptive Personality

To investigate the effects of altering the rate at which individuals initiate, follow an initiator, and cancel a movement, Gautrais added a constant, referred to as a "k factor," to the rate calculations of the collective movement model [3]. Since this k factor can either increase or decrease the three decision-making rates for an individual, it was an ideal means with which the effects of personality could be incorporated into the model.

Three important points were considered in integrating personality with the collective movement model. First, personality has been observed in natural systems to affect the events used in this model in different ways. For example, a bold personality should result in a higher initiation rate and lower following and canceling rates, while a shy personality should result in a lower initiation rate and higher following and canceling rates [4]. Second, the magnitude with which a shy personality affects the model should be the same as a bold personality so as not to bias the model towards one personality over another. Since k had a non-inclusive lower limit of 0, the non-inclusive upper limit of 1 was chosen to ensure balance. In the simulations described below, personalities were limited to the range $[0.1 : 0.9]$ to ensure these limits were satisfied. Lastly, although the original model, nor the observations on which the model was based, discuss personality of the individual animals involved, one can assume that the individuals could be classified as having either bold or shy personalities. Therefore, the integration of personality incorporated the concept of a moderate personality ($p = 0.5$) that produced the same results as the original model.

The initiator's personality was updated after every collective movement initiation attempt using the following standard update (or learning) rule [1, 6, 10]:

$$p_{t+1} = p_t(1 - \lambda) + \lambda r \tag{1}$$

where p_t was the initiator's personality for the current movement, p_{t+1} was the personality for the next movement, λ was the rate at which updates changed the personality, and r was the reinforcement value used to update the personality. When λ was low, the personality was primarily determined through long-term historical success and changes

were minor. When λ was high, the personality was primarily determined through short-term success, namely the last initiation attempt, and changes from one attempt to the next were significant. For the simulations described in this work, a low value of lambda was chosen ($\lambda = 0.02$) to emphasize long-term initiation success. For successful initiations, the reinforcement was $r = 1$, while it was $r = 0$ for unsuccessful initiations.

2.2 Numerical Implementations

Numerical simulations of the collective movement model were implemented in Java using the same algorithm as in previous work [3]. The time of each event was calculated as a random number drawn from an exponential distribution using the appropriate rate. As such, the simulations use continuous time events and not discrete time. The original model was only evaluated with a group size of 10, but other work has shown that the success of collective movement initiations increases as the group size is increased, with diminishing effects beyond a group size of 100 [2]. As such, evaluating different group sizes presents an opportunity to evaluate the effects of personality with different group dynamics. To evaluate the impact of the initial personality value, treatments were performed using the following personality values for all individuals within a group: shy ($p_v = 0.2$), moderate ($p_v = 0.5$), and bold ($p_v = 0.8$). Within each treatment, group sizes from 10 to 150 were used. Fifty evaluations were performed for each group size, each with a different random seed. A single evaluation consisted of $2,000 \times N$ simulations, where N was the group size. Each simulation constituted a single attempt at a collective movement and ended in either success (all individuals participating in the movement) or the initiator canceling. Individual personality values were reset at the beginning of each evaluation and persisted from one simulation to the next. The model parameters used were the same as those used in the original model [3, 8].

To analyze trends in personality values of successive simulations in an evaluation, the R package `strucchange` was used [11]. This software package allowed for the identification of structural shifts in time series data. In our simulations, these shifts, referred to as breakpoints, represent a personality transition. Since personalities are not constant and the analysis produces a linear approximation of a portion of personality value time series, we defined a personality to be bold if a segment of the personality had a value greater than or equal to 0.775.

3 Results & Analysis

Figure 1 shows the success of initiators in leading collective movements (i.e., movements that ended with all individuals participating). All simulations using personality, regardless of the initial value, performed statistically significantly better than simulations using the original model (Kolmogorov-Smirnov test, $p << 0.0001$). As with the original model, leadership success increased as the group size increased. However, simulations using an initial personality of shy and moderate predicted an initial loss in success when increasing the group size from 10 to 15.

Figure 2 depicts the personality histories for two different evaluations using initial shy personalities and a group size of 10. In the first evaluation, a leader with a bold personality differentiates rapidly (under 1,000 simulations), while a leader with a bold personality took over 7,000 simulations to differentiate in the second. Since the number of simulations needed for bold personalities to emerge depends on the group size, Figure 3 shows the mean percentage of the total number of simulations within an evaluation for bold personalities to emerge and differentiate from shy personalities (mean/SE). For a group size of 10, evaluations using initial bold personalities

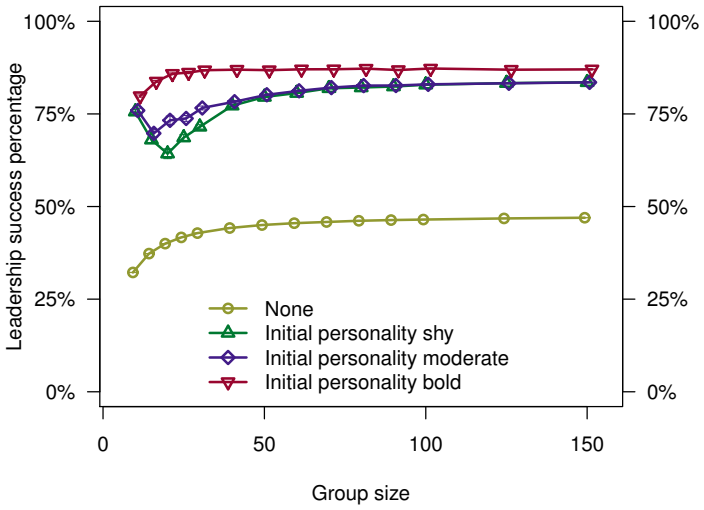
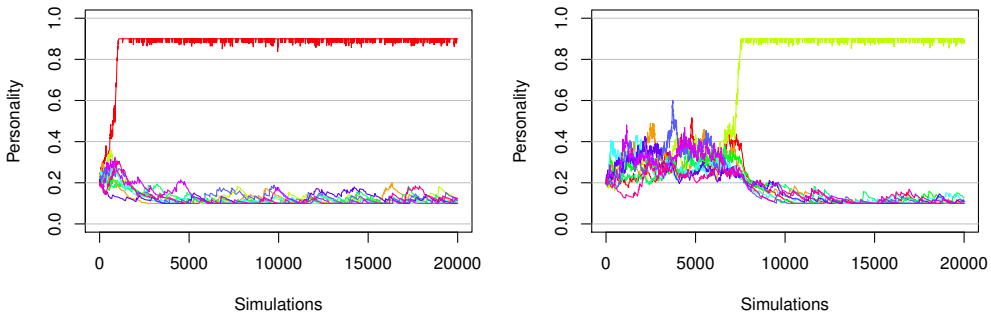


Figure 1: The mean leadership success in initiating collective movements is shown for different group sizes and personality values. All individuals within the group were given the same initial personality value, but individuals adapted their personalities based on experience in initiating collective movements (mean/SE).



(a) Fast Adaptation (b) Slow Adaptation

Figure 2: Histories of personality adaptation for two different evaluations using a group size of 10 and an initial personality of 0.2 are shown. In both evaluations, personalities were distributed at the extremes of the bold/shy continuum after adaptation, but the number of simulations required for adaptation differed between evaluations.

take longer to differentiate that evaluations using initial shy or moderate personalities. However, for group sizes of 40 and larger, evaluations using initial bold personalities differentiate faster.

4 Discussion

Studies have shown that differentiation into specific roles can improve a group's success (e.g., [5]). The collective movement model used here produces similar predictions, as shown in Figure 1. Evaluations in which personalities were allowed to differentiate into bold and shy predict far higher initiation success than those in which personality was nonexistent or fixed, in some group sizes doubling the success rate. This improved

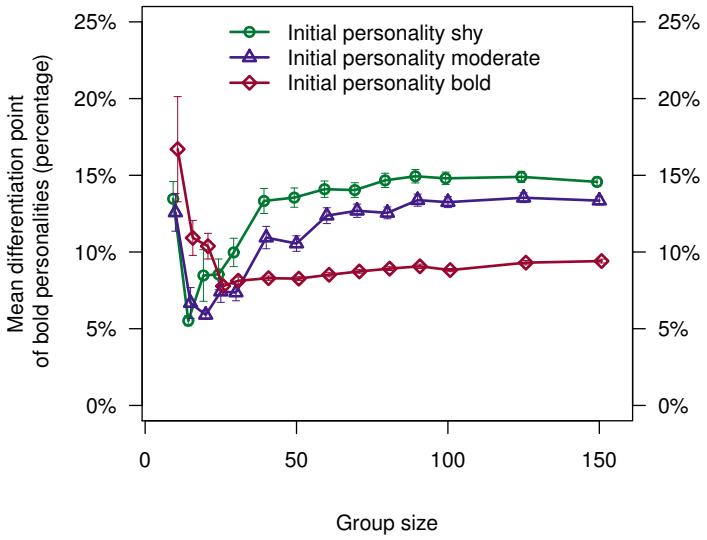


Figure 3: The mean percentage of the total number of simulations within an evaluation required for bold personalities to differentiate from shy individuals (i.e., become bold) (mean/SE).

success rate is due to both bold and shy personalities being present in the group. An individual with a bold personality was more likely to initiate movements due to a higher initiation probability. Furthermore, since bold personalities are less responsive to other individuals within the group, they are less likely to cancel. In contrast, shy personalities are more likely to follow an initiator, providing the bold initiator with more followers faster and reducing the probability that the initiator would cancel.

To ensure that the addition of personalities in and of themselves did not bias the results, we performed evaluations with fixed personalities of shy, medium and bold. The results were identical to evaluations that did not include personalities at all. If all personalities are bold, then the initiator is less likely to cancel, but all the potential followers are also less likely to follow. On the other hand, if all personalities are shy, potential followers are more likely to follow, but the initiator is also more likely to cancel. It is the combination of bold and shy personalities that produces improved initiation success.

Since the differentiation of personalities is essential to the improved initiation success, reducing the amount of experience needed to differentiate directly impacts the initiation success. Although a larger λ value can be used to increase the rate at which personalities change, we were interested to learn if the choice of initial personality affected the amount of experience needed for differentiation. Figure 3 shows that for groups of 40 or less, the differentiation rates for different initial personality values are not consistent. However, for groups of 50 or more, the differentiation rates are consistent, with an ordering from fastest to slowest of bold, moderate, and shy.

Acknowledgments

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