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COMMUNICATION

Influence of a mobile robot on the spatial behaviour of quail chicks

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Abstract
Quail chicks encountered an autonomous mobile robot during their early development. The robot incorporated a heat source that stimulated following of chicks. The spatial behaviour of grown-up chicks was tested in an exploration test and a detour test. Chicks that grew with the mobile robot exhibited better spatial abilities than chicks grown with a static heat source. We discuss these results in the perspective of animal–robot interaction and of the role of early spatial experience on the behavioural development.

1. Introduction
Animal–robot interaction is a field of growing interest, both as a new experimental tool for ethological studies (e.g. Michelsen et al 1992, Göth and Evans 2004, Kubinyi et al 2004, Faria et al 2010) and as a way to control animal groups (e.g. Vaughan et al 2000, Halloy et al 2007). The fundamental and applied interests of the Ethorobotics method have been reviewed by De Schutter et al (2001), Bekoff (2004) and Detrain and Deneubourg (2009). Because a robot can be mobile, have time perception and sense events in its environment, it can exhibit animal-like, dynamic behaviour, while remaining fully controllable by the experimenter who writes its control program. Hence, robots placed within a group of animals can be innovative tools to remotely control the environment of animals, and to assess how animals adapt their behaviour to changing conditions.

An original perspective is to make robots intervene during early animal development, to study influences of the environment of animals on their behavioural ontogeny. Here we present a first study where an autonomous mobile robot was used to control the early spatial experience of quail chicks.

Precocial chicks are known to receive epigenetic influences from the mothering hen during the first days after hatching. The presence and behaviour of the mothering hen can have deep, long-lasting influences on several aspects of the behavioural development of chicks. For instance, Richard-Yris et al (2005) demonstrated that quail chicks raised by an emotional hen tend to develop a high emotional reactivity, even in the absence of a genetic link between hen and chicks. Non-genetic transmissions of social motivation and rhythmicity have also been reported (Formanek et al 2008, 2009).

An influence of the hen on the spatial behaviour of chicks has also been suggested, because brooded chicks tend to follow their mother and hence explore the environment more thoroughly (Wauters et al 2002a, 2002b). However, the importance of this early following on the development of spatial skills of chicks is not easy to test properly, as one cannot control a mothering hen’s movements without modifying other factors (e.g. access of chicks to the mother, mother’s stress level, mother’s vocal behaviour). In order to correctly address this issue, we made chicks follow a robot, and tested if this following had an influence on their later spatial abilities. The control situation was easily obtained with the same robot with its locomotor feature disabled. As we wanted to focus on the effect of movement alone, the robot was only provided with the minimal relevant features (heat source and movement). This allowed ruling out ‘higher-level’ maternal influences through vocalizations or active stimulation of exploration.

2. Material and methods
2.1. Chicks
We used 24 Japanese quail chicks (Coturnix coturnix japonica) from a commercial strain (Cailles de Chanteloup, Corps-Nuds,
France). Eggs were hatched in a collective incubator. Twelve hours later (day 0), chicks were distributed in six flocks of four chicks that remained unchanged throughout the experiment. Each flock was reared in a 0.7 m × 0.4 m × 0.3 m cage (L × W × H), with ad libitum food, water and an infrared 60 W heating lamp. The six cages were placed under artificial lighting (LD 12:12) at 22 °C ambient temperature. The experiment started 24 h later (day 1). Days 1–10 were devoted to robot–chick meeting. Three flocks of four chicks encountered the mobile heating robot (MHR group). The three other flocks met the same heating robot, but with the locomotion feature disabled (HR group). There was no meeting on day 5.

2.2. Robot

The wheeled robot (figure 1(a)) had the shape of a 20 cm sided cube with a corridor in-between the wheels, the height of which could be set from 4 to 7 cm to adapt to chick growth. The metallic top of the corridor was heated through electric resistors. A surface temperature of 40 °C was set, so that chicks had to establish direct contact to significantly gain heat, as they do with a real mother. Two infrared rangefinders on the front of the robot measured the distance to walls. They were placed at 16 cm height so that chicks did not interfere in the robot’s movements. The robot was controlled autonomously through an on-board microcontroller (www.arduino.cc) and powered by an NiMh battery. The robot followed a wall avoidance algorithm based on Braitenberg (1986). It advanced in short moves at a maximum speed of 0.075 m s⁻¹, according to the following standard locomotor activity cycle:

- Remain static for 10 min.
- Then make a 6 s move (≈ 0.4 m) every minute for 10 min.
- Then start a new cycle.

To prevent habituation of chicks to this cycle, all durations were randomized within ±33% of the default values. The 20 min periodicity of the activity cycle was inspired from Lumineau et al (2000). This standard cycle was modified on days 1–3 (see section 2.3).

2.3. Meeting schedule

Each flock of four chicks met the robot for 1 h/day. With MHR flocks, the robot achieved approximately three activity cycles (i.e. 30 moves). The meeting sessions took place in a 1.8 × 1.2 m arena (figure 1(b)) at 20 °C. Sessions took place between 9:00 AM and 6:30 PM. The daily order of sessions for the six flocks was randomized.

At the beginning of each session, a transport box containing the four chicks was placed opposite to the robot, and automatically opened after 1 min. The chicks were free to explore the arena and eventually to reach the robot. If the chicks did not reach the robot within 5 min, they were manually placed under the robot to prevent hypothermia. Similarly, throughout the meeting sessions, if all four chicks stayed outside the robot for 5 min, without any feeding activity, they were manually placed back under the robot.

On the first days of meeting, the amount of movement of the robot with MHR flocks was progressively adjusted to facilitate following of chicks: the move duration was 0 s on day 1 (static robot), 3 s on day 2, 10 s on day 3 (excessive movement) and 6 s from days 4–10.
At the end of each meeting session, the robot was manually retrieved, and the four chicks were left for 5 more minutes in the arena, before transporting them back to their rearing cage.

An observer hidden behind a two-way mirror recorded variables throughout the sessions:

- The time before a chick spontaneously entered the robot at the beginning of the session (5 min max).
- Throughout the 60 min session, the number of chicks under the robot was sampled at 30 s interval. A chick was considered to be under robot if its body (or at least a part of it) was under the corridor.
- We also counted the distress calls emitted by chicks during 5 min after the retrieval of the robot.

2.4. Individual behavioural tests

Individual behavioural tests were performed after the end of the meeting period, in order to quantify each chick’s spatial and social behaviour:

- Day 13: ‘chick and robot test’. The chick was placed in the arena using the transport box. After opening, for 5 min the chick was free to explore the arena containing the robot (heating and static). We measured the time before the chick came out of the box (‘emergence latency’) and the time before it eventually reached the robot (‘robot rejoining latency’; as the chick could see the robot from the opened transport box, the emergence latency was included in the robot rejoining latency). We also measured the proportion of the arena explored by the chick (using 0.3 × 0.3 m units traced on the floor, figure 1(b)) and the number of emitted distress calls.
- Day 14: ‘alone chick test’. This test was the same as on day 13, except that the robot was not present in the arena.
- Day 15: ‘detour test no 1’. In this test the chick coming out of the transport box faced a grid (figure 1(c)) placed between him and three unfamiliar chicks of the same age. To reach its conspecifics, the chick needed to make a detour around lateral opaque barriers, hence briefly loosing visual contact and increasing its distance to other chicks (Regolin and Rose 1999). We measured the emergence latency and the time needed to perform the detour task (‘detour latency’, including emergence latency), within 5 min max.
- Day 20: ‘detour test no 2’. The same test as on day 15 was replicated.

3. Results

3.1. Meeting period: general observations

From the first day, chicks rested under the heating robot for sustained periods of time, with their heads and backs against the corridor top. Two types of outings were mainly observed: short trips of a single chick around the robot, and longer outings to the feeding troughs, which usually involved the whole flock. After such feeding periods, chicks usually found their way back to the robot, but sometimes the four chicks aggregated against the wall of the arena, presumably in need of heat. If this situation lasted more than 5 min, we placed the chicks back under the robot. These manual contacts were mainly needed in the first few days (figure 2). Most flocks did not need any intervention after day 6.

On the other hand, situations where chick flocks autonomously reached the robot were frequent and observed quite early. As soon as day 1, one flock left the robot for the feeding troughs and went back under it 10 min later. On day 2, two flocks spontaneously reached the robot at the beginning of the session. These behaviours progressively generalized to all flocks on the following days.

MHR chicks started to undergo robot moves on day 2. From the start, they exhibited the ability to follow the robot for a few consecutive moves, but following usually stopped after a few minutes, and the chicks went either to the feeding troughs or against the arena wall, hence exhibiting a ‘part-time’ following behaviour. They possibly went back under the robot after a few minutes, or a manual contact was needed. From day 4, the following behaviour was more pronounced, although remaining a ‘part-time’ following, interrupted with feeding periods. The chicks got in contact again with the robot easily, especially on days 6–8.

When the robot was retrieved for 5 min at the end of meeting sessions, the most frequent observation was that chicks did not emit distress calls, in both HR and MHR flocks (HR: 0–21 calls, median 0; MHR: 0–18 calls, median 0).

3.2. Meeting period: quantification of the spatial interaction of chicks with robot

Figure 3(a) presents the evolution of the initial robot-rejoining latency. The first occurrences of a spontaneous reunion were on day 2. In both HR and MHR flocks, this behaviour progressively generalized, and was systematic on days 8–10.

Figure 3(b) presents the percentage of time in the meeting session spent under the robot. Note that due to the influence of possible manual contacts on the sequence of events during meeting sessions, this variable only partly reflects the spontaneous behaviour of chicks. HR and MHR chicks spent
similar amounts of time under the robot, with a decrease from about 2/3 of time in the first days to 1/3 or less in the last days. For MHR flocks, figure 3(c) shows the effect of robot locomotor activity on the percentage of time under the robot. The moves of the robot did not prevent the frequentedation of the robot by MHR chicks, a first indication that chicks followed the robot.

Using the 30 s interval-sampled data, we estimated the number of spontaneous entries of chicks under the robot during the meeting session, by counting every increment of the number of chicks under robot. This variable covers all entries of chicks after any cause of separation (e.g. outing of chicks into the arena or feeding area, move of the robot), at the exclusion of entries due to manual contacts. Figure 3(d) shows that there were from 10 to 64 entries per meeting session, the highest values being attained on days 4–8. This demonstrates that chicks, both HR and MHR, did not only spend time under the robot, but also frequently reached it spontaneously after a separation. Moreover, in MHR chicks, a large proportion of spontaneous entries (46% overall) occurred during the robot’s activity phase. This implies that chicks regularly went under the robot after it had changed position, i.e. followed the robot.

As a consequence of the robot-following behaviour, MHR chicks progressively went across a large surface of the arena. Figure 4 synthesizes the spatiotemporal distribution of chicks on day 7. While HR chicks tended to mainly occupy the static robot and the feeding troughs, the spatial distribution of MHR chicks through the meeting session was more widely spread.

3.3. Individual behavioural tests

Table 1 presents the results and statistics for the four behavioural tests conducted after the meeting period. Despite strong variation within groups for most variables, there were a few interesting significant behaviour differences between HR and MHR chicks.

During the ‘chick and robot test’ (day 13), MHR chicks adopted a more active behaviour than HR chicks. After coming out of the transport box, MHR chicks moved around the arena much more actively (58% versus 15% of the arena explored, median values), and emitted more distress calls (129.5 versus 55.5). However, MHR chicks were not significantly more prone to rejoin the robot. 6/12 MHR chicks made at least one passage under the robot, versus 4/12 HR chicks (p = 0.68, Fisher test).

On day 14, during the ‘alone chick test’, MHR chicks remained somewhat more active than HR chicks according to median values (38% versus 8% of arena explored, 98.5 versus 45 emitted calls), but this difference was no longer significant. Complementary matched-samples tests showed that this was mainly due to a significant decrease in the activity of MHR chicks from day 13 to day 14 (T = 3.0, Z = 2.82, p = 0.005 for the proportion of arena explored; T = 11.0, Z = 2.20, p = 0.03 for the number of emitted calls; Wilcoxon tests).

During the ‘detour test no 1’ on day 15, MHR chicks solved the detour task more rapidly than HR chicks (158 s versus 300 s, median values). 9/12 MHR chicks solved the detour within 5 min, versus only 3/12 HR chicks (p = 0.04, Fisher test).

When the same test was replicated on day 20 (‘detour test no 2’), the significant difference was lost, due to a significant
performance improvement of HR chicks ($T = 0.00$, $Z = 2.37$, $p = 0.02$ for detour latency, Wilcoxon test). The number of HR chicks making the detour increased to 7/12, close to 8/12 for MHR chicks ($p = 1.0$, Fisher test).

Finally, complementary tests showed that none of the above significant differences between HR and MHR chicks were caused by spurious effects of sex ratio, body weight or number of experienced manual contacts. Within groups, the flock of origin did not influence the results either.

4. Discussion

4.1. Spatial interaction of chicks with robot

Our results show that chicks became motivated to ‘spatially interact’ with the robot: all flocks, in both groups, progressively rejoined the robot at the beginning of daily sessions (figure 3(a)), suggesting an increase of the interest of chicks for the robot, and/or that chicks progressively learned to
rejoin it. Moreover, throughout meeting sessions, spontaneous entries under robot were frequent (figure 3(d)).

On the other hand, the decrease of the amount of time spent under the robot through time (figure 3(b)) suggests that chicks were able to use the robot as a heat source from the first day, but that this source progressively became less important as their thermic needs decreased. The overall proportion of time spent under the robot was very similar in the HR and MHR groups. Both groups experienced a similar amount of contact with the robot, no matter if it moved or not.

The fact that ‘spatial interaction’ also occurred during robot locomotor activity in MHR chicks (MHR+ in figures 3(c) and (d)) is noteworthy. Beyond indicating that chicks followed the robot, this implies that MHR chicks coped with a much more demanding spatial experience, as their resting/heating area repeatedly changed its place and orientation, as well as the relative position of the feeding area (about 240 moves of the robot for each MHR flock). The moving robot deeply modified the spatial experiences of MHR chicks (figure 4).

Our robot was designed so that physical contact in the corridor was used to transfer heat to chicks. Beyond the motivating nature of pure heat gain, it is probable that physical contact enhanced the interaction of chicks with the robot, by (i) facilitating the precise localization of the heat source and (ii) amplifying the positive reinforcement effect with a more concentrated heat transfer. This is supported by the reported importance of physical contact in the onset of the mother–young relationship in precocial birds (Richard-Yris and Leboucher 1987a).

4.2. Attachment of chicks to the robot

The reported sensible period for visually imprinting a quail chick on a conspicuous object is between 12 and 24 h of age (Ozmon 1970, Ten Cate 1989). In our experiment, flocks of chicks met the robot only 36 h after hatching; hence, conditions for an unconditional attachment were probably not met. However, as late filial attachment of chicks has been reported (Vidal 1976, Richard-Yris and Leboucher 1987b), the question of attachment deserves discussion, especially if robot movement can have a role in this issue (Ten Cate 1986, 1989).

The observed following behaviour is one of the classic measures of imprinting success (e.g. Ozmon 1970), but another more specific criterion is the emission of calls at the removal of the object (Ten Cate 1989), something that we did not observe at the end of our meeting sessions. Moreover, when a chick was with the robot, but without its siblings (day 13 test), even though some chicks rejoined the robot, lots of distress calls were emitted, showing that the robot did not satisfy the chick’s social need. In this situation, MHR chicks even emitted more calls than HR chicks; hence, movements of the robot visibly did not improve its social or parental significance.

We conclude that in the conditions of our experiment, a true filial or social attachment of chicks to the robot did not happen, even with the moving robot. Nevertheless, because chicks followed the robot (most probably motivated and reinforced by the heat source), the moving robot succeeded in modifying the spatial experience of chicks, which was the main goal of our experiment.

4.3. Effect on chicks’ spatial behaviour development

The ‘enriched spatial experience’ of each MHR chick had an influence on its individual behaviour, as measured after the meeting period and in the absence of robot movement.

When placed in the arena with the static robot and without siblings (day 13), MHR chicks adopted a much more active ‘social search’ behaviour, exploring a larger part of the arena, while emitting more calls. Hence, MHR chicks visibly had a better ability to carry out an active spatial-search strategy and/or a higher sensibility to social isolation.

An alternative hypothesis could be that MHR chicks were only trained by the mobile robot for higher locomotor activity,

| Table 1. Results of individual behaviour tests performed after the meeting period. |
|---------------------------------|-----------------|-----------------|-----------------|
|                                | Median value (full range) | Mann–Whitney test |
|                                | HR (n = 12)         | MHR (n = 12)    | U    | Z   | p    |
| Day 13: chick and robot test   |                                |                |
| Emergence latency (s)          | 46 (4–300)          | 27 (4–136)      | 51.5 | 1.15| 0.25 |
| Robot rejoining latency (s)    | 300 (127–300)       | 294.5 (90–300)  | 61.0 | 0.61| 0.5  |
| Proportion of arena explored   | 15% (0–46%)         | 58% (33–88%)    | 6.0  | 3.78| 0.0001 |
| Emitted calls                  | 55.5 (0–142)        | 129.5 (16–237)  | 18.0 | 3.09| 0.002 |
| Day 14: alone chick test       |                                |                |
| Emergence latency (s)          | 82 (2–300)          | 15 (2–300)      | 52.5 | 1.09| 0.27 |
| Proportion of arena explored   | 8% (0%–67%)         | 38% (0%–92%)    | 47.0 | 1.41| 0.15 |
| Emitted calls                  | 45 (0–200)          | 98.5 (2–247)    | 51.0 | 1.18| 0.24 |
| Day 15: detour test no 1       |                                |                |
| Emergence latency (s)          | 43 (2–300)          | 7 (2–300)       | 52.5 | 1.1 | 0.27 |
| Detour latency (s)             | 300 (131–300)       | 158 (41–300)    | 30.5 | 2.37| 0.014 |
| Day 20: detour test no 2       |                                |                |
| Emergence latency (s)          | 9 (3–82)            | 7.5 (3–300)     | 69.0 | 0.14| 0.88 |
| Detour latency (s)             | 207.5 (27–300)      | 152 (15–300)    | 59.0 | 0.72| 0.48 |

a Difference with the same group in a preceding test at p < 0.01 (Wilcoxon matched sample test).

b Idem at p < 0.05.
without true spatial learning. However, MHR chicks only travelled a few meters more daily by following the robot, which represents a very small addition to the daily locomotor activity that all chicks performed in the meeting arena as well as in the rearing cages. Interestingly, HR chicks did not spend more time resting under the robot, nor performed fewer entries under it (figures 3(b) and (d)). Both groups performed a similar amount of locomotor activity, which suggests that a ‘purely locomotor effect’ of the mobile robot on MHR chicks is improbable. More likely, the repeated changes in the distribution/orientation of items in the environment of MHR chicks, caused by the robot movements, improved the spatial learning of chicks, and explain the significant differences of exploration skills that we measured during the tests.

When the test was replicated, without the robot (day 14), the active search by MHR chicks was significantly weakened (lower exploration and calling rate). This could be the result of habituation to social isolation. It is also possible that the presence of the robot acted as a stimulator of social search on day 13. If so, the robot could in fact have had an indirect social significance, i.e. chicks associated it with the presence of other chicks.

The fact that MHR chicks solved the detour task more rapidly (day 15) is another, more direct evidence of better spatial abilities, or possibly higher social motivation (the goal of the detour being a group of conspecifics).

The replication of the detour task (day 20) was interesting. The fact that HR chicks significantly improved their detour performance indicates that they did not lack social motivation. Hence, their low performance at the initial test (day 15) was probably really caused by delayed spatial abilities, relative to MHR chicks. Still, the congruence of the performance of both groups on day 20 also shows that this difference in spatial abilities was probably transitory.

In summary, the testing period revealed that MHR chicks exhibited signs of improved spatial abilities, and possibly stronger social motivation, compared to HR chicks. This modified behaviour was detectable 5 days after separation from the robot, attesting that the effect goes beyond purely reactive processes.

From the applied robotics point of view, our results point out a tentative influence of an autonomous robot on the behavioural development of animals, an exciting perspective that to our knowledge has not been reported before. However related accounts exist: Ishii et al (2006) have successfully used autonomous robots for learning tasks to adult rats. In human medicine, robots are used for healing the behaviour of children with autism (e.g. Dautenhahn and Werry 2004). The influence we measured was obtained with a very simple robot that essentially trades warming contacts against spatial stimulation (guidance of chicks to the feeding troughs, clutch gathering calls, etc). Moreover, as the mobility of the robot was modest compared to a real hen, this effect of mother mobility is probably stronger in natural conditions than what we were able to measure experimentally, and could be critical for the normal development of spatial behaviour.

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