Animal Behavior and Cognition

ABC 2025, 12(2):172-234
DOI: https://doi.org/10.26451/abc.12.02.02.2025

Step Aside! Assessing Body Awareness In Pigs Using A Body-As-An-Obstacle Task

Kimberly Brosche[1*‡], Jim McGetrick[1,2‡], and Jean-Loup Rault[1]

[1]Institute of Animal Welfare Science, University of Veterinary Medicine Vienna, Vienna, Austria
[2]Department of Behavioral & Cognitive Biology, University of Vienna, University Biology Building (UBB), Vienna, Austria

*Corresponding author (Email: broschekimberly@gmail.com)
‡ These authors contributed equally.

Citation – Brosche, K., McGetrick, J., & Rault, J-L. (2025). Step aside! Assessing body awareness in pigs using a body-as-an-obstacle task. *Animal Behavior and Cognition, 12*(2), 172-234. https://doi.org/10.26451/abc.12.02.02.2025

Abstract – Body awareness allows animals to perceive their own body as a tool or even an obstacle when interacting with their environment. Body-as-an-obstacle tasks have been employed to test body awareness in human infants, elephants, and dogs. Investigating body awareness in a farm animal species for the first time, we tested young domestic pigs (*Sus scrofa domesticus*, N = 17, 8 male and 9 female, 7 weeks old) in a modified body-as-an-obstacle task. Pigs learned to push a sliding panel with their snout to access food rewards. This was achievable from two different positions: left or right, corresponding to on or off a mat. In the test condition, the mat on which pigs were positioned was attached to the panel via a chain. If body-aware, pigs were expected, after unsuccessfully trying from the mat side, to step off the mat and push from the other side. Subjects stepped off the mat and solved 52% of the "attached" trials. Additionally, they were significantly quicker, and more likely, to push from the other side after stepping off in this condition than when an external obstacle visibly blocked the panel from behind. However, pigs' behavior in a newly introduced control condition, in which the panel was blocked for a reason unknown to the pig, did not differ significantly from that in the attached condition. Hence, similar to previously tested species, pigs can flexibly adjust their behavior to solve a body-as-an-obstacle task. Importantly, our findings also highlight the necessity of determining whether animals simply switch strategies and, thereby, succeed in body-as-an-obstacle tasks whenever they cannot identify the reason for the obstruction, or whether their success indeed constitutes evidence for body awareness.

Keywords – Self-awareness, Body awareness, Body-as-an-obstacle task, Domestic pig, *Sus scrofa domesticus*

Self-awareness allows animals to become the object of their own attention (Duval & Wicklund, 1972; Gallup, 1998) and the protagonist of their actions (Damasio, 2003; Lage et al., 2022). Self-aware individuals can discriminate between "mine" and "others'" (Bekoff & Sherman, 2004) and experience themselves as spatio-temporally continuous subjects (Gallup, 1998; Morin, 2011). Despite previously being regarded as a uniquely human trait (Crook, 1980), the possibility of self-awareness in non-human animals has increasingly become the focus of research (for a review see Lage et al., 2022).

Self-awareness in non-human animals is of especial scientific interest due to its potential to alter animals' perception of their environment. First, being self-aware can confer advantages on animals in their natural (physical) environment (e.g., apes navigating the canopies of the rainforest, Povinelli & Cant, 1996). Second, self-awareness may open up a wide range of possibilities in the domain of social cognition, as it is thought to be associated with abilities such as deception, exploitation, and manipulation of conspecifics (Gallup, 1998; Johnson et al., 2005; Krachun et al., 2019) as well as cognitive empathy (Preston & de Waal, 2002). Finally, self-awareness has been suggested to change how animals experience captive environments.

For instance, Sommerville and Broom (1998) uphold that memories of aversive experiences are more likely to compromise wellbeing if animals are self-aware. Consequently, self-awareness is not only crucial to understanding species' adaptation to challenges of the physical and social environment but might also carry profound implications for animal welfare.

Given the unavailability of self-report in non-human animals and pre-verbal children, self-awareness has extensively been investigated in the domain of visual self-recognition. The most common paradigm applied for this purpose is the mirror mark (mirror self-recognition) test (Gallup, 1970), in which a color mark is painted on the animal's forehead to later observe the subject's reaction to its own mirror image. Among these reactions, especially instances of self-inspection (or mark inspection) are frequently interpreted as indicative of a form of self-awareness. So far, numerous species have shown these reactions and hence "passed" the mirror mark test without explicit training: among these are chimpanzees (*Pan troglodytes*) (Povinelli et al., 1997), rhesus macaques (*Macaca mulatta*) (Rajala et al., 2010), Asian elephants (*Elephas maximus*) (Plotnik et al., 2006), bottlenose dolphins (*Tursiops truncatus*) (Morrison & Reiss, 2018; Reiss & Marino, 2001), horses (*Equus caballus*) (Baragli et al., 2021), magpies (*Pica pica*) (Prior et al., 2008), and more recently even fish (cleaner wrasses (*Labroides dimidiatus*), Kohda et al., 2019). Nevertheless, the mirror mark test comes with a couple of major methodological limitations. For instance, it has been argued that it is restricted to species with a) sufficient visual abilities, b) extremities that allow individuals to inspect and touch a mark on their body (though dolphins and fish have passed it) and c) the motivation to touch the mark (De Veer & van den Bos, 1999; Kakrada & Colombo, 2022). In addition to this lack of universal applicability, the ecological validity of mirror mark studies can be called into question. To overcome these limitations and complement the findings of mirror-mark studies, it is worthwhile to focus on alternative, less vision-centric approaches to investigating self-awareness.

Many alternatives to visual self-recognition tests exploit one particular component of self-awareness, namely body awareness. Body awareness is constituted by the ability to represent one's own body as an object situated in the environment, thereby enabling its perception as a tool or even as an obstacle (Brownell et al., 2007). For instance, body awareness is believed to be expressed in subjects estimating their bodily dimensions to plan their routes accordingly when navigating the environment (Franchak & Adolph, 2012). Building on this idea, snakes (*Elaphe radiata*) (Khvatov et al., 2019) and dogs (*Canis lupus familiaris*) (Lenkei et al., 2020) have demonstrated their ability to choose openings/doors that allow for passage based on their own body's dimensions and rats were shown to select bridges that support their body weight over bridges that do not (Khvatov et al., 2021).

Another body awareness test originally designed for human infants is the body-as-an-obstacle task (Bullock & Lütkenhaus, 1990; Geppert & Küster, 1983; Moore et al., 2007). In this paradigm, subjects must become aware of their body as a physical obstacle. In human infants at 18, 23 and 30 months of age, performance in a body-as-an-obstacle task (Geppert & Küster's (1983) "blanket task") is correlated with linguistic self-reference (using one's name or "I", "me", "my"), self-recognition in photographs, and, importantly, mirror self-recognition (Bullock & Lütkenhaus, 1990). A transfer of the original body-as-an-obstacle task to non-human animals has already been accomplished in two species: elephants (Dale & Plotnik, 2017) and pet dogs (Lenkei et al., 2021). In both cases, subjects were asked to pass an object (e.g., a toy) to the experimenter with their trunk or mouth. However, as the object was attached to the mat on which the animals were standing, success was dependent on the removal of their body weight from the mat. Both species were quicker to step off the mat when the object was attached to it than when a) the object was unattached (and subjects did not need to step off) or when b) the experimenter pulled at the mat to potentially induce foot discomfort. Additionally, dogs tested by Lenkei et al. (2021) took longer to step off when the task was unsolvable because the object was attached to the ground. These findings suggest that at least some non-human animals are able to recognize their body as a physical obstacle.

Despite these results for elephants and dogs, as well as the welfare implications discussed above, body awareness has, to the best of our knowledge, never been investigated in farm animals. Among these, the domestic pig is especially suitable to being tested in a body-as-an-obstacle task for a variety of reasons. First, pigs are one of the most widely farmed livestock species (Ritchie & Roser, 2017), conferring especial importance on the study of their welfare-related cognitive capacities. Second, pigs have already been shown to possess other cognitive abilities closely associated with self-awareness. For example, pigs have demonstrated episodic-like memory (Kouwenberg et al., 2009), exhibit advanced socio-cognitive skills, e.g., individual discrimination of conspecifics (McLeman et al., 2005) and humans (Koba & Tanida, 2001), use of conspecifics as a source of information (Held et al., 2000, 2010), counter-acting of exploitation in a social foraging task (Held et al., 2002), and, to some degree, visual perspective taking (Held et al., 2001). Also, pigs seem to be sensitive to the potential outcomes of their actions. That is, there is some evidence that they demonstrate means-end understanding (e.g., when operating the switch of a heater (Curtis, 1983), moving a cursor on a computer screen (Croney & Boysen, 2021) or instrumentalizing parts of their environment (Root-Bernstein et al., 2019; Sommer et al., 2016)).

Although pigs may be good candidates for investigating self-awareness, the mirror self-recognition paradigm is inappropriate for pigs. Not only do they lack primates' hands and elephants' trunks, but pigs also possess relatively poor visual acuity (Zonderland et al., 2008) and, being dichromats, their color discrimination abilities are limited to two colors (Neitz & Jacobs, 1989; Tanida et al., 1991). Furthermore, studies on instrumental mirror use in pigs have yielded inconclusive and contradictory results (Broom et al., 2009; but see Gieling et al., 2014) suggesting that mirrors might not be a suitable tool to assess self-awareness in pigs.

Body-as-an-obstacle tasks, on the other hand, are more congruent with pigs' species-specific characteristics than the mirror mark test, as pigs are highly explorative in nature and motivated to physically interact with items in their environment. However, the body-as-an-obstacle tasks previously applied to human infants, elephants, and dogs are similarly inappropriate for pigs, as they cannot easily be trained to pass an object to an experimenter. Therefore, we designed a body-as-an-obstacle task that fits pigs' behavioral repertoire. Similar to recent tasks that required pigs to either lift a wooden log (Koglmüller et al., 2021; Rault et al., 2021) or push a lid to uncover a food reward (Nestelberger, 2019), our modified body-as-an-obstacle task exploited pigs' natural rooting behavior. In our new set-up, subjects needed to horizontally push a sliding panel in order to access food rewards. Pushing the panel was possible from two distinct positions: on or off a mat (Figure 1). During the test, pigs were always positioned on the mat (using a target stick) and then encouraged to push from the mat side first. In the main test condition ("attached" condition), the mat on which the pig was standing was attached to the panel. Hence, the task was only solvable by stepping off and pushing from the other side.

Based on our hypothesis that pigs are body aware, we predicted that subjects would step off the mat in the attached condition (to push the panel from the other side) upon recognizing that their own body is blocking the sliding panel's movement. To rule out alternative explanations as to why pigs step off the mat and push from the other side, we included conditions that controlled for a) foot discomfort evoked by the mat's movement upon pushing the panel (similar to both Dale & Plotnik, 2017 and Lenkei et al., 2021) and b) pigs' baseline tendency to push from the other side if the task is unsolvable from the mat side (inspired by Lenkei et al.'s (2021) "attached to the ground" condition). If pigs' motive for stepping off the (attached) mat and pushing from the other side is the recognition of their body as an obstacle, they should differentiate between the attached condition (in which their body is an obstacle) and an unsolvable condition in which external obstacles block the panel. This means that, compared with the unsolvable condition, in the attached condition pigs should be a) more likely to push from the other side and b) quicker to push from the other side after stepping off the mat. Similarly, they should be less likely to search for an external obstacle blocking the panel from behind (rather than from the front, on the mat) by inspecting the back of the panel. Given that the difference between the attached condition and the unsolvable condition may be subtle, pigs can be expected to try pushing the panel from the other side also in the unsolvable condition. Hence, even if the probability of pushing from the other side might be comparable between the attached and the unsolvable condition, the latency to push from the other side should nevertheless diverge between conditions. In addition, pigs should *not* show signs of foot discomfort by stepping off earlier when an experimenter is gently tugging at the mat compared with a condition in which she merely pretends to pull.

However, even in the absence of body awareness, pigs could simply push from the other side whenever the reason for the obstruction is not evident to them, i.e., the way the attached condition would appear to subjects without body awareness. Thereby, they would seemingly differentiate between their body and visible external obstacles blocking the panel. What would hence provide even stronger evidence for body awareness is if pigs also differentiated between their body and "invisible" (unknown) external obstacles blocking the panel, relying on tactile feedback from the mat when the panel is being pushed (which is present in the attached condition but absent when external obstacles block the panel). Therefore, we also included a novel control condition in which the task was unsolvable for a reason unknown to the pig.

Methods

Ethics Statement

This study was approved by the Ethics and Animal Welfare Committee of the University of Veterinary Medicine, Vienna, Austria, in accordance with the University's guidelines for Good Scientific Practice (approval number: ETK-017/01/2022).

Subjects and Housing

The main study presented here, as well as a pilot study (see Supplementary Material 1), were both conducted at the VetFarm Medau (belonging to the University of Veterinary Medicine Vienna, Austria).

We randomly selected 20 piglets from 10 different litters (one castrated male and one female per litter). The number of pigs that could be included in the study was restricted by feasibility, given the time requirements of the training procedures. At 4 weeks of age, the pigs were weaned and transferred to the rooms in which they were trained, tested, and housed for the duration of the study. By the time of testing, pigs were approximately 7 weeks old. In line with numerous cognitive studies conducted with pigs (for an overview see Gieling et al., 2011), we tested young pigs rather than adult ones due to the limited availability of adult animals as well as the difficulties of keeping and handling them.

We regularly marked the pigs with livestock marking spray ("Kerbl Top Marker Spray Marker" Kerbl Austria Handels GmbH, Wirtschaftspark 1, A-9130 Poggersdorf, Austria; colors blue, green and pink) to allow for individual recognition. They were checked upon daily and received veterinary care whenever necessary. We split the pigs up into two pen groups of ten with equal numbers of males and females so that there was only one piglet from each of the ten sows in each group. The two groups were housed separately in two identical home pens measuring 543 cm × 242 cm each. The pens were lit from approximately 7 am, when the experimenter or the caretakers first entered the room, to dusk as, even with the artificial lights turned off, the windows of the room provided natural lighting. Approximately one third of the floor's area was slatted. For the remaining part, sawdust was used as litter. The pens were cleaned daily. Food, a standard weaner diet (17.5% crude protein, 7% crude fat; Garant-Tiernahrung GmbH, Austria) topped with a supplement (Biotronic Top3 and ProbioBac; Biomin®, Austria) provided in a hopper feeder, and water were available *ad libitum*. Straw, two jute ropes and two orange toy balls provided environmental enrichment.

Apparatus and Set-up

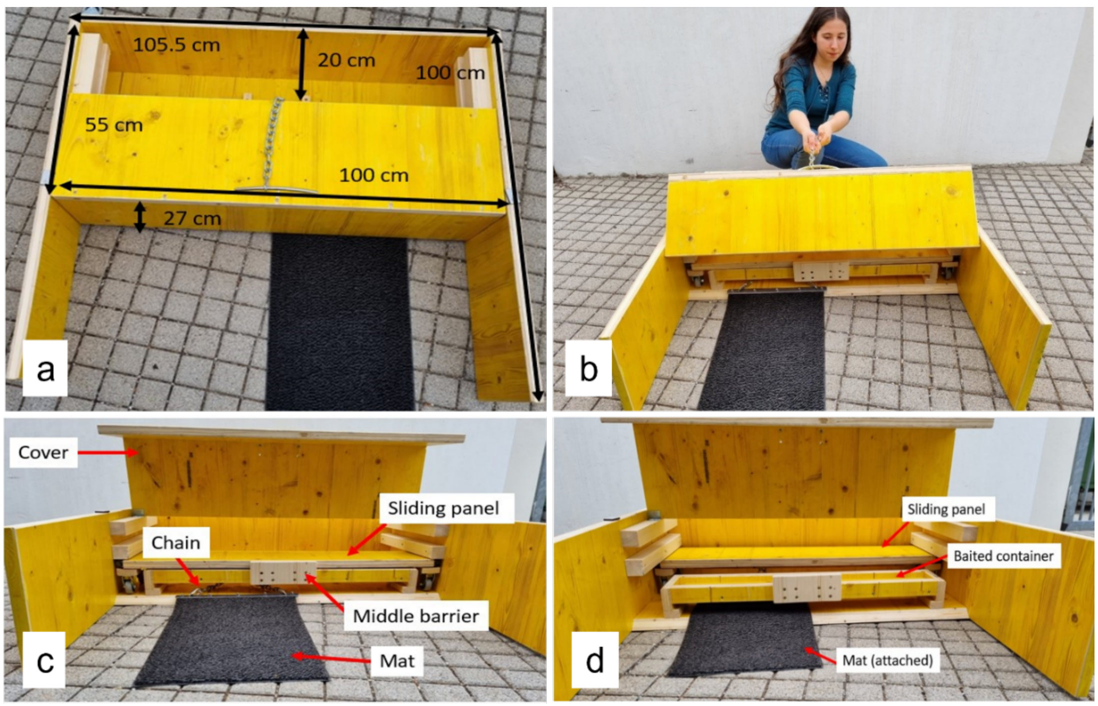
To test for body awareness, a box-shaped apparatus containing a sliding panel was used. The training and testing with this apparatus as well as most preceding training steps (for exceptions see below) took place in a test enclosure, i.e., an empty pen comparable to the home pens, and located in the same room as the pigs' home pens.

Apparatus

The apparatus (Figure 1) measured 105.5 cm × 100 cm × 27 cm on the outside. A cover attached to the top of the apparatus via two hinges at the back served the purpose of blocking access to the task in between trials and later provided a clear temporal marker for the start of a trial. It could be opened or closed (**Error! Reference source not found.**b) to either reveal or hide the most crucial part of the apparatus: a sliding panel moving on rails and wheels. Using their snouts, pigs could push this sliding panel, causing it to slide away and reveal the underlying baited food container (Figure 1c and 1d). A centrally placed wooden barrier (20 cm × 7.5 cm) was attached to the front of the food container. In this middle position, the wooden barrier blocked access to the panel, thus marking two distinct positions – left and right of the barrier – in front of the apparatus from which the panel could be pushed. The sliding panel measured 94 cm × 20 cm × 2 cm and completely covered the food container (measuring 84 cm × 15 cm × 3 cm on the outside and elevated to a height of 12 cm from the floor of the pen) when in the starting position. A space (20 cm) between the end of the cover and the back wall of the apparatus enabled the experimenter to manipulate the panel and bait the food container even when the cover was closed.

Figure 1

Pictures of the Body Awareness Apparatus



Note. Body awareness apparatus from different perspectives. a) Top view of the body awareness apparatus with the cover closed. b) Experimenter lifting the cover of the apparatus. c) Front view (pig's view) of the body awareness apparatus with the cover open and the sliding panel to the front. The middle barrier impeded the pigs from pushing the panel in an intermediate position, thus creating two clearly defined positions, left and right of the barrier, from which the panel could be pushed. d) Front view of the body awareness apparatus with the cover open and the sliding panel to the back. As the mat is attached to the panel in this image, it was dragged halfway into the apparatus with the panel

Mat and Set-up

In order to assess whether pigs can recognize their body as a physical obstacle in the test conditions, the panel-pushing task was combined with a rubber mat (55 cm × 35 cm) the pigs could stand on. Its width roughly equated to half the apparatus' width, creating two possible positions of the mat: either in front of the left or the right half of the apparatus. The mat was always attached to a chain, but only in the main test condition was this chain also connected to the sliding panel. Hence, in this condition, the task could not be solved, and the reward could not be accessed by a pig, as long as it stood on the mat and thereby blocked the panel from moving. To understand this, pigs could rely on the tactile feedback from the mat when they pushed the panel. If the pig stepped off, however, the mat could move with the panel and could be drawn into the apparatus in the space underneath the food container (Figure 1d).

Test Enclosure

Tests and training steps involving the apparatus and the mat were always conducted in the test enclosure, which was 245 cm × 245 cm in size. The apparatus was set up on one side of the enclosure with the back facing the wall and the front accessible to the pigs. Depending on the condition or training stage, the mat was present in front of one of the two sides and was either unattached or attached to the sliding panel. The experimenter was sitting or crouching behind the apparatus (between the apparatus and the wall) in all test trials except for the foot discomfort condition and the foot discomfort control condition (see The Test Conditions below). This prevented the pigs from seeing the experimenter and picking up on unintentional cues, e.g., gaze direction.

Training and Habituation

To allow us to draw inferences about the pigs' awareness of their body as a potential obstacle, the pigs needed to a) be trained to assume a certain starting position before each trial, i.e., on the mat, but b) also learn that this position (especially the mat) can be abandoned at any time during the experiment. Additionally, by the time of testing, they needed to have learned to push the sliding panel with their snout from either side. Over the course of three weeks (16 days, not necessarily consecutive), pigs were thus habituated to the experimenter, the food reward (apple pieces), and the test enclosure before they learned to position themselves in front of the apparatus and push the panel from both sides. All the stages of training that led up to the test week are visualized in **Error! Reference source not found.** and are outlined in the following sections. Each training day (e.g., day 1) corresponded to the same calendar day for all pigs. Details can be found in Supplementary Material 2.

On the first days after weaning, the pigs were habituated to the (female) experimenter, the food reward (apple pieces), and the test enclosure. In the subsequent training phase, pigs learned to follow a target stick (see Supplementary Video 2). This later allowed us to position pigs on the mat in the test (similar to Jønholt et al., 2021). First, pigs were trained with the target in the home enclosure for two days with all their penmates (nine other pigs) for 10 min per day per group. Then they received three 10-min target-training sessions in the test enclosure. We trained pigs in pairs in the first two of these target training sessions and later trained them individually.

In week 3, some target trials required pigs to step on the mat that was now also present in the test enclosure. Each pig received two of these sessions. On the same days but in separate 15-min sessions, pigs were also familiarized with the apparatus and learned to push the sliding panel. On day 1 of this phase, the food in the food container (equal amounts on both sides) was freely accessible to all pigs, as the experimenter had already pushed back the panel prior to the session. On days 2 and 3 of the training with the apparatus, pigs encountered the apparatus with the panel to the front, blocking access to the food container. Hence, pigs now had to push the sliding panel with their snout to retrieve the reward. Each trial was initiated by lifting the cover. Two blue blocks were placed behind the panel during the re-baiting process to familiarize pigs with this element of one of the test conditions (see below).

In the final five days of training (one session per day), all the elements from the previous phases were combined: Both the mat and the apparatus were present in the test enclosure. The mat was either placed on the left or the right side in front of the apparatus. The position of the mat was counterbalanced across subjects but always remained constant for one individual throughout training and testing (e.g., subject A was trained with the mat to the right while B always experienced it on the left). However, the mat was never attached to the sliding panel at this stage. Before each trial, the experimenter encouraged the pig to assume a pre-defined position in front of the apparatus (with the target or, alternatively, by luring it with food). The position, i.e., either on or off the mat, was semi-randomized across trials (with not more than four trials on the same side in a row). The procedure of each individual trial was the same as for the previous training stage: the cover was lifted, the blue blocks were taken out, and the pig was then expected to push the panel to access the food rewards.

In all training steps, all pigs from one pen group were trained first and then all pigs from the other group were trained. The order of groups alternated from day to day.

On the first day of the test week, i.e., after the weekend, one refresher session was conducted to ensure pigs remembered the task. This session followed the same protocol as the combined training (the previous training step) and lasted 10 min per pig. Testing commenced on the subsequent day. In order for pigs to be included in the test, they had to have reached the criterion of at least 10 successes (pushed the sliding panel far enough to be able to reach the food) with the apparatus on “mat trials”. In addition, they had to have pushed from the indicated (mat) side in at least 70% of the mat trials in the combined training.

Testing

The test sessions took place in the test enclosure on four consecutive days, after 3 weeks (16 days) of training when the pigs were approximately 7 weeks old. The time of day at which each individual was tested (and therefore also the order of pigs) remained constant (± 2 hr) across days. All sessions were video recorded.

One session consisted of a total of 12 test trials (two of each of six conditions) which alternated with 13 motivational trials (before and after each test trial). Pigs were positioned on the mat in all test and motivational trials, never off the mat. For the trial to be started, at least the pig’s front legs had to be on the mat. To determine whether a pig was standing on the mat or not, as well as for the analyses (e.g., stepping off), we only considered the front legs as some individuals were too long to comfortably fit on the mat with all four feet. Having two feet on the mat was sufficient to block the panel’s movement if the panel was attached to the mat. The procedure of the motivational trials exactly resembled that of the unattached condition (see below), hence pushing from the mat side was always successful. However, unlike in the unattached trials which always lasted 30 s, motivational trials ended as soon as the pig had finished eating the reward. In the test trials, after the 30 s, the experimenter closed the cover and prepared the apparatus for the next trial before calling the pig to the apparatus again.

The conditions were arranged in two blocks of six (one trial per condition per block), so that every condition had been run once before any condition was repeated. We chose this design to be able to analyze the very first trial of each condition, prior to the onset of any learning effects, separately (see Supplementary Material 5).

The experimenter removed the blue blocks that pigs had already encountered in the training from behind the panel at the start of each trial (except for one condition, see below) immediately after she had lifted the cover. If a pig left the mat again before the start of the trial (i.e., before the experimenter had opened the cover), the trial was started anew.

A motivational trial was repeated if pigs pushed from the non-mat side (other than indicated by the target stick) before trying from the mat side and if it was either a) the very first motivational trial of the session, or b) this had already happened once in the same session. If repeating the trial still did not lead to the pig pushing from the indicated (mat) side, the trial was repeated another time in the absence of the blue blocks to give the pig less time and incentive to switch sides before the experimenter had opened the cover and removed the blue blocks.

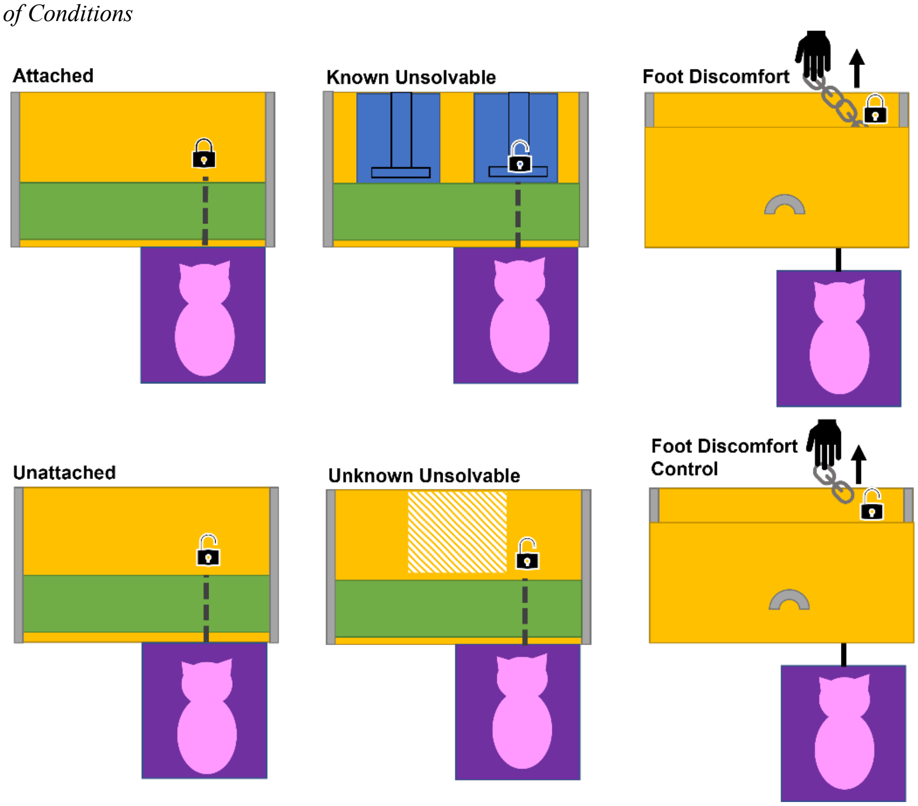
If pigs ceased to participate, lost motivation, or became too agitated, the session was interrupted and continued on the same day after all other pigs had been tested. As for the training, all pigs of one pen group (e.g., group 1) were tested before the first pig of the second group (e.g., group 2) could start. This also meant that interrupted sessions (e.g., those interrupted because the pig lost motivation) were continued after all other test sessions of that group, i.e., not necessarily at the end of the day.

The Test Conditions

To investigate whether pigs can recognize their body as a physical obstacle, we compared pigs' tendency to step off the mat and push the panel from the other side across six conditions (Figure 2).

Figure 2

Overview of Conditions



Note. Schematic overview (top view) of the six test conditions. In the attached condition, the mat and the panel were connected via the chain underneath the panel (as indicated by the closed padlock). In the unattached condition, the chain was attached to the mat but not to the panel (as indicated by the open padlock). In the known unsolvable condition, two visible obstacles (blue blocks) were placed behind the panel. In the unknown unsolvable condition, an inconspicuous cardboard box was placed behind the panel. In the foot discomfort condition, the experimenter (hand) was pulling at the chain (and, thereby, the mat) via a crane scale (not depicted). The cover remained closed, and the panel was inaccessible to the pig in the foot discomfort condition. In the foot discomfort control condition, the pig was standing on the mat in front of the closed apparatus, but, unlike in the foot discomfort condition, the experimenter pretended to pull at the loose chain without exerting any force on the mat. Whether or not the chain (depicted as a dashed line as it was underneath the panel) was attached to both the mat and the panel is indicated by the padlock symbol (open = unattached, closed = attached).

Attached Condition ("A")

In the attached condition, which was the main test condition, subjects began on the mat, which was attached to a small carabiner on the back of the sliding panel via a chain underneath the panel (Figure 2, Supplementary Video 1). When attached to the mat pigs were standing on, the chain blocked the panel so that it could only be moved approximately 2 cm, not far enough for the pig to access the food rewards. As a result, pigs were not able to uncover the food container by pushing the panel as long as they were standing on the mat at least with their front legs. For the pigs, the principal cue indicating that their own body weight was blocking the panel was the tugging of the mat underneath their feet every time they pushed the panel. Only by stepping off the mat and attempting on the other side, next to the mat, could they access the rewards underneath the panel. We expected the pigs to leave the mat and solve the task if they had identified the cause of the problem, i.e., their body weight, in this condition relying on tactile feedback. If pigs' reason for pushing from the other side in the attached condition was truly body awareness, we would have expected them to be more likely and quicker to do so compared with the unsolvable conditions.

Unattached Condition ("UA")

The unattached condition primarily allowed us to verify that pigs had learned to push the panel. This condition resembled both the training in the last phase (combined training) and the motivational trials. The mat pigs were standing on was not attached to the panel (Figure 2, Supplementary Video 1) and the blue blocks were taken out at the beginning of each trial. Pigs were thus expected to push the panel from the mat side and only step off the mat afterwards to also retrieve the food from the other side of the food container.

Known Unsolvable Condition ("KUS")

The purpose of the known unsolvable condition was to rule out the possibility that coming off the mat and pushing from the other side is pigs' general strategy for coping with (seemingly) unsolvable tasks, regardless of whether this brings them closer to success (cf. "attached to the ground" condition in Lenkei et al., 2021). This control was especially important in our set-up compared with those of previous studies (Dale & Plotnik, 2017; Lenkei et al., 2021), because we gave pigs two positions from which the panel could be pushed. Hence, pushing from the other side is a likely alternative strategy if initial attempts on the mat side are not successful – regardless of the reason.

Because the obstacles needed to be salient enough for pigs to acknowledge their presence, we used two blue blocks of wood (Figure 3, Supplementary Video 1). The blocks resembled an upside-down "T" and measured 28 cm × 22.5 cm at ground level. They were 19 cm high. A small blue panel was attached to the front of the block. This panel, i.e., the part of the blocks visible to the pigs, amounted to approximately 35 cm per block.

In the known unsolvable condition, the cause of the unsolvability was, in theory, understandable, given that the obstacles were visible to the pig. As described above, the pigs already encountered the blue blocks in the training, allowing them to associate the blocks with the (initial) unsolvability of the task. In the KUS condition, the blue blocks were not removed at the beginning of the trial and therefore blocked the panel, making it impossible to push the panel from either side. Unlike in the attached condition, the mat was not attached to the panel in the unsolvable condition and pigs' own body weight was not blocking the panel. Thus, pigs could not perceive any tugging of the mat as in the attached condition.

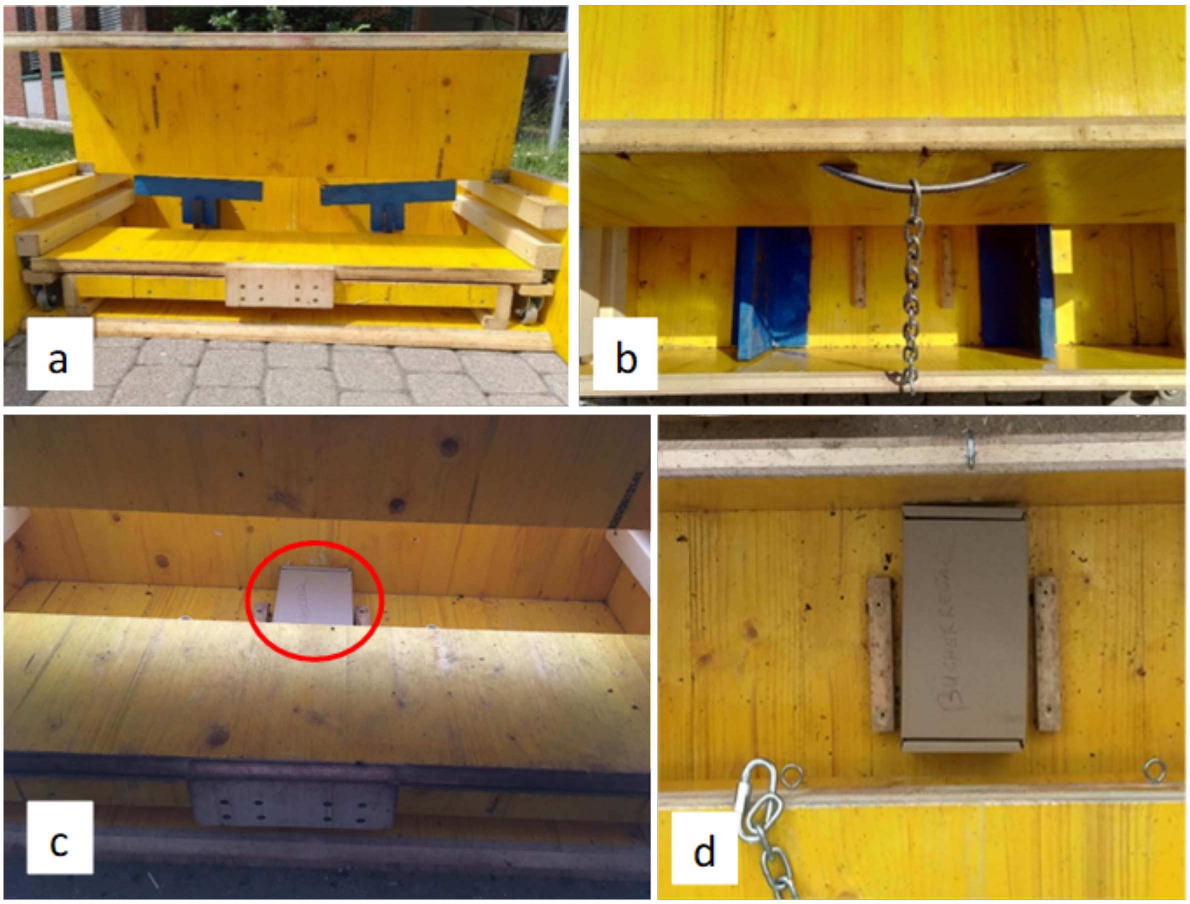
Unknown Unsolvable Condition ("UUS")

We hypothesized that, if pigs do not possess body awareness, the attached condition might appear unsolvable to them. However, the reason for their failure would be unknown to them, unlike in the KUS condition. To explore the possibility that the pigs' potentially differential reaction to the A condition and the KUS condition merely depends on whether they know (KUS condition) or do not know (A condition if pigs are not body-aware) why the panel cannot be pushed, we introduced the unknown unsolvable condition. In this condition, a flat, inconspicuous cardboard box (21 cm × 12 cm × 5 cm) was placed behind the panel. It was high enough to block the panel's movement but flat and subtle enough not to be noticeable to the pigs unless they made an effort to peek behind the panel (Figure 3, Supplementary Video 1).

It is plausible that pigs would push from the other side relatively quickly in the UUS condition even if they are body aware, simply because they resort to an alternative strategy when the panel is blocked for a reason unknown to them. Nevertheless, it is also possible that pigs differentiate between their body clearly being the obstacle (when they feel the tugging of the mat) and an unknown obstacle (no tugging and no visible obstacle). That is, pigs might give up (i.e., stop pushing and/or leave the apparatus) earlier, and hence not push from the other side or push later than in the A condition, if they cannot identify the obstacle but at the same time can rule out their body as the source of the obstruction. Consequently, a difference between the A and UUS condition would provide even stronger evidence for pigs' recognition of their body as an obstacle, while a lack of difference would not allow us to unambiguously conclude whether pigs are body aware.

Figure 3

Pictures of the Body Awareness Apparatus in the Unsolvable Conditions



Note. Apparatus in the KUS and UUS condition. **a**) Front view of the apparatus in the KUS condition with two blue blocks rendering the task unsolvable. The obstacles were visible and hence the cause of the obstruction was presumably identifiable for the pigs. Despite the mat being present in the KUS condition, it is not depicted here. **b)** Top view of the blue blocks inside the apparatus. **c**) Front view of the apparatus in the UUS condition with the cardboard box blocking the panel; the circle indicates the position of the cardboard box. **d**) Top view of the cardboard box inside the apparatus. Note that the chain visible in these pictures was not the one used to attach the mat to the panel but the chain with which the experimenter opened the cover.

Food Discomfort Condition ("FD")

Finally, the foot discomfort condition addressed another possibility, namely that the pressure perceived underneath pigs' feet when pushing the panel in the attached condition is what drives them off the mat. To control for this, a so-called foot discomfort condition was included, which is in line with the study design used for both elephants (Dale & Plotnik, 2017) and dogs (Lenkei et al., 2021). In our version of the foot discomfort condition, subjects were standing on the mat in front of the closed apparatus (hence, the panel was inaccessible and no reward could be obtained) while the experimenter gently tugged at the mat (see Supplementary Video 1). To be able to accurately mimic the mat's movement (in the attached condition) with her pulling, it was necessary for the experimenter to know the amount of force with which pigs would push the panel in the attached condition. For this purpose, we conducted a pre-test (see Supplementary Material 3) with a subset of pigs from the pilot group in which the experimenter used a crane scale (Mini Crane Scale Model WH – C300 Series by ColeMeter) to measure the pigs' force.

Later, in the test, she used the same scale to keep her own pulling at this value, i.e., 25,000 N, for all individuals. The experimenter tugged at the mat approximately 2-3 times per second. As soon as the pig stepped off, the experimenter stopped pulling, but continued to move the scale and chain, to prevent the mat from being pulled into the apparatus.

Foot Discomfort Control Condition ("FDC")

All other conditions differed from the FD condition in several regards (e.g., accessibility of the panel, position of the experimenter) and to be able to preserve the essence of the FD condition, we did not consider it useful to eradicate these differences. For example, we opted against letting pigs interact with the panel or giving them another distraction task (similar to Dale & Plotnik, 2017), as this might have distorted pigs' willingness to stay on the mat even in the presence of foot discomfort. Therefore, instead of comparing the FD condition with the very different A condition, we compared it with a foot discomfort control condition which we developed to be able to isolate the factor of foot discomfort and its potential to drive pigs off the mat. That is, in both the FD and the FDC condition, pigs' motivation to stay in front of the apparatus was limited by the fact that there was no task to be solved. The only difference between the FD condition and the FDC condition consisted in the presence or absence of a tugging force on the mat. Even though we decided against directly comparing the FD condition with the A condition, the insights gained from the FD-FDC comparison allowed us to infer whether or not foot discomfort might have influenced pigs' behavior also in the A condition. Noteworthily, we assumed that pigs would be even more likely to step off the mat because of foot discomfort if there is no task to distract them and keep them on the mat (FD condition) than when their discomfort is potentially overridden by their motivation to interact with the panel (A condition). In other words, if pigs' behavior is not influenced by foot discomfort in the FD condition, we can conclude that their behavior in the A condition is even less likely to be influenced by foot discomfort.

In the FDC condition, pigs were positioned on the mat in front of the closed apparatus, just as in the FD condition. However, in contrast to the FD condition, the experimenter merely pretended to tug at the mat without exerting any force on the mat (see Supplementary Video 1). To do so, she attached a loose chain to the scale and let it hang into the apparatus (hence, subjects could not see that the other end was not attached to the mat). She then moved the scale and chain in a way that mimicked the movements and sounds in the FD condition at the same rate as in the FD condition. If the pigs perceive the movement of the mat in the FD condition (and, presumably, the attached condition) as uncomfortable, their latency to step off should be shorter in the FD condition than in the FDC condition. If, on the other hand, pigs' latency to step off does not differ between the FD condition and the FDC condition, we would conclude that discomfort evoked by the tugging of the mat is not the only factor causing pigs to step off the mat in the FD condition and, consequently, also not the only factor causing them to step off and push from the other side in the A condition.

Behavior Coding

The timepoints in the video at which each of the behaviors explained in Table 1 occurred were manually extracted from the video recordings. Based on the time points and the relations between them, the variables explained in the analysis section were calculated.

Table 1

Ethogram Including the Experimental Conditions in Which Each Behavior Could be Coded

Behavior/Event	Definition	Condition
Start of the trial	The second in which the cover is fully up	A, UA, KUS, UUS
Start of the trial (FD)	The second in which the experimenter starts to pull at the chain	FD, FDC
End of the trial	A trial ended when a) 30 s had passed since the beginning of the trial, b) the cover was erroneously closed prematurely or c) the experimenter stopped pulling at the chain in the FD and FDC conditions. The trial continued even after the pig had succeeded (A and UA condition).	all
First pushing attempt before stepping off	Pig visibly pushes the panel with its snout (normally the movement of the panel can directly be observed); this is only recorded if it happens on the mat side, i.e., before stepping off with the front legs for the first time (the wooden middle barrier depicted in Fig. 1c served as a marker to separate the two positions)	A, UA, KUS, UUS[1]
Last pushing attempt before stepping off	The last time the pig's nose touches the panel on the mat side before the pig steps off with its front legs for the first time	A, UA, KUS, UUS[1]
Stepping off with the front legs	Pig removes the second front leg from the mat and steps off. This is only coded if it happens before the panel is pushed back (UA). The hind legs were not considered as they did not have to be on the mat to start a trial.	all
First pushing attempt after stepping off	The first time the pig pushes the panel with its snout from the other side (other side of the wooden barrier) after the first time it steps off the mat with its front legs	A, KUS, UUS[1, 2]
Success	Pig successfully pushes the panel far enough to be able to reach all of the food	A, UA
Inspecting the back of the panel	Pig stretches its head far enough to reach the back end of the panel with its snout. For this the pig may need to stand or lie on the panel. This is only coded before the pig pushes from the other side.	A, UA, KUS, UUS

Note. [1] Even when the chain (and, consequently, pigs' weight on the mat) or external obstacles made it impossible to push the panel all the way to the back, the panel could nevertheless be pushed approximately 2 cm, which was visible to the video coders. [2] Note that, even if theoretically possible also in the UA condition, pigs always solved the UA condition upon their first pushing attempt, i.e., from the mat side.

Statistical Analysis

All analyses were performed in R version 4.1.0 (R Core Team, 2021). All plots were created using the package *ggplot2* (version 3.3.5, Wickham, 2016) and/or the package *survminer* (version 0.4.9, Kassambra et al., 2021). For each of the models described below, to investigate the effect of condition on the response variable while avoiding cryptic multiple testing (Forstmeier & Schielzeth, 2011), we compared the full model with a model lacking condition (the predictor of interest) but resembling the full model in all other aspects, which we hereinafter refer to as "null model". For each full-null model comparison, we calculated a likelihood-ratio test (anova.merMod function, *lme4* R package (version 1.1.27.1, Bates et al., 2015)) to detect significant differences in the variance explained by the two models. Chi-squared, degrees of freedom, and the p-value of each comparison are reported in the results section. In case of significance, we performed pairwise post-hoc comparisons using the functions emmeans and pairs in the R package *emmeans* (version 1.7.5, Lenth, 2022) to further investigate a significant effect of condition. The R codes and outputs for each model as well as an explanation of the variables and additional plots can be found in Supplementary Material 4.

Excluded Trials and Subjects

In addition to cases in which pigs ceased to participate or experimenter error led to the complete omission of trials, trials were excluded for the following reasons: a) the pig did not attempt to push from the mat side before stepping off (it could hence not know which condition it was confronted with, except for potentially the KUS condition) or b) the pig managed to solve the attached condition from the mat side (e.g., by standing between the mat and the adjacent fence with at least one front leg). Note that to prevent biases arising from the exclusion of trials a), we conducted an analysis to confirm that the number of these trials did not differ systematically across trials (see below).

Three out of 20 pigs were excluded before the test due to motivational issues or distress. Hence, 17 pigs (eight males, nine females) that all fulfilled the training criteria were tested.

Out of 816 planned test trials (12 trials on each of 4 days for each of 17 pigs), some needed to be excluded for various reasons. On day 1, one pig ceased to participate and could only complete seven (out of 12) test trials. Another 15 trials did not take place due to experimenter error leading to the omission of these trials. Twenty-three trials were excluded during the analysis as pigs did not attempt to push the panel from the mat side before stepping off. Furthermore, a total of four pigs managed to solve the attached trials from the mat side at least once, rendering these trials invalid. One individual did so four times, a second one two times and two more pigs in one trial each. For three of these pigs, this happened in their first test session. These invalid trials are not considered in the analyses of the first trials. The remaining 765 trials could be analyzed. Apart from the exceptions mentioned above, all pigs participated in the same number of trials (12 trials per day on each of 4 days).

Inter-Rater Reliability

A second observer independently coded 20% of the trials. To assess the agreement between the two observers, the intraclass correlation coefficient (ICC) was calculated separately for each of the behavioral variables used in the analysis, i.e., "stepping off with the front legs", "first pushing attempt after stepping off" and the frequency of "inspecting the back of the panel". Using the R package IRR (version 0.84.1, Gamer et al., 2019), the agreement of the two observers was assessed in a two-way model. In addition, Fleiss' Kappa (κ) was calculated (kappam.fleiss function of the IRR package) to assess the reliability between the two observers for the occurrence (0 or 1) of "first pushing attempt before stepping off", "stepping off with the front legs", and "first pushing attempt after stepping off".

Reliability was excellent for the frequency of inspecting the back of the panel (ICC = 0.947, $p < .001$) as well as the time points of stepping off with the front legs (ICC = 0.943, $p < .001$), and first pushing attempt after stepping off (ICC = 0.926, $p < .0001$). Similarly, the agreement for the occurrence of stepping off with the front legs ($\kappa = 0.935$, $p < .0001$) and first pushing attempt after stepping off ($\kappa = 0.939$, $p < .001$) was excellent. All values for the occurrence of first pushing attempt before stepping off were identical between the two raters, therefore, reliability analysis was not conducted.

Probability of Pushing from the Mat Side Before Stepping Off

One of the exclusion criteria listed above is a pig's failure to attempt to push the panel from the mat side before stepping off. To avoid systematically excluding trials of a certain condition due to an overlooked pattern in the pigs' behavior (e.g., because they were more likely to refrain from pushing on the mat side in the known unsolvable condition), we wanted to check whether condition had a significant influence on this probability. Note that only conditions in which the panel was accessible, i.e., not the FD condition and the FDC condition, could be considered.

For this purpose, we fitted a GLMM with a binomial distribution. The fixed effects were condition (A, UA, KUS, or UUS), condition order (number of trials within a session, i.e., 1–12; z-transformed), and day (z-transformed). Subject and sow (litter from which each subject was taken) were included as random effects. To additionally reduce the risk of over-confident estimates due to pseudo-replication (Schielzeth & Forstmeier, 2009), we also included the random slopes of condition order, day, and condition (manually dummy coded and centered) within the random effects of subject and sow. The model was fitted using the glmer function of the *lme4* R package (version 1.1.27.1, Bates et al., 2015). The correlations between the random slopes and random intercepts were close to 1 or -1, indicating that they were unidentifiable (Matuschek et al., 2017), and were therefore excluded from the model. To assess collinearity among fixed effects, we employed the vif function of the R package *rms* (version 6.3.0, Harrell, 2022). There was no substantial collinearity among the fixed effects (all variable inflation factors < 1.532). Model stability on the level of the estimated coefficients and standard deviations was assessed by excluding the levels of the random effects one by one (Nieuwenhuis et al., 2012) using a function kindly provided by Roger Mundry. As can be seen in Figure S8 in Supplementary Material 4, stability was very good for the random effect of subject and the fixed effects; it was acceptable for the random effect of sow and the intercept. The analysis included 520 trials across 17 subjects and nine sows.

Probability of Pushing From the Other Side

To gain insights into pigs' motivation behind stepping off, we compared the probability of attempting to push the panel from the other side after stepping off with the front legs between the attached and unsolvable conditions (KUS and UUS). We deliberately decided against comparing the probability of *stepping off the mat* – and/or the latency to do so – between the A condition and the unsolvable conditions as we do not deem stepping off a reliable behavioral indicator of body awareness. More precisely, there are at least two reasons why pigs might step off the mat in conditions in which the task is not solvable from the mat side. On the one hand, pigs might step off to try to push the panel from the other side (as expected in the attached condition if pigs recognize their body as an obstacle). On the other hand, however, pigs might also step off to leave the apparatus and give up without pushing from the other side (as expected in the unsolvable conditions if pigs understand that the task is unsolvable also from the other side). To disentangle these two explanations for the pigs' stepping off, it is more informative to focus on whether – and when – the behavior of interest (pushing from the other side) occurred after pigs had stepped off. Note that the probability of pushing from the other side also implicitly includes information about whether or not pigs stepped off the mat (at least for the more relevant one of the two reasons mentioned above) because pigs could not push the panel from the other side without stepping off the mat with the front legs.

To analyze the probability of pushing from the other side after stepping off, we fitted a Generalized Linear Mixed Effects Model with a binomial distribution, following the same procedures and including the same fixed and random effects as described for the probability of pushing from the mat side before stepping off. However, only the conditions A, KUS, and UUS but not the UA condition were relevant in this analysis. The correlations between the random slopes and random intercepts were close to 1 or -1, indicating that they were unidentifiable, and were therefore excluded from the model. No collinearity among the fixed effects was detected (all variable inflation factors < 1.528). Model stability was very good or good for the fixed effects, the random effect of sow, and the intercept. It was acceptable for the random effect of subject (see Figure S9). The model included 357 trials across 17 subjects and nine sows.

Frequency of Inspecting the Back of the Panel

As we were interested in whether pigs would be more likely to look for an external obstacle behind the panel in the KUS condition and the UUS condition than in the A condition (in which the obstacle was *in front* of the panel, on the mat), we compared the frequency of inspecting the back of the panel across these three conditions. As this behavior can only be performed as long as the panel is in the starting position, it is inherently less likely to occur in the attached condition that is, in principle, solvable. Therefore, we only considered the time *before* the subject tried to push the panel from the other side in each trial and counted every instance of "inspecting the back of the panel". The frequency per trial then acted as the response variable in a GLMM with a Poisson distribution with the same fixed and random effects as for the other models. Additionally, the log-transformed latency to push from the other side from the start of the trial was included as an offset term to control for differences in the amount of time during which the behavior could occur (i.e., if the latency to push from the other side is generally longer in one condition, the probability of counting a behavior that can only be shown before pushing from the other side, is inherently higher). The correlations between random slopes and random intercepts were equal or very close to 1 or -1, which is why we removed these correlations. Overdispersion was assessed using the overdisp_fun function (Bolker, 2022). The model was not overdispersed (dispersion parameter = 0.686) and the fixed effects were found to not be collinear (all variable inflation factors < 1.528). Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat. As can be seen in Figure S11, stability was acceptable for the fixed effect of condition and the random effect of subject. Stability was good or very good for all other fixed and random effects as well as for the intercept. However, the range of the intercept was extreme. The analysis included 370 trials across 17 subjects and nine sows.

Latency to Push from the Other Side After Stepping Off

We calculated subjects' latency to attempt to push the panel from the other side after stepping off with their front legs based on the time points specified in Table 1. Trials in which the pig never stepped off were assigned a latency of 30 s. We compared the resulting latency across the A condition, in which the task was solvable from the non-mat side, and the unsolvable conditions (KUS and UUS), in which pushing from the other side was always futile. To do so, a Cox Mixed Effects Model (R package *coxme*, version 2.2-16, Therneau, 2020) was fitted. The same fixed and random effects were used as for the model analyzing the probability of pushing from the other side (see above), with the exception that only day (z-transformed) could be included as a random slope for the random intercepts of subject and sow. The fixed effects were found to not be collinear (all variable inflation factors < 1.327). Model stability on the level of the estimated coefficients and standard deviations was assessed by excluding the levels of the random effects one by one (Nieuwenhuis et al., 2012). As for all Cox models in this study, correlations within random effects were excluded for the model stability analysis. As can be seen in Figure S12, stability for all fixed and random effects was very good. The analysis included 357 trials across 17 subjects and nine sows.

Foot Discomfort: Latency to Step Off

To precisely analyze the influence of foot discomfort, we compared the latency to step off the mat with the front legs between the FD condition (in which the experimenter pulled at the mat) and the FDC condition (in which the experimenter merely pretended to pull). The latency was counted from the start of the trial. Trials in which the subject never stepped off were assigned a latency of 30 s. As for the other latencies, a Cox Mixed Effects Model was fitted. The same fixed effects, random effects and random slopes as for the Cox model outlined above were used. No collinearity among fixed effects was detected (all variable inflation factors < 1.002). The model was based on 268 trials across 17 subjects and nine sows.

Unlike the latency to step off, we did not compare the probability of stepping off the mat between the FD and the FDC condition as the number of trials in which this did not happen was too low for a conclusive analysis (3 FD trials and 2 FDC trials).

Results

Descriptive Statistics

Pigs always succeeded when they attempted to push the panel in the unattached condition (122 valid unattached trials). That is, they always pushed the panel far enough to be able to access all the food rewards. However, unlike in the pilot study (Supplementary Material 1), the pigs' success with the attached condition was only at 52% (63 out of 121 trials, 16 out of 17 subjects succeeded at least once).

Pigs stepped off the mat with the front legs in 94% (114 out of 121 trials) of the attached trials. Note that they did not always succeed after stepping off as, even when pigs pushed from the other side, their hind legs were sometimes still on the mat. Nevertheless, stepping off with the front legs still allowed them to push from the other side, which is why this behavior is more informative than stepping off with the last (hind) leg. Pigs also frequently stepped off the mat with the front legs in the other conditions: They did so in 97% (124 out of 128 trials) of the UUS trials, 95% (120 out of 126 trials) of the KUS trials, 98% (131 out of 134 trials) of the FD trials and 96% (132 out of 137 trials) of the FDC trials. Note that UA trials in which the pig stepped off before pushing from the other side were excluded as pushing from the mat side was very likely to lead to success in this condition, hence, in valid UA trials, pigs never stepped off before succeeding.

Probability of Pushing From the Mat Side Before Stepping Off

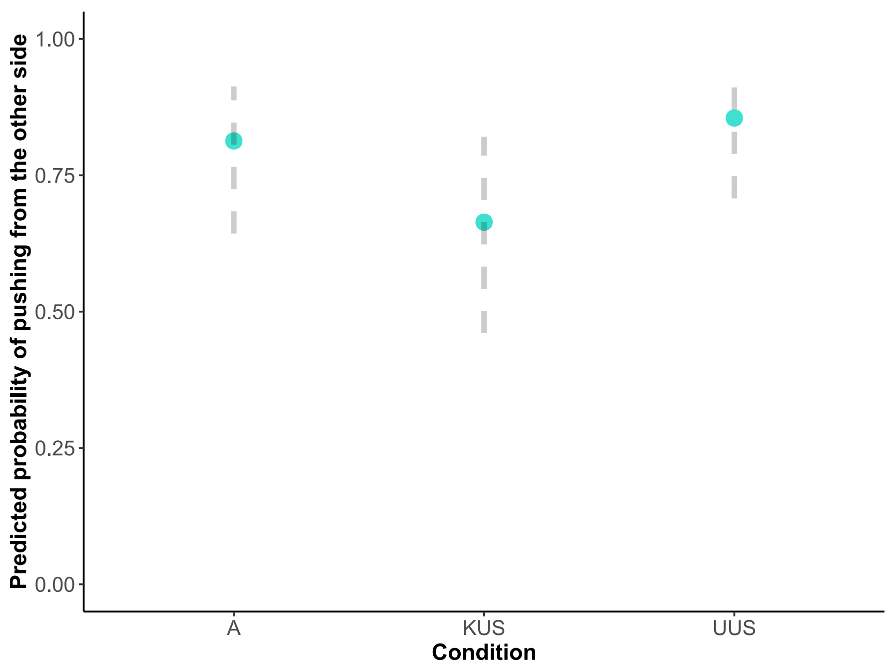
The probability of pushing from the mat side before stepping off, or refraining from doing so (leading to the exclusion of the trial), was not significantly influenced by the condition (full-null model comparison: $\chi^2 = 0.18$, $df = 3$, $p = .981$, see Figure S7).

Probability of Pushing From the Other Side After Stepping Off

The probability of pushing from the other side after stepping off was significantly influenced by the test condition (full-null model comparison: $\chi^2 = 9.46$, $df = 2$, $p = .009$; Figure 4, for full model output see Table S4). The pairwise post-hoc tests revealed that pigs were less likely to push from the other side in the KUS condition than in both the A condition ($p = .046$) and the UUS ($p = .003$) condition, whereas the difference between A and UUS did not reach statistical significance ($p = .661$), see Table S5.

Figure 4

Probability of Pushing from the Other Side



Note. Predicted probabilities of pushing the panel from the other side after stepping off across conditions (attached = "A", known unsolvable = "KUS", unknown unsolvable = "UUS"). Dashed lines indicate the 95% confidence intervals

Frequency of Inspecting the Back of the Panel

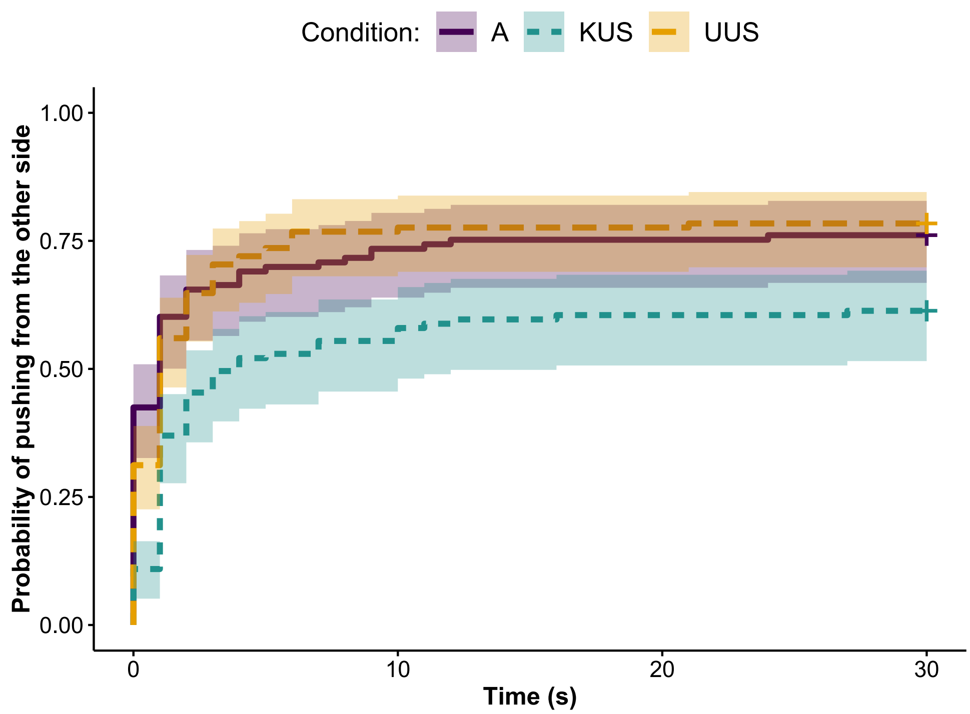
The frequency of inspecting the back of the panel varied significantly across conditions (full-null model comparison: $\chi^2 = 22.26$, $df = 2$, $p < .001$; for full model output see Table S6). Subjects looked behind the panel more often in the KUS condition than in both other conditions (Figure S10). This was confirmed by the post-hoc pairwise comparisons that revealed that both the condition pairs A – KUS ($p < .001$) and UUS – KUS ($p < .001$) differed significantly (Table S7).

Latency to Push From the Other Side After Stepping Off

Pigs were significantly slower to push from the other side after stepping off with the front legs if the task was visibly unsolvable (full-null model comparison: $\chi^2 = 20.66$, $df = 2$, $p < .001$; for full model output see Table S8). That is, both the comparisons between A – KUS ($p < .001$) and KUS – UUS ($p < .001$) were highly significant, whereas no significant difference between the A condition and the UUS condition was detectable ($p > .99$; see Figure 5 and Table S9).

Figure 5

Latency Push from the Other Side



Note. Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time in the attached condition ("A", solid line), known unsolvable condition ("KUS", dashed line), and unknown unsolvable ("UUS", long-dashed line) condition. Crosses indicate trials in which pigs had not pushed from the other side by the end of the trial

Latency to Step Off From the Start of the Trial in the FD Condition and the FDC Condition

When comparing the FD condition with the FDC condition, no significant difference in the latency to step off the mat with the front legs from the start of the trial emerged (full-null model comparison: $\chi^2 = 0.17$, $df = 1$, $p = .198$, see Figure S13).

Discussion

We found that pigs solved the attached condition, in which their body was an obstacle, and differentiated it from the known unsolvable condition, in which a visible external obstacle made the panel-pushing task unsolvable. In this respect, our evidence for body awareness in pigs is comparable to that obtained for dogs (Lenkei et al., 2021) and elephants (Dale & Plotnik, 2017). However, our study was the first to also include an unknown unsolvable condition. Unlike for the known unsolvable condition, pigs' behavior did not significantly differ from that shown in the attached condition when they could not see the external obstacle blocking the panel. Therefore, we cannot rule out the possibility that pigs switched strategies and thus accidentally succeeded in this body-as-an-obstacle task simply because they treated their body as though it were an unknown or unidentifiable obstacle.

In the attached condition, pigs demonstrated a large degree of behavioral flexibility by successfully pushing the panel from the other side in 52% of the trials (and 76% of the trials in the pilot study, Supplementary Material 1). After mastering the panel-pushing task with only a week of training with the apparatus, subjects spontaneously changed a learned response, i.e., pushing from the mat side, when their body was an obstacle. Moreover, pigs' success in the attached condition cannot be attributed to foot discomfort evoked by the mat's movement, as evidenced by the lack of a significant difference between the foot discomfort condition and the foot discomfort control condition.

Even more interestingly, the fact that pigs differentiated between the attached condition and the known unsolvable condition hints at a basic understanding of what caused the perceived obstruction in each of these conditions. This significant difference was also obtained in the pilot study (see Supplementary Material 1) with a different batch of pigs. Therefore, similar to the dogs in Lenkei et al. (2021), pigs differentiated between a condition solvable by recognizing their body as a physical obstacle and a visibly unsolvable condition. One could argue that these differences are the result of a potential distracting effect of the blue blocks in the KUS condition. However, such a distraction should not have only influenced pigs' propensity to push the panel from the other side after stepping off, but also their propensity to push from the mat side *before* stepping off. As no significant difference in the probability of pushing from the mat side before stepping off across conditions was detected, our conclusion – that pigs' differentiation reflects understanding rather than distraction – remains valid.

Despite the differentiation of conditions depending on whether an external obstacle was visible, pigs treated the attached condition as though it were unsolvable (from the mat side) for an unknown reason. Pigs were not significantly less likely or significantly slower to push from the other side after stepping off in the unknown unsolvable condition than in the attached condition. Moreover, they did not inspect the back of the apparatus more frequently when an inconspicuous cardboard box, and not their body's weight, was blocking the panel in the UUS condition. Therefore, pigs might not have solved the attached condition using body awareness but might instead have switched to an alternative strategy (i.e., pushing from the other side) in all cases in which the task was unsolvable from the mat side and no obvious reason for the obstruction could be identified. However, this was the first study to explore the possibility that pigs might not only differentiate between their body being an obstacle and visible external obstacles but also between their body and an unknown external obstacle. Whereas a significant difference between the A condition and the UUS condition would have provided strong evidence for pigs' body awareness, our results do not allow for definitive conclusions about the pigs' strategies in the body-as-an-obstacle task.

Even though the results obtained for dogs in Lenkei et al. (2021) show a less ambiguous contrast between an unsolvable condition and a body-as-an-obstacle condition than our results, one should be cautious in inferring that pigs' body awareness is inferior to dogs'. In fact, pigs solved the body-as-an-obstacle task, i.e., the attached condition, with a success rate comparable to dogs (at least in our pilot study, see Supplementary Material 1). The latter tried to pass the toy in 68% of the "test" trials (in which the toy was attached to the mat) after stepping off (27/32 dogs stepped off; Lenkei et al., 2021). Therefore, the difference between the species does not seem to lie in subjects' ability to solve a task in which their body is an obstacle but is rather attributable to dissimilarities in the way the unsolvable condition was implemented. That is, for both the unsolvable and the attached condition, the cues available to dogs (e.g., visual and tactile salience of the mat's movement) in Lenkei et al. (2021) were more informative than those that pigs had at their disposal. This also implies that Lenkei et al.'s unsolvable condition was more similar to our KUS condition (for which pigs *did* show a difference in the probability and latency to push from the other side compared with the attached condition) than to our unknown unsolvable condition. Note that a comparison with elephants is not possible, given that Dale and Plotnik (2017) did not conduct an unsolvable condition due to the strength of their subjects. In the future, dogs and other species could be tested in a body-as-an-obstacle task more comparable to our design (i.e., including an unknown unsolvable condition) to be able to draw inferences about differences in species' understanding of the body-as-an-obstacle task.

Apart from a lack of body awareness, pigs' treating the attached condition as unsolvable for an unknown reason could be attributed to shortcomings of the experimental design. First, the salience of the mat's movement was potentially insufficient for the pigs to perceive a difference between the A condition and the UUS condition. In contrast to previous body-as-an-obstacle tests (Bullock & Lütkenhaus, 1990; Dale & Plotnik, 2017; Geppert & Küster, 1983; Lenkei et al., 2021; Moore et al., 2007), our set-up only provided minimal visual cues when the mat was being tugged at. However, even if the visual cues had been more salient, pigs' low visual acuity (Zonderland et al., 2008) could have made it difficult for them to base their decisions on these cues. Additionally, the tactile cues were presumably less salient compared with the previous studies. That is, the movement of the mat in Lenkei et al. (2021) as well as in Dale and Plotnik (2017) must have followed a partly vertical path (since subjects lifted the front part of the mat with the toy/stick), rather than a horizontal one. In contrast, the mat in our set-up was dragged into the apparatus almost horizontally when the panel was pushed. Consequently, the pigs could have only felt the friction between the floor, the mat, and their feet, instead of the mat bending and moving upwards in front of/under their front legs. In conclusion, the potentially insufficient salience of the tugging in the attached condition could have led to the difference between the attached condition and the unknown unsolvable condition being minimal and not easily recognizable for the pigs.

A second constraint is that, in our set-up, pushing from the other side in the unsolvable conditions was not costly or disadvantageous but merely unnecessary. As a result, the costs of futilely pushing from the other side could have been too negligible for pigs to differentiate between the A condition and the UUS condition. This interpretation would be in line with human infants' apparent inability (or unwillingness) to correctly estimate an opening's size in relation to their body size if wrong choices result in entrapment rather than a more detrimental consequence, falling (Franchak & Adolph, 2012). Therefore, pigs might only differentiate between invisible external obstacles and bodily obstacles when the costs of wrong choices outweigh the additional effort or cost incurred by deliberating more carefully.

Another potential reason why we failed to observe a significant difference between the attached condition and the unknown unsolvable condition is the comparatively low success rate with the attached condition in the main study. In contrast to the pilot study (see Supplementary Material 1), pigs in the main study were only successful in 52% of the valid attached trials (as opposed to 76% in the pilot study). This was the case even though they stepped off the mat with their front legs, but did not necessarily push from the other side, in 94% of the trials. A reason for this discrepancy between studies could be the diverging number of conditions (four in the pilot study and six in the main study), leading to both a less favorable reward schedule (given that the KUS, UUS, FD and FDC condition were always unrewarded; see Denny, 1946) and an increase in session length and, presumably, complexity of the task in the main study. The frustration resulting from these factors may have affected pigs' decision-making (Van Rooijen & Metz, 1987; Wesley & Klopfer, 1962) and motivation to complete the task, thereby masking any potential differences between the attached condition and the unknown unsolvable condition in the main study.

Finally, it is possible that pigs are well able to differentiate between bodily and unknown external obstacles – but only once they reach a certain age. It would not be surprising if at the age of 7–8 weeks our pigs were still too young to recognize the difference between the attached condition and the unknown unsolvable condition, considering that self-awareness can be expected to develop gradually with age (de Waal, 2019). However, as in many previous studies on pigs (Gieling et al., 2011) it was unfeasible to test adult pigs in this first investigation of body awareness in pigs. In addition, we want to highlight that, despite their young age, pigs in our study did differentiate between their body and visible external obstacles blocking the panel, similar to adult dogs (Lenkei et al., 2021). Nevertheless, if sufficient financial and temporal resources are available, it would be desirable for future studies to focus on older, preferably adult, pigs.

What might, however, be more decisive to the development of body awareness than numerical age alone is the repeated exposure to situations in which individuals have the opportunity to perceive their body as an object. An argument in favor of an experience-driven emergence of body awareness can be made based on a comparison with other cognitive abilities and species. For instance, pigs' physical and social cognitive abilities were found to be dependent on individuals' previous experience and living environment

(Albiach-Serrano et al., 2012). The same seems to apply to the context of self-awareness: substantial cultural variation in human infants' mirror self-recognition has been reported (Broesch et al., 2011; Cebioğlu & Broesch, 2021) and even the chimpanzees in Gallup's original mirror mark experiment (Gallup, 1970) as well as in many subsequent studies (for a review see Kakrada & Colombo, 2022) only performed self- and mark-directed behaviors after sufficient exposure to a mirror. Therefore, pigs too might more clearly show body awareness if frequently exposed to situations in which they can come to understand their body's relation to other objects.

The insights gained from the current investigation can help researchers create more precise instruments to assess body awareness in pigs and other species. Apart from modifications of procedural details, such as test session length, number of conditions, and the desirability of testing older individuals, measures to make the movement of the mat more salient should be implemented. Also, if the current or a similar set-up including pre-defined positions to push the sliding panel is retained, caution must be taken to control for subjects' baseline tendency to switch sides – regardless of the type of obstacle (external or bodily). For example, the two positions could be placed farther apart to increase the costs of wrong choices, or more than two positions could be offered. Ultimately, it would be worthwhile to also test previously researched species, i.e., humans, elephants, and dogs, in a body-as-an-obstacle task more comparable to that for pigs or vice versa. Otherwise, no clear conclusions about potential species differences can be drawn. In particular, including an unknown unsolvable condition in our study proved to be an insightful extension of previous designs. For the moment, it can be concluded that, despite being unable to eliminate all potentially confounding factors, our newly developed body-as-an-obstacle task has significantly contributed to the identification of pitfalls associated with body awareness tests in non-human animals.

Conclusion

The present study has introduced a new variation of the body-as-an-obstacle task applicable to pigs and potentially other species unlikely to pass an object to an experimenter. Even though pigs demonstrated a high degree of behavioral flexibility and solved a condition in which their body was an obstacle, body awareness could not unambiguously be shown when controlling for alternative strategies. While subjects seemingly noticed the presence of visible external obstacles, they failed to differentiate between their body being an obstacle and a hidden external obstacle in a novel control condition. That is, pigs behaved as though the reason the panel could not be pushed from the mat side in the attached condition was unknown to them. Nevertheless, we cannot conclude that pigs are not body aware; nor can we conclude that pigs' understanding of their body as an obstacle is inferior to that of previously tested species, as our study was the only one to apply such strict criteria by also including an unknown unsolvable condition. Therefore, designing body-as-an-obstacle tasks that are comparable across species and convincingly control for subjects' reactions to unknown non-bodily obstacles is the next step towards elucidating the mechanisms and the evolution of body awareness.

Acknowledgements

We thank Christian Haberl and Karl Resch for building the experimental apparatus, Melanie Minichberger for coding videos for the inter-rater reliability assessment, Katharina Kreml for administrative assistance as well as Doris Verhovsek and the staff at the Vetfarm Medau for their support in caring for and testing the pigs.

Author Contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by K.B. and J.McG. The research was supervised by J.McG. and J.-L.R. The first draft of the manuscript was written by K.B. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding: No funding was received for conducting this study.

Conflict of Interest: The authors have no competing interests to declare that are relevant to the content of this article.

Data Availability: The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

References

Albiach-Serrano, A., Bräuer, J., Cacchione, T., Zickert, N., Amici, F. (2012). The effect of domestication and ontogeny in swine cognition (*Sus scrofa scrofa* and *S. s. domestica*). *Applied Animal Behaviour Science, 141,* 25–35. https://doi.org/10.1016/j.applanim.2012.07.005

Baragli, P., Scopa, C., Maglieri, V., Palagi, E. (2021). If horses had toes: demonstrating mirror self recognition at group level in *Equus caballus*. *Animal Cognition, 24,* 1099–1108. https://doi.org/10.1007/s10071-021-01502-7

Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Staistical Software, 67*, 1–48. https://doi.org/10.18637/jss.v067.i01

Bekoff, M., & Sherman, P. (2004). Reflections on animal selves. *Trends in Ecology & Evolution*, *19*(4), 176–180. https://doi.org/10.1016/J.TREE.2003.12.010

Bolker. (2022). Overdispersion: Testing for overdispersion/computing overdispersion factor. Github GLMM FAQ. https://bbolker.github.io/mixedmodels-misc/glmmFAQ.html#overdispersion (accessed: 9th of August 2023)

Broesch, T., Callaghan, T., Henrich, J., Murphy, C., & Rochat, P. (2011). Cultural variations in children's mirror self-recognition. *Journal of Cross-Cultural Psychology*, *42*(6), 1018–1029. https://doi.org/10.1177/0022022110381114

Broom, D. M., Sena, H., & Moynihan, K. L. (2009). Pigs learn what a mirror image represents and use it to obtain information. *Animal Behaviour*, *78*(5), 1037–1041. https://doi.org/10.1016/j.anbehav.2009.07.027

Brownell, C. A., Zerwas, S., & Ramani, G. B. (2007). "So big": The development of body self-awareness in toddlers. *Child Development*, *78*(5), 1426–1440. https://doi.org/10.1111/j.1467-8624.2007.01075.x

Bullock, M., Lütkenhaus, P. (1990). Who am I? Self-understanding in toddlers. *Merrill-Palmer Quarterly*, *36,* 217–238. http://www.jstor.org/stable/23087232

Cebioğlu, S., & Broesch, T. (2021). Explaining cross-cultural variation in mirror self-recognition: New insights into the ontogeny of objective self-awareness. *Developmental Psychology*, *57*(5), 625–638. https://doi.org/10.1037/dev0001171

Croney, C., Boysen, S. (2021). Acquisition of a joystick-operated video task by pigs (*Sus scrofa*). *Frontiers in Psychoology*, *12,* 631755. https://doi.org/10.3389/fpsyg.2021.631755

Crook, J. H. (1980). *The Evolution of Human Consciousness*. Oxford University Press.

Curtis, S. (1983). Perception of thermal comfort by farm animals. In J. E. Martin, S. H. Ison, & E. M. Baxter (Eds.), *Farm Animal Housing and Welfare* (Vol. 163, pp. 59–67). Martinus Nijhoff Publishers. https://www.sciencedirect.com/science/article/pii/S0168159114003098

Dale, R., & Plotnik, J. M. (2017). Elephants know when their bodies are obstacles to success in a novel transfer task. *Scientific Reports*, *7*(1), 46309. https://doi.org/10.1038/srep46309

Damasio, A. (2003). Mental self: The person within. *Nature*, *423*, 227. https://doi.org/10.1038/423227a

De Veer, M. W., & van den Bos, R. (1999). A critical review of methodology and interpretation of mirror self-recognition research in nonhuman primates. *Animal Behaviour*, *58*(3), 459–468. https://doi.org/10.1006/anbe.1999.1166

de Waal, F.B.M. (2019). Fish, mirrors, and a gradualist perspective on self-awareness. *PLoS Biology*, *17,* e3000112. https://doi.org/10.1371/journal.pbio.3000112

Denny, M. R. (1946). The role of secondary reinforcement in a partial reinforcement learning situation. *Journal of Experimental Psychology*, *36*(5), 373–389. https://doi.org/10.1037/h0056389

Duval, S., & Wicklund, R. A. (1972). *A Theory of Objective Self Awareness*. Academic Press.

Forstmeier, W., & Schielzeth, H. (2011). Cryptic multiple hypotheses testing in linear models: Overestimated effect sizes and the winner's curse. *Behavioral Ecology and Sociobiology*, *65*(1), 47–55. https://doi.org/10.1007/s00265-010-1038-5

Franchak, J. M., & Adolph, K. E. (2012). What infants know and what they do: Perceiving possibilities for walking through openings. *Developmental Psychology*, *48*(5), 1254–1261. https://doi.org/10.1037/a0027530

Gallup, G. G. (1970). Chimpanzees: Self-recognition. *Science*, *167*(3914), 86–87. https://doi.org/10.1126/science.167.3914.86

Gallup, G. G. (1998). Self-awareness and the evolution of social intelligence. *Behavioural Processes*, *42*(2), 239–247. https://doi.org/10.1016/S0376-6357(97)00079-X

Gamer, M., Lemon, J., Singh, I.F.P. (2019). Various Coefficients of Interrater Reliability and Agreement. R packages version 0.84.1. https://CRAN.R-project.org/package=irr (accessed: 27th of August 2022)

Geppert, U., & Küster, U. (1983). The emergence of "wanting to do it oneself": A precursor of achievement motivation. *International Journal of Behavioral Development*, *6*(3), 355–369. https://doi.org/10.1177/016502548300600305

Gieling, E. T., Mijdam, E., van der Staay, F. J., & Nordquist, R. E. (2014). Lack of mirror use by pigs to locate food. *Applied Animal Behaviour Science*, *154*, 22–29. https://doi.org/10.1016/j.applanim.2014.02.016

Gieling, E. T., Nordquist, R. E., & van der Staay, F. J. (2011). Assessing learning and memory in pigs. *Animal Cognition*, *14*(2), 151–173. https://doi.org/10.1007/s10071-010-0364-3

Harrell, F. (2022). rms: Regression Modeling Strategies. R package version 6.3-0. https://CRAN.R-project.org/package=rms (accessed: 9th of September 2022)

Held, S., Byrne, R., Jones, S., Murphy, E., Friel, M., Mendl, M. (2010). Domestic pigs, *Sus scrofa*, adjust their foraging behaviour to whom they are foraging with. *Animal Behaviour*, *79*, 857–862. https://doi.org/10.1016/j.anbehav.2009.12.035

Held, S., Mendl, M., Devereux, C., & Byrne, R. W. (2000). Social tactics of pigs in a competitive foraging task: The 'informed forager' paradigm. *Animal Behaviour*, *59*(3), 569–576. https://doi.org/10.1006/anbe.1999.1322

Held, S., Mendl, M., Devereux, C., Byrne, R.W. (2001). Behaviour of domestic pigs in a visual perspective taking task. *Behaviour, 138*, 1337–1354. https://doi.org/10.1163/156853901317367627

Held, S., Mendl, M., Devereux, C., & Byrne, R. W. (2002). Foraging pigs alter their behaviour in response to exploitation. *Animal Behaviour*, *64*(2), 157–165. https://doi.org/10.1006/anbe.2002.3044

Herskin, M.S., Bundgaard, C.J., Ottesen, J.L., Sørensen, D.B., Marchant-Forde, J.N. (2020). The Pig, in: D. B. Sørensen, S. Cloutier, & B. N. Gaskill (Eds.), *Animal-centric Care and Management*. CRC Press. https://doi.org/10.1201/9780429059544

Johnson, A. K., Barnacz, A., Yokkaichi, T., Rubio, J., Racioppi, C., Shackelford, T. K., Fisher, M. L., & Keenan, J. P. (2005). Me, myself, and lie: The role of self-awareness in deception. *Personality and Individual Differences*, *38*(8), 1847–1853. https://doi.org/10.1016/j.paid.2004.11.013

Jønholt, L., Bundgaard, C. J., Carlsen, M., & Sørensen, D. B. (2021). A case study on the behavioural effect of positive reinforcement training in a novel task participation test in Göttingen mini pigs. *Animals*, *11*(6), Article 6, 1610. https://doi.org/10.3390/ani11061610

Kakrada, E., & Colombo, M. (2022). Mirror mirror on the wall, it's not the mark I care about at all. *Learning and Motivation*, *77*, 101785. https://doi.org/10.1016/j.lmot.2022.101785

Kassambra, A., Kosinki, M., Biecek, P. (2021). survminer: Drawing Survival Curves using "ggplot2". R package version 0.4.9. https://CRAN.R-project.org/package=survminer (accessed: 15th of November 2022)

Khvatov, I. A., Sokolov, A. yu, & Kharitonov, A. (2021). Rats may take into account their own body weight. *Experimental Psychology (Russia)*, *14*, 40–49. https://doi.org/10.17759/exppsy.2021140303

Khvatov, I.A., Sokolov, Kharitonov, A. (2019). Snakes *Elaphe Radiata* may acquire awareness of their body limits when trying to hide in a shelter. *Behavioral Sciences, 9*, 67. https://doi.org/10.3390/bs9070067

Koba, Y., & Tanida, H. (2001). How do miniature pigs discriminate between people?: Discrimination between people wearing coveralls of the same colour. *Applied Animal Behaviour Science*, *73*(1), 45–58. https://doi.org/10.1016/S0168-1591(01)00106-X

Koglmüller, M., Wondrak, M., Camerlink, I., Rault, J.-L., Huber, L. (2021). Are free-ranging Kune Kune pigs (*Sus scrofa domesticus*) able to solve a cooperative task? *Applied Animal Behaviour Science, 240,* 105340. https://doi.org/10.1016/j.applanim.2021.105340

Kohda, M., Hotta, T., Takeyama, T., Awata, S., Tanaka, H., Asai, J., Jordan, A.L. (2019). If a fish can pass the mark test, what are the implications for consciousness and self-awareness testing in animals? *PLoS Biology, 17*, e3000021. https://doi.org/10.1371/journal.pbio.3000021

Kouwenberg, A.-L., Walsh, C.J., Morgan, B.E., Martin, G.M. (2009). Episodic-like memory in crossbred Yucatan minipigs (*Sus scrofa*). *Applied Animal Behaviour Science, 117*, 165–172. https://doi.org/10.1016/j.applanim.2009.01.005

Krachun, C., Lurz, R., Mahovetz, L. M., & Hopkins, W. D. (2019). Mirror self-recognition and its relationship to social cognition in chimpanzees. *Animal Cognition*, *22*(6), 1171–1183. https://doi.org/10.1007/s10071-019-01309-7

Lage, C. A., Wolmarans, D. W., & Mograbi, D. C. (2022). An evolutionary view of self-awareness. *Behavioural Processes*, *194*, 104543. https://doi.org/10.1016/j.beproc.2021.104543

Lenkei, R., Faragó, T., Kovács, D., Zsilák, B., & Pongrácz, P. (2020). That dog won't fit: Body size awareness in dogs. *Animal Cognition*, *23*(2), 337–350. https://doi.org/10.1007/s10071-019-01337-3

Lenkei, R., Faragó, T., Zsilák, B., Pongrácz, P. (2021). Dogs (*Canis familiaris*) recognize their own body as a physical obstacle. *Scientific Reports, 11,* 2761. https://doi.org/10.1038/s41598-021-82309-x

Lenth, R.V. (2022). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.7.5. https://CRAN.R-project.org/package=emmeans (accessed: 27th of August 2022)

Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., & Bates, D. (2017). Balancing Type I error and power in linear mixed models. *Journal of Memory and Language*, *94*, 305–315. https://doi.org/10.1016/j.jml.2017.01.001

McLeman, M., Mendl, M., Jones, B., White, R., Wathes, C. (2005). Discrimination of conspecifics by juvenile domestic pigs, *Sus scrofa*. *Animal Behaviour, 70*, 451–461. https://doi.org/10.1016/j.anbehav.2004.11.013

Moore, C., Mealiea, J., Garon, N., & Povinelli, D. J. (2007). The development of body self-awareness. *Infancy*, *11*(2), 157–174. https://doi.org/10.1111/j.1532-7078.2007.tb00220.x

Morin, A. (2011). Self-Awareness part 1: Definition, measures, effects, functions, and antecedents. *Social and Personality Psychology Compass*, *5*(10), 807–823. https://doi.org/10.1111/j.1751-9004.2011.00387.x

Morrison, R., Reiss, D. (2018). Precocious development of self-awareness in dolphins. *PLoS One, 13*, e0189813. https://doi.org/10.1371/journal.pone.0189813

Neitz, J., & Jacobs, G. (1989). Spectral sensitivity of cones in an ungulate. *Visual Neuroscience*, *2*, 97–100. https://doi.org/10.1017/S0952523800011949

Nestelberger, M. (2019). *Problem-solving ability in free ranging Kune Kune pigs (*Sus scrofa domesticus*) according to their position in the social network* (Master's thesis). Vienna, Austria: University of Veterinary Medicine Vienna. Retrieved from: https://www.vetmeduni.ac.at/hochschulschriften/diplomarbeiten/AC15605254.pdf (accessed: 14th of June 2022)

Nicol, C. J., & Pope, S. J. (1994). Social learning in sibling pigs. *Applied Animal Behaviour Science*, *40*(1), 31–43. https://doi.org/10.1016/0168-1591(94)90085-X

Nieuwenhuis, R., Grotenhuis, M. te, Pelzer, B. (2012). influence.ME: Tools for detecting influential data in mixed effects models. *The R Journal, 4,* 38–47. https://doi.org/10.32614/RJ-2012-011

Oostindjer, M., Bolhuis, J. E., Mendl, M., Held, S., van den Brand, H., & Kemp, B. (2011). Learning how to eat like a pig: Effectiveness of mechanisms for vertical social learning in piglets. *Animal Behaviour*, *82*(3), 503–511. https://doi.org/10.1016/j.anbehav.2011.05.031

Plotnik, J. M., Waal, F. B. M. de, & Reiss, D. (2006). Self-recognition in an Asian elephant. *Proceedings of the National Academy of Sciences*, *103*(45), 17053–17057. https://doi.org/10.1073/pnas.0608062103

Povinelli, D., & Cant, J. (1996). Arboreal clambering and the evolution of self-conception. *The Quarterly Review of Biology*, *70*, 393–421. https://doi.org/10.1086/419170

Povinelli, D., Gallup, G. G., Eddy, T. J., Bierschwale, D. T., Engstrom, M. C., Perilloux, H. K., & Toxopeus, I. B. (1997). Chimpanzees recognize themselves in mirrors. *Animal Behaviour*, *53*(5), 1083–1088. https://doi.org/10.1006/anbe.1996.0303

Preston, S. D., & de Waal, F. B. M. (2002). Empathy: Its ultimate and proximate bases. *The Behavioral and Brain Sciences*, *25*(1), 1–71. https://doi.org/10.1017/s0140525x02000018

Prior, H., Schwarz, A., Güntürkün, O. (2008). Mirror-induced behavior in the magpie (*Pica pica*): Evidence of self-recognition. *PLoS Biology, 6*, e202. https://doi.org/10.1371/journal.pbio.0060202

R Core Team. (2021). R: A Language and Environment for Statistical Computing. R version 4.1.0. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/ (accessed: 10th of August 2023)

Rajala, A.Z., Reininger, K.R., Lancaster, K.M., Populin, L.C. (2010). Rhesus monkeys (*Macaca mulatta*) do recognize themselves in the mirror: Implications for the evolution of self-recognition. *PLoS One, 5,* e12865. https://doi.org/10.1371/journal.pone.0012865

Rault, J.-L., Camerlink, I., Goumon, S., Mundry, R., & Špinka, M. (2021). The Joint Log-Lift Task: A Social Foraging Paradigm. *Frontiers in Veterinary Science*, *8*, 1158. https://doi.org/10.3389/fvets.2021.745627

Reiss, D., & Marino, L. (2001). Mirror self-recognition in the bottlenose dolphin: A case of cognitive convergence. *Proceedings of the National Academy of Sciences*, *98*(10), 5937–5942. https://doi.org/10.1073/pnas.101086398

Ritchie, H., Roser, M. (2017). Meat and Dairy Production. In: Our World Data. https://ourworldindata.org/meat-production [accessed 6.23.2022].

Root-Bernstein, M., Narayan, T., Cornier, L., Bourgeois, A. (2019). Context-specific tool use by *Sus cebifrons*. *Mammalian Biology, 98*, 102–110. https://doi.org/10.1016/j.mambio.2019.08.003

Schielzeth, H., & Forstmeier, W. (2009). Conclusions beyond support: Overconfident estimates in mixed models. *Behavioral Ecology*, *20*(2), 416–420. https://doi.org/10.1093/beheco/arn145

Sommer, V., Lowe, A., & Dietrich, T. (2016). Not eating like a pig: European wild boar wash their food. *Animal Cognition*, *19*(1), 245–249. https://doi.org/10.1007/s10071-015-0903-z

Sommerville, B. A., & Broom, D. M. (1998). Olfactory awareness. *Applied Animal Behaviour Science*, *57*, 269–286. https://doi.org/10.1016/S0168-1591(98)00102-6

Tanida, H., Senda, K., Suzuki, S., Tanaka, T., & Yoshimoto, T. (1991). Color Discrimination in Weanling Pigs. *Nihon Chikusan Gakkaiho*, *62*(11), 1029–1034. https://doi.org/10.2508/chikusan.62.1029

Therneau, T.M. (2020). coxme: Mixed Effects Cox Models. R package version 2.2-16. https://cran.r-project.org/package=coxme (accessed : 27th of August 2022)

Van Rooijen, J., & Metz, J. H. M. (1987). A preliminary experiment on T-maze choice tests. *Applied Animal Behaviour Science*, *19*(1), 51–56. https://doi.org/10.1016/0168-1591(87)90202-4

Veit, A., Wondrak, M., & Huber, L. (2017). Object movement re-enactment in free-ranging Kune Kune piglets. *Animal Behaviour*, *132*, 49–59. https://doi.org/10.1016/j.anbehav.2017.08.004

Wesley, F., & Klopfer, F. D. (1962). Visual Discrimination Learning in Swine. *Zeitschrift Für Tierpsychologie*, *19*(1), 93–104. https://doi.org/10.1111/j.1439-0310.1962.tb00764.x

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis* (2nd ed. 2016 Edition). Springer.

Zonderland, J., Cornelissen, A. H. M., Fillerup, M., & Spoolder, H. A. M. (2008). Visual acuity of pigs at different light intensities. *Applied Animal Behaviour Science*, *111*, 28–37. https://doi.org/10.1016/j.applanim.2007.05.010

Supplementary Materials

Supplementary Video 1

An overview of the test conditions of the body-as-an-obstacle task in pigs

https://doi.org/10.6084/m9.figshare.28926293.v1

Supplementary Video 2

Example of (parts of) a target training session

https://doi.org/10.6084/m9.figshare.28926302.v1

Supplementary Material 1

Before the main study, we conducted a pilot study with a smaller sample size to assess the feasibility of our planned methods. The methodology and results from this pilot study, as well as a comparison between the studies (batches of pigs), are outlined below. The methodological differences between the main study and the pilot study are described in the section “Changes Implemented in the Main Study” in Supplementary Material 2.

Methods

Subjects and Housing

At 4 weeks of age, 12 piglets from 6 different litters (1 castrated male and 1 female per litter) were selected, weaned, and transferred to the rooms in which they were trained, tested and housed for the duration of the study. By the time of testing, pigs were approximately 7 weeks old. We regularly marked the pigs with livestock marking spray to allow for individual recognition. They were checked upon daily and received veterinary care whenever necessary.

All 12 pigs were jointly housed in one home pen measuring 543 cm × 242 cm. Approximately one third of the floor’s area was slatted. For the remaining part, sawdust was used as litter. The pen was cleaned daily. Water and food (in hopper feeders) were available *ad libitum*. Straw, two jute ropes and two orange toy balls provided environmental enrichment.

Apparatus and Set-up

To test for body awareness, the same apparatus, mat, set-up and test enclosure as in the main study were used.

Training and Habituation

To allow us to draw inferences about the pigs’ awareness of their body as a potential obstacle, the pigs needed to a) be trained to assume a certain starting position before each trial, i.e., on the mat, but b) also learn that this position (especially the mat) can be abandoned at any time during the experiment. Additionally, by the time of testing, they needed to have learned to push the sliding panel with their snout from both sides. Over the course of three weeks (16 days, not necessarily consecutive), pigs were thus habituated to the experimenter, the food and the test enclosure before they learned to position themselves in front of the apparatus and push the panel from both sides. All the stages of training that led up to the test week are visualized in Table S1 and are outlined in the following sections. Details can be found in Supplementary Material 2.

Table S1

Overview of the Training Procedure

Week	Wk1	Wk2					Wk3					Wk4				Wk5				
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FH																				
HT																				
TTH																				
TTT																				
TMT																				
AT																				
AMT																				
T																				

Note. Table visualizing the timing of every training step as well as the testing for the pilot study. FH = food habituation, HT = habituation to the test enclosure, TTH = target training in the home enclosure, TTT = target training in the test enclosure, TMT = target and mat training, AT = training with the apparatus, AMT = training with both the mat and the apparatus in combination, and T = testing.

On the first days after weaning, the pigs were habituated to the (female) experimenter, the food reward (apple pieces), and the test enclosure, in which the other training steps and the testing took place. In the subsequent training phase, pigs learned to follow a target stick. This later allowed us to position pigs on the mat in the test (similar to Jønholt et al., 2021). First, pigs were trained with the target in the home enclosure for two days with the entire group of pigs present and then they received three 15-minute individual sessions in the test enclosure. In week 3, some target trials required pigs to step on the mat that was now also present in the test enclosure.

On the same days but in separate 15-minute sessions, pigs were also familiarized with the apparatus and learned to push the sliding panel. On the first day of this phase, the food in the food container (equal amounts on both sides) was freely accessible to all pigs, as the experimenter had already pushed back the panel prior to the session. On days 2 and 3 of the training with the apparatus, pigs encountered the apparatus with the panel to the front, blocking access to the food container. Hence, pigs now had to push the sliding panel with their snout to retrieve the reward. Each trial was initiated by lifting the cover. A blue block was placed behind the panel during the re-baiting process and taken out before each session to prepare pigs for one of the test conditions (see below).

In the final five days of training, all the elements from the previous phases were combined: Both the mat and the apparatus were present in the test enclosure. The mat was either placed on the left or the right side in front of the apparatus. The position of the mat was counterbalanced across subjects but always remained constant for one individual throughout training and testing (e.g., subject A was trained with the mat to the right while B always experienced it on the left). However, the mat was never attached to the sliding panel at this stage. Before each trial, the experimenter encouraged the pig to assume a pre-defined position in front of the apparatus (with the target or, alternatively, by luring it with food). The position, i.e., either on or off the mat, was semi-randomized across trials (with not more than four trials on the same side in a row). The procedure of each individual trial was the same as for the previous training stage: the cover was lifted up, the blue block was taken out and the pig was then expected to push the panel to access the food rewards.

On the first day of the test week, i.e., after the weekend, a refresher session was conducted to ensure pigs remembered the task. This session followed the same protocol as the combined training (the previous training step) and lasted 10 min per pig. Testing commenced on the subsequent day. In order for subjects to be included in the test, they had to have reached the criterion of at least 10 successes (pushed the sliding panel far enough to be able to reach the food) with the apparatus on "mat trials" and pushed from the indicated (mat) side in at least 70% of the mat trials in the combined training.

Testing

The test sessions took place in the test enclosure on four consecutive days, after 3 weeks (16 days) of training. The time of day at which each individual was tested (and therefore also the order of pigs) remained constant (± 2 hr) across days. All sessions were video recorded.

One session consisted of a total of eight test trials (two of each of four conditions) which alternated with nine motivational trials (before and after each test trial). Pigs were positioned on the mat in all test and motivational trials, never off the mat. The procedure of the motivational trials exactly resembled that of the unattached condition (see below), hence pushing from the mat side was always successful. But, whereas a motivational trial ended as soon as the pig had finished eating the reward, the test trials had a pre-determined length of 30 s. After the 30 s, the experimenter closed the cover and prepared the apparatus for the next trial before calling the pig to the apparatus again.

The conditions were arranged in two blocks of four (one trial per condition per block), so that every condition had been run once before any condition was repeated. We chose this design to be able to analyze the very first trial of each condition, prior to the onset of any learning effects, separately (see Supplementary Material 5).

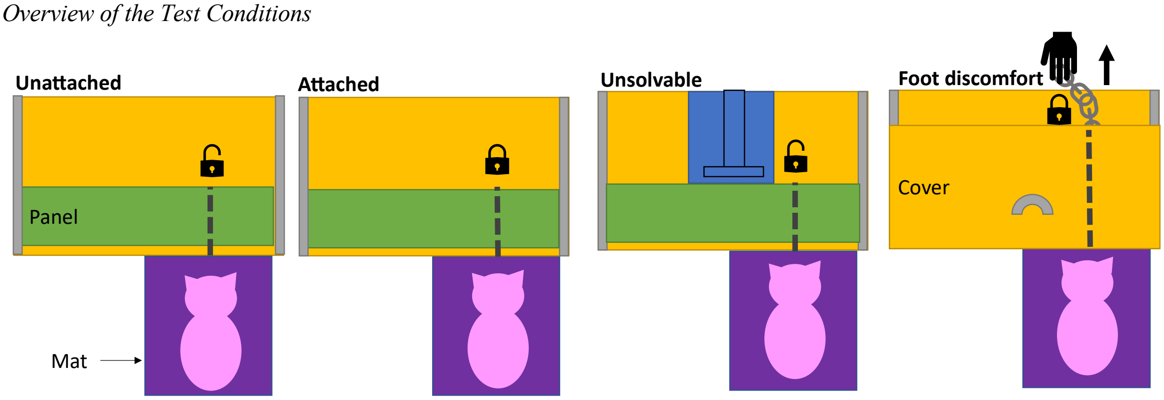
If pigs ceased to participate, lost motivation or became too agitated, the session was interrupted and continued on the same day after all other pigs had been tested. This occurred for 23 out of 320 planned trials.

The Test Conditions

To investigate whether pigs can recognize their body as a physical obstacle, we compared pigs' tendency to step off the mat and push the panel from the other side across four conditions (see Figure S1).

Figure S1

Overview of the Test Conditions



Note. Schematic overview (top view) of the four conditions run in the test of the pilot study. In the unattached condition, the chain (represented by a dashed line as it was underneath the panel) was attached to the mat but not to the panel (as indicated by the open padlock). In the attached condition, the mat and the panel were connected via the chain (as indicated by the closed padlock). In the unsolvable condition, an obstacle (blue block) was placed behind the panel. In the foot discomfort condition, the experimenter (hand) was pulling at the chain (and, thereby, the mat) via a crane scale (not depicted). The cover remained closed and the panel was inaccessible to the pig in the foot discomfort condition.

Attached condition ("A")

In the attached condition, which was the main test condition, pigs began on the mat, which was attached to a small carabiner on the back of the sliding panel via a chain (see Figure S1). When attached to the mat pigs were standing on, the chain blocked the panel so that it could only be moved approximately 2 cm, not far enough for the pig to access the food rewards. As a result, pigs were not able to uncover the food container by pushing the panel as long as they were standing on the mat. For the pigs, the principal cue indicating that their own body weight was blocking the panel was the tugging of the mat underneath their feet every time they pushed the panel. Only by stepping off the mat and attempting on the other side, next to the mat, could they access the reward underneath the panel. Assuming that the training was successful, we expected the pigs to leave the mat and solve the task once they had identified the cause of the problem in this condition. If pigs' reason for pushing from the other side in the attached condition was truly body awareness, we would have expected them to be more likely and quicker to do so compared with the unsolvable condition.

Unattached condition ("UA")

The *unattached* condition primarily allowed us to verify that pigs had learned to solve the task. This condition resembled both the training in the last phase (combined training) and the motivational trials. The mat pigs were standing on was not attached to the panel (see Figure S1) and the blue block was taken out at the beginning of each trial. Pigs were thus expected to push the panel from the mat side and only step off the mat afterwards to also retrieve the food from the other side of the food container.

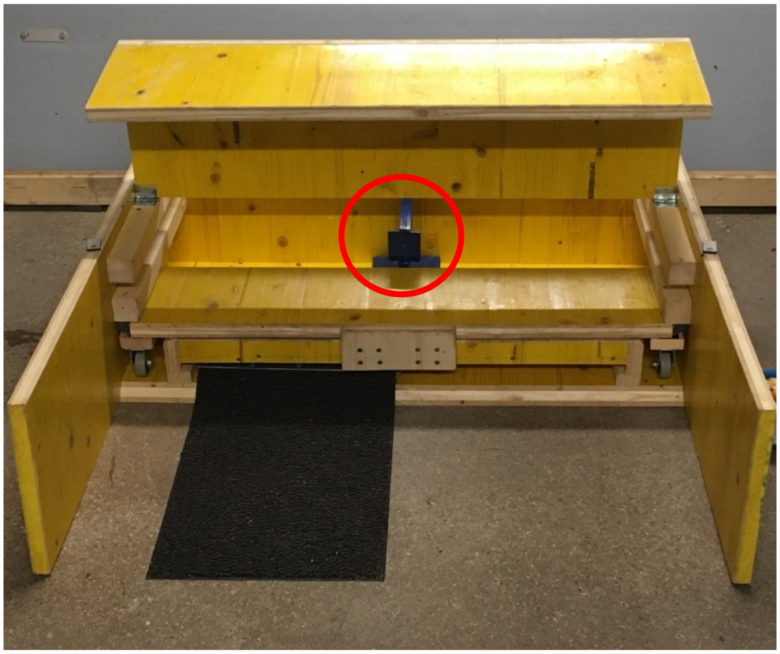
Unsolvable condition ("US")

The purpose of the *unsolvable* condition was to rule out the possibility that coming off the mat and pushing from the other side is pigs' general strategy for coping with (seemingly) unsolvable tasks, regardless of whether this brings them closer to success (cf. "attached to the ground" condition in Lenkei et al., 2021). This control was especially important in our set-up compared with those of previous studies (Dale & Plotnik, 2017; Lenkei et al., 2021), because we gave pigs two positions from which the panel could be pushed. Hence, pushing from the other side is a likely alternative strategy if initial attempts on the mat side are not successful – regardless of the reason.

Because the obstacle needed to be salient enough for pigs to acknowledge its presence, a blue block of wood was used (see Figure S2). The block measured 28 cm × 22.5 cm at ground level and was 19 cm high. As described above, the blue block was already encountered by the pigs in the training, allowing them to associate it with the (initial) unsolvability of the task. In the US condition, the blue block was not removed at the beginning of the trial and therefore blocked the panel, making it impossible to push the panel from either side. Unlike in the attached condition, the mat was not attached to the panel in the unsolvable condition and pigs' own body weight was not blocking the panel. Thus, pigs could not perceive any tugging of the mat as in the attached condition.

Figure S2

Picture of the Body Awareness Apparatus in the Unsolvable Condition



Note. Front view of the apparatus in the unsolvable condition. The circle indicates the blue block behind the panel.

Foot discomfort condition ("FD")

Finally, the foot discomfort condition addressed another possibility, namely that the pressure perceived underneath pigs' feet when pushing the panel in the attached condition is what drives them off the mat. To control for this, a so-called foot discomfort condition was included, which is in line with the study design used for both elephants (Dale & Plotnik, 2017) and dogs (Lenkei et al., 2021). In our version of the foot discomfort condition, subjects were standing on the mat in front of the closed apparatus while the experimenter gently tugged at the mat. To be able to accurately mimic the mat's movement (in the attached condition) with her pulling, it was necessary for the experimenter to know the amount of force with which pigs would push the panel in the attached condition. For this purpose, we conducted a pre-test (see Supplementary Material 3) in which the experimenter used a crane scale (Mini Crane Scale Model WH – C300 Series by ColeMeter) to measure the pigs' force.

Later, in the test, she used the same scale to keep her own pulling at this value, i.e., 25,000 N, for all individuals. The experimenter pulled approximately 2-3 times per second. As soon as the pig stepped off, the experimenter stopped pulling but continued to move the scale and chain to prevent the mat from being pulled into the apparatus. The FD condition here served as a pilot for the main study and was therefore not included in the analysis for the pilot study.

Behavior Coding

The timepoints in the video at which each of the behaviors explained in Table S2 occurred were manually extracted from the video recordings. Based on the time points and the relations between them, the variables explained in the analysis section were calculated.

Table S2

Ethogram

Behavior/Event	Definition	Condition
Start of the trial	The second in which the experimenter starts to lift the cover	A, US, UA
Start of the trial (FD)	The second in which the experimenter starts to pull at the chain	FD
End of the trial	A trial ended when a) 30 s had passed since the beginning of the trial, b) the cover was erroneously closed prematurely or c) the experimenter stopped pulling at the chain in the FD condition. The trial continued even after the pig had succeeded (A and UA condition).	all
First pushing attempt before stepping off	Pig visibly pushes the panel with its snout (normally the movement of the panel can directly be observed); this is only recorded if it happens on the mat side, i.e., before stepping off with the front legs for the first time (the wooden middle barrier depicted in Fig. 1c served as a marker to separate the two positions)	A, US, UA
Last pushing attempt before stepping off	The last time the pig's nose touches the panel on the mat side before the pig steps off with its front legs for the first time	A, US, UA
Stepping off with the front legs	Pig removes the second front leg from the mat and steps off. This is only coded if it happens before the panel is pushed back (UA). The hind legs were not considered as they did not have to be on the mat to start a trial.	all
First pushing attempt after stepping off	The first time the pig pushes the panel with its snout from the other side (other side of the wooden barrier) after the first time it steps off the mat with its front legs	A, US
Success	Pig successfully pushes the panel far enough to be able to reach all of the food	A, UA
Inspecting the back of the panel	Pig stretches its head far enough to reach the back end of the panel with its snout. For this the pig may need to stand or lie on the panel. This is only coded before the pig pushes from the other side.	A, US, UA

Note. Ethogram for the pilot study including the experimental conditions in which each behavior could be coded.

Statistical Analysis

All analyses were performed in R version 4.1.0 (R Core Team, 2021). All plots were created using the package *ggplot2* (version 3.3.5, Wickham, 2016) and/or the package *survminer* (version 0.4.9, Kassambra et al., 2021). The R codes and outputs for each model as well as an explanation of the variables and additional plots can be found in Supplementary Material 4.

Excluded Trials and Subjects

In addition to cases in which pigs ceased to participate or experimenter error led to the complete omission of trials, trials were excluded for the following reasons: a) the subject did not attempt to push from the mat side before stepping off (it could hence not know which condition it was confronted with, except for potentially the US condition) or b) the subject managed to solve the attached condition from the mat side (e.g., by standing between the mat and the adjacent fence with at least one front leg).

During the training phase of the pilot study, two pigs were excluded due to a lack of food motivation. The remaining ten pigs all fulfilled the training criteria (see above) and entered the testing phase. In the testing phase, the physical condition of one pig only allowed us to test him on two days (day 2 and day 3; he completed all but three trials on the other days).

Among the other trials, subjects did not push from the mat side before stepping off on three occasions and one pig once solved the attached condition from the mat side. Out of the 320 planned trials 297 trials were included in the analysis.

Inter-Rater Reliability

A second observer independently coded 20% of the trials. To assess the agreement between the two observers, the intraclass correlation coefficient was calculated for the behavioral variables used in the analysis, i.e., "stepping off with the front legs" and "first pushing attempt after stepping off" in the pilot study. Using the R package IRR (version 0.84.1, Gamer et al., 2019), the agreement of the two observers was assessed in a two-way model. In addition, Fleiss' Kappa was calculated (kappam.fleiss function of the IRR package) to assess the reliability between the two observers in judging whether the subject pushed from the other side after stepping off (1) or not (0).

Reliability was excellent for both the time point ($ICC = 0.999$, $p < .001$) and the occurrence ($\kappa = 1$, $p < .001$) of pushing from the other side as well as for the time point of stepping off with the front legs ($ICC = 0.997$, $p < .001$).

Probability of Pushing from the Mat Side Before Stepping Off

One of the exclusion criteria listed above is a subject's failure to attempt to push the panel from the mat side before stepping off. To avoid systematically excluding trials of a certain condition due to an overlooked pattern in the pigs' behavior (e.g., because they were more likely to refrain from pushing on the mat side in the unsolvable condition), we wanted to check whether condition had a significant influence on this probability. Note that only conditions in which the panel was accessible, i.e., not the FD condition, could be considered. However, the number of trials in which pigs did not push the panel from the mat side before stepping off was too low (3 out of 224 trials) to allow for a conclusive analysis.

Probability Of Pushing From The Other Side

To gain insights into pigs' motivation behind stepping off, the probability of attempting to push the panel from the other side after stepping off with the front legs was compared between the attached and unsolvable condition. A Generalized Linear Mixed Effects Model with a binomial distribution was fitted. The fixed effects were condition, condition order (number of trial within a session, i.e., 1–8; z-transformed) and day (z-transformed). Subject and sow (litter from which each subject was taken) were included as random effects. The random slopes of condition order, day and condition (manually dummy coded and centered) were included within the random effects of subject and sow. The model was fitted using the glmer function of the *lme4* R package (version 1.1.27.1, Bates et al., 2015). The correlations between the random slopes and random intercepts were close to 1 or -1, indicating that they were unidentifiable, and were therefore excluded from the model. To assess collinearity among fixed effects, we employed the vif function of the R package *rms* (version 6.3.0, Harrell, 2022). No collinearity was found (all variable inflation factors < 1.004). Model stability on the level of the estimated coefficients and standard deviations was assessed by excluding the levels of the random effects one by one (Nieuwenhuis et al., 2012) using a function kindly provided by Roger Mundry. As can be seen in Figure S14 in Supplementary Material 4, stability for the fixed and random effects was very good or good; stability for the intercept was acceptable. The full model was compared with a null model lacking the crucial fixed effect of condition and resembling the full model in all other aspects. A likelihood-ratio test (anova function) was calculated to detect significant differences in the variance explained by the two models. Chi-squared and the p-value are reported in the results section. We considered 141 trials across nine subjects and five sows in the analysis.

Frequency of Inspecting the Back of the Panel

As we were interested in whether pigs would be more likely to look for an external obstacle behind the panel in the unsolvable condition than in the attached condition (in which the obstacle was *in front* of the panel, on the mat), we wanted to compare the frequency of inspecting the back of the panel across conditions. Unfortunately, the number of trials in which the behavior occurred was insufficient (seven occurrences across six out of 221 valid trials – five US trials and one A trial) for a conclusive analysis.

Latency To Push From The Other Side After Stepping Off

Subjects' latency to attempt to push the panel from the other side after stepping off with their front legs was calculated based on the time points specified in Table S2. Trials in which the pig never stepped off were assigned a latency of 30 s. The resulting latency was compared between the attached condition, in which the task was solvable from the non-mat side, and the unsolvable condition, in which pushing from the other side was always futile. To do so, a Cox Mixed Effects Model (R package *coxme*, version 2.2-16, Therneau, 2020) was fitted. The same fixed and random effects were used as for the model analyzing the probability of pushing from the other side (see above), with the exception that only day (z-transformed) could be included as a random slope for the random intercepts of subject and sow. The correlations between the random slopes and random intercepts were removed from the model as they were very close or equal to 1 or -1. Model stability on the level of the estimated coefficients and standard deviations was assessed by excluding the levels of the random effects one by one (Nieuwenhuis et al., 2012). As for all Cox models in this study, correlations within random effects were excluded for the model stability analysis. As can be seen in Figure S15, stability for all fixed and random effects was very good. The procedures for the full-null model comparison and the assessment of collinearity were the same as described above. No collinearity was detected (all variable inflation factors < 1.013). The model was fitted based on 139 trials across nine subjects and five sows.

Between-Batch Comparisons

To investigate potential effects of the subtle differences in the procedure and set-up between the pilot study and the main study, two variables were compared between the two studies.

First, subjects' success in the attached condition was compared between batches of pigs. A binomial model with the fixed effects batch (pilot study or main study), day and condition order was fitted. These were complemented with the random effects of subject and sow with the random slope(s) of condition order, or condition order, and day, respectively. The correlations between random slopes and random intercepts were close to 1 or -1 and were therefore excluded. No collinearity among fixed effects was detected (all variable inflation factors < 1.0873). Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat for the pilot study. Stability seemed to be good or very good for all fixed and random effects as well as the intercept (see Figure S16). This full model was compared with a null model lacking the fixed effect of batch. We included 192 trials across 27 subjects and 14 sows in the analysis.

Second, the blue blocks for the KUS condition in the main study were designed to be more salient for the pigs. To verify that this indeed led the pigs to pay more attention to the blue blocks behind the panel, the relative frequency of inspecting the back of the panel was compared between the KUS condition of the main study and the US condition of the pilot study. For this purpose, a GLMM with a Poisson distribution with fixed and random effects identical to those described for the probability of succeeding in the attached condition was fitted. Additionally, the log-transformed latency to push from the other side from the start of the trial was included as an offset term to control for differences between the two studies in the amount of time during which the behavior could occur. The correlations between random slopes and random intercepts were close to 1 or -1 and were therefore excluded. Overdispersion was assessed as described above. The model was not overdispersed (dispersion parameter = 0.890) and no collinearity among fixed effects was detected (all variable inflation factors < 1.134). Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat for the pilot study. As can be seen in Figure S17, stability was very good for the random effects as well as for the fixed effects of day and condition order, and good for the fixed effect of batch and for the intercept. The full model was compared with the null model lacking the fixed effect batch (study). The sample for this model included 201 trials across 27 subjects and 14 sows.

Results

Descriptive Statistics

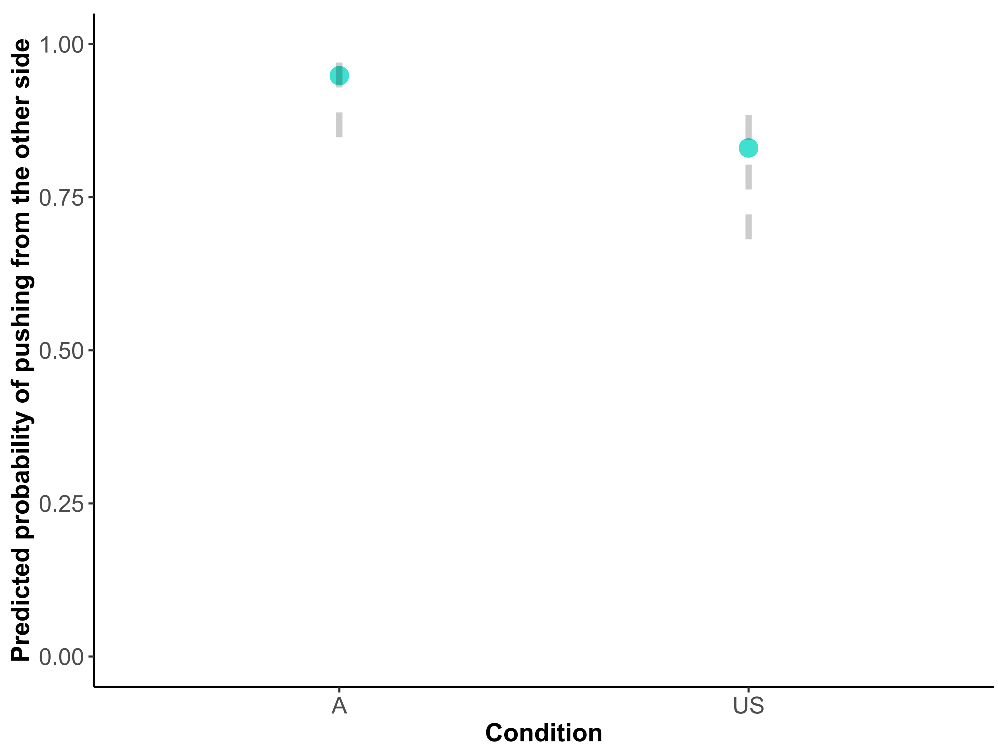
Subjects were always successful in obtaining the food in the unattached condition when they tried to push the panel (all 75 valid unattached trials). They never stepped off the mat before they succeeded in this condition. In contrast, *after* attempting to push the panel from the mat side, pigs stepped off the mat with the front legs in 94% (71 out of 76 trials) of the unsolvable trials, 96% (73 out of 76 trials) of the foot discomfort trials and 97% (73 out of 75 trials) of the attached trials. Furthermore, pigs solved 76% (55 out of 72 trials) of the valid attached trials (by stepping off and pushing from the other side). All ten subjects succeeded in the attached condition at least once and all nine subjects tested on day 1 were successful in their very first attached trial.

Probability of pushing from the other side

Pigs tended to push the panel from the other side more in the attached condition (89% of trials) compared with the unsolvable condition (79% of trials; full-null model comparison: $\chi^2 = 3.73$, $df = 1$, $p = .053$, Figure S3, for full model output see Table S10).

Figure S3

Probability of Pushing From the Other Side



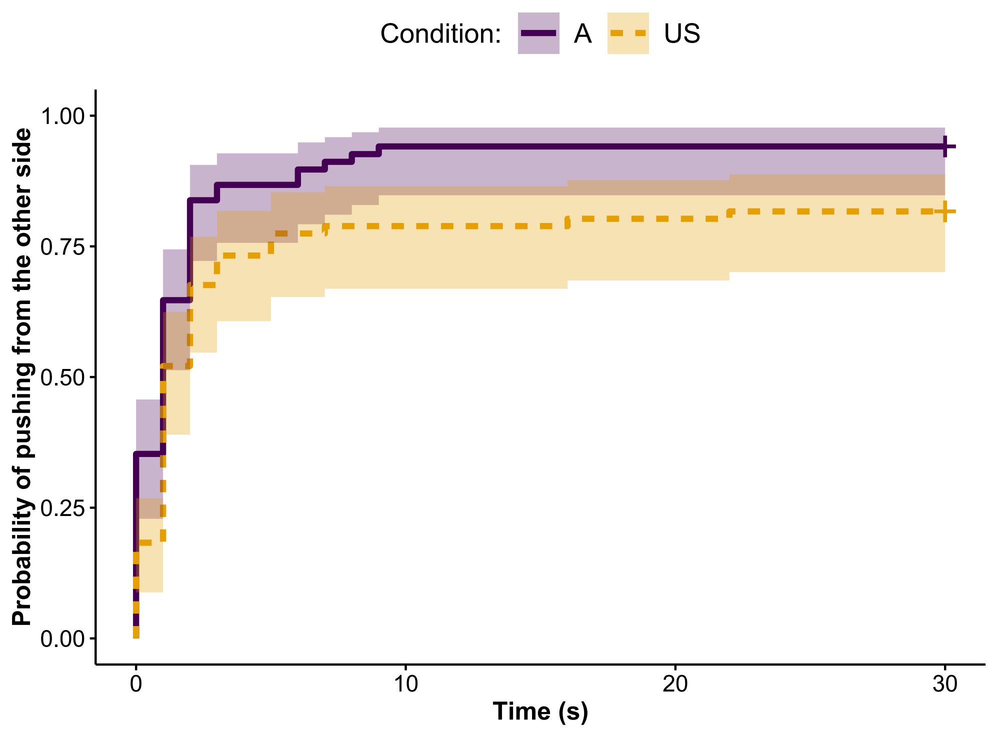
Note. Predicted probabilities of pushing the panel from the other side after stepping off for the attached ("A") and the unsolvable ("US") condition in the pilot study. Dashed lines indicate the 95% confidence intervals.

Latency to Push From the Other Side After Stepping Off

Pigs were significantly (full-null model comparison: $\chi^2 = 8.63$, $df = 1$, $p = .003$; see also Table S11) quicker to push the panel from the other side after stepping off with the front legs in the attached condition compared with the unsolvable condition (Figure S4).

Figure S4

Latency to Push From the Other Side



Note. Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time in the attached condition (solid line, "A") and unsolvable condition (dashed line, "US") in the pilot study. Crosses indicate trials in which pigs had not pushed from the other side by the end of the trial.

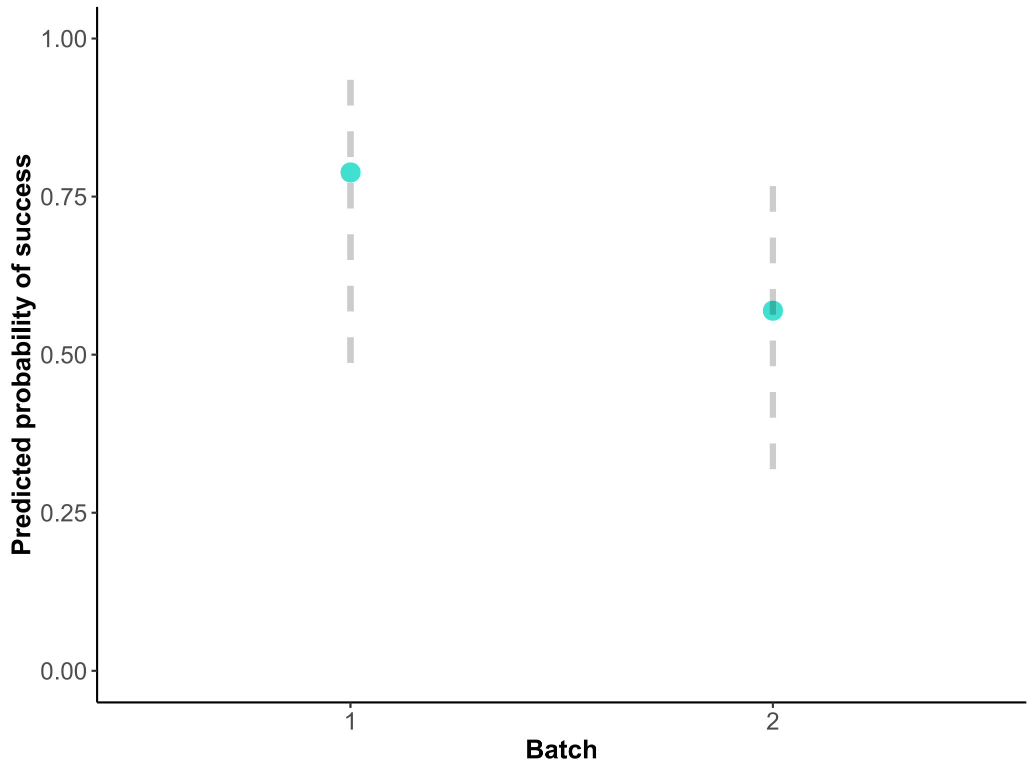
Between-batch comparisons

Success in the attached condition

Even though pigs were considerably more successful (see Figure S5) in the attached trials of the pilot study (76%) compared with the main study (52%), this difference did not reach statistical significance (full-null model comparison: $\chi^2 = 1.48$, $df = 1$, $p = .223$).

Figure S5

Probability of Succeeding in the Attached Condition



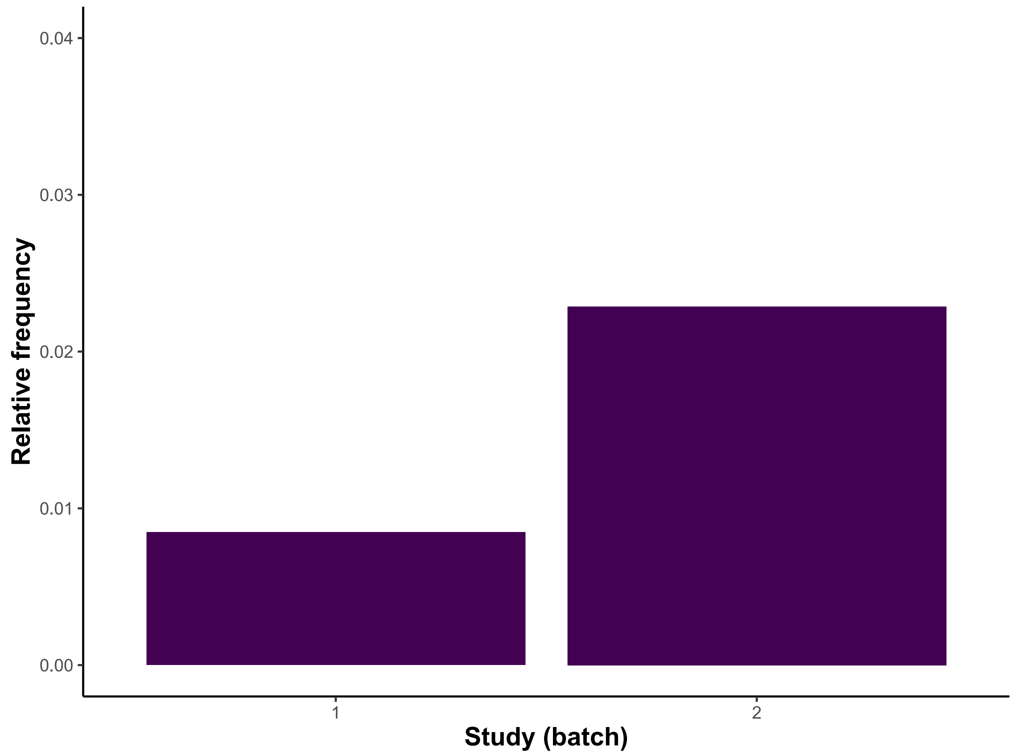
Note. Predicted probabilities of succeeding in the A condition between batches of pigs (studies). Dashed lines indicate the 95% confidence intervals. Pilot study = 1, main study = 2.

Inspecting the back of the panel

Comparing the US condition of the pilot study with the KUS condition of the main study, a visibly higher frequency of inspections of the back of the panel in the main study became evident. The full-null model comparison revealed a significant difference between the studies ($\chi^2 = 9.23$, $df = 1$, $p = .002$, see Figure S6; for full model output see Table S12).

Figure S6

Frequency of Inspecting the Back of the Panel



Note. Frequency of inspecting the back of the panel relative to the latency to push from the other side and the number of trials per study between batches of pigs (studies). Pilot study = 1, main study = 2.

Supplementary Material 2: Details of the Training Procedure

The first part of this supplementary material refers to the protocol established in the pilot study. The differences in training between the pilot study and the main study can be found in the section "Changes Implemented in the Main Study".

Habituation to the Food and the Experimenter

On the first two days after weaning, the young pigs were habituated to the food type that was later used as a reward in the training and testing. At the same time, this first phase allowed subjects to become familiarized with the (female) experimenter conducting all the training and testing sessions. To achieve this, pigs were hand-fed apple pieces by the experimenter in their home pen for 15 min a day. The experimenter tried to ensure that every pig ate at least one piece per session and noted down every subject that failed to do so.

Habituation to the Test Enclosure

Habituating subjects not only to the reward but also to being alone in the test environment is especially crucial when working with pigs (Herskin et al., 2020). As most of the training sessions and all the tests took place in the test enclosure, pigs thus needed to be habituated to the novel environment until they were comfortable staying there with the experimenter in the absence of conspecifics. In a first step, pigs were brought into the test enclosure in groups of three and left there to explore it for 30 min a day for 2 days. The composition of groups was randomized each day.

Target Training in the Home Enclosure

To later allow us to precisely position pigs on the mat, target and clicker training were used. This approach has recently also proven successful in guiding pigs onto a novel surface (Jønholt et al. 2021).

In the present study, an extendable metal stick (~1 m long) with a small blue ball at the end was used as a target (AniOne Target Stick, catalogue number: 1232743, Fressnapf Tiernahrungs GmbH Westpreußenstr. 32-38, D-47809 Krefeld). Pigs were reinforced by sounding an integrated clicker and, additionally, by praising them verbally and rewarding them with food every time they touched the target with their snout.

The first stage of target training took place in the home enclosure with the entire group of pigs present. In these 20 min per day, the experimenter gave every pig the chance to form an association between the target and the food reward by bringing the target very close to their snout or even actively touching it. The group setting also gave pigs the chance to learn socially from their peers, which they are known to be capable of (Nicol & Pope, 1994; Oostindjer et al., 2011; Veit et al., 2017). Indeed, pigs were highly motivated to follow the target and many already learned the target-food association on the first day of training.

Target Training in The Test Enclosure

As soon as the pigs were habituated to the test enclosure, the individual target training could proceed there with one single pig at a time. The maximum duration of each session was 15 min; however, sessions were terminated earlier if pigs were already very successful in following the target or showed signs of agitation (distress vocalizations, attempts to escape the enclosure). No more than one session was conducted per pig and day. However, one pig was trained twice on day 2 and another pig was omitted that day due to a mistake. The order of sessions (pigs) was randomized across days.

These individual sessions also allowed us to assess the food preferences of each pig. For pigs that refused to eat apples, alternative food types (bananas and raisins) were tried out. Based on their subjectively evaluated preference for bananas, the reward type for two individuals was switched from apples to bananas from this point on.

The procedure of the training itself was similar to the previous stage in the home enclosure. But, in contrast to the first two days of target training, pigs now needed to locomote to reach the target as it could be presented anywhere in the enclosure.

For very agitated pigs, the experimenter tried to calm them down by kneeling on the floor next to them and/or spreading some food in the enclosure. Because this still did not suffice for some individuals, pigs were trained in pairs on the last day of this stage (and the first day of the subsequent stage) except for the four most successful individuals that never showed signs of distress.

Target and Mat Training

On the next three days, the mat was present in the test enclosure during the sessions. In some of the trials, touching the target now required the pigs to stand on the mat, at least with their front legs. After each mat-trial, the experimenter presented the target in a different location in the test enclosure, hence the pigs needed to step off again. This was performed to train the pigs to approach the target (and step onto the mat) from anywhere in the enclosure.

As mentioned before, the first of these sessions was conducted in pairs for eight of the 12 pigs. On the other two days, every pig was trained individually. Sessions lasted 10-15 min and the order of pigs was randomized each day.

Training With the Apparatus

In week 3, pigs were also familiarized with the apparatus and learned to push the sliding panel, the task to be performed later in the testing.

On the first day of this phase, the food in the food container was freely accessible to all pigs since the panel had already been pushed back by the experimenter prior to the session. As in the testing, equal amounts of food were available in both sides of the container such that approaching it from the left and the right was equally rewarding. This procedure aimed at preventing pigs from developing a side bias. After the pig had finished eating, the cover was closed and the container was re-baited. This procedure was repeated for 10 min per pig.

On days 2 and 3 of the training with the apparatus, pigs encountered the apparatus with the panel pushed to the front, blocking access to the food container. Hence, pigs now had to push the sliding panel with their snout to retrieve the reward.

No mat was present in these sessions yet. However, pigs that already reliably followed the target (in the target and mat sessions) were positioned in front of the apparatus (left or right) before each trial. Again, a trial was initiated by lifting the cover. A blue block was placed behind the panel during the re-baiting process and taken out before each session to prepare pigs for the unsolvable condition. As soon as the cover was up and the blue block was out, pigs were free to interact with the panel and learn how to access the food. If necessary, the experimenter moved the panel a bit to the back so that a gap between the panel and the container became visible, making it easier for the pigs to discern where they had to push. Additionally, the experimenter tried to re-attract distracted pigs' attention by calling them, showing them the food or knocking on the wood. If an individual nonetheless had not succeeded after 2 min, the panel was pulled back by the experimenter and the pig was allowed to eat the apple pieces in order to maintain the pig's motivation to solve the task.

If a pig already started to develop a side bias (i.e., approached and pushed from the "preferred" side at least twice in a row, even if the experimenter had indicated the other side with the target stick), the experimenter counter-acted this by closing the apparatus again if the pig pushed from the preferred side and/or by putting apple pieces on the floor/on the panel on the less preferred side to encourage the pig to approach from there.

The sessions on days 2 and 3 of the training with the apparatus lasted 15 min per pig and day. The order of subjects was randomized across days. Additionally, because they took place on the same days as the target and mat sessions, the order in which these two training blocks were carried out was alternated across days.

Combined Training

In the final week of training (5 days), all the elements from the previous phases were combined: Both the mat and the apparatus were present when the subject entered the test enclosure. The mat was either placed on the left or the right side in front of the apparatus, which was counterbalanced across subjects but always remained constant for one individual throughout training and testing (e.g., subject A was trained with the mat being to the right while B always experienced it on the left). However, the mat was never attached to the sliding panel at this stage; thus, these sessions resembled the procedure of the later "unattached" trials.

Before each trial, the pig was encouraged to assume a pre-defined position in front of the apparatus (with the target or, alternatively, by luring it with food). The position, i.e., either on or off the mat, was semi-random across trials (with not more than four trials on the same side in a row). The pig had to remain in the given position at least until the cover of the apparatus was lifted, otherwise the first step was repeated. If a subject failed to fulfil this criterion in three consecutive attempted trials, a "free" trial without a pre-defined starting position was included to maintain motivation. The procedure of each individual trial was the same as for the previous training stage: the cover was lifted, the blue block was taken out and the pig was then expected to push the panel to access the food reward. Each session was 10-15 min long, the order in which pigs were trained every day was randomized.

In order for subjects to be included in the test, they had to have reached the criterion of at least 10 successes with the apparatus on "mat trials" and pushed from the indicated (mat) side in at least 70% of the mat trials in the combined training.

Refresher Session

On the first day of the test week, i.e., after the weekend, a refresher session was conducted to ensure pigs remembered the task. This session followed the same protocol as the combined training and lasted 10 min per pig. Testing commenced on the subsequent day. An overview of all training stages is provided in Table S3.

Table S3

Overview of the Training Procedure

Week	Wk1	Wk2					Wk3				Wk4				Wk5				
Day	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20
FH																			
HT																			
TTH																			
TTT																			
TMT																			
AT																			
AMT																			
T																			

Note. Table visualizing the timing of every training step as well as the testing. FH = food habituation, HT = habituation to the test enclosure, TTH = target training in the home enclosure, TTT = target training in the test enclosure, TMT = target and mat training, AT = training with the apparatus, AMT = training with both the mat and the apparatus in combination, and T = testing. The lighter shade of purple indicates that only one of the two groups was trained on these days.

Changes Implemented in the Main Study

The target training sessions in the home pen as well as in the test enclosure were shortened to 10 min each, because most pigs began to lose interest after 15 min in the pilot study and, in general, shorter sessions are recommended to keep pigs' motivation and concentration up (Herskin et al., 2020).

Based on the experience with the pilot study, pigs were trained in pairs on the first two days of target training in the test enclosure. First, this should have alleviated the effects of isolation from the group, allowing pigs to focus on the task. Second, social learning and/or food competition could have enhanced their learning success. The partners with which pigs were brought into the test enclosure were assigned randomly, with the exception that pigs were trained in a different dyad on the second day.

In the target training phase, only two days of target training without the mat were conducted, hence the first time that the pigs were alone with the experimenter in the test enclosure was on the first day of the mat training. These sessions followed the same protocol as for the pilot study. Based on its subjectively assessed food preferences, one pig was trained and tested with bananas instead of apples from this point on.

Due to the increased time requirements of training 20 (instead of 12) pigs, the target-mat and apparatus sessions (for all pigs) could not always be carried out on the same day on days 8 to 10. That is, instead of having two sessions per day and pig (as for the pilot study) in this phase, only 1.5 sessions were conducted, extending this training phase to four days and reducing the number of mat sessions to two (instead of three). On the first day of this phase, day 8, both groups (all 20 pigs) received their first session with the apparatus (the one in which the panel was open), but only one group was trained with the target and the mat in a separate session. The same procedure was carried out on the second day with the other group receiving a mat and target session. On the third day, all pigs were brought in for two sessions, one with the mat and one with the apparatus. The final day only consisted of sessions with the apparatus for both groups.

In the apparatus sessions, the experimenter again tried to counteract the development of a side bias, as described for the pilot study. However, in contrast to the pilot study, she already started to do so on days 2 and 3 of the apparatus training and did not wait for the combined sessions. Furthermore, the (old) blue block was only introduced on day 3 of the apparatus training (second day on which the panel was closed). It was replaced by the two new blocks on the fourth day of the combined training.

In the final week of training, each pig received four combined training sessions (with the mat in front of the apparatus). The position of the mat was counterbalanced across subjects so that it was always on the right for five pigs of each group and on the left for the other five. The refresher session on the first day of the last week, the day before the first test session, simultaneously acted as a fifth combined training session.

Supplementary Material 3: Measuring the Pigs' Force for the Foot Discomfort Condition

To determine the pulling force to be applied by the experimenter in the FD condition, a pre-test was conducted. For this purpose, three pigs that had reliably pushed the panel during the previous training sessions were selected for a pre-test. These pigs were of average or above-average size (and, presumably, strength).

In the pre-test, the experimenter was standing on the mat, which was attached to the sliding panel via a chain and the scale while the pig was pushing from the other side. Unlike in the attached condition, the chain (with the scale) was placed on (rather than under) the panel to allow the experimenter to read from the display of the scale. The pig was encouraged to push from the other side (from off the mat) for about 10 s. After these 10 s, the experimenter stepped off and allowed the pig to move the panel and retrieve the food reward.

The maximum force measured during each of the three trials was noted down, averaged across the three pigs and converted from kilograms to Newtons. The resulting mean force exerted on the mat by the pigs was approximately 25,000 N (2.5 kg).

Even though it would have been more representative to measure the force of each individual subject, we chose to only use three pigs to avoid all pigs becoming frustrated or confused by the unusual set-up and/or already gaining experience with the mat being attached to the panel.

Supplementary Material 4: R Codes and Stability Plots of Statistical Models

Main Study

Probability of Stepping Off Before the First Attempt to Push the Panel

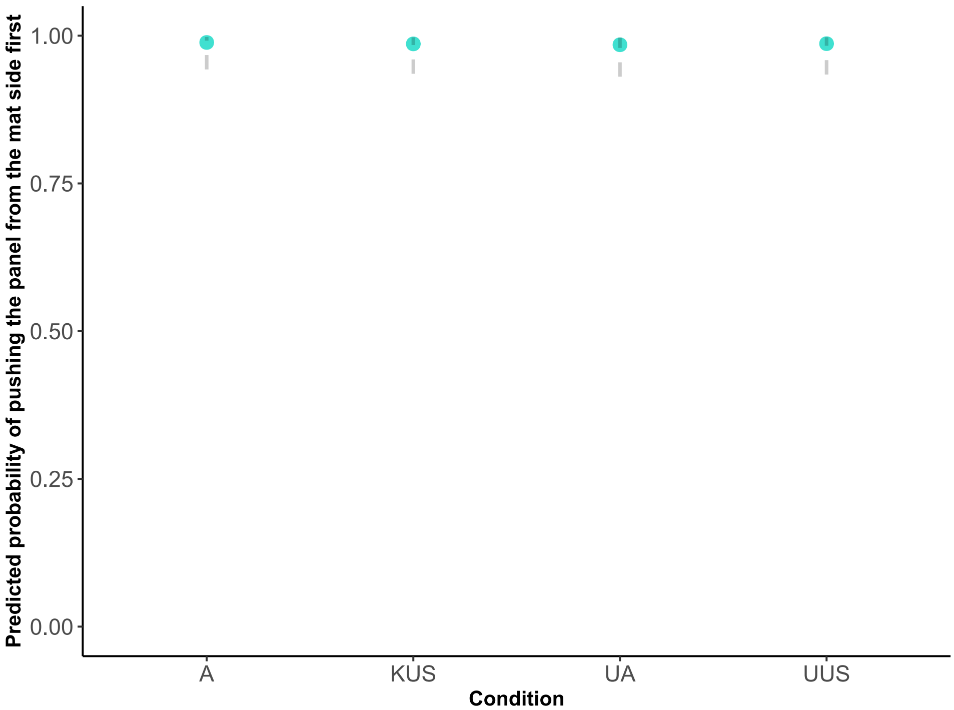
full = glmer(pushed_before ~ Condition + z.Day + z.Condition_Order + (1 + z.Condition_Order + Condition.UA + Condition.KUS + Condition.UUS + z.Day||Subject) + (1 + z.Condition_Order + Condition.UA + Condition.KUS + Condition.UUS + z.Day||Sow), data=xdata, family=binomial, control = glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

Variables

- Pushed_before: binary variable indicating whether a pig pushed the panel before stepping off the mat (1) or not (0)
- Condition: test condition, in this case attached (A), unattached (UA), unknown unsolvable (UUS) or known unsolvable (KUS); manually dummy coded and centered for inclusion as a random slope
- z.Day: see above
- z.Condition_Order: number indicating when in a session a trial appeared, can take values from 1 to 12, z-transformed

Figure S7

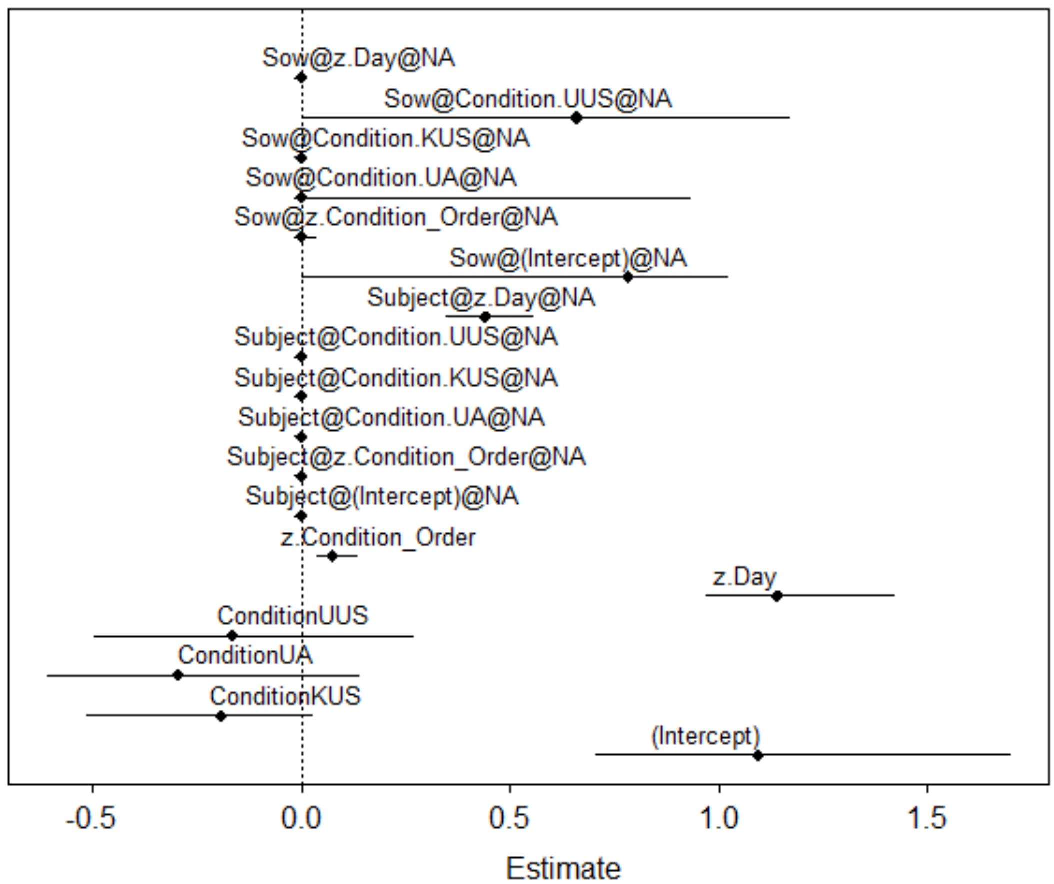
Probability of Pushing From the Mat Side



Note. Predicted probabilities of pushing the panel from the mat side before stepping off for the attached, known unsolvable, unattached, and unknown unsolvable condition. Dashed lines indicate the 95% confidence intervals

Figure S8

Model Stability Probability of Pushing From the Mat Side



Note. Model stability plot for the probability of pushing from the mat side before stepping off. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the term before the first at sign representing a grouping variable (i.e., Sow or Subject) and the term after the first at sign denoting a random intercept (indicated by "(Intercept)") or a random slope). Correlations within the random effects are indicated by the presence of a second at sign and a third term. For this model, the third term is always "NA" as the correlations between random slopes and random intercepts were excluded from the model

Probability of Pushing From the Other Side After Stepping Off

full = glmer(attemptafter ~ Condition + z.Day + z.Condition_Order + (1 + z.Condition_Order + Condition.UUS + Condition.KUS + z.Day||Subject) + (1 + z.Condition_Order + Condition.UUS + Condition.KUS + z.Day||Sow), data=xdata, family=binomial, control = glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)))

Variables

- Condition: test condition, i.e., attached (A), unknown unsolvable (UUS) or known unsolvable (KUS); manually dummy-coded and centered for inclusion as a random slope
- Other variables: see above

Table S4

Model Output Probability of Pushing From the Other Side

Term	Estimate	SE	*Z*	*p*[3]	Lower CI	Upper CI
Intercept	3.337	0.653	5.114		2.058	4.617
Condition.KUS[1]	-0.788	0.332	-2.372	**.009**	-1.450	-0.137
Condition.UUS[1]	0.304	0.351	0.868		-0.383	0.992
z.Day[2]	-0.409	0.195	-2.100		-0.792	-0.027
z.Condition_order[2]	-0.126	0.050	-2.541		-0.223	-0.029

Note. Full model output for the fixed effects of the GLMM analyzing the probability of pushing from the other side in the main study. [1]Condition was dummy coded with “A” being the reference category. The reference category is not listed in this table. [2]The variables Condition order and Day were z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean and standard deviation being 6.422 and 3.405 or 2.502 and 1.117, respectively. [3]p-value obtained from the full-null model comparison.

Table S5

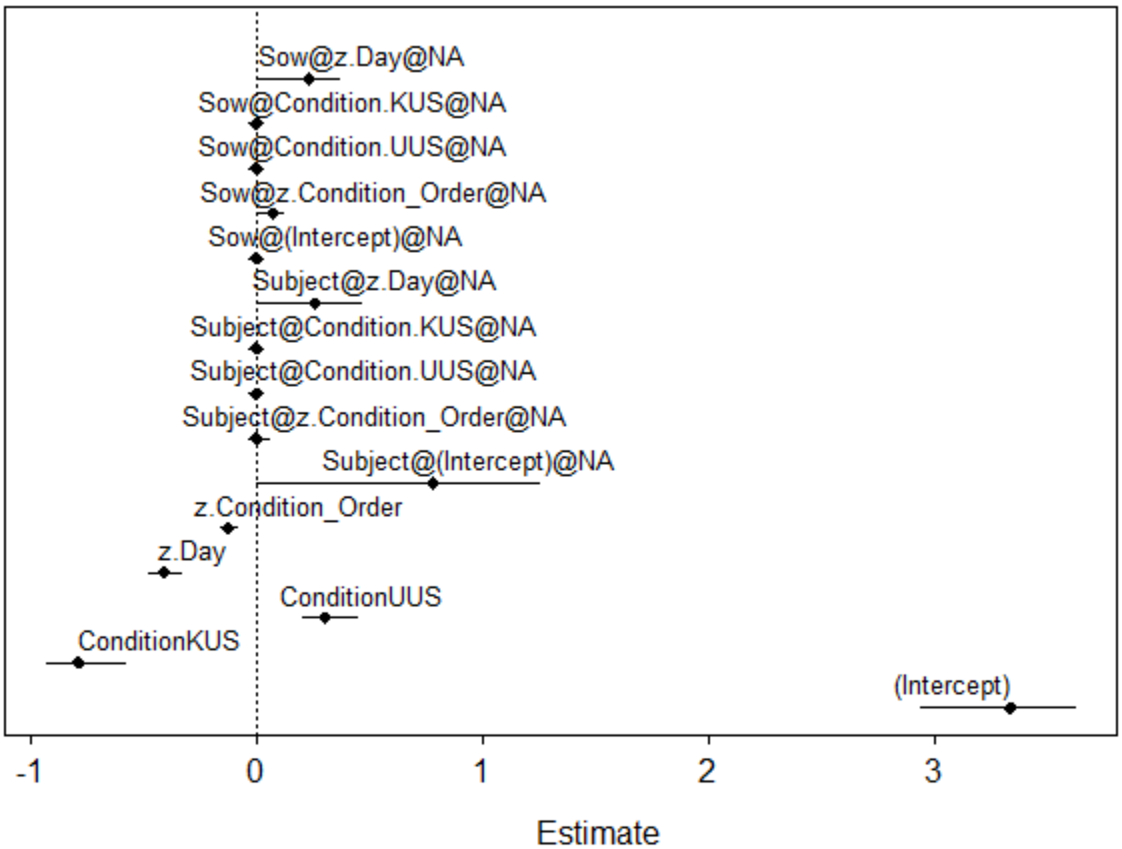
Pairwise Comparisons Probability of Pushing From the Other Side

Comparison	Estimate	SE	*Z*	*p* (corrected)
A – KUS	0.788	0.332	2.372	**.047**
A – UUS	-0.304	0.351	-0.868	.661
KUS – UUS	-1.093	0.334	-3.267	**.003**

Note. Pairwise comparisons of levels of fixed effect condition for the GLMM analyzing the probability of pushing from the other side after stepping off in the main study.

Figure S9

Model Stability Probability of Pushing From the Other Side



Note. Model stability plot for the probability of pushing from the other side after stepping off the mat. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the term before the first at sign representing a grouping variable (i.e., Sow or Subject) and the term after the first at sign denoting a random intercept (indicated by "(Intercept)") or a random slope. Correlations within the random effects are indicated by the presence of a second at sign and a third term. For this model, the third term is always "NA" as the correlations between random slopes and random intercepts were excluded from the model.

Frequency of Inspecting the Back of the Panel

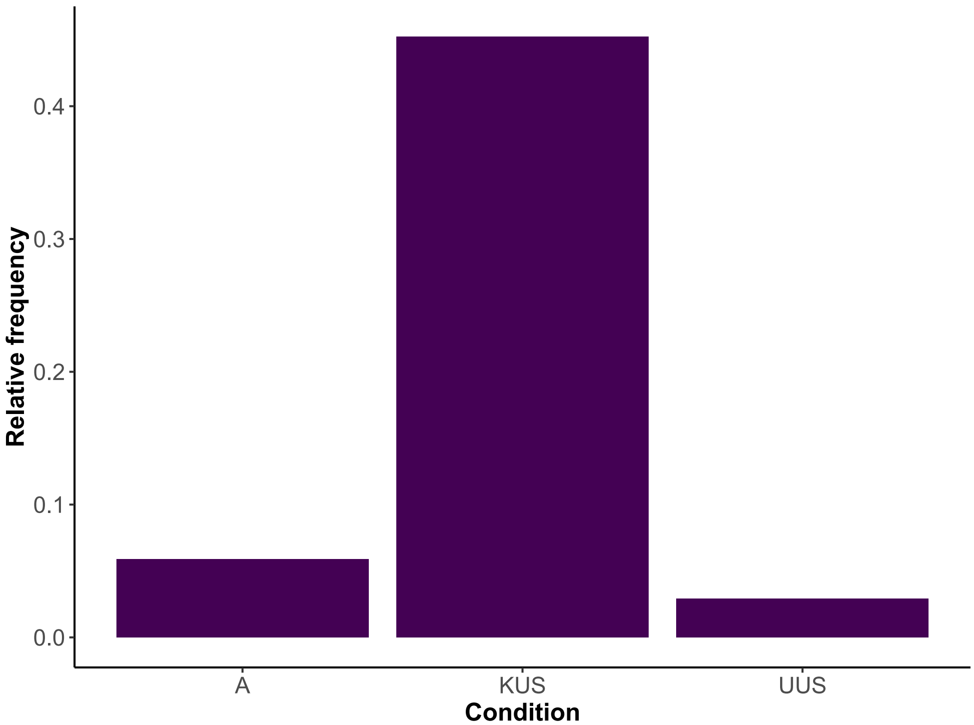
full = glmer(inspect_before ~ Condition + z.Condition_Order + z.Day + offset(log(inspect_time)) + (1 + z.Condition_Order + Condition.KUS + Condition.UUS + z.Day||Subject) + (1 + z.Condition_Order + Condition.KUS + Condition.UUS + z.Day||Sow), data=xdata, family=poisson, glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

Variables

- inspect_before: number of investigations of the back of the panel before the first pushing attempt from the other side per trial
- Condition: see model for the probability of stepping off before the first attempt to push the panel
- Inspect_time: time from the start of the trial until the first pushing attempt from the other side, i.e., time during which inspections of the back of the panel were counted
- Other variables: see above

Figure S10

Frequency of Inspecting the Back of the Panel



Note. Relative frequency (i.e., the number of occurrences per trial divided by the latency to push from the other side from the start of the trial) of "inspecting the back of the panel" across conditions.

Table S6

Model Output Frequency of Inspecting the Back of the Panel

Term	Estimate	SE	*Z*	p^3	Lower CI	Upper CI
Intercept	-6.170	0.630	-9.792		-7.405	-4.935
Condition.KUS[1]	1.841	0.379	4.864	**< .001**	1.099	2.583
Condition.UUS[1]	-0.981	0.802	-1.223		-2.552	0.591
z.Condition_order[2]	0.024	0.052	0.461		-0.078	0.127
z.Day[2]	0.140	0.123	1.136		-0.102	0.382

Note. Full model output for the fixed effects of the GLMM analyzing the frequency of inspecting the back of the panel across conditions in the main study. [1]Condition was dummy coded with "A" being the reference category. The reference category is not listed in this table. [2]The variables Condition order and Day were z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean and standard deviation being 6.468 and 3.432 or 2.546 and 1.109, respectively. [3]p-value obtained from the full-null model comparison.

Pairwise Comparisons

Table S7

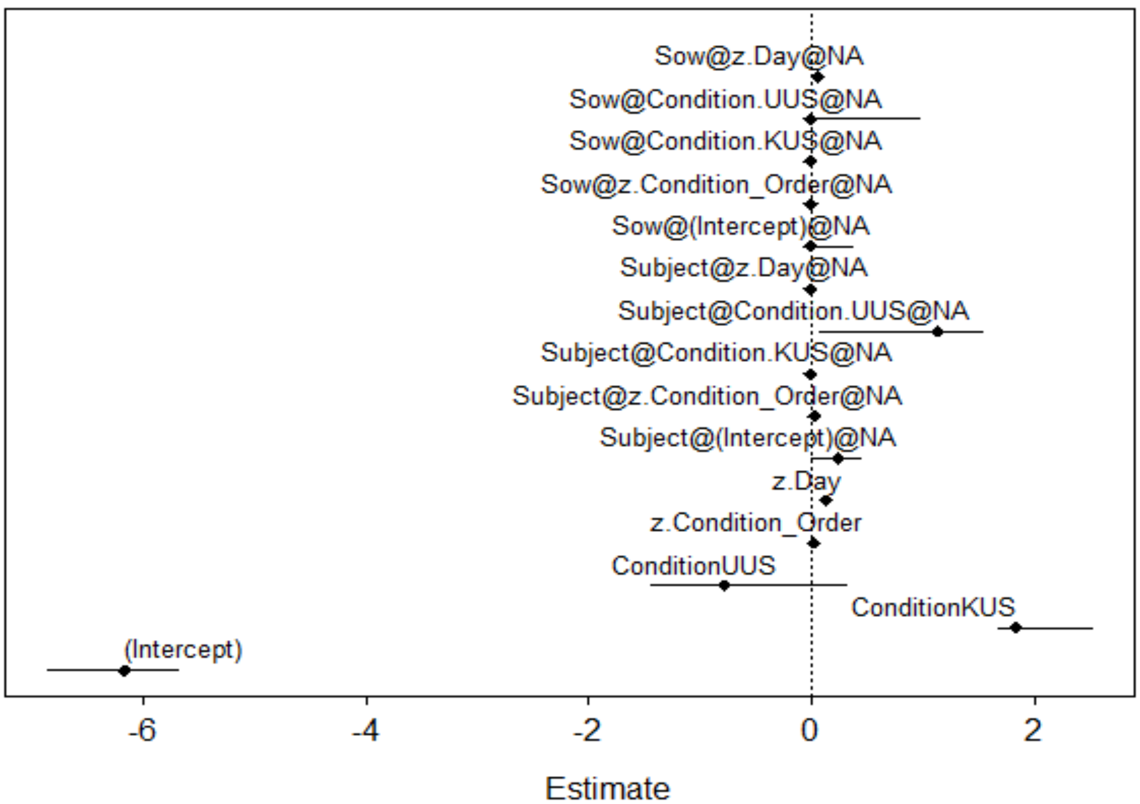
Pairwise Comparisons Frequency of Inspecting the Back of the Panel

Comparison	Estimate	SE	*Z*	*p* (corrected)
A – KUS	-1.84	0.378	-4.864	**< .001**
A – UUS	0.98	0.80	1.223	.433
KUS – UUS	2.82	0.729	3.873	**< .001**

Note. Pairwise comparisons of levels of fixed effect condition for the GLMM analyzing the frequency of inspecting the back of the panel in the main study.

Figure S11

Model Stability Frequency Inspecting the Back of the Panel



Note. Model stability plot for the frequency of inspecting the back of the panel. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the term before the first at sign representing a grouping variable (i.e., Sow or Subject) and the term after the first at sign denoting a random intercept (indicated by "(Intercept)") or a random slope. Correlations within the random effects are indicated by the presence of a second at sign and a third term. For this model, the third term is always "NA" as the correlations between random slopes and random intercepts were excluded from the model. One out of 26 models did not converge.

Latency to push from the other side after stepping off the mat

```
full = coxme(faa ~ Condition + z.Condition_Order + z.Day + (1 + z.Day|Subject) + (1 +  z.Day | Sow), data=xdata)
```

Variables

- See above

Table S8

Model Output Latency to Push From the Other Side

Term	coef	exp(coef)	se(coef)	*Z*	*p*[3]
Condition.KUS[1]	-0.617	0.540	0.162	-3.81	**< .001**
Condition.UUS[1]	0.001	1.001	0.150	0.01	
z.Condition_order[2]	-0.046	0.955	0.018	-2.49	
z.Day[2]	-0.166	0.847	0.085	-1.95	

Note. Full model output for the fixed effects of the Cox mixed effects model analyzing the latency to push from the other side in the main study. [1]Condition was dummy coded with "A" being the reference category. The reference category is not listed in this table. [2]The variables Condition order and Day were z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean and standard deviation being 6.422 and 3.405 or 2.502 and 1.117, respectively. [3]p-value obtained from the full-null model comparison.

Pairwise Comparisons

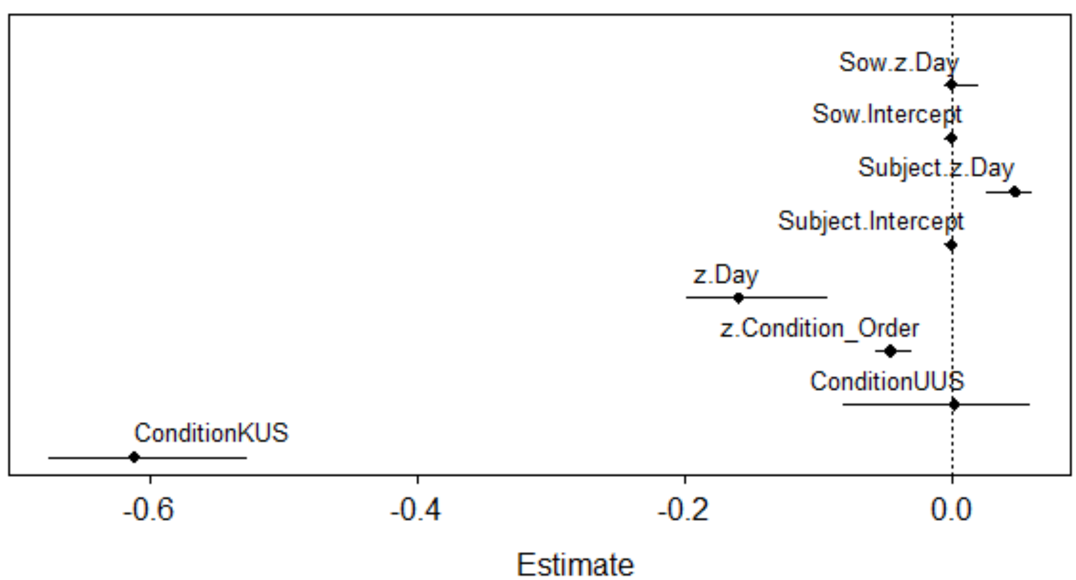
Table S9

Pairwise Comparisons Latency to Push From the Other Side

Comparison	Estimate	SE	*Z*	*p* (corrected)
A – KUS	0.617	0.162	3.813	**< .001**
A – UUS	-0.001	0.150	-0.006	> .999
KUS – UUS	-0.618	0.158	-3.919	**< .001**

Figure S12

Model Stability Latency to Push From the Other Side



Note. Model stability plot for the latency to push from the other side after stepping off. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Names starting with "Sow" or "Subject" are random effects, with the second term denoting a random slope or intercept

Latency To Step Off The Mat With The Front Legs From The Start Of The Trial (Fd And Fdc Condition)

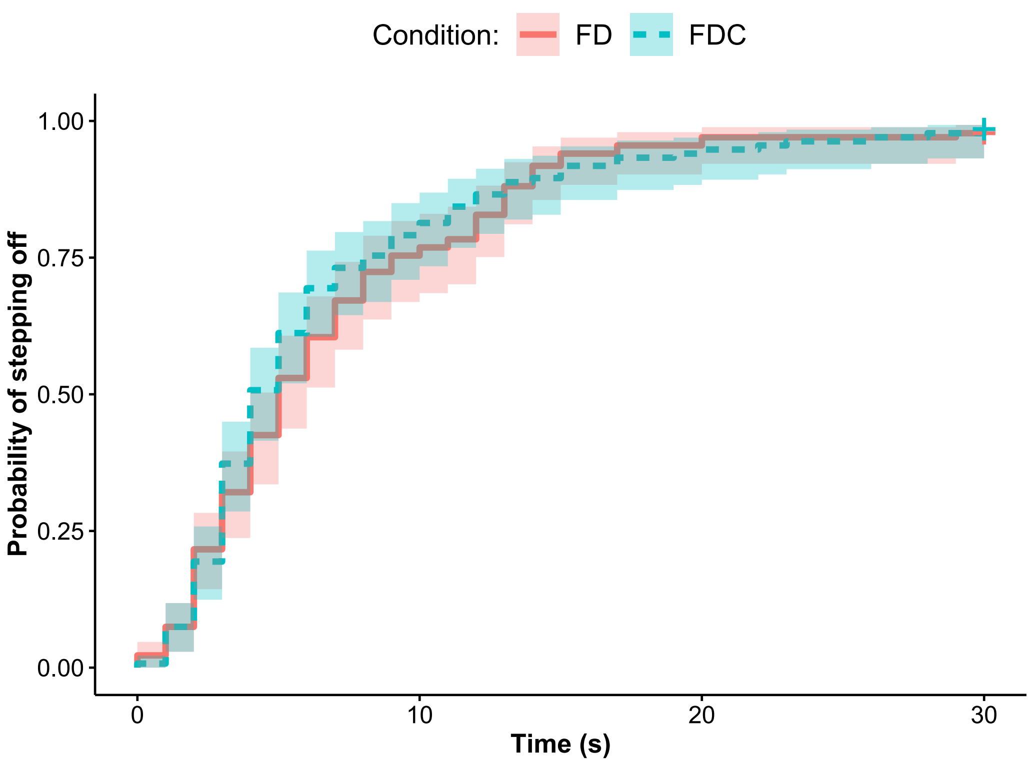
full = coxme(sso ~ Condition + z.Condition_Order + z.Day + (1 + z.Day|Subject) + (1 + z.Day| Sow), data=xdata)

Variables

- sso: response variable combining the latency to step off the mat with the front legs and whether it happened, created using the Surv() function of the coxme package (Therneau 2020)
- Condition: test condition, either foot discomfort (FD) or foot discomfort control (FDC); manually dummy-coded and centered
- Other variables: see above

Figure S13

Latency to Step Off the Mat in the FD and FDC Condition



Note. Cumulative incidence plot depicting the probability of stepping off from the start of the trial in the foot discomfort condition ("FD", solid line) and the foot discomfort control condition ("FDC", dashed line) across time. Crosses indicate trials in which pigs did not step off within 30 s.

Pilot Study

Probability of Pushing From the Other Side After Stepping Off the Mat

full = glmer(attemptafter ~ Condition + z.Condition_Order + z.Day + (1 + z.Condition_Order + Condition.A + z.Day||Subject) + (1 + z.Condition_Order + Condition.A + z.Day||Sow), data=xdata, family=binomial, control = glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)))

Variables

- attemptafter: Binary variable indicating whether the subject pushed from the other side after stepping off (1) or not (0)
- Condition: Test condition, i.e., attached (A) or unsolvable (US); manually dummy coded and centered for inclusion as a random slope
- z.Condition_Order: number indicating when in a session a trial appeared, can take values from 1 to 8, z-transformed to a mean of 0 and a standard deviation of 1
- z.Day: day, i.e., test session 1–4, z-transformed
- Subject: subject ID (identity of each individual tested in the pilot study)
- Sow: Litter from which the subject was taken (6 different sows)

Table S10

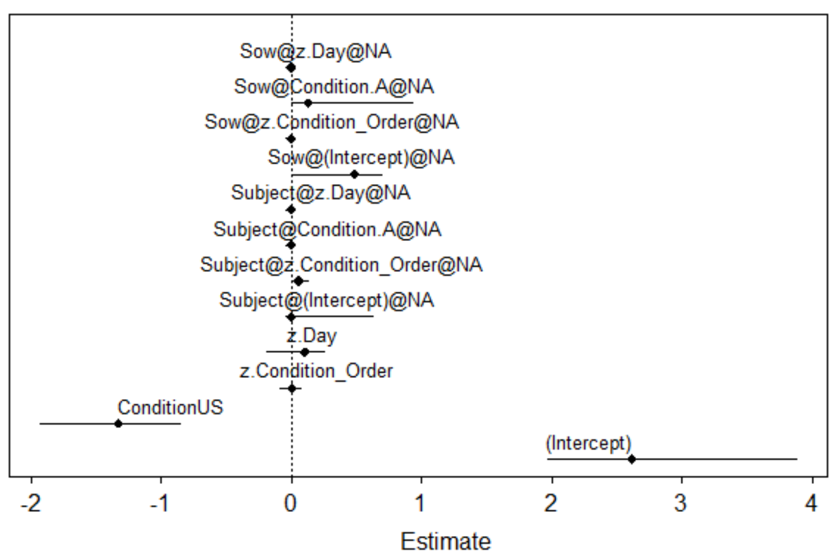
Model Output Probability of Pushing From the Other Side (Pilot)

Term	Estimate	SE	Z	p^3	Lower CI	Upper CI
Intercept	2.615	0.960	2.724		0.734	4.497
Condition[1]	-1.326	0.608	-2.178	.053	-2.518	-0.133
z.Condition_order[2]	0.008	0.122	0.063		-0.230	0.246
z.Day[2]	0.105	0.240	0.438		-0.366	0.577

Note. Full model output for the fixed effects of the GLMM analyzing the probability of pushing from the other side in the pilot study. [1]Condition was dummy coded with "A" being the reference category. [2]The variables Condition order and Day were z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean and standard deviation being 4.504 and 2.314 or 2.510 and 1.118, respectively. [3]p-value obtained from the full-null model comparison.

Figure S14

Model Stability Probability of Pushing From the Other Side (Pilot)



Note. Model stability plot for the probability of pushing from the other side after stepping off the mat. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the term before the first at sign representing a grouping variable (i.e., Sow or Subject) and the term after the first at sign denoting a random intercept (indicated by "(Intercept)") or a random slope. Correlations within the random effects are indicated by the presence of a second at sign and a third term. For this model, the third term is always "NA" as the correlations between random slopes and random intercepts were excluded from the model.

Latency to Push From the Other Side After Stepping Off the Mat

full = coxme(faa ~ Condition + z.Condition_Order + z.Day + (1|Subject) + (0 + z.Day|Subject) + (1|Sow) + (0 + z.Day|Sow), data=xdata)

Variables

- faa: first attempt after, response variable combining the latency to push from the other side and whether it happened, created using the Surv() function of the coxme package (Therneau 2020)
- Other variables: see above

Table S11

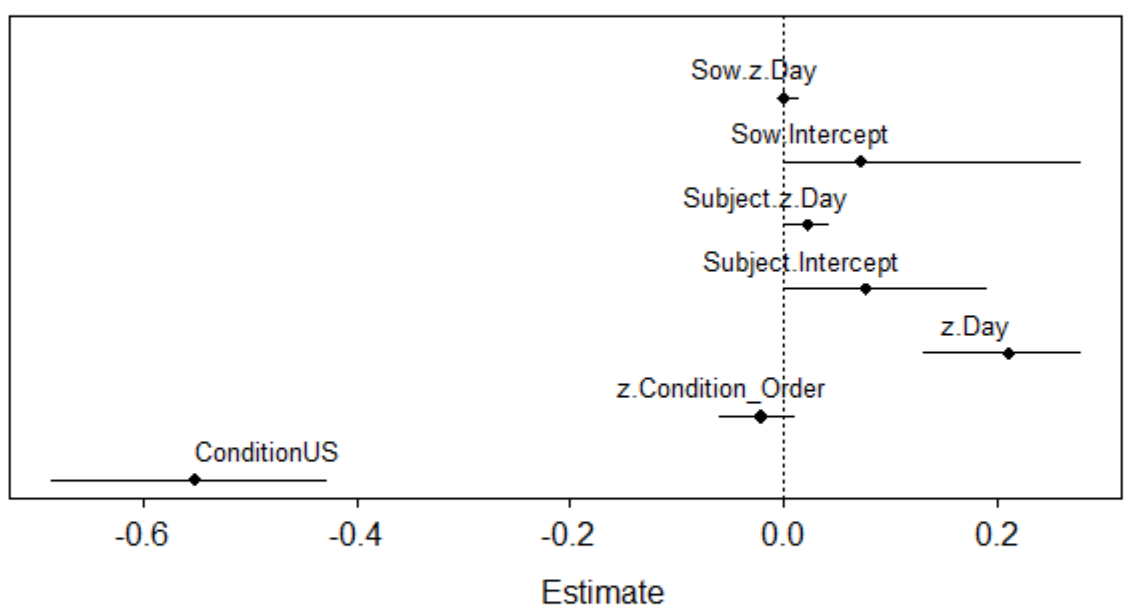
Model Output Latency to Push From the Other Side (Pilot)

Term	coef	exp(coef)	se(coef)	*Z*	*P*[3]
Condition	-0.551	0.576	0.187	-2.95	**.003**
z.Condition_order[1]	-0.021	0.979	0.040	-0.53	
z.Day[1]	0.211	1.235	0.100	2.10	

Note. Full model output for the fixed effects of the Cox mixed effects model analyzing the latency to push from the other side in the pilot study. [1]Condition was dummy coded with "A" being the reference category. [2]The variables Condition order and Day were z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean and standard deviation being 4.504 and 2.314 or 2.510 and 1.118, respectively. [3]p-value obtained from the full-null model comparison.

Figure S15

Model Stability Latency to Push from the Other Side



Note. Model stability plot for the latency to push from the other side after stepping off. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Names starting with "Sow" or "Subject" are random effects, with the second term denoting a random slope or intercept.

Between-Batch Comparisons

Probability of Succeeding in the Attached Condition Between Batches

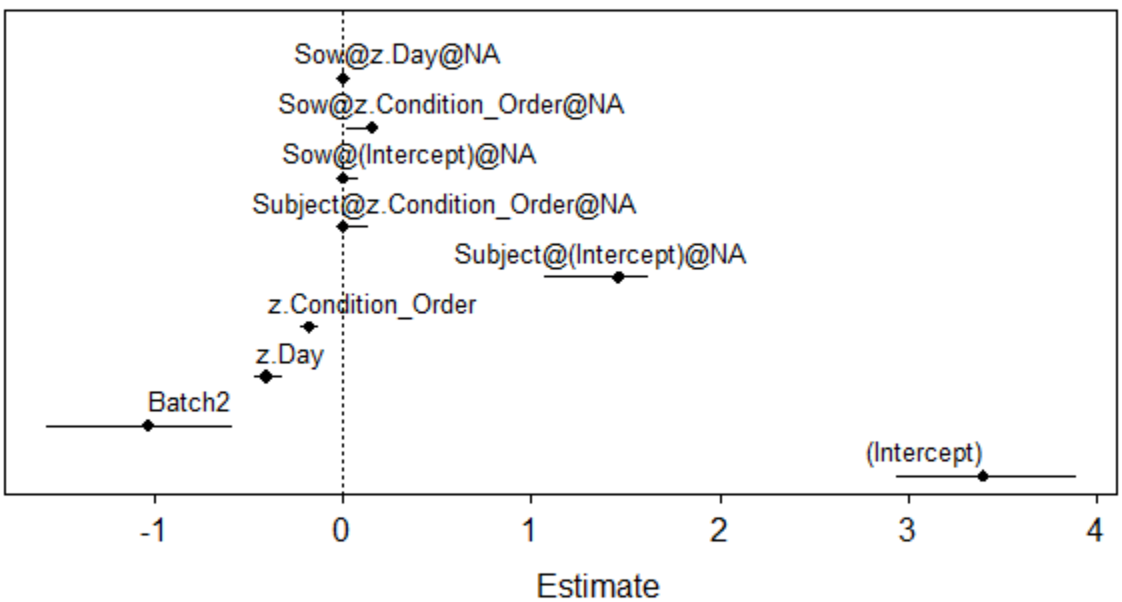
full = glmer(succeeded ~ Batch + z.Day + z.Condition_Order + (1 + z.Condition_Order ||Subject) + (1 + z.Condition_Order + z.Day||Sow), data=xdata, family=binomial, control = glmerControl(optimizer ="Nelder_Mead"))

Variables

- succeeded: binary variable indicating whether a subject was successful in pushing the panel from the other side and obtaining the food reward (1) or not (0)
- Batch: batch (study) the subject belonged to, i.e., batch 1 (pilot study) or batch 2 (main study); manually dummy-coded and centered for inclusion as a random slope
- Subject could now take 27 different values and sow 16 different values
- Other variables: see above

Figure S16

Model Stability Probability of Succeeding Between Batches



Note. Model stability plot for the probability of succeeding between batches. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the term before the first at sign representing a grouping variable (i.e., Sow or Subject) and the term after the first at sign denoting a random intercept (indicated by "(Intercept)") or a random slope. Correlations within the random effects are indicated by the presence of a second at sign and a third term. For this model, the third term is always "NA" as the correlations between random slopes and random intercepts were excluded from the model. Out of 39 models, seven failed to converge, hence the results of the stability assessment ought to be interpreted with caution.

Frequency of Inspecting the Back of the Panel in the (Known) Unsolvable Condition Between Batches

full = glmer(inspect_before ~ Batch + z.Day + z.Condition_Order + offset(log(time_inspection)) + (1 + z.Condition_Order||Subject) + (1 + z.Condition_Order + z.Day||Sow), data=xdata, family=poisson, glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

Variables

- See above

Table S12

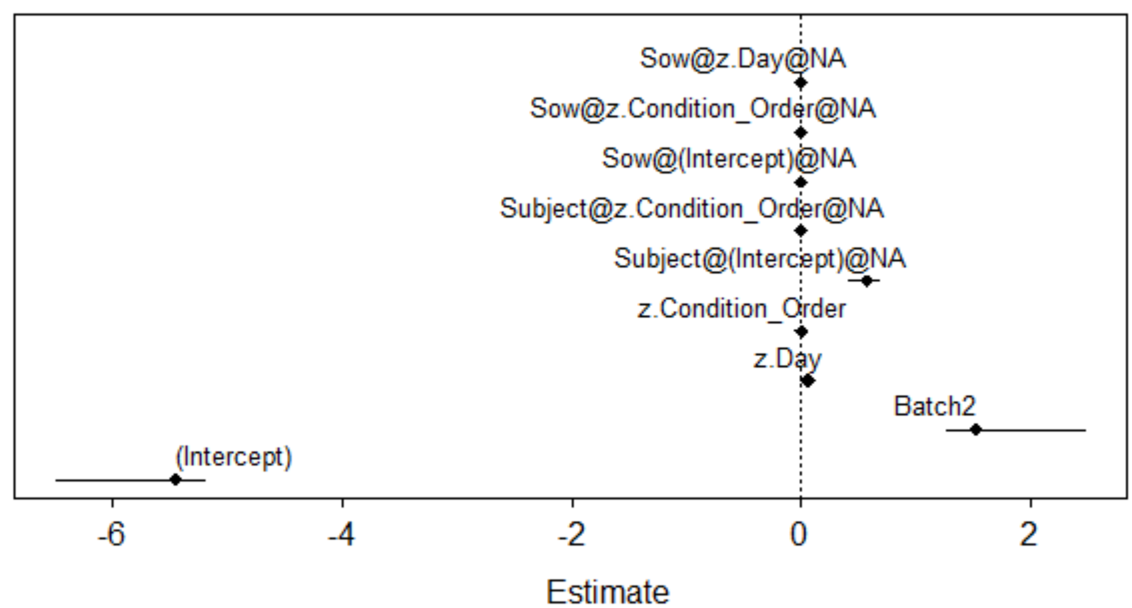
Model Output Frequency of Inspecting the Back of the Panel Between Batches

Term	Estimate	SE	Z	p^3	Lower CI	Upper CI
Intercept	-5.450	0.591	-9.224		-6.608	-4.292
Batch[1]	1.518	0.514	2.951	**0.002**	0.510	2.527
z.Day[2]	0.057	0.115	0.498		-0.169	0.283
z.Condition_order[2]	0.002	0.038	0.059		-0.072	0.076

Note. Full model output for the fixed effects of the GLMM analyzing the frequency of inspecting the back of the panel between studies (batches of pigs). [1]Batch was dummy coded with "1" being the reference category. [2]The variables Condition order and Day were z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean and standard deviation being 5.710 and 3.191 or 2.502 and 1.110, respectively. [3]p-value obtained from the full-null model comparison.

Figure S17

Model Stability Frequency of Inspecting the Back of the Panel Between Batches



Note. Model stability plot for the frequency of inspecting the back of the panel between batches. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates are based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the term before the first at sign representing a grouping variable (i.e., Sow or Subject) and the term after the first at sign denoting a random intercept (indicated by "(Intercept)") or a random slope. Correlations within the random effects are indicated by the presence of a second at sign and a third term. For this model, the third term is always "NA" as the correlations between random slopes and random intercepts were excluded from the model. Out of 41 models, one failed to converge.

Supplementary Material 5: Analyses of the First Trials

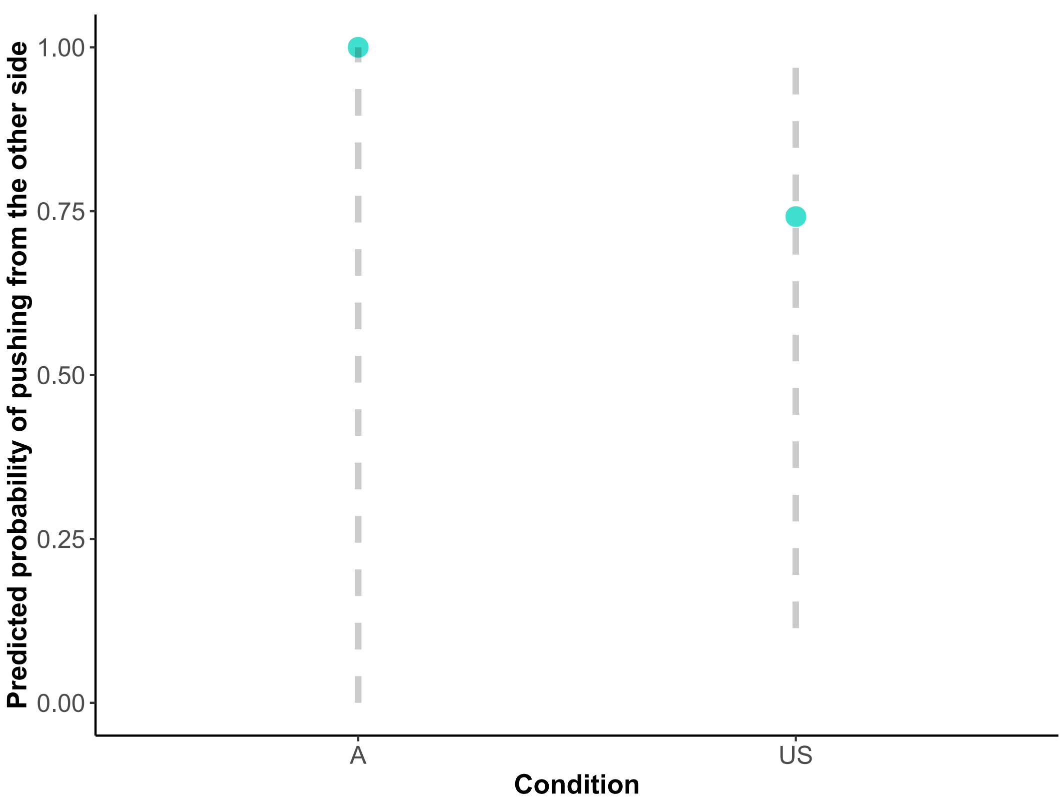
To investigate the influence of potential learning effects across trials and sessions (days), we performed the analyses described in the main manuscript separately for the first trials (on the first day) of each condition each subject experienced. If not stated otherwise, the statistical procedure was identical to that described for the full sample with the two exceptions that a) day was not included in the models (neither as a fixed effect nor as a random slope) because it could only take one value (1) and b) condition and condition order could not be included as random slopes within the random intercepts of subject and sow in the pilot study and most models in the main study (for details see below). Considering that only focusing on the first trials substantially reduced the number of observations included in the analysis, the results listed below ought to be interpreted with caution and serve mainly a descriptive purpose.

Probability of Pushing From the Other Side After Stepping Off – Pilot Study

The model included 18 observations across nine subjects and five sows and no collinearity between fixed effects was detected (all variable inflation factors < 1.024). The full-null model comparison revealed that the difference in the probability of pushing from the other side after stepping off observed in the full sample was already present in the first trials ($\chi^2 = 5.55$, $df = 1$, $p = .0185$). That is, pigs were more likely to push from the other side in the attached condition than in the unsolvable condition (see Figure S19 and Table S13).

Figure S18

Probability of Pushing From the Other Side in the First Trials (Pilot)



Note. Predicted probabilities of pushing from the other side after stepping off across conditions (US and A) in the first trials of the pilot study. Dashed lines indicate 95% confidence intervals.

Table S13

Model Output Probability of Pushing From the Other Side in the First Trials (Pilot)

Term	Estimate	SE	*Z*	*p*[3]	Lower CI	Upper CI
Intercept	17.033	1075.663	0.016		-2091.229	2125.294
Condition[1]	-17.677	1075.663	-0.016	**.019**	-2125.939	2090.584
z.Condition_order[2]	0.746	1.116	0.669		-1.440	2.932

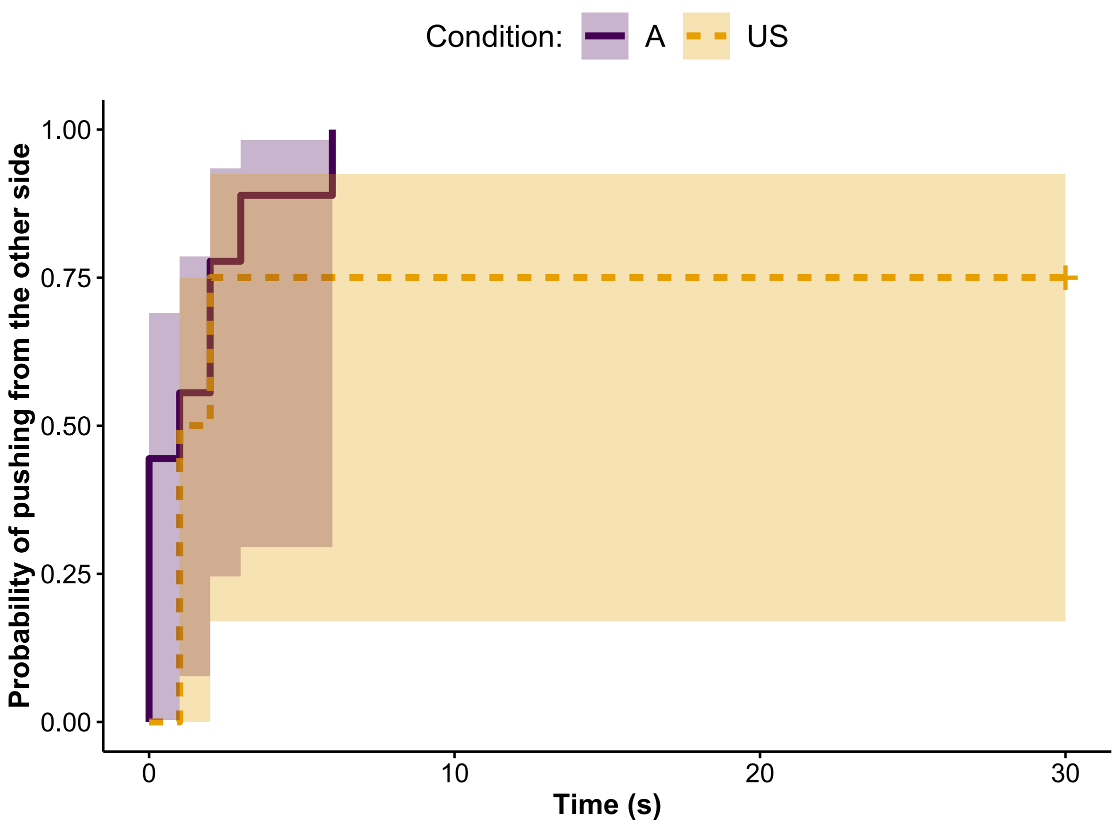
Note. Full model output for the fixed effects of the GLMM analyzing the probability of pushing from the other side in the first trials of the pilot study. [1]Condition was dummy coded with "A" being the reference category. [2]The variable Condition order was z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean being 2.278 and the untransformed standard deviation being 1.127. [3]p-value obtained from the full-null model comparison.

Latency to Push From the Other Side After Stepping Off – Pilot Study

Seventeen observations across nine subjects and five sows were included in the analysis. The fixed effects were not collinear (all variable inflation factors < 1.033). The difference between the attached condition and the unsolvable condition did not reach statistical significance ($\chi^2 = 1.52$, $df = 1$, $p = .2178$). Nevertheless, Figure S20 illustrates that pigs already tended to be quicker to push from the other side after stepping off in the first attached trials of the pilot study than in the unsolvable trials.

Figure S19

Latency to Push From the Other Side in the First Trials (Pilot)



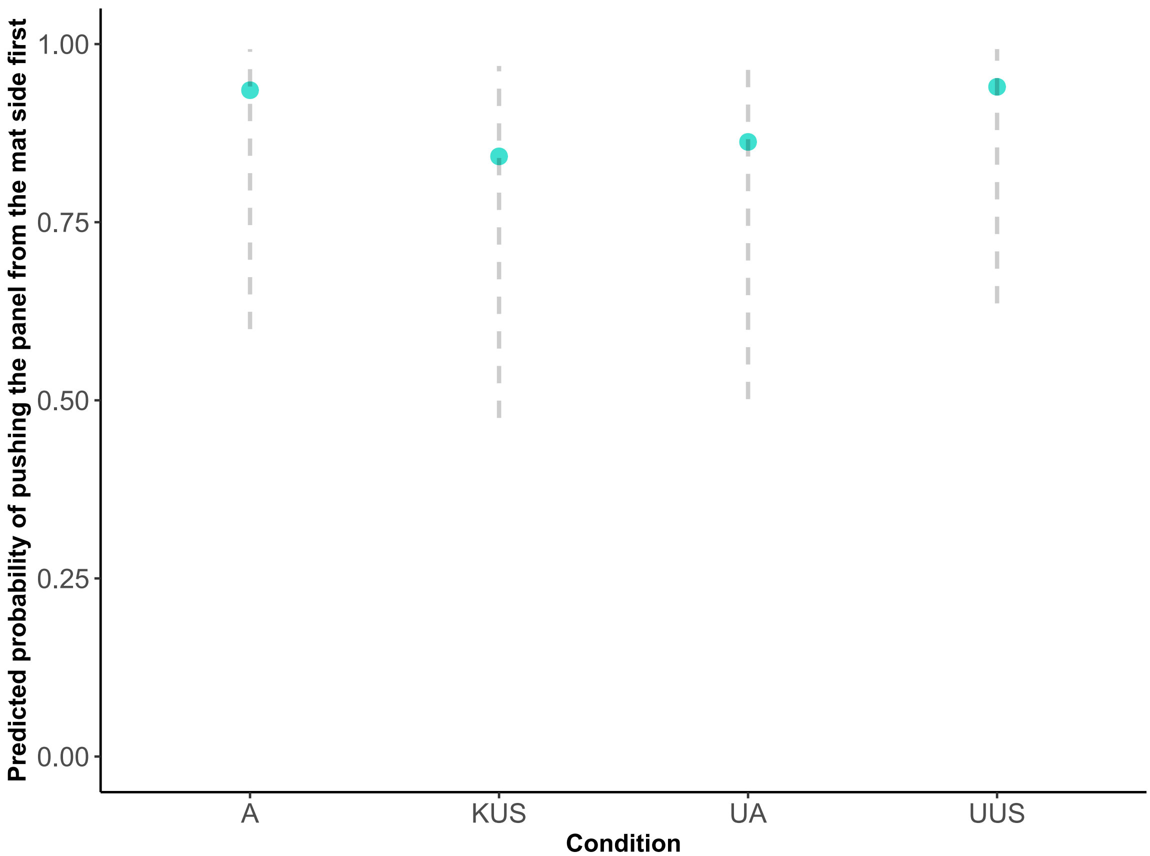
Note. Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time in the first trials of the attached condition ("A", continuous line) and the unsolvable ("US", dashed line) condition of the pilot study. Crosses indicate trials in which pigs had not pushed from the other side by the end of the trial.

Probability of Pushing From the Mat Side Before Stepping Off – Main Study

A total of 64 observations across 17 subjects and nine sows were considered in the analysis. Condition order could be included as a random slope for both random intercepts, i.e., subject and sow. The fixed effects were found to not be collinear (all variable inflation factors < 1.67). As for the entire sample, there was no significant difference in the probability of pushing from the mat side before stepping off with the front legs in the first trials (χ^2 = 1.53, df = 3, p = .675; Figure S21).

Figure S20

Probability of Pushing From the Mat Side First in the First Trials



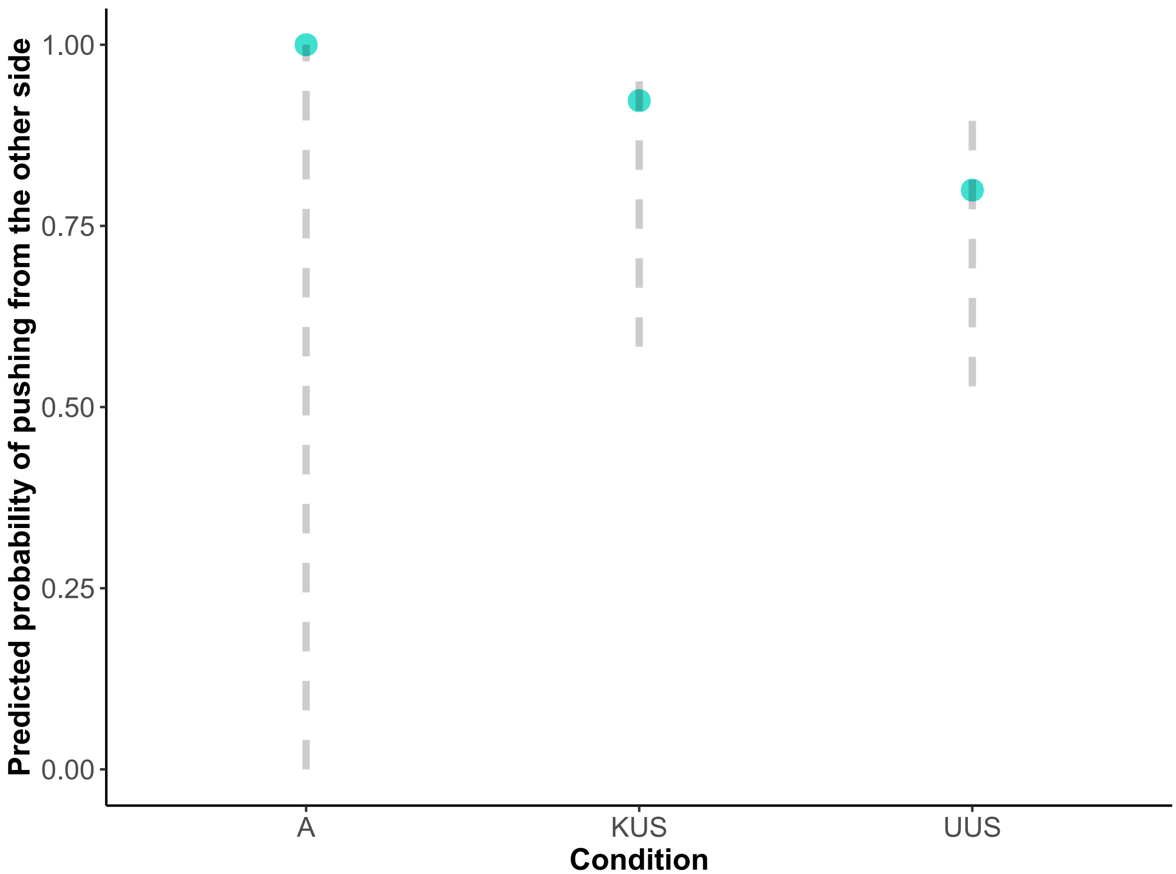
Note. Predicted probabilities of pushing from the mat side before stepping off across conditions in the first trials of the main study. Dashed lines indicate 95% confidence intervals.

Probability of Pushing From the Other Side After Stepping Off – Main Study

The sample for this model consisted of 38 observations across 16 subjects and nine sows. No collinearity between fixed effects was detected (all variable inflation factors < 1.368). Even though subjects were less likely to push from the other side in both unsolvable conditions than in the attached condition (see Figure S21), the difference did not reach statistical significance (χ^2 = 3.62, df = 3, p = .164).

Figure S21

Probability of Pushing From the Other Side in the First Trials



Note. Predicted probabilities of pushing from the other side after stepping off across conditions (UUS, KUS and A) in the first trials of the main study. Dashed lines indicate 95% confidence intervals.

Frequency of Inspecting the Back of the Panel – Main Study

The fixed effects were found to not be collinear (all variable inflation factors < 1.5). Of the 40 observations (across 16 subjects and nine sows) considered in this model, the event (inspecting the back of the panel) only happened three times, always in the KUS condition. Therefore, a significant difference across conditions was detected (χ^2 = 7.78, *df* = 2, *p* = .020; Table S14). However, none of the corrected p-values obtained for the pairwise comparisons remained significant (Table S15).

Table S14

Model Output Frequency of Inspecting the Back of The Panel in the First Trials

Term	Estimate	SE	*Z*	p^3	Lower CI	Upper CI
Intercept	-25.692	2896.310	-0.009		-5702.354	5650.971
Condition.KUS[1]	22.202	2896.309	0.008	**.020**	-5654.461	5698.864
Condition.UUS[1]	0.281	2896.309	< 0.001		-5676.381	5676.944
z.Condition_order[2]	-0.188	0.354	-0.531		-0.881	0.505

Note. Full model output for the fixed effects of the GLMM analyzing the frequency of inspecting the back of the panel in the first trials of the main study. [1]Condition was dummy coded with "A" being the reference category. The reference category is not listed in this table. [2]The variable Condition order was z-transformed to a mean of 0 and a standard deviation of 1, with the untransformed mean being 3.400 and the untransformed standard deviation being 1.707. [3]p-value obtained from the full-null model comparison.

Pairwise Comparisons

Table S15

Pairwise Comparisons Frequency of Inspecting the Back of the Panel in the First Trials

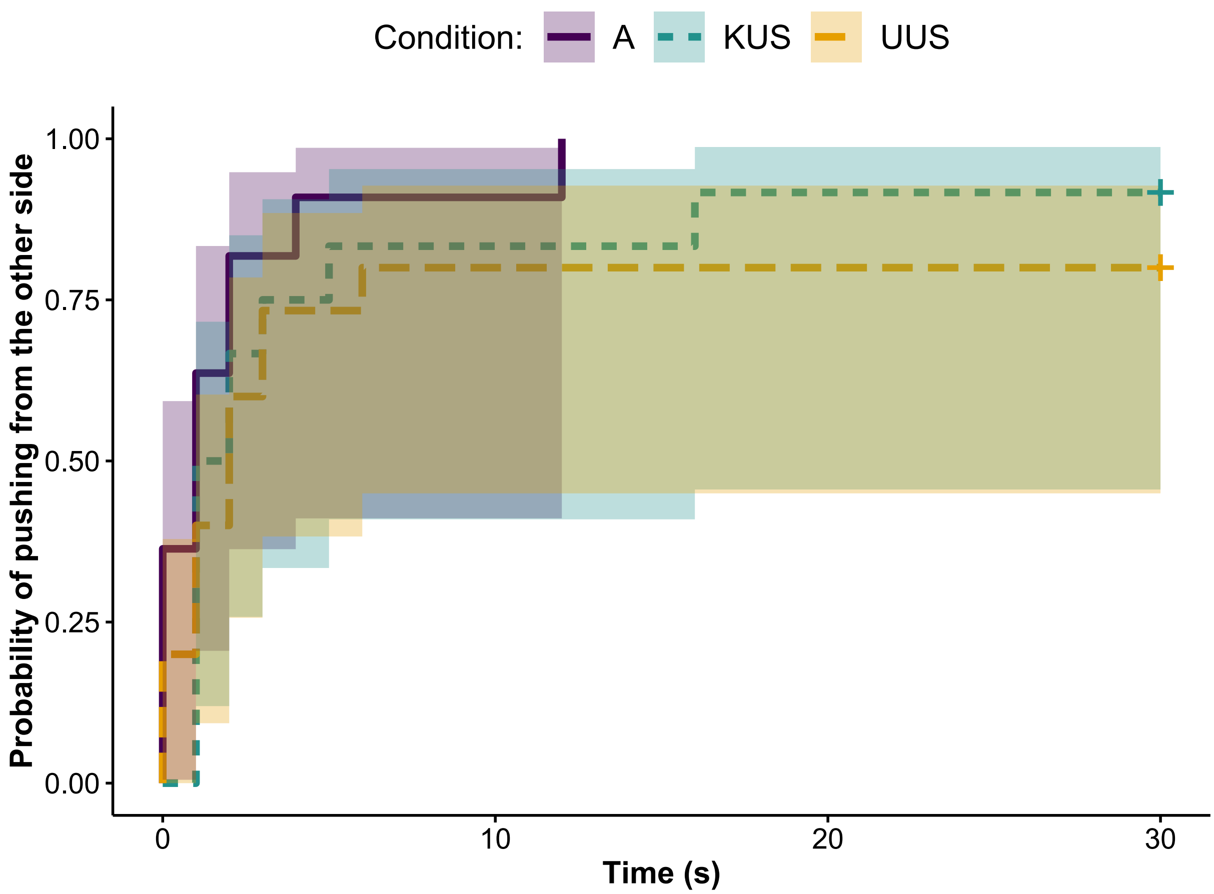
Comparison	Estimate	SE	*Z*	*p* (corrected)
A – KUS	-22.201	2896	-0.008	> .999
A – UUS	-0.281	2896	< 0.001	> .999
KUS – UUS	21.920	4096	0.005	> .999

Latency to Push From the Other Side After Stepping Off – Main Study

The analysis was based on 38 observations across 16 subjects and nine sows, the fixed effects were not collinear (all variable inflation factors < 1.57). Despite Figure S22 suggesting a shorter latency to push from the other side after stepping off in the attached condition than in both unsolvable conditions, the full-null model comparison revealed no significant differences across conditions ($\chi^2 = 2.30$, $df = 2$, $p = .317$).

Figure S22

Latency to Push From the Other Side in the First Trials



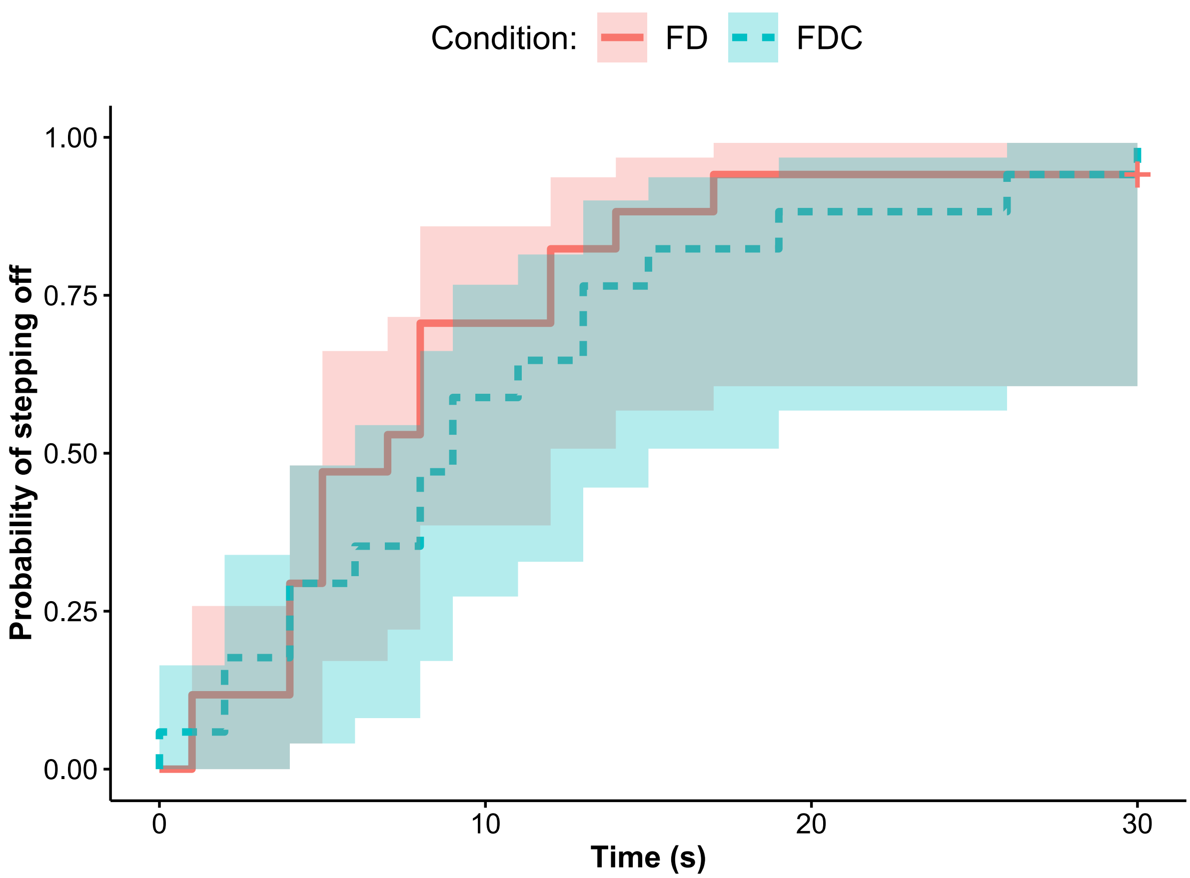
Note. Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time in the first trials of the attached ("A", continuous line), known unsolvable ("KUS", dashed line) and unknown unsolvable ("UUS", long-dashed line) condition of the main study. Crosses indicate trials in which pigs had not pushed from the other side by the end of the trial.

Latency to Step Off From the Start of the Trial in the FD Condition and the FDC Condition – Main Study

The analysis included 34 observations across 17 subjects and nine sows. No significant difference in the latency to step off with the front legs from the start of the trial between the FD condition and the FDC condition was found ($\chi^2 = 1.64$, $df = 1$, $p = 0.200$; see Figure S23).

Figure S23

Latency to Step Off the Mat in the First Trials of the FD and FDC Condition



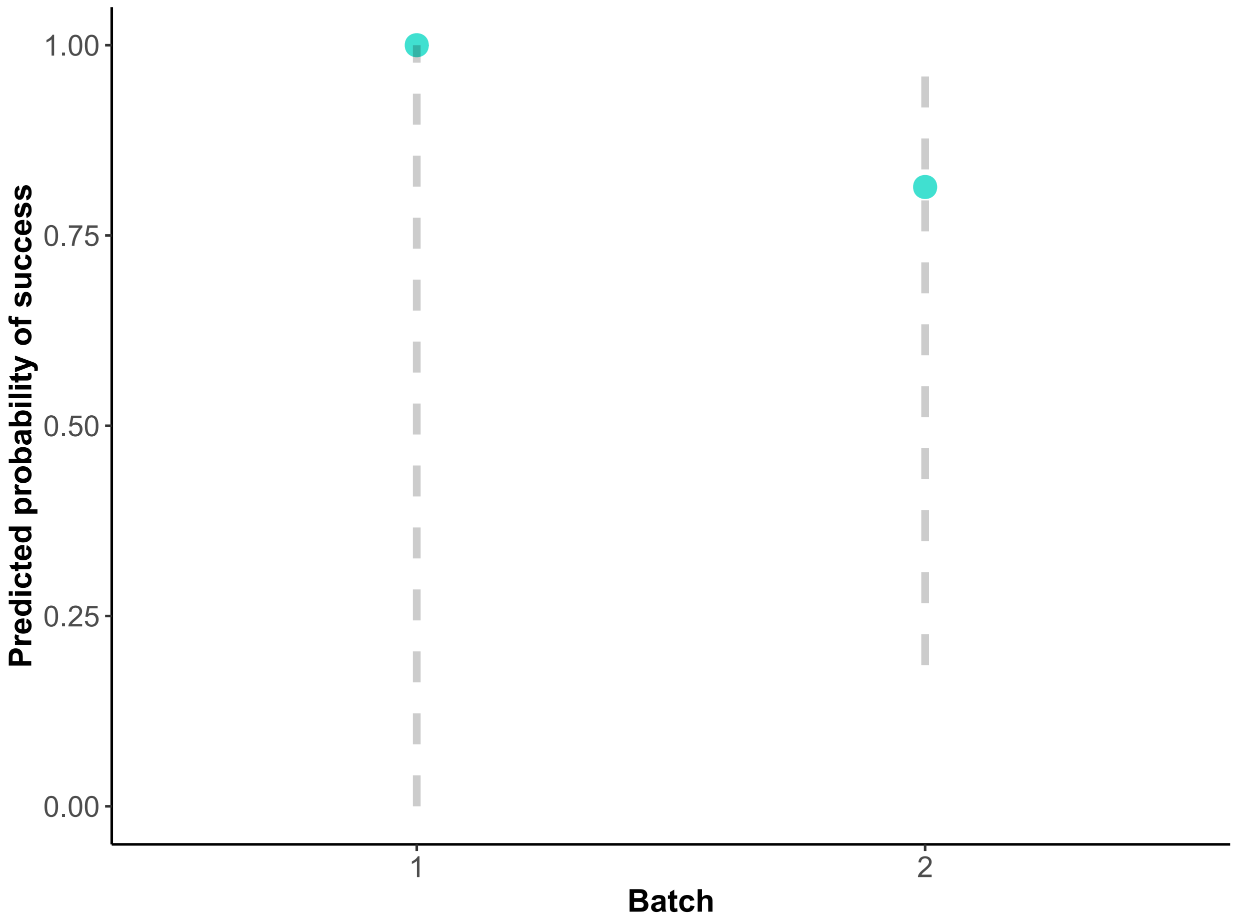
Note. Cumulative incidence plot depicting the probability of stepping off with the front legs across time in the first foot discomfort condition ("FD", solid line) and the foot discomfort control condition ("FDC", dashed line) of the main study. Crosses indicate trials in which pigs had not stepped off by the end of the trial.

Probability of Succeeding in the Attached Condition Between Batches

A total of 21 observations across 21 subjects and 14 sows could be included in this analysis. No collinearity between the fixed effects was detected (all variable inflation factors < 1.08). Pigs in the pilot study were more successful in their first attached trial (all nine pigs were successful) than the pigs in the main study (see Figure S24). Nevertheless, the difference between batches (studies) was not statistically significant ($\chi^2 < 0.001$, $df = 1$, $p > .999$).

Figure S24

Probability of Succeeding Between Batches in the First Trials



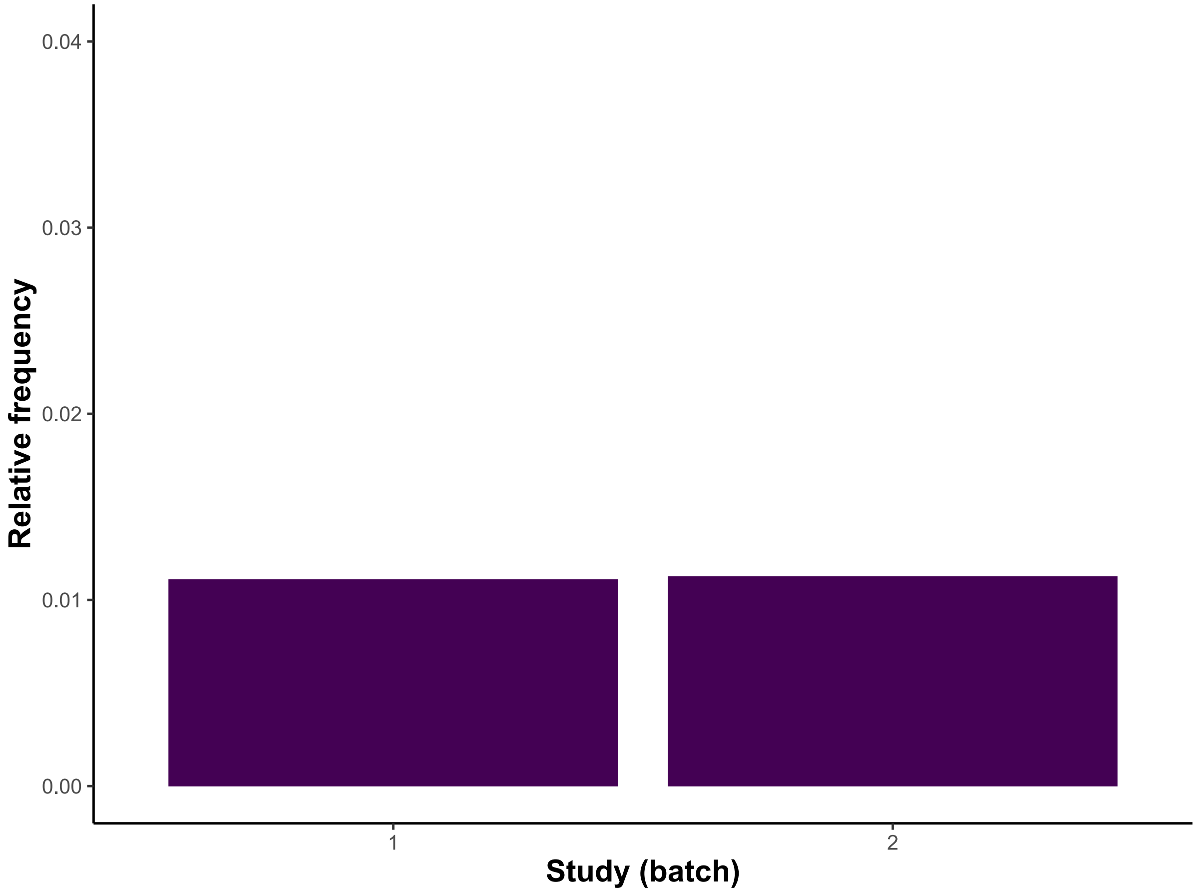
Note. Predicted probabilities of succeeding in the first trial of the A condition between batches of pigs (studies). Dashed lines indicate the 95% confidence intervals. Pilot study = 1, main study = 2.

Frequency of Inspecting the Back of the Panel Between Batches

This analysis was based on 22 observations across 22 subjects and 13 sows. The model was overdispersed (dispersion parameter = 1.43), the fixed effects were found to not be collinear (all variable inflation factors < 1.237). Unlike in the comparison for the full sample, no significant difference emerged between the two batches/studies (χ^2 = 0.93, df = 1, p = .334; see Figure S25).

Figure S25

Frequency of Inspecting the Back of the Panel Between Batches in the First Trials



Note. Frequency of inspecting the back of the panel in the first (K)US trials – relative to the latency to push from the other side and the number of trials per study – between batches (studies). Pilot study = 1, main study = 2.