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Groups have a larger cognitive capacity than individuals

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Increasing the number of options can paradoxically lead to worse decisions, a phenomenon known as cognitive overload [1]. This happens when an individual decision-maker attempts to digest information exceeding its processing capacity. Highly integrated groups, such as social insect colonies, make consensus decisions that combine the efforts of many members, suggesting that these groups can overcome individual limitations [2–4]. Here we report that an ant colony choosing a new nest site is less vulnerable to cognitive overload than an isolated ant making this decision on her own. We traced this improvement to differences in individual behavior. In whole colonies, each ant assesses only a small subset of available sites, and the colony combines their efforts to thoroughly explore all options. An isolated ant, on the other hand, must personally assess a larger number of sites to approach the same level of option coverage. By sharing the burden of assessment, the colony avoids overtaxing the abilities of its members.

Nest site selection by *Temnothorax* ants exemplifies collective decision-making without well-informed leaders [5]. When a colony must find a new home, it can choose the better of two new sites even when no single ant assesses both. Instead, comparison emerges from a competition between recruitment efforts. Upon finding a site, an ant recruits nestmates to it with a probability that depends on the site's quality, as determined by entrance diameter, cavity size, light level, and other features [6]. Her recruits make their own quality-dependent recruitment decisions, creating positive feedback that directs the colony towards the better nest. Consensus is further enhanced by a quorum rule that accelerates recruitment once a site's population has surpassed a threshold [5].

Although this process does not require individuals to compare sites, they have the ability to do so; an isolated ant that assesses two sites of different quality can reliably choose the better one [7]. We took advantage of this fact to compare the cognitive capacity of groups and individuals. We induced subjects (either whole colonies or isolated ants of *T. rugatulus*) to select a new nest in one of two conditions. In the simpler condition they chose between only two nests, one good and one poor. In the more challenging condition, they chose among eight options, four good and four poor (Figure 1A). Good nests differed only in having a smaller entrance, a strongly favored feature [6]. Decision performance was measured by noting which type of nest the subject moved into.

We found that individuals performed significantly worse when the number of options was eight rather than two, indicating that they experienced cognitive overload ($\chi^2 = 4.18$, $N = 43$, $df = 1$, $p < 0.05$). In the two-nest condition, over 80% of ants chose a good nest, but in the eight-nest condition, only 50% did, indistinguishable from random performance. Colonies, on the other hand, performed equally well with either two or eight options, with at least 90% choosing a good nest in each condition ($\chi^2 = 0.36$, $N = 40$, $df = 1$, $p = 0.55$) (Figure 1B). Thus colonies achieved a significantly higher decision performance in the face of increased processing load than did individuals (partial χ^2 test: $\chi^2 = 8.75$, $N = 3$, $df = 3$, $p = 0.03$).

We hypothesized that colonies better handle higher option numbers because their members do not have to assess as many sites as isolated individuals. If so, we predicted that each colony member visits a smaller number of nests than an isolated ant. To test this, we repeated the eight-nest treatment, but counted the number of sites visited by each ant. The results of this second experiment confirmed our prediction: isolated ants assessed significantly more sites than did colony members (Wilcoxon rank test: $W = 1819$, $N_{isolated} = 10$,

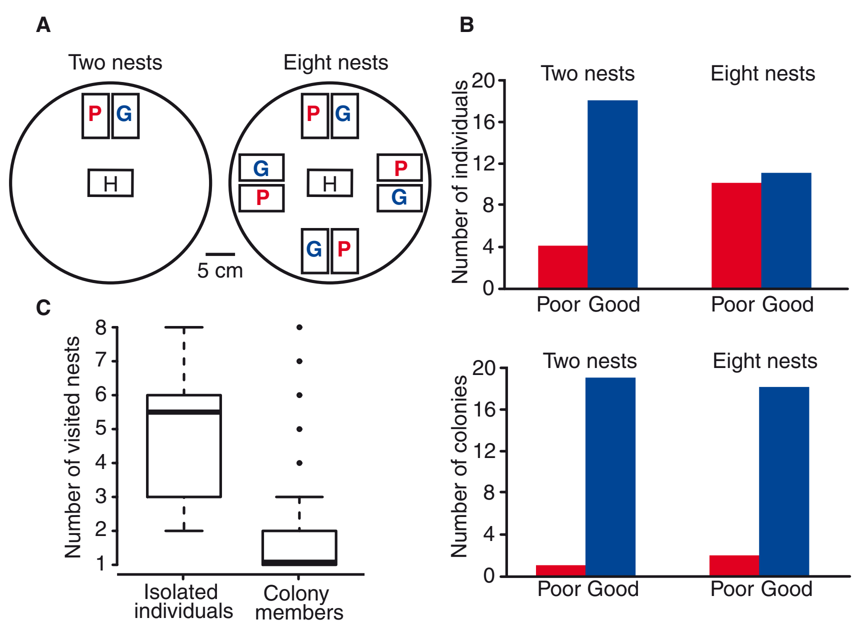

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Figure 1. Effect of option number on decision performance.
(A) Experimental arenas. Subjects (whole colonies or isolated ants) were made to abandon their home nest (H) and choose a new nest from an array of either two or eight good (G) and poor (P) options. (B) Numbers of subjects choosing good or poor nests in each treatment. Isolated ants made worse decisions with eight options than with two (top chart), but colonies nearly always chose a good nest regardless of the number of options (bottom chart). (C) In the eight-nest condition, isolated ants visited more nests than did individual colony members. Boxes delimit the 1st and 3rd quartiles, the horizontal line indicates the median, and whiskers show the range. Open circles are outliers.

N_{colony} = 209, $p < 0.01$) (Figure 1C). Importantly, although each colony member visited very few sites, the colony collectively assessed all eight sites.

The inferior performance of isolated ants cannot be explained as a simple artifact of isolating these normally very social animals. Lone ants performed just as well as colonies when choosing between two sites; only with an increase in option number did their ability to select a good nest decline (Figure 1B). Nor can the colony advantage be ascribed to a higher probability of finding a good site. Because half of the options were good in both conditions, the probability of finding a good nest did not depend on the number of options available for either colonies or individuals (see the Supplemental Information for details). Furthermore, when isolated ants were tracked in the second experiment, all of them found at least one good nest. Indeed, they found many more sites than did all but a few individual colony members (Figure 1C). The small minority of colony members that visited a large number of nests contributed little to total transport effort, and thus to the colony's decision (see the Supplemental Information for details). Therefore we attribute the worse performance of isolated ants to the difficulty of processing a greater load of data. We cannot say why isolated ants do not avoid this problem by simply assessing fewer sites. However, we speculate that they prolong their search for new nests because they lack social interactions, such as quorum attainment, that would normally trigger earlier acceptance of a site.

Cognitive overload is a growing issue for human decision-making, as unprecedented access to data poses new challenges to individual processing abilities [1]. Human groups also solve difficult problems better when each group member has only limited access to information [8]. For social insects, this advantage is likely much greater, because natural selection on colony-level phenotypes has shaped particularly elaborate and highly integrated group cognition. This is because selection acts largely through the reproductive success of whole colonies, rather than that of the sterile workers that make them up [9].

It has long been recognized that collective choice can improve accuracy by averaging out the random errors of inaccurate individual decisions [3]. The advantage we find here is different: rather than combining many essentially identical choices, colonies truly distribute their decision-making. No worker must carry out the full task of assessing and comparing all options, allowing the colony as a whole to process more information, more effectively. This advantage can serve as a model for the rapidly developing field of collective robotics, which looks to the robust, decentralized group behavior of social animals for biologically inspired design ideas [10].

Supplemental Information

Supplemental Information includes experimental procedures, results and two figures and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2012.07.058.

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