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Lack of mirror use by pigs to locate food

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ABSTRACT

Many mammalian species, as well as birds, are able to use a mirror either in the context of self-recognition, or instrumentally for discovering and manipulating objects that cannot be perceived directly. A noteworthy study by Broom et al. (2009) investigated the ability of pigs (*Sus scrofa*) to use a mirror to locate a hidden food source. The mirror-experienced pigs appeared to be able to bypass a solid barrier that blocked direct view of a food bowl when the food bowl could be seen via a mirror. We tried to replicate these findings using 2 groups of 11 piglets each. The procedure used for testing the first group of 11 pigs followed Broom's description as closely as possible. Only two of the pigs of the first group were able to locate the hidden food bowl during the mirror test. Therefore, measures were taken to increase the number of pigs noticing the mirror in the second group of 11 pigs. Now, although pigs notice the mirror significantly earlier, only 1 of the mirror-experienced pigs and none of the mirror-naive pigs used the detour around the partition wall to reach the hidden food. We take this observation as evidence that the pigs did not understand what the mirror image represents, and did not use the mirror to locate food. This indicates that not all pigs are capable of using mirrors under all circumstances, and thus that mirror use may be at the upper limits of cognitive capacity of these animals at this age.

1. Introduction

Mirror use has been studied in a large range of species, either in the context of self-recognition, or of using a mirror instrumentally for discovering and manipulating objects that cannot be perceived directly. A number of species show signs of recognizing themselves in a mirror, generally using a test in which a mark which can only be viewed using a mirror, for instance on the forehead, is applied to the animal. The animal's response to its own reflection is then gauged, with an attempt to touch the mark on itself (and not in the reflection) taken as evidence for self-recognition. Examination of body parts not usually visible without a mirror, such as the inside of the mouth or ano-genital areas, can also be taken as evidence of self-recognition. Using tests of this genre, evidence of self-recognition has been seen in chimpanzees (*Pan troglodytes*) (Povinelli et al., 1993, 1997), dolphins (*Tursiops truncates*) (Reiss and Marino, 2001), elephants (*Elepahs maximus*) (Plotnik et al., 2006) and magpies (*Pica pica*) (Prior et al., 2008).

Instrumental mirror use is the use of a mirror to solve a problem. In primates, this often involves using a mirror to guide hand movements to a target object, usually food. Instrumental mirror use has been found in primates, such as chimpanzees (*P. troglodytes*) (Menzel et al., 1985),

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different species of macaques (*Macaca tonkeana*, *Macaca fascicularis*) (Anderson, 1986), and marmosets (*Callithrix jacchus*) (Heschl and Burkart, 2006). In non-primates, generally mirror use is tested by showing the animal a target (also usually food) that is not in direct line of sight, but visible in a mirror, and observing whether the animals move toward the mirror or the actual location of the target. Evidence of instrumental mirror use is also found in a broad range of non-primate species, including elephants (*Elepahs maximus*) (Povinelli, 1989); avians such as parrots (*Psittacus erithacus*) (Pepperberg et al., 1995) and crows (*Corvus macrorhynchos*) (Medina et al., 2011) also show evidence of using a mirror to detect and manipulate objects. Dogs (*Canis familiaris*) show very little (if any) evidence of mirror use (Howell and Bennett, 2011). Interestingly, in general primates which do not fall into the category of great apes generally fail self-recognition tests, but are capable of instrumental mirror use (Anderson and Gallup, 2011). Similar patterns are seen in some types of crows (Medina et al., 2011). Thus, the ability of self-recognition in the mirror is not a prerequisite for the ability to use a mirror image for finding and manipulating objects (Heschl and Burkart, 2006; Povinelli, 1989).

Broom and colleagues (Broom et al., 2009) published the results of a noteworthy study about the use of a mirror to locate a food source by pigs (*Sus scrofa*). Mirror experienced pigs of 4–8 weeks of age appeared to be able to bypass a solid barrier that blocked direct view of a bowl that was visible via a mirror and which they had been trained to associate with food. This behaviour was present with short latency times, with 7 out of 8 of the mirror-experienced pigs tested reaching the mirror-visible food in 46 s or less. Pigs that had no previous experience with a mirror, i.e. "mirror naïve", were reported to search behind the mirror rather than using the reflection to locate the food. Furthermore, mirror experienced pigs responded differently to a mirror than hole covered in wire mesh through which the food bowl was visible in the same place that it was apparently located in the mirror reflection. Together, this points toward the ability of pigs to use a mirror instrumentally. This accomplishment requires complex cognitive processing of the visual information as well as good visual abilities.

Pigs are able to learn complex cognitive tasks (Gieling et al., 2011a; for reviews see: Gieling et al., 2011b; Kornum and Knudsen, 2011). Moreover, accounting for the cognitive ability of animals in human managed husbandry systems may be a way to improve animal welfare (Gonyou, 1994; Broom, 2010). It is also known that a 'proven' level of a species' awareness and abilities can influence the human attitude toward the species (Mendl et al., 2001; Broom, 2003). Besides ethical considerations as put forward by Broom (2010), another reason for being aware of a species' capabilities is to be able to meet its behavioural needs. If pigs are demonstrated to have a high level of awareness, it may be important to keep pigs in a more challenging environment. From a neurobehavioural research point of view, measuring pigs' intellectual capabilities provides us with additional information about the translational value of research with pigs as model species for humans; this is important as pigs are increasingly being used as model animals in biomedical research (Gieling et al., 2011a; de Groot et al., 2005). Moreover, this information is useful when deciding which species to use to answer a specific neurobehavioural question.

The study conducted by Broom and colleagues produced potentially important results, which should be tested for robustness in a close replication, using different experimenters and laboratories. Because of the large potential implications of complex intellectual abilities in pigs for both pigs as model animals in neurobehavioural research, and for pig welfare in commercial pig management systems, we attempted a replication of Broom's (2009) mirror experiment.

2. Material and methods

2.1. Ethical note

The study was reviewed and approved by the local ethics committee (DEC, *dier*experimenten*commissie*), and was conducted in accordance with the recommendations of the EU directive 86/609/EEC. All efforts were made to minimize the number of animals used and to avoid suffering.

2.2. Subjects and apparatus

Where details about subjects or apparatus differed from the Broom study (Broom et al., 2009), this will be mentioned explicitly. This also accounts for experimental details that were not explicitly described in Broom et al. (2009).

2.2.1. Animals

11 male and 11 female piglets [Duroc × (Fin × York)] born at the pig-breeding farm of Utrecht University were used in the experiment. The piglets were tested in two successive batches of 11 animals (group 1 and group 2, see Table 1) Piglets were selected after weaning and mixing. At the age of 4–6 weeks they were moved to our experimental facility. The piglets in the Broom study (Broom et al., 2009) were 4–8 weeks old between moving to the facilities and testing.

Each piglet was randomly assigned to one of the two groups. Within the first group, 6 piglets were assigned to the "Mirror exposed" (*ME*) condition; the other 5 animals were assigned to the "Mirror naïve control" (*MNC*) condition. Within the second group, 5 piglets were assigned to the ME condition; the other 6 animals were assigned to the MNC condition (see Table 1).

2.2.2. Housing

The piglets were group-housed in a former horsebox (5.0 m × 4.0 m), adapted for housing piglets, in a large, naturally ventilated and lighted stable. The concrete floor was covered with straw bedding. Minimal and maximal temperatures in the stable were registered daily (range: −6 °C (nighttime) to 12 °C). The enriched pen contained a covered piglet nest (breadth 2.50 m × depth 1.24 m, height at front 0.66 m, height at back 1.23 m). The floor of the nest box was covered with a rubber mat and a thick layer or sawdust and

Table 1
Random assignment of 22 male and female piglets to group 1 or 2, and to the experimental conditions "Mirror naïve control" or "Mirror exposed". Sex was balanced over the four groups. Note that the testing protocols of groups 1 and 2 were slightly different. The 3rd column shows the numbers of animals that were used in the Broom study (Broom et al., 2009).

	Group 1 Duroc × (Fin × York)		Group 2 Duroc × (Fin × York)		Broom study Large White × Landrace	
	Female	Male	Female	Male	Female	Male
Mirror naïve control (MNC)	2	3	3	3	5	6
Mirror exposed (ME)	3	3	3	2	4	4

straw. Transparent plasticized PVC slats, hanging in front of the entrance to the nest box protected the animals from the cold; the temperature inside the piglet nest stayed within their thermo neutral zone.

All pigs were ear-tagged and could easily be identified at a distance by symbols spray-painted on their backs. Standard feed for weaned piglets and water were available ad libitum. Between 7.00–19.00 h, including during testing, a radio was playing in the stable.

2.2.3. The testing arena

Behavioural tests were performed in a modified horse box (the details of the setup correspond as closely as possibly with the Broom study, see Fig. 1) next to the pen that housed the piglets. The floor was covered with a layer of sawdust (straw in the Broom study) and several heat lamps providing sufficient light and warmth were suspended equally above the setup. The behaviour of the pigs in the testing arena was video recorded with two cameras; one was used to register the choice of the animal, and the other registered the behaviour of the pig in front of the mirror. During testing piglets were not distracted by observers.

2.3. Test procedures

2.3.1. Habituation

Details about habituation of the piglets in the Broom study were not given in the paper. Based on personal communication with the authors, habituation of the piglets was matched with the original study as closely as possible. The habituation period consisted of three phases.

First, the pigs were trained to consume M&M chocolates from a red food bowl. Four red food bowls were placed in the pen of the piglets, twice a day on three successive days. They were removed as soon as the piglets had consumed the M&Ms. Next, the piglets were presented a red food bowl in the corridor outside their pen, one pig a time. The food bowl contained one M&M chocolate. When the pig had consumed the M&M, the bowl was displaced and rebaited to stimulate a piglet to quickly approach the red food bowl from a distance. This procedure was repeated 9 times, twice a day for 2 days, with an inter-session interval of at least 1 h.

Second, the piglets as a group were habituated in 10-min sessions to the test arena (no mirror present) twice a day on 2 successive days, and once on the third day in groups of four animals. Finally, the pigs were placed in the test arena alone for 1 min twice a day on two consecutive days.

Because of the behavioural results of group 1 (measures explained in 2.3.4–2.3.6) some slight procedural modification were applied to group 2 to yield possible mirror use. Before the last habituation session of group 2, we slightly modified the test arena and the procedure. A partition wall (P_2 in Fig. 1) was added to direct the pigs attention toward the location of the mirror (M) and thereby increase the chance that it would notice the mirror, and to equalize the width between the end of partition P and the partition containing the mirror and the width between the end of the partition wall placed rectangular on the mirror and the wall of the arena (line 1 in Fig. 1). In addition, a red food bowl was placed in front of the mirror position (C in Fig. 1) during the last habituation session to stimulate approach to the location where the mirror would be presented during the mirror test.

Third, the piglets of the ME condition were exposed to the mirror in the testing arena before testing took place. One day after training to find food in the food bowl and staying in the test arena alone, the pigs of the ME condition were allowed to stay in the test arena in pairs (and one triplet) for 5 h, as in the study of Broom et al., 2009. For the pigs from the first group (see Table 1, and "Animals"), the guillotine door to the waiting area (W) was closed during this 5 h period (see Fig. 1), whereas the door stayed open for the pigs of the second group. This was done to habituate animals to the waiting area because, during the actual mirror test, it was observed that the animals of group 1 spent time exploring the relatively unfamiliar waiting area rather than directly entering the test arena after the door was opened. Animals that did not freely enter the test arena were gently pushed into the test arena and the guillotine door was closed behind them. From the study by Broom et al. (2009) it is unknown if the piglets had access to this waiting area during the 5 h mirror period.

2.3.2. Testing

One hour after the end of the 5-h session, three different tests were performed with the ME and the MNC pigs as was done in the Broom study. The actual mirror test was followed by two control trials (a 'wire mesh test' and a 'double food bowl test').

2.3.2.1. Mirror test. During the mirror test, the red food bowl was placed in position A (see Fig. 1). A piglet was brought into the waiting area of the test arena and stayed there for 1 min. The pig could see the mirror through wire mesh in the guillotine door that gave access to the testing arena. From the waiting area, the food bowl could be seen through the mirror. Then, the guillotine door was opened,

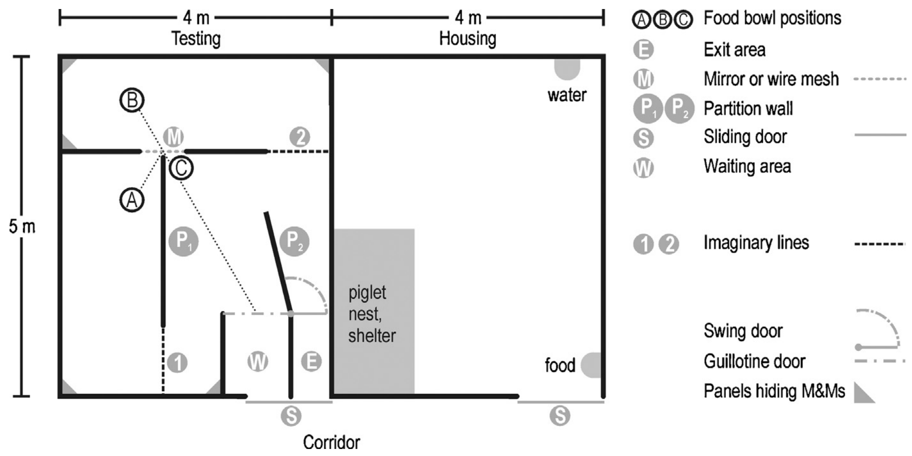

Fig. 1. Floor plan of the testing arena and the adjacent housing of the piglets. The testing arena could be reached via a corridor. The guillotine door of the waiting area contained a window across nearly the entire breadth, which allowed viewing the mirror. The mirror measured 60 cm × 70 cm and could be replaced by wire mesh. All walls subdividing the testing arena were approximately 140 cm high. Inaccessible M&M's used to control for olfactory cues were hidden behind perforated panels. Partition wall P2 and food bowl C were only introduced with testing group 2 to stimulate animals to focus on the mirror area when leaving the waiting area and entering the testing arena.

and the pig had free access to the arena. The trial started as soon as the pig had moved into the test arena with its forelegs. A pig did not gain access to the food bowl when crossing line 2 (see "L_2" in Fig. 1), whereas crossing line 1 (see "L_1" in Fig. 1) was the correct route leading to the food. Once having entered the test arena, the pig was allowed 1 min to explore the arena. When crossing one of the two lines, the time was stopped and the test was terminated. If the pig crossed line 1, it was allowed to go to the food bowl and consume the M&M chocolates. The pig was then returned to its pen.

2.3.3. Control tests

In addition and as replication of the study by Broom et al. (2009), two control trials were run, starting 1 h after the mirror test. In the first control trial, the mirror was replaced by wire mesh, and the food bowl was placed in position B. This test was performed to check whether the choice of the pig was based on place preference. Place preference would be shown if the pigs would have crossed line 1 again (the correct choice in the mirror test) in this test with no mirror present and a food bowl presented behind the wire mesh in place of the mirror. If this were the case, the area behind the partition would be preferred above the area behind the mirror/wire mesh. This preference would interfere with the performance in the actual test.

In the second control trial, 1 h after the first control trial, the mirror was placed back, and two food bowls were used; the bowl in position A was empty, whereas the food bowl in position B was baited with M&Ms. This test was performed to assess whether the choice of the pig was guided by visual or olfactory cues.

2.3.4. Behaviours registered

Noticing (first view) and mirror directed behaviour was registered during the first 30 min of the 5-h habituation period. Only 'noticing the mirror' and 'line crossing' was recorded during the mirror test and the two control trials following the mirror test.

'Noticing the mirror' was scored whenever two of the following three criteria were fulfilled: (1) the pig approaches the mirror, head raised and directed toward the mirror; (2) the pig is within a 50 cm radius of the mirror; and (3) the pig shows mirror-directed behaviour, such as sniffing at the mirror, see-sawing (horizontally and vertically) across the mirror with the snout, and attempts to insert the snout between the mirror (M) and the partition wall (P_1). The total time looking at the mirror, and the time from the start of the 5-h observation period to the last time the pig looked at the mirror (i.e. the time point at which a pig stopped showing this behaviour) were taken as index for duration looking at the mirror, and the time point where interest in the mirror ceased.

2.3.5. Group 1: close replication of procedures from Broom (2009)

Procedures were replicated closely from Broom and colleagues (2009) when possible and known The main differences (for practical reasons) were the breed of the animals; [Duroc × (Fin × York)] in the present study versus [Large White × Landrace] in Broom et al. (2009), and the way of masking the smell of the rewards; hiding M&M's behind partitions in all corners of the setup versus a ventilator spreading the scent molecules (Broom et al., 2009).

2.3.6. Group 2: procedural modifications between group 1 and 2

We slightly modified the test environment and mirror exposure for the second group. The experimental setup of the first group closely followed the description given by Broom et al. (2009). However, because only 3 ME pigs from group 1 looked into the mirror during the mirror test (see below), a number of small modifications were implemented between testing the first and second group: a partition wall (see "P_2" in Fig. 1) was installed to guide the behaviour of the pigs toward the mirror, a red food bowl (position "C" in Fig. 1) was placed in front of the mirror during the last habituation session, and the door to the waiting area ("W" in Fig. 1) was left open during the 5-h exposure period.

2.4. Statistical analysis

The effect of modifying the test environment and mirror exposure on the latency to first approach of the mirror was analysed using the non-parametric Kruskal–Wallis test.

For the mirror test, effects of pre-exposure to the mirror on the number of MNC and ME pigs crossing line 1 or 2 as first choice, and number of pigs reaching the mirror were analysed separately for groups 1 and 2, and for the groups combined by the two-tailed Fisher's exact probability test.

3. Results

3.1. Behaviour during the first hour of the 5-h exposure to the mirror

In the ME condition, all pigs of group 1 and 2 looked into the mirror. During the first hour of the 5-h mirror exposure period, the ME pigs of the second group noticed the mirror earlier (latencies ± SEM: 6.8 ± 1.2 s) than the ME pigs of the first group (175.0 ± 41.6 s) (see Fig. 2A; $\chi^2_{(1)} = 7.64$, $p = 0.0057$).

However, in groups 1 and 2 of the ME condition, the period of showing interest in the mirror ($\chi^2_{(1)} = 1.633$, $p = 0.2012$, see Fig. 2B; latencies ± SEM: 449 ± 47 s, group 2: 628 ± 136 s), as well as the time at which mirror interest ceased ($\chi^2_{(1)} = 0.335$, $p = 0.8548$; see Fig. 2C; latencies ± SEM group 1: 649 ± 73 s, group 2: 635 ± 135 s) was similar.

In 5 of the 11 animals exposed to the mirror during the 5-h exposure period, an initial fright response was observed when they noticed the mirror for the first time. After noticing the mirror, mirror-directed behaviours as approaching, touching and pushing against the mirror were seen. Piglets made vertical and horizontal head movements when facing the mirror (frontal or sideways). Also piglets attempted to move through the visual 'gap' between the mirror and the partition wall. Except for the initial fright response, all behaviours were observed in all ME animals with a frequency of 1 or more.

3.2. Behaviour in the mirror test (see Table 2)

13 Pigs looked at the mirror (3 of the 11 pigs from group 1 and 10 of the 11 pigs from group 2).

Two pigs of the first, and 1 pig of the second group crossed the correct line ("L_1" in Fig. 1). These three pigs were mirror experienced. Two of the three successful pigs noticed the mirror according to our definition before crossing line 1.

A total of 12 pigs crossed the incorrect line ("L_2" in Fig. 1), of which 7 pigs were mirror experienced and 5 pigs were mirror naïve.

3.3. Behaviour in control trials

3.3.1. Behaviour in the first control trial (mirror replaced by wire mesh (see Table 2))

There were no differences between the ME and MNC pigs for any of the three measures (see Table 2).

3.3.2. Behaviour in the second control trial (mirror and two food bowls present, with food in bowl B (see Table 1))

A higher number of ME (7 of 11) than MNC pigs (1 of 11) crossed line 1 (see Table 2). However, only 5 ME and 1 MNC pig(s) choosing correctly noticed the mirror before crossing line 1.

4. Discussion

We were unable to corroborate the findings by Broom et al. (2009). In the mirror test performed following his protocol as closely as possible, i.e. in group 1, only two of the mirror exposed pigs crossed line 1 and found the hidden food reward. We take this observation as evidence that the majority of the pigs in the present experiment did not understand what the mirror image represents, and that they did not use the mirror to locate the food.

Surprisingly, during the second control trial using baited and unbaited bowls to control for olfaction, a much higher number of ME than MNC pigs crossed line 1, which could potentially indicate mirror use. However, not all of these pigs noticed the mirror before crossing line 1, which makes the conclusion that the pigs used the mirror much less likely. As our criteria for 'noticing the mirror' were relatively strict, this could have caused exclusion of some pigs not fulfilling them. Because broadening the definition of 'noticing' also increases subjectiveness of the observations, we decided against this. As mirror-experienced pigs showed a significantly better performance compared to the mirror-naïve animals, we could speculate that increased mirror exposure could lead to a better understanding of the mechanism. Being alone in the environment during the actual mirror test (compared to exposure to the mirror in pairs during the 5 h period) possibly enhances vigilance and might lead to a better perception and understanding of the environment. Considering the behaviour in the mirror test and the first control test, the result of the 2nd control trial should be interpreted carefully and it most likely do not reflect efficient mirror use.

Further, it is unlikely that the piglets learned where the food was located from the first test (piglets crossing the incorrect line never found the rewarded food bowl), but as they are given a 'second chance', this could have increased the likelihood to choose correctly. However, it is also possible that they learned about the mechanisms of a mirror from the extra mirror experience, when finding no reward behind the mirror the first time. Despite this, we argue that 'noticing the mirror' is a prerequisite for making a correct choice and from the first group, only 3 animals did so. Crossing the correct line without first noticing the mirror would be a chance hit, or a choice based on other strategies or senses than understanding what the mirror represents.

As a consequence of this failure to replicate Broom's (2009) study with the first group of pigs, we slightly

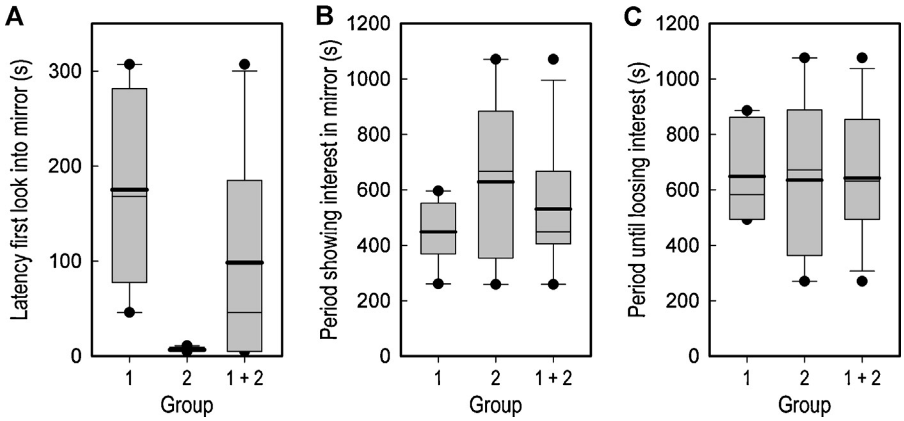

Fig. 2. Behaviour during the 5-h mirror exposure prior to the mirror test in the ME group. Latency to first look into the mirror (left panel), duration of the period in which pigs showed interest in the mirror (centre panel), and time point at which the pigs lost interest in the mirror (measured from the start of the mirror-exposure session) in two groups of pigs that are exposed to a mirror during a 5-h period preceding the mirror test, and for the two groups combined. The mean (thick line), median, 10th, 25th, 75th and 90th percentiles are visualized as vertical boxes with error bars.

modified the procedure of exposing the pigs of the second group to the testing arena and the mirror. We placed a partition which was aimed to guide the animals' movement toward the mirror, thereby increasing the chance that the pig would notice the mirror. During the individual habituation sessions, we also placed a red food bowl, which the pigs associated with rewards, just in front of the mirror area to create a preference for this area. Although these modifications did help to guide the pigs toward the mirror during the 5-h mirror exposure session preceding the mirror tests, they did not yield the expected result in the subsequent mirror test. Despite an increased number of animals noticing the mirror (10 of the 11 piglets looked into the mirror during the mirror test) only 1 of the mirror-exposed pigs, and none of the mirror-naive pigs used the detour around the partition wall (crossing line 1; see Fig. 1)

Table 2
Number of pigs that crossed the correct line (line 1 in the mirror test, line 2 in the first control trial) or the incorrect line (line 2 in the mirror test, line 1 in the first control trial) first, and number of pigs noticing the mirror in the mirror test, and in the first and second control test. Fisher's exact probability test was performed separately for group 1 (*N* = 11) and 2 (*N* = 11), and for groups 1 and 2 combined (*N* = 22). Line 1 and line 2: see Fig. 1.

Mirror test	Crossing line 1 (correct)			Crossing line 2 (incorrect)			Noticing mirror		
	Group 1	Group 2	All pigs	Group 1	Group 2	All pigs	Group 1	Group 2	All pigs
Mirror naïve pigs (MNC)									
Yes	0	0	0	4	1	5	2	6	8
No	5	6	11	1	5	6	3	0	3
Mirror exposed pigs (ME)									
Yes	2	1	3	3	4	7	1	4	5
No	4	4	8	3	1	4	5	1	6
Fisher's exact probability	0.45	0.45	0.21	0.55	0.08	0.67	0.55	0.45	0.39
First control test	Crossing line 1 (incorrect)			Crossing line 2 (correct)			Noticing wire mesh		
	Group 1	Group 2	All pigs	Group 1	Group 2	All pigs	Group 1	Group 2	All pigs
Mirror naïve pigs (MNC)									
Yes	0	2	2	4	2	6	1	6	7
No	5	4	9	1	4	5	4	0	4
Mirror exposed pigs (ME)									
Yes	3	2	5	3	2	5	1	5	6
No	3	3	6	3	3	6	5	0	5
Fisher's exact probability	0.18	0.65	0.36	0.55	1.00	1.00	1.00	1.00	1.00
Second control test	Crossing line 1			Crossing line 2			Noticing mirror		
	Group 1	Group 2	All pigs	Group 1	Group 2	All pigs	Group 1	Group 2	All pigs
Mirror naïve pigs (MNC)									
Yes	1	0	1	3	4	7	2	6	8
No	4	6	10	2	2	4	3	0	3
Mirror exposed pigs (ME)									
Yes	4	3	7	2	2	4	4	2	6
No	2	2	4	4	3	7	2	3	5
Fisher's exact probability	0.24	0.06	0.02	0.57	0.57	0.39	0.57	0.06	0.66

that prevented direct access to the hidden food bowl. It is difficult to know exactly how the animals experienced the mirror during the mirror exposure period; future studies could examine whether gradual introduction of mirror use, i.e. using progressively more difficult hiding places for rewards, can facilitate use by pigs.

The amount of time given to solve the mirror problem may be an issue in testing. We used a 1 min test based on the study by Broom et al. (2009) that we aimed to replicate. However, this may have been too short, as a number of pigs did not cross line 1 or 2 within the 1-min testing period. More ME than MNC pigs tended to cross line 1 or 2 (ME: 10 pigs crossed one of the two lines, 1 pig did not; MNC: 5 pigs crossed one the two lines, 6 pigs did not; two-tailed Fisher's exact probability = 0.063), i.e. experience with the mirror may have stimulated exploration of the testing arena per se. However, if only the data of the 15 pigs were considered that crossed one of these lines during the mirror test, the conclusion holds that ME pigs chose the correct route at chance levels (Fisher's exact probability = 0.51). By comparison, the 7 out of 8 pigs that solved the task in Broom's study, all did so within the 1-min test period.

Age may be an important factor in learning to use a mirror. This has been documented for mirror self-recognition in both non-human primates (Povinelli et al., 1993) and human children (Rochat, 2003). Children are capable of understanding the contingency between seen and felt movements in a mirror from approximately 2 years of age onwards (Rochat, 2003). After the 5 h of mirror experience the pigs in the present experiments appear to have gained the knowledge that what is perceived in the mirror is different from what is perceived in the surrounding environment. As children go through the developmental stages leading to self-recognition over a fairly long period of time (stage 5 is reached around 4–5 years of age (Rochat, 2003)), we speculate that if pigs are able to progress further in mirror use the time and exposure to a mirror surface needed to do so have to be extended. The pigs in the present study were subjected to the mirror test in the age range from six to eight weeks, similar to the four to eight weeks of age those in Broom's study, as part of our attempt to replicate his findings. For future studies, testing in adolescent or adult pigs (as stages or milestones in piglet 'childhood' are difficult to define), may be preferable.

Another line of future research to test whether pigs can use mirrors could be the use of a mirror-directed choice task, such as that used in New Caledonian crows (*Corvus moneduloides*) by Medina and colleagues (2011). In that task, animals were trained to remove food from one of four compartments, with the food visible only through a mirror. In tasks in chimpanzees (*P. troglodytes*; described in Menzel et al., 1985) or monkeys (*M. tonkeana* and *M. fascicularis*: described in Anderson, 1986), animals were trained to retrieve a food reward or touch a target associated with reward which was visible only through a mirror or televised equivalent of a mirror. Such operant paradigms have the advantage that responses can be more clear-cut for scoring, and that several trials can be conducted per animal, reducing variability in results. Mirror-mediated spatial locating, which entails more exploration-based paradigms (as used in the present experiment) require little training, but particularly non-responses can be more difficult to interpret; furthermore, testing is generally one-trial, increasing variability. However, mirror-mediated spatial locating, as used in the present experiment, can test a more complex use of mirrors, as the task cannot be solved using trial and error. A choice task may be a fruitful starting point for testing pigs in moving toward resolving the discrepancy in mirror use seen between the present study and the pigs tested by Broom and colleagues (2009).

We were not able to replicate Broom's finding, even after procedural modifications that facilitated orientation toward the mirror. In Broom's (2009) study, as in our present attempt to replicate his findings, hybrid pigs were used. This may increase the inter-individual differences as a consequence of heterogeneous samples. It has been shown that small sample sizes increase the chance of false positive findings (already discussed by Tversky and Kahneman (1971)). Moreover, one single observation per pig is obtained to estimate use of the mirror for locating the food reward, which may make the test prone to chance findings. Of course, both the original study and the present failure to replicate it could have suffered similarly from the risks associated with using heterogeneous, relatively small samples. However, one would expect replicability/repeatability of results if findings were reflecting a robust trait (van der Staay et al., 2010), and this was what we expected considering the persuasive results by Broom et al. (2009). Repeatability can be affected by many factors (see e.g. Bell et al., 2009). Most aspects of the Broom et al. study were closely replicated: piglets' age, the experimental setup and the habituation phase (as far as known from Brooms' article and personal communication). A main difference was that the pig line used differed from the line used in the original experiment. As far as we know the differences (visual capacity, cognitive performance) of those lines have never been compared, thus we cannot rule out effects of line on our results.

Given our results and the points of discussion mentioned above, we conclude that effective use of information provided by a mirror may not be an ability shared by all pigs of this age and/or pig lines.

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