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Evolution of division of labor: Emergence of different activities among group members

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HIGHLIGHTS

- We investigate under what conditions division of labor (DL) should evolve.
- DL likely evolves when group size is large and skill learning is important.
- DL also likely evolves when there is food sharing within a group.
- DL by gender likely evolves when the difference between genders is large.
- We discuss the evolution of DL in hominids.

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ABSTRACT

The division of labor is an important component of the organization of human society. However, why this division evolved in hominids requires further investigation. Archeological evidence suggests that it appeared after the emergence of *Homo sapiens* and contributed to the great success of our species. We develop a mathematical model to investigate under what conditions division of labor should evolve. We assume two types of resources the acquisition of which demands different skills, and study the evolution of the strategy that an individual should use to divide its lifetime into learning and using each skill. We show that division of labor likely evolves when group size is large, skill learning is important for acquiring resources, and there is food sharing within a group. We also investigate division of labor by gender under the assumption that the genders have different efficiencies in acquiring each resource. We show that division of labor by gender likely evolves when skill learning is important and the difference in efficiencies between genders in acquiring resources is large. We discuss how the results of our analysis might apply to the evolution of division of labor in hominids.

1. Introduction

The division of labor within groups of hominids, e.g., modern humans, is an important component of the organization of human society. For example, in the recent past hunter–gatherers have generally divided their labor by gender and age, i.e., men hunt, women and children gather (Dahlberg, 1975; Marlowe, 2010), although there are some exceptions (Estioko-Griffin and Griffin, 1981). Agricultural and industrial societies have more complex divisions of labor. Some insect societies also appear to have division of labor (Gordon, 1999). However, why such divisions evolved remains to be explained.

Although studies of division of labor have a long history in economics, business, and sociology (e.g., Smith, 1776; Marx, 1867), they have mainly discussed the most efficient division of labor and have not taken an evolutionary perspective. Since natural selection acts on individuals, not groups (although group selection may sometimes occur), we should consider the fitness of individuals when we address the *evolution* of division of labor, especially its emergence in hominids. Since the fitness of each individual is affected by others' strategies in the context of social behaviors, evolutionary game theory provides a useful approach to this problem.

In modeling the evolution of hominid division of labor, we attempt to take anthropological evidence into consideration. The division of labor is composed of three factors, the formation of a group, food (resource) sharing within a group, and different activities among group members. Taking anthropological evidence into account, let us explore when each factor might have evolved in hominids.

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Since group structure varies among extant ape species, that of the common ancestor of chimpanzees and humans is uncertain; the evolution of group structure in hominids is one of the key topics in paleoanthropology (Nakahashi and Horiuchi, 2012). Fossil evidence suggests that A.L.333, an *Australopithecus afarensis* group known as the “First Family,” may have included at least 17 hominids: nine adults, three adolescents, and five juveniles (Johanson, 2004). The Laetoli footprints (Leakey and Hay, 1979) also strongly suggest that *A. afarensis* was not a solitary creature. Therefore, we can assume that the group formation had already evolved in *A. afarensis*.

Food sharing within a group is universal in current hunter–gatherer societies (Kaplan and Gurven, 2005). Although apes sometimes share food (de Waal, 1989; Silk et al., 2013), the oldest evidence of hominid food sharing may be found in *Homo erectus*. A toothless individual of *H. erectus* about 1.8 million years ago survived for a lengthy period (Lordkipanidze et al., 2005), possibly because of the support of other group members. It is also well known that a Neanderthal individual with a withered right arm survived for a long time (Stewart, 1977). A hominid species in the Levant hunted large game about 200,000–400,000 years ago, which strongly suggests that cooperative hunting and food sharing existed in that species (Stiner et al., 2009). In short, we can consider that food sharing had already evolved, at least in *H. erectus*.

Other activities that differ among group members may have evolved later in hominids. Kuhn and Stiner (2006) studied the archeological record in Eurasia and concluded that gender-specific activities did not appear there until the beginning of the Upper Paleolithic. In the Middle Paleolithic, Neanderthals apparently had more narrowly focused economies, depending mainly on large game, which suggests that women's activities were more closely aligned with those of men. On the other hand, in the Upper Paleolithic, *Homo sapiens* engaged in a wider range of economic and technological tasks, similar to those of contemporary hunter–gatherer societies, suggesting that women and men were engaged in different activities in their societies.

In this study, we focus on the emergence of different activities among group members, which is the last component of the division of labor. Although the evolution of group formation and food sharing are important and worth investigating, as described above, these appear to have evolved earlier than different activities among group members. Here, we investigate conditions under which groups evolve so that members are engaged in different activities; this can be regarded as the evolution of division of labor, provided group formation and food sharing have already evolved.

Kuhn and Stiner (2006) suggested that the division of labor was likely to arise in the semiarid tropical environments of Africa and Asia because food resources other than large game are more diverse and abundant in low-latitude ecosystems. In fact, human fossil footprints in Tanzania, dated to about 120,000 years ago, suggest that males and females at that time were already engaged in different activities (Richmond et al., 2011; reported in Gibbons, 2011). The behavioral changes and the division of labor in *H. sapiens* may have provided expanding populations with a demographic advantage over other hominids in Eurasia (Kuhn and Stiner, 2006). We discuss whether this hypothesis is reasonable in terms of the results from our models.

Human division of labor differs from the genetically determined division of labor in eusocial animals in that it appears to require learning. For example, among hunter–gatherers, boys learn to hunt and girls learn to gather (Kamei, 2010), although there are some kinds of joint foraging. Therefore, it is important to elucidate the evolution of learning strategies that could promote and support the evolution of such a division of labor, although most theoretical research on the evolution of learning strategies has not addressed this problem. Although what to learn is important in the division of labor, most researchers have focused on how to learn (e.g., individual and social learning: Boyd and Richerson, 1988; Rogers, 1988; Feldman et al., 1996; Enquist et al., 2007; Aoki and Nakahashi, 2008; Nakahashi, 2010, 2013), from whom to learn (Henrich and Boyd, 1998; McElreath and Strimling, 2008; Nakahashi, 2007; Nakahashi et al., 2012), and when to learn (Aoki et al., 2012; Lehmann et al., 2013). Moreover, although theoretical research has shown how social structure might affect cultural evolution (Henrich, 2004; Kobayashi and Aoki, 2012; Kobayashi and Wakano, 2012; Lehmann et al., 2010), the ways in which cultural evolution and learning strategies might affect social structure have not been well studied.

Henrich and Boyd (2008) considered the evolution of division of labor in the context of learning strategies. They assumed that the population is divided into two subpopulations in each of which individuals may have different strategies. Their model may apply to the evolution of division of labor by gender; that is, we can consider the subpopulations to be males and females with a same-sex learning bias. However, their model is not applicable to the evolution of intragroup division of labor among members with similar abilities, which is an important component of human social systems.

In this paper, we develop a new model that incorporates what to learn. We assume two types of resources, whose acquisition demands different skills, and consider the evolutionarily stable strategy (ESS; Maynard Smith, 1982) that partitions lifetimes into skill learning, and exploitation using the learned skills. We apply standard methods of adaptive dynamics (Geritz et al., 1997) to derive conditions for evolutionary branching to occur and confirm the results by Monte-Carlo agent-based simulations. We consider six models whose assumptions are summarized in Table 1. The results may also be relevant to non-human species in which castes or other subgroups may have specific roles.

2. Models for division of labor

2.1. Model 1: Basic model

Consider two types of resources (e.g., animals and plants), which are acquired in different ways; we will call these ways of obtaining resources “skills” and denote them by H and G. An individual may learn H or G or both. All individuals have the same lifespan, during which they may carry out four possible

Table 1
Assumptions of models.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Total yield of a group is constant	Yes	No	Yes	Yes	Yes	Yes
Food sharing exists	Yes	Yes	No	Yes	Yes	Yes
Division of labor by gender is considered	No	No	No	Yes	Yes	Yes
All time can be assigned to both learning and exploitation	Yes	Yes	Yes	Yes	No	Yes
Experience functions as learning	No	No	No	No	No	Yes