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Ants Can Anticipatively and Correctly Increment the Last Quantity of a Learned Arithmetic Sequence

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Abstract

It has previously been shown that *Myrmica sabuleti* ant workers trained to an increasing (1 to 4) or decreasing (5 to 2) arithmetic sequence can expect that the next quantity will be larger or smaller. Here we show that they anticipate the exact next quantity by correctly incrementing the last quantity of the learned sequence by +1 or -1 and not by +2 or -2. Correctly anticipating the following quantity in an arithmetic sequence may result from the ants' ability of acquiring conditioning, of memorizing lived events, and of perceiving the running time.

Keywords: Anticipation, Expectative Behavior, *Myrmica sabuleti*, Numerosity Abilities, Operant Conditioning

1. Introduction

1.1 Generalities

The workers of the ant *Myrmica sabuleti* Meinert, 1861 possess several numerosity abilities (Cammaerts & Cammaerts, 2020b, d). They can add and subtract one element to and from a number of elements if they see the result of the operation during training. They natively locate the amounts on a left to right oriented number line. They acquire the notion of zero through experiences. They can acquire numerical symbolisms and use these symbols for adding and subtracting, including a symbol for zero. Moreover, we recently showed that, trained to an increasing (1, 2, 3, then 4) or a decreasing (5, 4, 3, then 2) sequence of number of elements, they can expect that the following quantity will be larger or smaller than the last perceived numerosity (Cammaerts & Cammaerts, 2021). In the latter work, the ants were finally tested in front of the numbers of the sequence and of the following one, i.e. the last number of the learned sequence plus 1 or minus 1 and no other number. More precisely, either they were trained to the sequence 1, 2, 3, 4 then tested in front of the five numbers 1, 2, 3, 4, 5, ranked in their increasing order, or they were trained to the sequence 5, 4, 3, 2 then tested in front of the five numbers 5, 4, 3, 2, 1, ranked in their decreasing order. It could thus be not ascertained if they simply forethought a larger or a smaller number of elements or if they anticipatively correctly incremented by +1 or -1 the last number of the learned arithmetic sequence. Further experimental work was therefore needed to find out whether ants can learn the exact incremental value and use it to anticipate the next quantity in the sequence. This work should be similar to the previous one (Cammaerts & Cammaerts, 2021), but by training the ants to either successively 1, 2, 3, and 4 elements or to 6, 5, 4, and 3 elements, and testing then finally in front of the numbers seen during training, the correct next number and the wrong still next number. They thus must be tested in front of 1, 2, 3, 4, 5, and 6 elements or 6, 5, 4, 3, 2, and 1 elements arranged in this sequential order. If the ants respond essentially to 5 or 2 elements respectively, then they anticipate the exact next number of the sequence. If the ants respond equally to 5 and 6 elements or equally to 2 and 1 elements, then they simply expect that the next number of the sequence will be larger or smaller. As a preamble, we situate below the skills of the ant *M. sabuleti* among the anticipatory behaviors and related numerical abilities of other animals.

1.2 Animals' Expectative Behavior Including Linked Numerical Abilities

Expectative behavior has mainly been demonstrated in vertebrates. Scrub jays (*Aphelocoma californica*) are able to expect future needs of food according to a learned situation and independently of their present needs (Raby, Alexis, Dickinson, & Clayton, 2007; Correia, Dickinson, & Clayton, 2007). Great apes (bonobos, chimpanzees, orangutans) can save tools for a future use (Mulcahy & Call, 2006), can exhibit self-control behavior in order to obtain more in the future (Osvath & Osvath, 2008), and prepare an object for a future exchange for food (Dufour, Pelé, Sterck, & Thierry, 2007; Osvath & Persson, 2013; Bourjade, Call, Pelé, Maumy, & Dufour, 2014). Kea parrots (*Nestor notabilis*) can also wait in favor of a preferred reward, showing forward-planning and cost-effectiveness assessment of the situation (Schwing, Weber, & Bugnyar, 2017). When squirrel monkeys (*Saimiri sciureus*) are deprived of water and have the choice between a lot of or few food, they chose the smallest portion of food, what allows them not suffering from thirst thereafter. Rats cannot do so (Naqshbandi & Roberts, 2006). As for the invertebrates, when bumblebees (*Bombus appositus*) collect nectar from flowers, they clearly expect a sufficient amount of food allowing them recovering the energy used during this task; below this expected amount, the bumblebees leave the exploited flowers for trying other ones (Hodges, 1981). The workers of *M. sabuleti* can expect the time as well as the location of the following food availability (Cammaerts & Cammaerts, 2016a, b). Only foragers 2 to 3 years old can do so, the young ants cannot (Cammaerts & Cammaerts, 2015).

Concerning linked numerical abilities, monkeys trained to the numerosities 1, 2, 3 and 4 in an ascending or descending order could order novel exemplars of these numerosities as well as the novel numerosities 5 to 9 on unreinforced trials, showing that these monkeys could represent these numerosities on an ordinal scale, the accuracy of their response depending on distance and magnitude effects (Brannon & Terrace, 1998, 2000). Although it was not the aim of these studies, their results suggest that monkeys would be able to anticipate the next quantity in a numerical sequence. Chimpanzees could also be learned to imagine the next number in a sequence of numerical symbols (Biro & Matsuzawa, 2001).

It can be presumed that honeybees should be able to react anticipatively when confronted to quantities because they present numerosity abilities of a rather high level. They can discriminate numerosities (Bortot, Agrillo, Avarguès-Weber, Bisazza, Miletto Petrazzini, Giurfa, 2019). Trained through classical conditioning to add 1 element to 1, 2, or 4 elements when they are blue colored and to subtract 1 element from 2, 4 or 5 elements when they are yellow, the bees are able to respectively add or subtract 1 element from 3 elements when no longer concretely seeing the addend of the operation (Howard, Avarguès-Weber, Garcia, Greentree, Dyer, 2019a, b).

M. sabuleti ants can learn a behavioral sequence and acquire serial recognition, but only if rewarded (Cammaerts & Cammaerts, 2018a, b). Simultaneously conditioned to a cue associated with meat and a cue associated with sugar water, when deprived of meat they react, to the cue previously associated with meat, and when deprived of sugar water, they react to that previously associated with sugar water (Cammaerts & Cammaerts, 2018c). They can thus present an acquired conditional behavior in a subsequent situation. They can also expect if the next quantity of a numerical sequence presented over time will be larger or smaller (Cammaerts & Cammaerts, 2021).

1.3 Aim of the Present Work

We intend to examine if, after having been trained to a continuous increasing or decreasing arithmetic numerosity sequence (1, 2, 3, 4 or 6, 5, 4, 3), the workers of the ant *M. sabuleti* could anticipate the exact following quantity in the sequence by testing them in front of 1, 2, 3, 4, 5, 6 or of 6, 5, 4, 3, 2, 1 elements. As the present work is the logical continuation of our previous one (Cammaerts & Cammaerts, 2021), the experimental design, protocol and statistical analysis were similar and are thus somewhat briefly described.

2. Material and Methods

2.1 Collection and Maintenance of Ants

The experiments were performed on two colonies of *M. sabuleti* collected in an abandoned quarry located at Olloy/Viroin (Ardenne, Belgium). They were maintained in the laboratory in one to two glass tubes half filled with water, a cotton plug separating the ants from the water. The nest tubes of each colony were set in a tray (30 cm x 15 cm x 5 cm) the borders of which being lightly covered with talc to prevent ants' escaping. The trays served as foraging areas. In them, pieces of *Tenebrio molitor* larvae (Linnaeus, 1758) were deposited three times per week and cotton plugged tubes filled of sugar water were permanently set. The environmental conditions, suitable for the species, were: ambient temperature ca 20°C, humidity ca 80%, lighting ca 330 lux while working on ants, and electromagnetism ca 2 μWm^2.

2.2 Experimental Planning

We first examined if ants could expect the next number of an increasing arithmetic sequence, then if they could expect the next number of a decreasing arithmetic sequence. Each time, during a first part of the experiments, the ants were trained to either an increasing (1 to 4) or a decreasing (6 to 3) numerical sequence, and were tested over this training for checking if they successively learned each presented number of elements. After that, in a second part of the experiments, the ants were simultaneously confronted to the four numbers of the sequence, as well as to the last number plus or minus 1, and to the last number plus or minus 2. More precisely, they were tested faced with 1, 2, 3, 4, 5, 6 elements or with 6, 5, 4, 3, 2, 1 elements.

2.3 Cues Presented to the Ants, Experimental Protocol

The cues presented to the ants were blue (for the increasing sequence) or yellow (for the decreasing sequence) circles (diameter = 0.2 cm) drawn in a white square (2 cm x 2 cm) using Microsoft Word® software. We used blue elements for the increasing sequence and yellow ones for the decreasing sequence, knowing that *M. sabuleti* workers very well distinguish these two colors (Cammaerts, 2007). The squares with 1, 2, 3, 4, 5 or 6 blue circles as well as those with 6, 5, 4, 3, 2, or 1 yellow circles were printed, cut, and each one was tied with extra transparent sticky paper on the front face of a stand. This was done a fortnight before starting the experimental work; the cues had thus no particular odor. Each stand was made of Steinbach® (Malmedy, Belgium) strong white paper (250 g/m^2), had a vertical part (2 cm x 2 cm) and was maintained vertically thanks to a horizontal part [2 x (1 cm x 0.5 cm)] duly folded (see photos in Figures 2, 3).

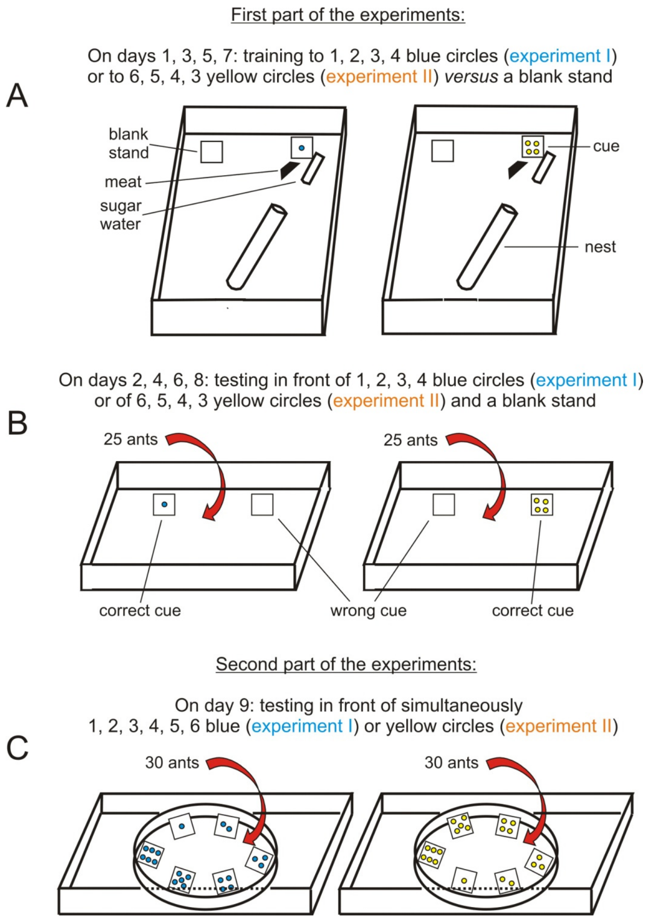

Figure 1. Experimental design

Experimental design used, **A:** to condition the ants to an increasing or a decreasing sequence of numbers, **B:** for checking over this conditioning if ants duly acquired it, **C:** for examining if ants could expect the exact following number of the increasing sequence (i.e. 5) or the decreasing one (i.e. 2). Details are given in the text and photos are shown in Figures 2 and 3.

During the first part of the experiments, on days 1, 3, 5, and 7, the ants were trained in their foraging area (Figure 1A) to successively 1, 2, 3, and 4 blue circles or to successively 6, 5, 4, and 3 yellow circles set near the food *versus* zero circle set far from food. For obtaining the ants' conditioning, the numbers to successively memorize had to be located near the food (the reward), and the zero circle far from food. However, the food did not have to be located in exactly the same place; it could vary by one centimeter during the conditioning period. All along the ants' training, at days 2, 4, 6, and 8, the ants were tested in a tray (21 cm x 15 cm x 7 cm) containing the number set near the food and zero circle (Figure 1B).

During the second part of the experiments, on day 9, the ants were tested in an enclosure set in a tray (Figure 1C), made of strong white paper (Steinbach®), and measuring 3 cm height, 15 cm in diameter, the seam allowance on the perimeter equaling 2.2 cm. In these enclosures, six cues were arranged along the rim, i.e. the four numbers used during training, the last number of the sequence plus or minus 1, and the last number of the sequence plus or minus 2, all of them in their sequential order. The ants were thus tested in front of 1, 2, 3, 4, 5, and 6 blue circles or in front of 6, 5, 4, 3, 2, and 1 yellow circles. It was essential to locate the numbers in the order they were presented over time during the training so that the ants could perceive the sequence to which they had been trained and chose the correct next number corresponding to the sequence. The cues used for testing the ants were not those used for training, but novel, identical ones.

It should be noted that the ants' counting ability is not significantly affected by the size, the color or the location of the elements to be counted (Cammaerts & Cammaerts, 2020c). The here used location of the different presented circles on the stands should not have affected the ants' counting, memorizing, and choosing, and therefore the obtained results.

2.4 Assessments of the Ants' Responses and Statistics

2.4.1 First Part of the Experiments

During their successive training to increasing or decreasing numbers of circles, the ants of the two colonies present in the vicinity of the provided cues were counted six times each two days for each presented number of circles (total number of counts for each presented number of circles = 6 times x 2 days x 2 colonies = 24). This counting was made to check if ants could sufficiently and equally perceive the different presented cues. The mean of these counts was established and is given in Tables 1 and 2.These mean numbers of ants counted near the different cues were compared to those expected if the ants equally foraged all around the four successive presented cues using the χ^2 non-parametric goodness-of-fit test.

To check their conditioning acquisition, for each presented cue, the ants were tested in a separate tray in which the 'correct' cue was randomly set on the left or on the right, and the 'wrong' cue (i.e. the zero circle) on the other side. To make a test on a colony, 25 ants were transferred in the middle of their tray devoted to testing. The ants perceived the cues and freely moved towards them, staying 2 to 20 seconds near those of their choice. Half a minute after the ants were in the separate tray, we began to count punctually, every 30 seconds over 10 experimental minutes (thus 20 times), those ants sighted at a distance less than 2 cm of each kind of cue. The 40 counts (20 x 2 colonies) allowed calculating the proportion of ants choosing the correct cue i.e. that set near the food during training. After each test, the ants were returned into their foraging area near their nest entrance. The numbers obtained for each cue for the two colonies were added in their chronological order and the 20 corresponding sums ordered and added by four, providing so 5 chronological groups of numbers. The five successive groups of numbers obtained for the 'correct cue' were compared to the five successive groups of numbers obtained for the 'wrong' cue (the one set far from food during training) using the non-parametric matched-pairs signed-ranks test of Wilcoxon (Tables 1 and 2, upper part), which critical one-tailed p value was read in the table for small sample sizes given in Siegel and Castellan (1988). The non-parametric χ^2 goodness-of-fit test was also used for comparing the total number of ants near the 'correct' and the 'wrong' cues with the values expected if the ants equally visited the two cues. Details on this second statistical analysis are given in Tables 1 and 2. The statistical results of successively the Wilcoxon and the χ^2 goodness-of-fit tests are also given in the Results section. Using the Benjamini-Hochberg adjusting procedure for multiple comparisons with a false discovery rate of 0.05 (McDonald, 2014) did not change the obtained p values.

2.4.2 Second Part of the Experiments

The ants were here confronted at the same time to the numbers of elements to which they have been trained, to the last presented numbers plus or minus 1, and to the last number plus or minus 2, all these numbers being circularly arranged. For making a test on a colony, 30 ants were transported in the center of the enclosure devoted to testing. The ants sighted the six cues located in the enclosure and freely moved towards those of their choice. For each two colonies, half a minute after the ants were in the enclosure, those approaching each of the six cues were counted 20 times over 10 experimental minutes, and the numbers obtained for each cue for the two colonies were added (see Tables 1 and 2, lower part). These six numbers as well as the numbers corresponding to the two last cues were compared to those expected if ants randomly visited the six cues using the non-parametric χ^2 goodness-of-fit test.

3. Results

3.1 Experiment I: Learning an increasing Sequence, Expecting Its Following Number

Numerical results are given in Table 1 and a few photos are shown in Figure 2.

Table 1. Results of the experiment I made to know if ants could anticipatively add the increment of an arithmetic sequence to its last learned element

First part of the experiment: Conditioning to an increasing sequence of blue circles.

Training: mean n° of ants near the cues	Training: number of presented circles	Days of the tests	Tests: n° of ants of colonies A; B sighted near each cue	Tests: % of correct responses	Tests: n° of ants of the two colonies sighted near each cue and chronologically ordered by four	Wilcoxon test N	T	p
3.5	1 *vs* 0, at days 1, 2	2	43 *vs* 8 ; 34 *vs* 10	81.0%	12,12,12,17,24 *vs* 0,3,5,5,5	5	15	0.031
4.3	2 *vs* 0, at days 3, 4	4	44 *vs* 12 ; 39 *vs* 16	74.8%	22,17,14,15,15 *vs* 4,7,5,7,5	5	15	0.031
5.6	3 *vs* 0, at days 5, 6	6	43 *vs* 17 ; 34 *vs* 2	80.2%	12,18,19,14,14 *vs* 2,3,4,6,4	5	15	0.031
5.1	4 *vs* 0, at days 7, 8	8	53 *vs* 7 ; 36 *vs* 9	84.8%	13,23,19,21,13 *vs* 2,2,4,4,4	5	15	0.031

Presented numbers of blue circles	N° of ants sighted near each cue, colonies A + B	χ^2 goodness-of-fit test χ^2	df	p
1 *vs* 0	77 *vs* 18	36.64	1	< 0.001
2 *vs* 0	83 *vs* 28*	27.25	1	< 0.001
3 *vs* 0	77 *vs* 19	35.04	1	< 0.001
4 *vs* 0	89 *vs* 16	50.76	1	< 0.001

*: for colony B, the numbers were 39 *vs* 16, what gives the partial result: $\chi^2 = 9.62$, df = 1, $0.005 < p < 0.001$.

Second part of the experiment: On day 9, response to 1 to 6 blue circles.

N° of blue circles:	1	2	3	4	5	6	
N° of Ants of colony A sighted in front:	1	0	2	4	55	13	
N° of Ants of colony B sighted in front:	0	6	2	1	46	2	Comparison with equal responses:
Total:	1	6	4	5	101	15	$\chi^2 = 345.5$, df = 5, $p < 0.001$

In the first part of the experiment, the ants were trained to successively 1, 2, 3 and 4 blue circles presented *versus* 0 circle, and their acquisition of conditioning was checked in the course of this training. Then, in the second part, they were confronted to 1 to 6 blue circles simultaneously presented, and they responded the more to 5 circles, not to 6 circles, having thus anticipatively correctly incremented 4 by 1, i.e. 5.

Table 2. Results of the experiment II made to know if ants could anticipatively subtract the decrement of an arithmetic sequence to its last learned element

First part of the experiment: Conditioning to a decreasing sequence of yellow circles.

Training: mean n° of ants near the cues	Training: number of presented circles	Days of the tests	Tests: n° of ants of colonies A; B sighted near each cue	Tests: % of correct responses	Tests: n° of ants of the two colonies sighted near each cue and chronologically ordered by four	Wilcoxon test N	T	p
4.4	6 *vs* 0, at days 1, 2	2	46 *vs* 6 ; 41 *vs* 2	91.6%	15,14,24,21,22 *vs* 4,3,7,0,6	5	15	0.031
6.3	5 *vs* 0, at days 3, 4	4	29 *vs* 7 ; 43 *vs* 10	80.9%	11,12,19,17,13 *vs* 1,5,7,2,2	5	15	0.031
4.9	4 *vs* 0, at days 5, 6	6	44 *vs* 11 ; 72 *vs* 7	86.6%	24,25,21,23,23 *vs* 6,5,2,4,1	5	15	0.031
5.0	3 *vs* 0, at days 7, 8	8	47 *vs* 11 ; 57 *vs* 3	88.1%	17,20,20,24,23 *vs* 3,2,2,4,3	5	15	0.031

Presented numbers of yellow circles	N° of ants sighted near each cue, colonies A + B	χ^2 goodness-of-fit test χ^2	df	p
6 *vs* 0	87 *vs* 8	65.69	1	< 0.001
5 *vs* 0	72 *vs* 17	33.99	1	< 0.001
4 *vs* 0	116 *vs* 18	71.67	1	< 0.001
3 *vs* 0	104 *vs* 14	68.64	1	< 0.001

Second part of the experiment: On day 9, response to 6 to 1 yellow circles.

N° of yellow circles:	6	5	4	3	2	1	
N° of Ants of colony A sighted in front:	3	3	0	2	66	8	
N° of Ants of colony B sighted in front:	3	1	1	2	73	9	Comparison with equal responses:
Total:	6	4	1	4	139	17	$\chi^2 = 519.5$, df = 5, $p < 0.001$

In the first part of the experiment, the ants were trained to successively 6, 5, 4 and 3 yellow circles presented near the food *versus* 0 circle set far from food, and their acquisition of conditioning was checked in the course of this training. Then, in the second part, the ants were confronted to 6 to 1 yellow circles simultaneously presented, and they responded the more to 2 circles, not to 1 circle, having thus anticipatively correctly decremented 3 by 1, i.e. 2.

During their training to successively 1, 2, 3 and 4 blue circles, the ants of colonies A and B were sufficiently numerous around the cues for seeing and memorizing them. They were also equally present all around the four presented cues: $\chi^2 = 0.58$, df = 3, $p = 0.90$. When tested successively to these numbers of blue circles *versus* 0 circle, the ants duly responded essentially to every number of blue circles (each time: $p = 0.031$ as well as $p < 0.001$), with high conditioning scores (respectively 81.0%, 74.8%, 80.2% and 84.8%).

Simultaneously confronted with 1 to 6 blue circles, the ants of the two colonies went preferentially towards the 5 circles, less towards 6 circles, and very seldom towards 1 to 4 circles. These responses statistically differed from those expected if the ants randomly went to each presented number of circles ($p < 0.001$). Also, the number of ants responding to 5 circles statistically differed from that of ants responding to 6 circles ($\chi^2 = 50.74$, df = 1, $p < 0.001$). Thus, the ants correctly anticipated the next number in the sequence, i.e., the last learned number plus the sequence increment, i.e. 4 + 1 = 5 elements.

3.2 Experiment II: Learning a Decreasing Sequence, Expecting Its Following Number

Numerical results are given in Table 2 and a few photos are shown Figure 3.

During their training to successively 6, 5, 4 and 3 yellow circles, the ants of colonies A and B were sufficiently numerous around the cues for seeing and memorizing them. There was also no significant difference between the numbers of ants present in the vicinity of each of the four presented cues: $\chi^2 = 0.38$, df = 3, $0.90 < p < 0.95$. When faced with these numbers of circles and 0 circles, the ants essentially responded with high scores to the numbers of circles (91.6%, 80.9%, 86.6%, and 88.1% for respectively 6, 5, 4, and 3 circles). These scores were statistically significant ($p = 0.031$ as well as $p < 0.001$).

Simultaneously faced with 6 to 1 yellow circles, the ants of the two colonies reacted very similarly. They went preferentially towards the 2 circles, clearly less towards 1 circle, and nearly not towards 3 to 6 circles. Their responses statistically differed from those expected if they randomly visited each presented number ($p < 0.001$). The number of ants responding to 2 circles was statistically much larger than that of ants responding to 1 circle ($\chi^2 = 95.41$, df = 1, $p < 0.001$). Thus, the ants correctly anticipated the next number in the sequence, i.e., the last learned number minus the decrement of the sequence, i.e. 3 - 1 = 2 elements.

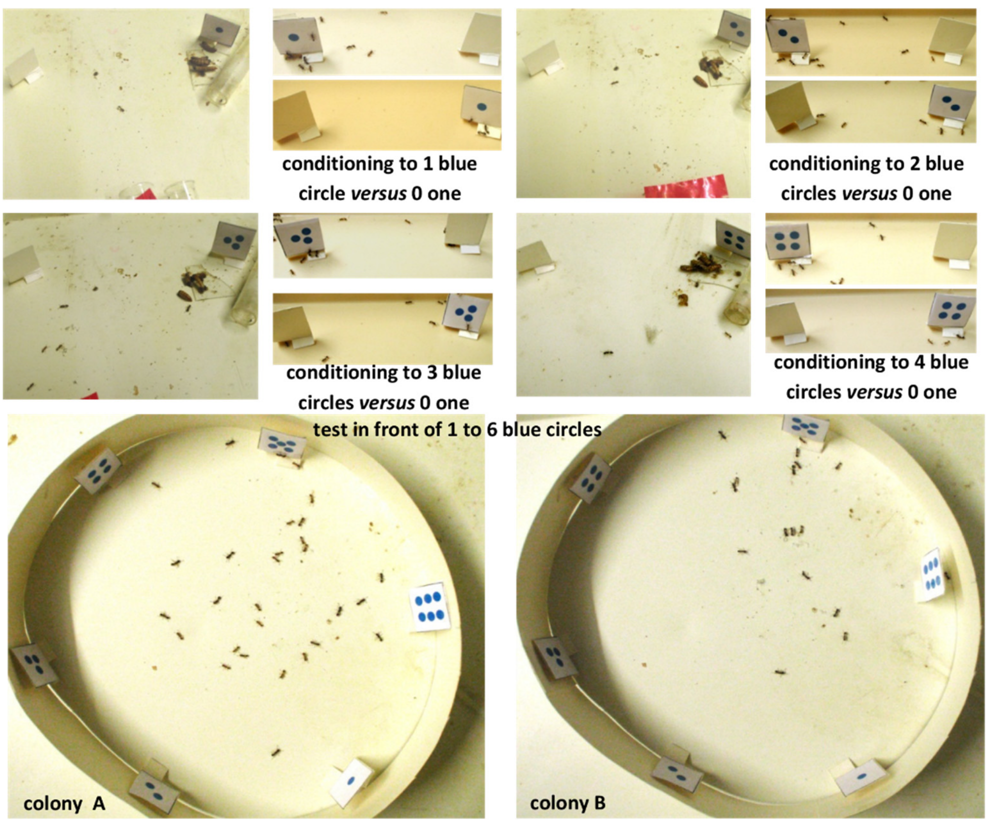

Figure 2. Some views of experiment I

Upper part: the ants were firstly successively trained to 1, 2, 3, and 4 blue circles, and their conditioning acquisition was checked for each presented number of circles. Lower part: they were then confronted to 1 to 6 blue circles simultaneously presented, and they reacted essentially to 5 blue circles, having thus anticipated that the next number would be 4 plus the increment 1. Differences in color are due to the photographic process.

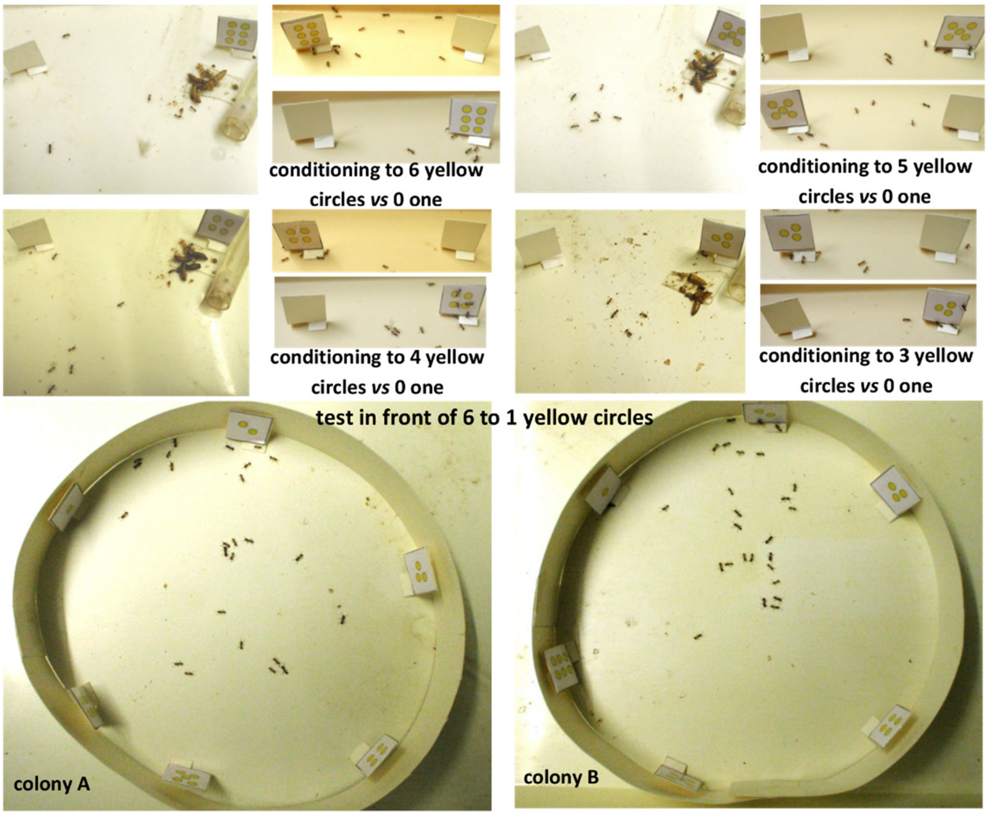

Figure 3. Some views of experiment II

Upper part: the ants were firstly successively trained to 6, 5, 4, and 3 yellow circles, and their conditioning acquisition was checked for each presented number of circles. Lower part: they were then confronted to 6 to 1 yellow circles simultaneously presented, and they reacted essentially to 2 yellow circles, having thus anticipated that the next number would be 3 minus the decrement 1. Differences in color are due to the photographic process.

4. Discussion

It had previously been shown (Cammaerts & Cammaerts, 2021) that the workers of the ant *M. sabuleti* trained to an increasing or a decreasing numerical sequence could expect that the following quantity would be larger or smaller. The present work needed to train the ants in the same way, and the obtained conditioning scores (first part of the experiments) were of a similar level, ca 80%. Such as in the previous work, the learning of the second cue (2 elements in the increasing sequence and 5 elements in the decreasing sequence) led to a lower conditioning score than that of the first presented cue (respectively 1 and 6 elements). This may be due to the ants' remembering their previous conditioning to 1 or 6 circles, while the higher scores relative to 3 (or 4) and 4 (or 3) circles could result from the ants' progressive learning of an increasing or decreasing sequence of number of circles. The highest score was observed for 6 circles and can be explained by the very obvious difference between 6 and 0 circles, i.e. a distance effect.

In the previous work (Cammaerts & Cammaerts, 2021) it was not defined if the ants could expect that the following quantity would be the last one incremented by the constant difference between the terms of the sequence. Here, we show that the ants perceived the increment or decrement of the sequence and used it "on" the last learned term to find the next one. In other words, they could expect the following correct quantity in an arithmetic sequence learned through conditioning. They thus once more presented expectative behavior, but at a precise level. Nevertheless, it remains to be demonstrated that ants do not anticipate the number of circles in the arithmetic sequence if tested without seeing the series of numbers arranged in their sequential order. We tested them in the sequential order because we know that the ants can add and subtract only if seeing simultaneously the terms of the operations (Cammaerts & Cammaerts, 2019a, b, c; 2020a).

It remains also to demonstrate that the ants do not anticipate the following number when characteristics of the cues are not constant all over the arithmetic sequence such as the sum of the area of the circles or the perimeters of the entire group of circles presented on a stand. However, we should note that it has been proved that the ants' counting of elements is not overly impacted by the size, the color and the relative position of the elements to count (Cammaerts & Cammaerts, 2020d).

Even if the behavioral competence demonstrated here seems *a priori* to be the result of a high level of cognitive skills, anticipating a following event in a sequence could be based on the ability to acquire conditioning and to have episodic-like memory, i.e. to remember past experienced events together with their sequential order. Indeed, *M. sabuleti* ants can easily acquire conditioning (e.g. Cammaerts, Rachidi, & Cammaerts, 2011), can memorize encountered cues and how to respond to them (e.g. Cammaerts & Rachidi, 2009), and have the notion of the running time (Cammaerts, 2010). The individual can then react with anticipation, without necessary having an immediate need. Previous experiments showed that the workers of the ant *M. sabuleti* can act with anticipation, for instance, expecting the time as well as the location of the following food delivery in the laboratory (Cammaerts & Cammaerts, 2016a, b). In the experiments on sequence learning (Cammaerts & Cammaerts, 2021 and in the present work), food was always available at the food sites, including the day of their final testing (was present all over the entire experimental work), and the ants reacted thus anticipatively without an immediate need for food. Young ants (less than two years old) may not yet detain expectative behavior as do foragers more than two years old, since they are not able to expect the location of a next food delivery (Cammaerts & Cammaerts, 2015).

As developed in Cammaerts and Cammaerts (2021), it is likely that the foragers' behavior relied on an associative learning process. Indeed, theoretical modeling (Enquist, Lind, & Ghirlanda, 2016) and simulations (Lind, 2018) show that expectative behavior can simply result from associative learning by chaining through conditioned reinforcement. In other words, successive behavioral responses acquired through conditioning over time can lead to take decisions for a future situation, this without being immediately rewarded, a process that can rely on episodic-like memory (Enquist, Lind, & Ghirlanda, 2016). The ants might thus acquire over time the mental representation of an arithmetic sequence, and might at the same time update the information. The benefit of operant conditioning is that it enables to get behavior optimally adapted to environmental changes.

Adult humans are more expert in presenting anticipatory behavior. They can, through language, increase this skill by means of collective mental simulations and debrief of lived and memorized experiences (Snelgrove & Fernando, 2018).

5. Conclusion

After having been trained to an increasing or decreasing arithmetic sequence, the workers of the ant *M. sabuleti* could expect that the following quantity in the sequence will be the last one plus the increment or the decrement of the sequence. They could thus present exact anticipatory behavior as for a quantity represented by numerosity. In doing so, at the same time, they foresaw a future need regardless of current ones. Such a behavior may rely on the ants' ability to acquire operant conditioning, and to have episodic-like memory. It may result from an associative learning process which allows acquiring over time a mental updated representation of the visually experienced sequence.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Ethics statements: we affirm having maintained the ants in the best environmental conditions possible (temperature, humidity, food, lighting, electromagnetic field).

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