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„Step aside! – The body-as-an-obstacle task in pigs"

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Abstract

Body awareness allows animals to perceive their own body as a tool or even an obstacle when interacting with the environment. Although human infants, elephants and dogs have already demonstrated this capacity in so-called body-as-an-obstacle tasks, this study is the first to investigate body awareness in a farm animal species, the domestic pig. For the purpose of a modified body-as-an-obstacle test, young pigs (n = 27) learned to push a sliding panel with their snout to access a food reward. This could be achieved from two different positions (left or right, corresponding to on or off a mat). In the test condition, the mat pigs were positioned on was attached to the panel via a chain. If body-aware, pigs were expected to step off the mat – after unsuccessfully trying from the mat side – and push from the other side. Subjects generally stepped off the mat and solved the “mat 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 both sides. However, the same was not observed if the panel was blocked for a reason unknown to the pig. Hence, pigs can flexibly adjust their behavior to solve a body-as-an-obstacle task, but the results from our control conditions do not provide clear evidence of body awareness. Future studies should disentangle pigs’ general problem-solving abilities from body awareness given the high welfare relevance of self-awareness in animals.

Zusammenfassung

Körperbewusstsein („Body Awareness“) erlaubt es Tieren, ihren Körper als Werkzeug oder gar als Hindernis wahrzunehmen, wenn sie mit ihrer Umwelt interagieren. Nachdem Kinder, Elefanten und Hunde diese Fähigkeit bereits in sogenannten Körper-als-Hindernis Tests gezeigt haben, untersucht die vorliegende Studie erstmals Körperbewusstsein in einer Nutztierart, dem Hausschwein. Zum Zwecke eines angepassten Körper-als-Hindernis Tests wurde Jungschweinen (n = 27) beigebracht, ein Rollbrett mit der Schnauze zu schieben, um eine darunterliegende Futterbelohnung freizulegen. Dies war von zwei verschiedenen Positionen aus möglich (links oder rechts, d.h. auf oder neben einer Matte). In der Haupt-Testcondition war die Matte, auf der die Schweine positioniert wurden, durch eine Kette am Brett befestigt. Falls Schweine körperbewusst sind, erwarteten wir, dass sie – nach erfolglosen Versuchen auf der Matten-Seite – hinuntersteigen würden, um von der anderen Seite zu schieben. Tatsächlich stiegen die meisten Schweine in den „Mat Attached“ Trials (in denen die Matte angehängt war) von der Matte und lösten die Aufgabe. Außerdem schoben sie in dieser Condition nach dem Heruntersteigen signifikant rascher und öfter von der anderen Seite, als wenn die Aufgabe aufgrund externer Hindernisse sichtbar von beiden Seiten unlösbar war. Jedoch trat dies nicht ein, wenn das Brett aus einem den Schweinen unbekannten Grund blockierte. Folglich können Schweine ihr Verhalten flexibel anpassen, um einen Körper-als-Hindernis-Test zu bestehen, die Ergebnisse unserer Control Conditions weisen jedoch nicht eindeutig auf Körperbewusstsein hin. Zukünftige Studien sollten versuchen, Körperbewusstsein von allgemeinen Problemlösefähigkeiten des Schweins zu trennen, angesichts der hohen Tierwohlrelevanz von Selbstbewusstsein.

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1. Introduction

Self-awareness allows animals to become the object of their own attention (Duval & Wicklund, 1972; Gallup, 1998) and the protagonist of their actions (Lage et al., 2022). Furthermore, 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), more recently the possibility of self-awareness in non-human animals has become the focus of researchers' attention (for a review see Lage et al., 2022).

Self-awareness in non-human animals is of especial scientific interest due to its paramount importance to animal welfare. First, some degree of awareness is postulated to be indispensable for sentience (Broom, 2006; Francione, 2012; Sommerville & Broom, 1998). For sentient beings, feelings (i.e., emotional or sensational mental states that can either be pleasant or unpleasant (DeGrazia, 1996)) are not merely *present* but also *matter* (Broom, 2006, 2007; Proctor, 2012; Webster, 2005) which results in an inherent drive to stay alive (Francione, 2012). Animal sentience, in turn, carries profound implications for a species' moral status, its standing in public, and ultimately its welfare. Therefore, questions of animal sentience and awareness have exercised animal ethics for centuries (Bentham, 1879; Singer, 1982).

Second, not just corollaries of self-awareness but also the capacity itself can be considered inherently welfare-relevant. This is because self-awareness can alter animals' perception of anthropogenetic environments. For instance, Sommerville and Broom (1998) uphold that self-aware animals' wellbeing is more likely to be compromised by memories of aversive experiences. One example for such aversive experiences are the restricted and confining environments predominant in modern intensive farming. Therefore, these husbandry practices can be expected to result in an even higher degree of frustration if farm animals are self-aware.

For self-aware individuals to be favored by natural selection, self-awareness must also alter the way animals experience their *natural* habitat. Several attempts have been made to understand in what these potential evolutionary advantages of self-awareness consist. For example, one popular theory, the arboreal clambering hypothesis, posits that self-awareness evolved to enhance the efficiency and safety of locomotion in the canopies of the rainforests humans' and apes' ancestors inhabited (Povinelli & Cant, 1996). An alternative, less primate-centric explanation put forward by Gallup suggests that self-awareness opened up a wide range of possibilities in the domain of social cognition (Gallup, 1998).

According to Gallup's theory, sophisticated socio-cognitive abilities such as deception, exploitation and manipulation of conspecifics can only evolve in self-aware species. These abilities all require an extrapolation from oneself (and one's own experiences) which logically hinges on an awareness of the self as a starting point. On the other hand, the opposite claim can be postulated: to become aware of oneself, awareness of others is an indispensable prerequisite (Mead, 1934). Regardless of the directionality, social cognition hence appears to be inextricably intertwined with and/or constitutive of self-awareness.

This interconnectedness between awareness of the self and socio-cognitive capacities suggests that self-awareness is more likely to be present in species exhibiting a complex social structure. Several arguments can be formulated to support this claim. First, self-awareness could present a valuable evolutionary advantage to social animals when interacting with conspecifics (Gallup, 1998). Second, the social environment and the possibility to recognize a self-other distinction (a hallmark of self-awareness (Bekoff & Sherman, 2004)) might be the principal factor giving rise to self-awareness in the first place (Mead, 1934). And third, social skills such as deception have been shown to positively correlate with self-awareness scores in both humans (Johnson et al., 2005) and chimpanzees (Krachun et al., 2019) suggesting that social cognition and self-awareness indeed are measurably linked. To further test the postulated interrelation between self-awareness and social cognition, comparative studies of self-awareness across species are called for.

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 established paradigm that has been applied for this purpose is the mirror mark (mirror self-recognition) test (Gallup, 1970). In the mirror mark test, a color mark is painted on the animal's forehead to later observe the subject's reaction upon seeing 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 indicators and hence "passed" the mirror mark test without explicit training: not only primates such as chimpanzees (Povinelli et al., 1997) and rhesus monkeys (Rajala et al., 2010), but also non-primate species, for example elephants (Plotnik et al., 2006) and dolphins (Morrison & Reiss, 2018; Reiss & Marino, 2001). Likewise, some bird species, namely magpies (Prior et al., 2008), to a lesser degree also Clark's nutcrackers (Clary & Kelly, 2016), and more recently even a fish species (Kohda et al., 2019) demonstrated self-recognition in front of a mirror. But, however useful the mirror mark test might be, it comes with a couple of major methodological limitations. For instance, it is restricted to species with a) sufficient visual abilities, b) extremities that allow individuals to inspect and touch a mark on their body and c) the motivation to do so (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. For example, Moore et al. (2007) propose that body awareness is best studied in locomotion when individuals navigate their environment, the context body awareness has most likely evolved in, rather than by using highly artificial set-ups. Focusing more on locomotion and how it is facilitated by a sense of self-agency (Moore et al., 2007; Povinelli & Cant, 1996) could also help researchers complement the findings of mirror mark studies. For this purpose, alternative, locomotion-based paradigms to assess self-awareness in animals have been developed.

Many alternative approaches to testing self-awareness 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 expressed in subjects estimating their bodily dimensions to plan their routes accordingly when navigating the environment (Franchak & Adolph, 2012). Building on this idea, subjects can be given the choice between two differently sized doors/openings or the size can be reduced progressively. This approach to testing body awareness has been realized in two recent studies in snakes (Khvatov et al., 2019) and dogs (Lenkei et al., 2020). However, merely observing whether animals attempt to pass through one available opening (varying in size across trials) is not as conclusive as letting them actively change something about their predicament. If, on the other hand, subjects are given the choice between two options (e.g., two differently sized openings or, in another design, two bridges that either do or do not support the subject's weight (rats: Khvatov et al., 2021)), trial-and-error learning must be carefully controlled for.

Another body awareness test originally designed for human infants may remedy these two shortcomings. In so-called body-as-an-obstacle tasks, children's own body needs to be (re)moved for the successful completion of a task, such as handing over a mat one is sitting on or pushing a shopping cart attached to that mat (Bullock & Lütkenhaus, 1990; Geppert & Küster, 1983; Moore et al., 2007). In these paradigms, subjects must recognize their body as a physical obstacle and then act on this realization by stepping off the mat to successfully move the object requested by the experimenter. Success in doing so correlates well with the ability to pass the mirror mark test in human infants (Moore et al., 2007), thereby confirming body-as-an-obstacle tasks' validity in testing self-awareness. A convincing transfer of the original body-as-an-obstacle task to non-human animals has already been accomplished in two species, namely elephants (Dale & Plotnik, 2017) and recently also 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 the animals were standing on, 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), b) the task was unsolvable because the object was attached to the ground (only in Lenkei et al., 2021) or when c) the experimenter pulled at the mat to potentially induce foot discomfort. These findings suggest that at least some non-human animals are able to recognize their body as a physical obstacle.

Despite these remarkable results for elephants and dogs as well as the welfare implications discussed above, body awareness has never been investigated in farm animals. Among these, the domestic pig (*Sus scrofa domesticus*) 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. That is, in 2019, pig meat contributed 33% to the global meat production, with 502,000 tons being produced in Austria (FAO, 2021). The intensive livestock farming systems necessary to meet the global demand for meat are associated with practices bound to collide with self-aware animals' welfare. For example, the aforementioned ability to conceive of the self as a temporally coherent entity (Povinelli & Cant, 1996; Tulving, 2005) could directly impact animals' wellbeing by modulating their experiences. Consequently, evidence of self-awareness in pigs would need to be considered when critically (re-)evaluating the effects of various husbandry practices on pig welfare.

Second, pigs have already been shown to possess other cognitive capacities closely associated with self-awareness. As outlined above, a sense of spatio-temporal continuity is counted among the cognitive manifestations of self-awareness (Gallup, 1998; Morin, 2011). Regarding the temporal component, self-awareness is hypothesized to be linked to episodic memory (Morin, 2011; Tulving, 2002). Not only pigs' episodic memory, recollecting the "what", "where" and "which" of a past event (Kouwenberg et al., 2009) but also remarkable findings on pigs' spatial cognition provide promising pre-requisites for self-awareness in pigs. For example, pigs can remember food locations after a retention interval of 10 min or 2 h (Mendl et al., 1997), with their memory exhibiting a susceptibility to disturbances comparable to the effects observed in humans and other animals. Furthermore, pigs can flexibly adjust their behavior, remember the "when" and "what" of food sources to prioritize sites of higher value (Held et al., 2005) and have proven their excellent working and reference memory skills in a complex spatial discrimination (holeboard) task (Arts et al., 2009; Bolhuis et al., 2013). Hypothesizing that the representation of one's body in space is contingent on sufficiently advanced spatial cognition, pigs' outstanding performance in this domain adds to the list of self-awareness prerequisites this species fulfills.

Third, pigs exhibit a high degree of social complexity, making them likely candidates for self-awareness. Given that the ability to understand and predict others is correlated with self-awareness, species living in social groups can be expected to excel at self-awareness tests. Among these socially complex species pigs can certainly be counted, owing to their gregarious lifestyle in matrilineal family groups (Mendl et al., 2010; Wood-Gush, 1983). Pigs' suitability is further supported by the remarkable abilities in the realm of social cognition pigs are endowed with: They discriminate between in- and outgroup based on familiarity and experience rather than genetics (Stookey &

Gonyou, 1998) and can even learn to tell unfamiliar individuals with a high degree of relatedness/similarity (littermates) apart (McLeman et al., 2005). However, these abilities are not restricted to conspecifics as pigs can also utilize different sensory cues to discriminate between individual humans (Koba & Tanida, 2001). In general, pigs' socio-cognitive abilities become most apparent in competitive contexts. When foraging, pigs can use others as a source of information in the "informed forager paradigm" (Held et al., 2000) and adjust their foraging behavior accordingly (Held et al., 2010). However, not just the naïve pigs but also informed subjects altered their tactics in this social foraging situation to counter-act exploitation (Held et al., 2002). Additionally, at least one individual showed evidence of visual perspective taking in another foraging task by Held et al. (2001). All these findings paint a picture of pigs as a socially and cognitively multi-faceted species, making them ideal study subjects to expand our knowledge on self-awareness.

Despite these promising findings on pigs' cognitive abilities and preliminary indicators of self-awareness, the paradigmatic mirror self-recognition test is inappropriate for pigs. Not only do they lack primates' hands and elephants' trunks, but also pigs rely more strongly on the olfactory compared with the visual sense (Croney et al., 2003) 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, as pigs are highly explorative in nature and motivated to physically interact with items in their environment. Therefore, body-as-an-obstacle tasks can be deemed a viable alternative to the mirror mark test when investigating self-awareness in pigs. In addition to enhanced practicability, a higher degree of ecological validity could be attained compared with classical mirror mark studies (Moore et al., 2007; Povinelli & Cant, 1996). One important similarity between mirror mark tests and body-as-an-obstacle tests is that both probe subjects' understanding of their actions' (e.g., locomotion) consequences. In both tasks, success should also be predicted by species' understanding of causal connections.

There is ample support for the idea that pigs are sensitive to the (potential) outcomes of their actions, i.e., show means-end understanding. For example, Curtis (1983) reports how pigs learned to operate a switch to regulate the ambient temperature in a barn according to their preferences. In another experiment (Croney & Boysen, 2021), pigs were successfully trained to move a cursor on a computer screen. Furthermore, not only instances of food-washing in European wild boars (Sommer et al., 2016) but also the first observed occurrence of tool use in pigs (Visayan warty pigs) has recently been documented (Root-Bernstein et al., 2019). Taken together, pigs' understanding of social, spatial, temporal and causal relations allow us to hypothesize that pigs could recognize their body as an obstacle in a pertinent test, thereby demonstrating body awareness.

To test the hypothesis that pigs possess body awareness, the body-as-an-obstacle task designed for dogs (Lenkei et al., 2021) and elephants (Dale & Plotnik, 2017) was adapted in the present study to better match pigs' ecology. Similar to three 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 pig-friendly variation of the original body-as-an-obstacle task exploits pigs' natural rooting behavior. In this new set-up, subjects needed to horizontally push a sliding panel in order to access a food reward. Pushing the panel was possible from two distinct positions: on or off a mat. During the test, pigs were always positioned on the mat (using a target stick) and encouraged to push from the mat side first. In the main test condition ("attached" condition), the mat the pig was standing on 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, carefully selected control conditions were included. These conditions controlled for a) foot discomfort evoked by the mat's movement upon pushing the panel and b) pigs' baseline tendency to push from the other side if the task is unsolvable from the mat side. If the reason for pigs' 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 unsolvable conditions (in which there is an external obstacle). This means that, compared with unsolvable conditions, in the attached condition pigs should be a) more likely to push from the other side, b) quicker to push from the other side after stepping off the mat (with their front legs), and c) less likely to search for an external obstacle blocking the panel from behind (rather than in front of it, on the mat) by inspecting the back of the panel/apparatus. Additionally, 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 is merely pretending to pull.

To test our predictions, a total of 27 pigs were subjected to the conditions of the described body-as-an-obstacle task. By subsequently comparing the behaviors just described across conditions, we aimed to draw conclusions on the pigs' understanding of their body as an obstacle and, ultimately, body awareness.

2. Ethical approval

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

3. Study 1

The present study was conducted at the VetFarm Medau (belonging to the University of Veterinary Medicine Vienna) in Oedlitz/Berndorf, Austria. Two consecutive batches of pigs were used to conduct two studies slightly differing in methodology, hereinafter referred to as "study 1" and "study 2" (see section 4). The first batch of pigs (n = 12) was trained and tested between the 24th of March and the 22nd of April 2022.

3.1 Methods

3.1.1 Subjects and housing

In the beginning of the study, 12 piglets from 6 different litters (1 castrated male and 1 female per litter) were selected. At 4 weeks of age, these animals were weaned and transferred to the rooms in which they were trained, tested and housed for the duration of the study. Pigs were regularly marked 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 1/3 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.

3.1.2 Apparatus and set-up

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

Apparatus

The cuboidal apparatus (see 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 (see top right picture in Figure 1) 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 (see bottom left and right pictures in Figure 1). A centrally placed wooden barrier (20 cm × 7.5 cm) attached to the front of the food container marked two distinct positions – left and right – 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. Wheels on the back side of the apparatus allowed for the transportation of the box.

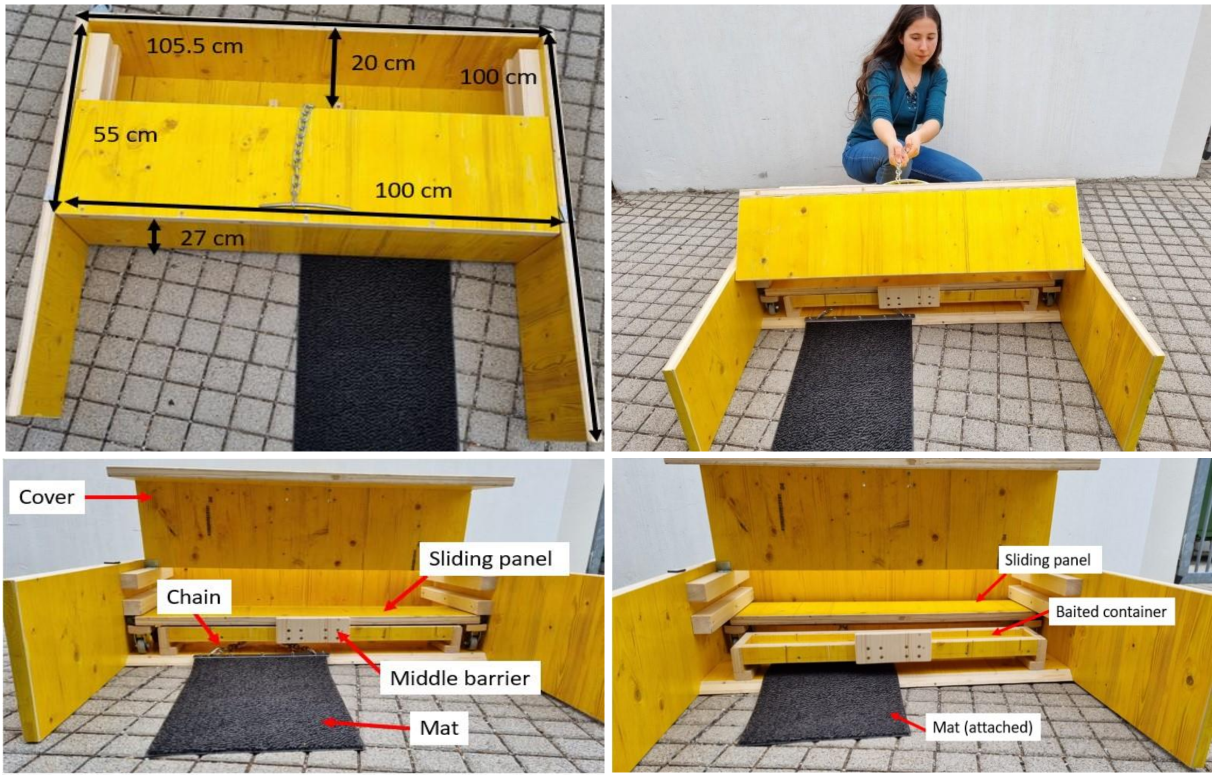

Figure 1: Body awareness apparatus from different perspectives. Top left: Top view of the body awareness apparatus with the cover closed. Top right: Experimenter lifting the cover of the apparatus. Bottom left: Front view (pig's view) of the body awareness apparatus with the cover open and the sliding panel to the front. Bottom right: 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, see Figure 2) 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. In the main test condition, this mat was connected to the sliding panel via a chain. Hence, 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. If the pig stepped off, however, the mat could move with the panel and be drawn into the apparatus in the space underneath the food container (see bottom right picture in Figure 1).

Figure 2: Mat pigs were standing on during the experiment and chain used to attach the mat to the sliding panel inside the apparatus.

Test enclosure

The apparatus and the mat were always encountered 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 wheels (the back) facing the wall and the front being 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 (see section 3.1.5). This prevented the pigs from seeing the experimenter and picking up on unintentional cues, e.g., gaze direction. The set-up is illustrated in Figure 3.

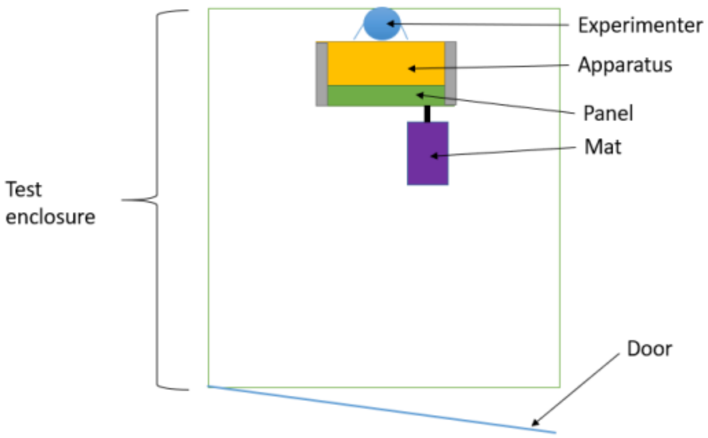

Figure 3: Set-up and spatial arrangement of the test enclosure during the testing and training. The experimenter operated from behind the apparatus, with her back facing the wall. The apparatus was placed equidistant from both corners of the enclosure.

3.1.3 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 should have learned to push the sliding panel with their snout from both sides. In the course of three weeks (16 days, not necessarily consecutive), pigs were thus habituated to the experimenter, the food and the test enclosure. 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 1 and are outlined in the following sections.

Table 1: Table visualizing the timing of every training step as well as the testing for study 1. 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.

Week	W1	W2					W3					W4				W5				
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FH	X	X																		
HT		X	X																	
TTH			X	X																
TTT					X	X	X													
TMT								X	X	X										
AT								X	X	X										
AMT											X	X	X	X	X	X				
T																	X	X	X	X

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 (see section 3.1.2), 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 being 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 appear everywhere 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 (see section 3.1.2) 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 made the target appear 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 described in section 3.1.2 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 one of the test conditions (see section 3.1.5). 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 to be 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 (see section 3.1.5).

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 fulfill 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.

3.1.4 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 thereby also the order of pigs) remained constant (± 2 hours) across days. All sessions were video recorded.

One session consisted of a total of eight test trials (two of each of four conditions) interspersed 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 section 3.1.5), 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. The experimenter then closed the cover and prepared the apparatus for the next trial before calling the pig to the apparatus again.

Trials were repeated if subjects stepped off before the cover was opened or if the apparatus was malfunctioning (e.g., blocking in the unattached condition).

The conditions were arranged in two blocks of four (one trial per condition), so that every condition had been run once before any condition was repeated. This design was chosen to be able to analyze the very first trial of each condition, prior to the onset of any learning effects, separately (see section 6.2 in the appendix).

If pigs ceased to cooperate, lost motivation or became too agitated, the session was interrupted and continued on the same day after all other pigs had been tested. This was necessary for three subjects on day 1 (4 trials, 1 trial, 4 trials), two subjects on day 2 (3 trials, 4 trials) and one subject on days 3 and 4 (6 trials on day 3, 2 trials on day 4).

3.1.5 The test conditions

To investigate whether pigs can recognize their body as physical obstacle, pigs' tendency to step off the mat and push the panel from the other side was compared across four conditions (see Figure 4). In the main test condition (attached condition), the mat that pigs were standing on was attached to the panel. Therefore, their body constituted an obstacle and the task could only be solved by stepping off and pushing the panel from the other side. To rule out other reasons why pigs might step off the mat in the attached condition, an unattached, an unsolvable and a foot discomfort condition were run (see also: Dale & Plotnik, 2017; Lenkei et al., 2021).

The unattached ("UA") condition allowed us to verify that pigs had learned to solve the task. This condition also controlled for pigs' baseline tendency to step off before pushing from the mat side. Pigs that stepped off before pushing from the mat side could not have known which condition they were confronted with (except for potentially the unsolvable condition, see below). For this reason, trials in which subjects did not push from the mat side before stepping off were later excluded from the analysis. As this could lead to a systematic bias if pigs were more likely to step off before pushing in some conditions than in others, the subjects' probability of pushing from the mat side first needed to be compared across all conditions – including the UA condition. Additionally, because the unattached trials were identical to the motivational trials, their inclusion made the appearance of test trials less predictable. That is, trials in which the panel could not be pushed (A, US and FD trials) and the training-like motivational trials did not exactly alternate (as they would have if we had included only the three other conditions, i.e., A, US and FD).

The unsolvable ("US") condition was included 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. 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 equally attractive and valid solutions (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.

Finally, the foot discomfort condition (short "FD") 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.

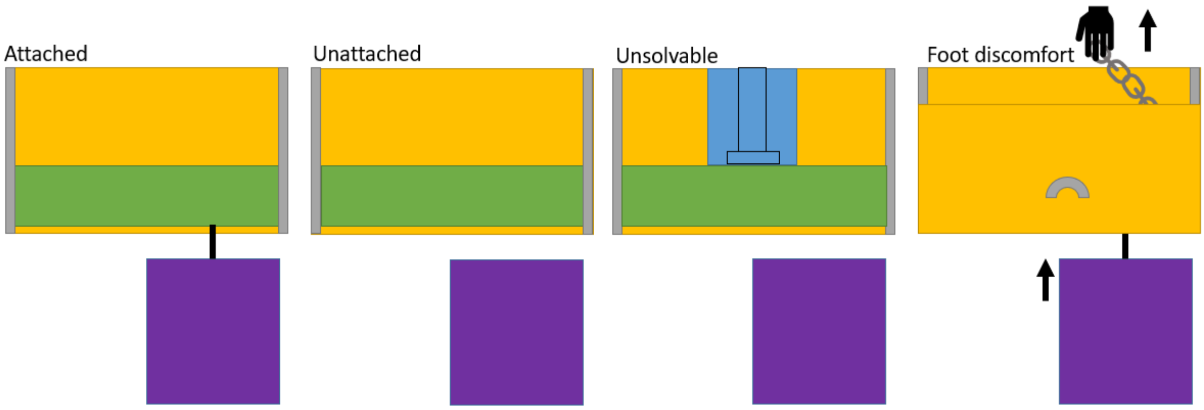

Figure 4: Schematic overview (top view) of the four conditions run in the test of study 1. The mat (in this example always on the right side) is depicted in purple, the panel in green. In the attached condition, mat and panel were connected via a chain (black). In the unsolvable condition, an obstacle (blue) was placed behind the panel. In the foot discomfort condition, the experimenter (hand) was pulling at the chain (and, thereby, the mat) via the 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, subjects started off on the mat, which was attached to a small carabiner on the back of the sliding panel via a chain (see diagram on the very left in Figure 4). The chain considerably restricted the panel's ability to move. As a result, pigs were not able to uncover the food container by pushing the panel. Only by stepping off the mat and attempting on the other side, next to the mat, could they access the otherwise unattainable 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 is truly body awareness, they should be more likely and quicker to do so compared with the unsolvable condition.

Unattached condition (UA)

The unattached 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 second diagram from the left in Figure 4) 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 unsolvable condition was designed in an attempt to mimic Lenkei et al.'s (2021) "attached to the ground" condition. In their version of an unsolvable condition, the toy that dogs had to pick up was not attached to the mat the dog was standing on but to a rope tightly anchored in the ground. Instead of locking the sliding panel in place by connecting it to the ground, which would not have been feasible in our test set-up, a physical obstacle was placed behind the panel (see second diagram from the right in Figure 4). Because the obstacle needed to be salient enough for pigs to acknowledge its presence, a blue block of wood was used (see Figure 5). Pigs' dichromatic color vision (Kittawornrat & Zimmerman, 2011) restricts the spectrum of colors they can perceive. However, based on physiological (Neitz & Jacobs, 1989) and behavioral (Tanida et al., 1991) evidence, blue should be among the colors that pigs can perceive and identify. 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. The unsolvable condition was the only test condition in which the blue block was not removed at the beginning of the trial but instead remained behind the panel for the entire duration of the trial. Consequently, the panel was physically and externally blocked and attempts to push it from either side were always unsuccessful. If pigs can realize that, unlike in the attached condition, the obstacle is not their body but an external object in the unsolvable condition, they should be more reluctant to futilely push from the other side.

In addition, if pigs realize that an external obstacle, and not their body, is blocking the panel in the unsolvable condition (when they do not feel any tugging of the mat), they might search for this external obstacle behind the panel. They should hence be more likely to inspect the back of the apparatus (where the blue block was in the unsolvable condition) in the unsolvable condition than in the attached condition.

Figure 5: Configuration of the apparatus in the unsolvable condition from the pig's perspective. The red circle indicates the blue block behind the panel.

Foot discomfort condition (FD)

Apart from an understanding of the task and an awareness of their own body, an alternative explanation for the pigs' potential tendency to step off the mat in the attached condition is foot discomfort. Foot discomfort could arise from the pressure exerted on the mat when the pigs attempt to push the sliding panel. 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). As in these previous studies, our subjects were standing on the mat 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, 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 a scale (Mini Crane Scale Model WH – C300 Series by ColeMeter, see Figure 6) 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.

Figure 6: Picture of the scale used to determine the pigs' strength of pushing in the attached condition and to later keep the force of the experimenter's pulling in the foot discomfort condition at this value. Hooks and carabiners could be attached to the two ends of the scale to connect it to the chain.

The maximum force measured during each of the three trials was noted down, averaged across the three pigs and converted from kilograms to Newton. 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 that all pigs become frustrated or confused by the unusual set-up and/or already gain experience with the mat being attached to the panel.

During the foot discomfort test trials, the experimenter used the scale in Figure 6 to keep the maximum pulling force at approximately 25,000 N, i.e., the strength of the pigs determined in the pre-test. 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.

As opposed to the other conditions, the cover of the apparatus was always closed in the foot discomfort condition. If it had been open, pigs would have presumably been distracted by the panel and/or the food, potentially distorting the results. On the other hand, the present set-up made the behavioral variables measured in the foot discomfort condition incomparable to the other conditions. For this reason, the foot discomfort condition was not analyzed for study 1, but served mainly as a feasibility evaluation of this approach. Based on the experience gained in study 1, we were able to implement an improved control for foot discomfort in study 2 (see section 4.1.5).

3.1.6 Behavior coding

The timepoints in the video at which each of the behaviors explained in Table 2 occurred were manually extracted from the video recordings. A second coder independently analyzed 20% of the trials. Based on the time points and their relations to each other, the variables explained in section 3.1.7 were calculated.

Table 2: Ethogram for study 1 including definitions and the conditions in which each behavior could be coded.

Behavior/Event	Definition	Condition
Start of the trial	Second in which the experimenter starts to lift the cover	A, US, UA
Start of the trial (FD)	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	all

	trial, b) the cover was closed prematurely or c) the experimenter stopped pulling at the chain (FD).	
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 (border = wooden barrier), i.e., before stepping off with the front legs for the first time	A, US, UA
Last pushing attempt before stepping off	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)	all
Stepping off with the last leg	Pig removes the last leg from the mat (can be a front or a hind leg) and steps off	all
First pushing attempt after stepping off	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 apparatus	Pig stretches its head far enough to reach the back end of the panel with its snout and visually/tactilely/olfactorily inspects what is behind the panel. For this the pig may need to stand or lie on the panel. This is only coded as long as the panel is still in the starting position. Instances that happened before "first pushing attempt after stepping off" were noted separately and only these were later analyzed.	A, US, UA

3.1.7 Statistical analysis

All analyses were performed in R Studio version 1.4.1717 (RStudio Team, 2021).

Excluded trials and subjects

In addition to cases in which pigs ceased to cooperate 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). The number of excluded trials per reason for exclusion were counted and are reported in the results section.

During the training phase of study 1, two pigs were excluded due to a lack of food motivation. The remaining ten pigs all fulfilled the training criteria (specified in section 3.1.3) 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). In addition, three more trials of this subject had to be excluded because, despite applying the right technique, he was physically unable to push the panel even in the unattached condition.

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. The remaining 297 trials were included in the analysis.

Descriptive measures

The percentages of successful attached and unattached trials were calculated and are reported in the results section.

Inter-rater reliability

To assess the agreement between the two coders, 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 study 1. Using the R package "IRR" (version 0.84.1) (Gamer et al., 2019), the agreement of the two raters 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 raters 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, $p < 0.0001$) and the occurrence (Fleiss' Kappa = 1, $p < 0.0001$) of pushing from the other side as well as for the time point of stepping off with the front legs (ICC = 0.997, $p < 0.0001$).

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. 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) in study 1.

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 full model was subsequently compared with a null model lacking the crucial fixed effect of condition and resembling the full model in all other aspects. Both models were fitted using the glmer function of the lme4 R package (version 1.1.27.1 ; Bates et al., 2015). A chi-squared 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. Overdisperson was assessed using the overdisp_fun function of the R package "remotes" (Csári et al., 2021). The model was not overdispersed (dispersion parameter = 0.966). To assess collinearity among fixed effects, the vif function of the R package “rms” (Harrell, 2022) was employed. No collinearity was found (all variable inflation factors < 1.004). The correlations between the random slopes and random intercepts were close to 1 or -1 and were therefore excluded from the model. 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 can be seen in Figure 18 (see Appendix), stability for the fixed and random effects was very good or good, stability for the intercept was acceptable.

141 trials across nine subjects and five sows (litters) were considered in the analysis.

Frequency of inspecting the back of the apparatus

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 apparatus across conditions. Unfortunately, as for the probability of pushing from the mat side before stepping off, the number of trials in which the behavior occurred was insufficient (6 occurrences in 5 out of 221 valid trials) 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 2. 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 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 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, correlations within random effects were excluded. As can be seen in Figure 19 (see Appendix), stability for all fixed and random effects was very good.

The model was fitted based on 139 trials across nine subjects and five sows.

3.2 Results

3.2.1 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, 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.

3.2.2 Probability of pushing from the other side

Pigs tended to push the panel from the other side more in the attached (89% of trials) compared with the unsolvable (79% of trials) condition (full-null model comparison: $\chi^2 = 3.7337$, $p = 0.05332$; see Figure 7).

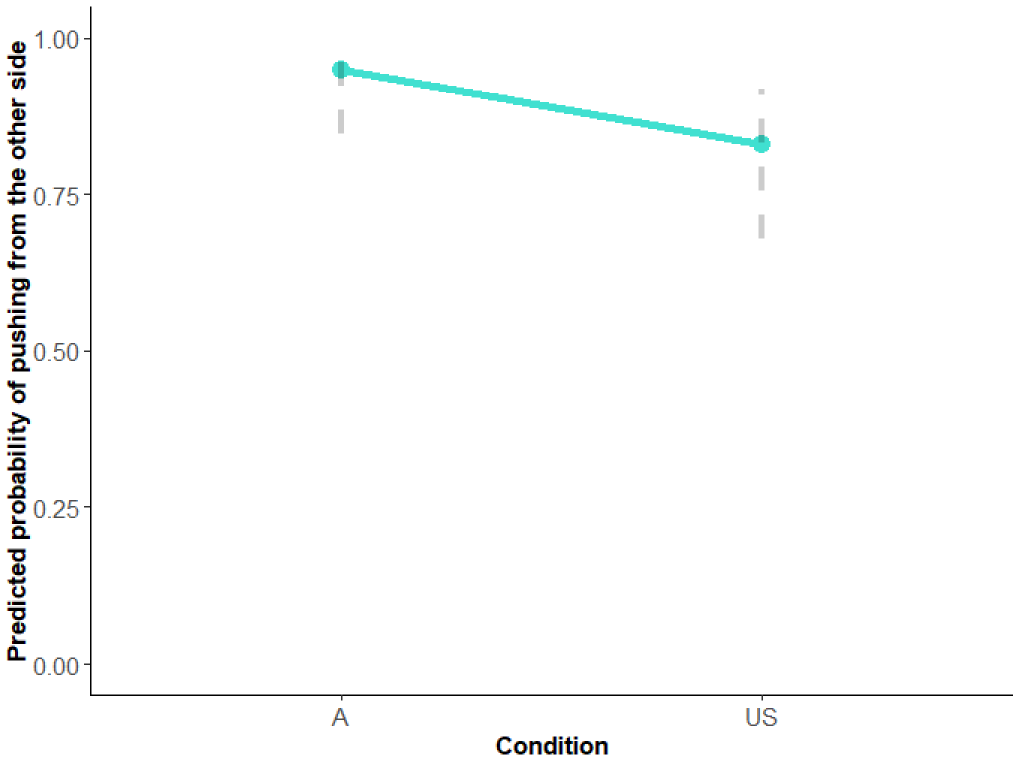

Figure 7: Predicted probabilities of pushing the panel from the other side after stepping off for the attached and the unsolvable condition. Dashed lines indicate the 95% confidence intervals.

3.2.3 Latency to push from the other side after stepping off

Pigs were significantly (full-null model comparison: $\chi^2 = 8.6276$, $p = 0.003$) quicker to push the panel from the other side after stepping off with the front legs in the attached compared with the unsolvable condition (see Figure 8).

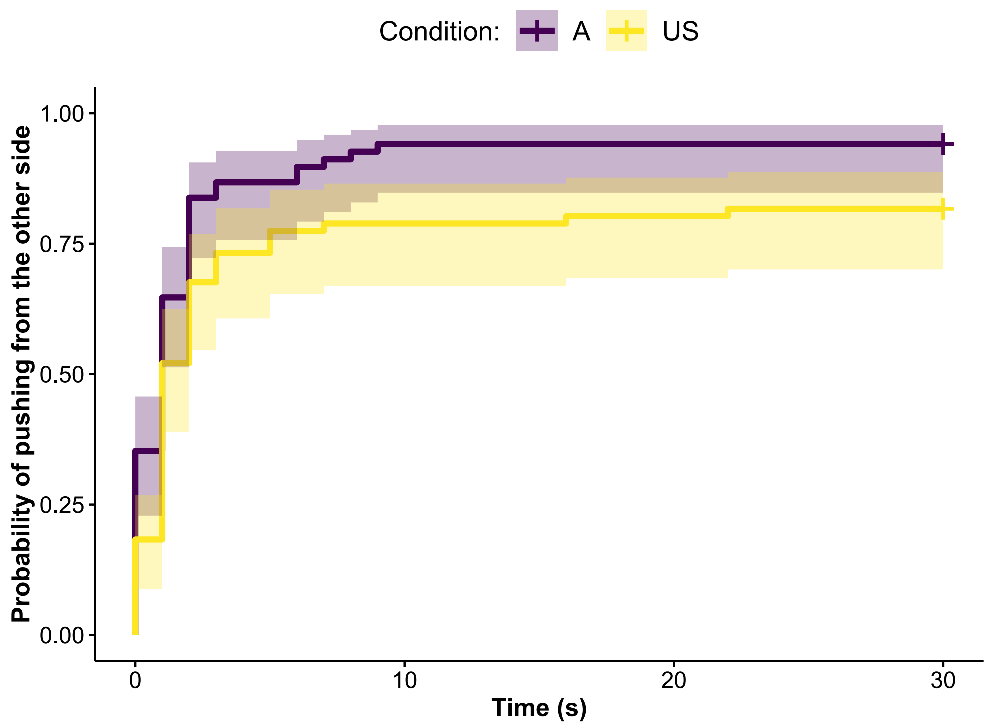

Figure 8: Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time. Crosses indicate trials in which pigs did not push from the other side until the end of the trial.

4. Study 2

Study 1 showed that pigs differentiate between a condition in which their body is an obstacle and a control condition in which a visible external obstacle renders the task unsolvable. However, it remained unclear whether a) subjects would also discriminate the attached condition from a condition unsolvable for a reason unknown to them (i.e., the way the attached condition would appear to individuals lacking body awareness) and b) whether foot discomfort could be the reason for the pigs' stepping off. Therefore, to more accurately tease apart the various potential mechanisms behind the pigs' behavior in the attached condition, more control conditions and a bigger sample were needed. For this reason, we conducted a second study (n = 20 pigs) between the 28th of April and the 27th of May 2022 addressing these outstanding questions.

4.1 Methods

4.1.1 Subjects and housing

The selection of subjects and their housing conditions were the same as described for study 1 (section 3.1.1), with the following exceptions.

A total of 20 piglets were selected from ten different sows and weaned on the 28th of April 2022. Subjects were split up into two groups of ten with equal numbers of males and females, but there were no littermates in the same group, and they were housed separately in two identical home pens.

4.1.2 Apparatus and set-up

The apparatus and set-up only deviated from the descriptions in section 3.1.2 in the following regards: A mirror was positioned next to the camera (above/behind the subject) to allow the experimenter to watch the subject's behavior during the training and test sessions. However, given that the subject was facing away from the mirror while it performed the task, it could still not have received any visual cues from the experimenter via the mirror. Furthermore, two (instead of one) new blue blocks were used to block the panel before each trial, as well as in one of the unsolvable conditions (see section 4.1.5). Even though the size of the blocks was the same as in study 1 (28 cm × 22.5 cm × 19 cm), the area visible to the pigs was enlarged. The width of this part was now approximately 35 cm.

4.1.3 Training and habituation

The training procedure for study 2 was almost identical to the protocol explained for study 1 with the following minor exceptions.

Given that the pigs were housed in two groups of ten for study 2, the training steps taking place in the home enclosure, i.e., food habituation and target training in the home pen, were conducted separately for the two groups. The order of these sessions (i.e., which group was first) alternated across days. Moreover, pigs were habituated to the test enclosure in four groups of five (instead of groups of three as in study 1).

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 study 1 and, in general, shorter sessions are recommended to keep pigs' motivation and concentration up (Herskin et al., 2020).

Based on the experience with study 1, 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 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 study 1. 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 study 1) 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 study 1. However, in contrast to study 1, 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 (see section 3.1.5) 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 (see section 4.1.5) 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.

All the changes described resulted in a slightly modified time plan for study 2, visualized in Table 3.

Table 3: Table visualizing the timing of every training step as well as the testing in study 2. 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.

Week	W1	W2					W3				W4				W5				
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																			

On all training days, all sessions for one group (e.g., group 1) were completed before the first pig of the second group (e.g., group 2) was brought in. The order of groups alternated from day to day. The same criteria as in study 1 were applied to identify successful pigs for the test.

4.1.4 Testing

The changes made to the apparatus (blue blocks) as well as the introduction of new conditions required some adjustments of the testing procedure applied in study 1.

Just as the blue block was taken out before every session (except for the US condition) in the first study, both blue blocks were taken out in the tests of study 2 (except for the KUS condition, see section 4.1.5). Given that this required the experimenter to use both hands, the subject had to wait longer after the cover was opened and fixed in the highest position. Switching sides before the blue blocks were taken out was, therefore, included as an additional reason to repeat a trial. Moreover, the definition of the start of the trials (for the analysis) was slightly modified (see section 4.1.6).

Motivational trials were repeated if pigs pushed from the wrong side and 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 again in the absence of the blue blocks.

As for the training, all pigs of one group (group 2) were tested before the first pig of the second group (group 1) could start. This also meant that interrupted sessions (e.g., because of a lack of motivation on the pig's side) were continued after all other test sessions *of that group*, i.e., not necessarily at the end of the day.

Due to the increased number of conditions, six instead of four, a total of 12 test trials (two blocks of six) and 13 motivational trials were conducted per session.

4.1.5 The test conditions

To more precisely tease apart the factors that could potentially motivate pigs to step off and push from the other side, three new test conditions were introduced. The unsolvable condition was split up into two conditions (known unsolvable and unknown unsolvable) and a so-called foot discomfort control condition was added (for an overview see Figure 9), whereas the attached, unattached and foot discomfort conditions remained unchanged.

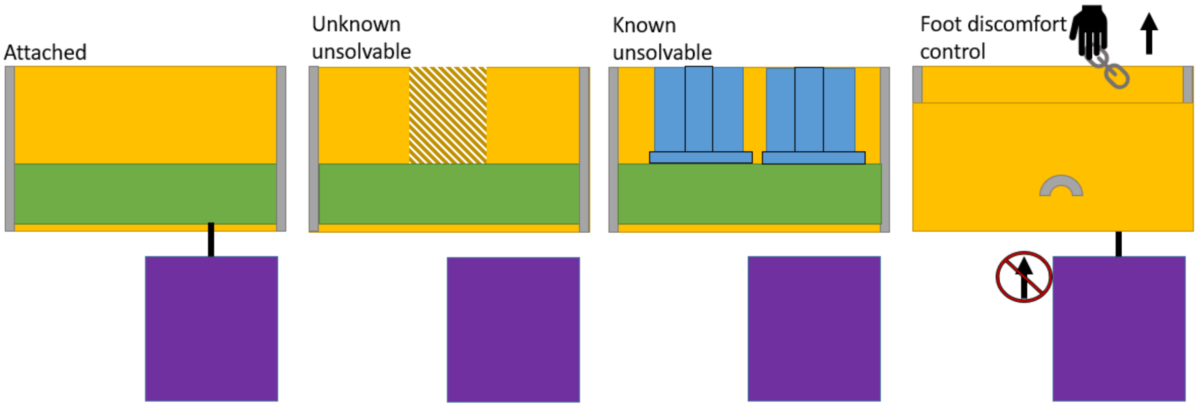

Figure 9: Schematic overview (top view) of the attached condition and the three new/modified conditions in study 2 (from left to right): unknown unsolvable (with an inconspicuous cardboard box behind the panel), known unsolvable (panel blocked by two big blue blocks) and foot discomfort control condition (subject stands on the mat in front of the closed apparatus and experimenter pretends to pull at a loose chain without exerting any force on the mat). The unattached and foot discomfort condition are not depicted.

The exact procedures for each of the conditions are elaborated in the following sections.

Attached condition (A)

The attached condition followed the exact same protocol as for study 1, with the exception that both blue blocks were taken out before each trial.

Unattached condition (UA)

The unattached condition followed the exact same protocol as for study 1, with the exception that both blue blocks were taken out before each trial.

Foot discomfort and foot discomfort control condition (FD and FDC)

As all other conditions of study 1 differed from the FD condition in several regards (e.g., accessibility of the panel) beyond the mere aspect of foot discomfort, the foot discomfort control condition was introduced to allow for a direct and valid comparison. This enabled us to isolate the factor of foot discomfort and its potential to drive pigs off the mat.

The FD condition followed the exact same protocol as for study 1. The average force exerted on the mat was again based on the results for the three individuals from study 1, no new tests were conducted for study 2. Hence, a maximum force of 25,000 N was applied by the experimenter.

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 actually exerting any force on the mat. 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. Presumably, the stimuli in this condition should have been equally attractive (e.g., rattling of the chain) or uninteresting (e.g., absence of any task, inaccessibility of the panel). Therefore, the only remaining difference between the FD and FDC condition was the potential factor of foot discomfort. 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 than in the FDC condition.

Known unsolvable condition (KUS)

Second, the two unsolvable conditions allowed us to investigate, in more detail, pigs' tendency to push from the other side when faced with a task (seemingly) unsolvable from the mat side (as in the attached condition). This was based on the assumption that pigs could potentially perceive the attached condition as "unsolvable for an unknown reason" (unlike the unsolvable condition in study 1) if they lack body awareness. Consequently, we deemed it necessary to include two different unsolvable conditions: a) one in which the cause of the unsolvability was visible and (in theory) understandable, the KUS condition, and b) one in which the panel was blocked for a reason unknown to the pigs (UUS condition, see next section).

The procedure of the KUS condition was very similar to that of the US condition in study 1. However, the blue block used in the US condition of study 1 was replaced by two bigger, more salient blocks (see Figure 10). This change aimed to facilitate the pigs' discrimination between the KUS and the UUS/A conditions.

Figure 10: Apparatus in the KUS condition with two blue blocks rendering the task unsolvable. Left: front view; right: top view of the blue blocks inside the apparatus.

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 unsolvable condition of study 1. To rule out the possibility that the pigs' differential reaction to the A and US condition observed in study 1 merely depended on whether they know (KUS condition) or do not know (A condition if pigs are not body-aware) why the panel cannot be pushed, the UUS condition was introduced in study 2. 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 (see Figure 11).

Figure 11: Left: front view (pig's view) of the apparatus in the UUS condition with the cardboard box blocking the panel; right: top view of the cardboard box inside the apparatus.

4.1.6 Behavior coding

The same behaviors as for study 1 were coded, with the following exception: Start was defined differently (for the A, UA, KUS and UUS condition) as it now took the experimenter longer to take the blue blocks out. Hence, the moment in which the cover was fully up (as opposed to the moment the experimenter started to lift it) was used as a marker. For the FDC condition, the definitions of the start and end of a trial were identical to those for the FD condition. Again, the same independent coder analyzed 20% of the trials for the subsequent assessment of inter-rater reliability.

4.1.7 Statistical analysis

Analyses were performed as described for study 1 in section 3.1.7 with the following exceptions.

For the probability of stepping off before the first attempt to push the panel, the probability of pushing from the other side after stepping off, the frequency of inspecting the back of the apparatus and the latency to push from the other side after stepping off, one more condition was included in the comparison as not only one but two (KUS and UUS) unsolvable conditions were conducted in study 2. Condition order could now take the values 1–12. Further changes are outlined below. Additionally, four new analyses were performed.

Excluded trials and subjects

In study 2, three out of 20 pigs were excluded before the test due to motivational issues or distress. Hence, 17 subjects that all fulfilled the criteria (see section 3.1.3) were tested.

As for study 1, some test trials 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 (wrong sequence). 23 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.

The remaining 765 trials could be analyzed.

Inter-rater reliability

The inter-rater reliability for the timepoints of the behaviors “stepping off with the front legs” and “first pushing attempt after stepping off” as well as for the frequency of “inspecting the back of the apparatus” was assessed as described for study 1 using the ICC. Fleiss’ Kappa was calculated 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 apparatus (ICC = 0.947, $p < 0.0001$) as well as the time points of stepping off with the front legs (ICC = 0.943, $p < 0.0001$) and first pushing attempt after stepping off (ICC = 0.926, $p < 0.0001$). Similarly, the agreement for the occurrence of stepping off with the front legs (Fleiss’ Kappa = 0.935, $p < 0.0001$) and first pushing attempt after stepping off (Fleiss’ Kappa = 0.939, $p < 0.0001$) was almost perfect. All values for the occurrence of first pushing attempt before stepping off were identical between the two raters, therefore reliability assessment was not necessary.

Probability of pushing from the mat side before stepping off

As explained above (see section3.1.7), only analyzing trials in which pigs pushed from the mat side before stepping off with the front legs could lead to the disproportional exclusion of trials of a certain condition and thereby distort the results. This is especially true for the KUS condition (and the US condition of study 1) in which pigs could, in principle, realize that the task is unsolvable from both sides as soon as they see the blue blocks. Therefore, a potentially interesting tendency to refrain from pushing more often in one condition (especially the KUS condition) could remain unnoticed when blindly excluding trials.

To rule out the erroneous exclusion of KUS trials, the probability of pushing the panel from the mat side before stepping off with the front legs was compared across the KUS, UUS, A and UA condition. For this purpose, a GLMM with a binomial distribution was fitted. The fixed and random effects as well as random slopes were the same as for the GLMMs described in section 3.1.7. Overdispersion and collinearity were assessed as described for study 1 in section 3.1.7. The model was not overdispersed (dispersion parameter = 0.593), nor was there substantial collinearity among the fixed effects (all variable inflation factors < 1.532). As for the other models, the correlations between the random slopes and random intercepts were equal or very close to 1 or -1 and were therefore excluded. Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat for study 1. As can be seen in Figure 20 (see Appendix), 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.

520 trials across 17 subjects and nine sows were considered in the analysis.

Probability of pushing from the other side

A GLMM (binomial distribution) with the fixed and random effects described in section 3.1.7 was fitted. Assessing overdispersion according to the method described above did not reveal overdispersion (dispersion parameter = 0.801). Also, no collinearity among the fixed effects was detected (all variable inflation factors < 1.369). The correlations between random slopes and random intercepts were equal or very close to 1 or -1, which is why we removed these correlations. Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat for study 1. 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 21 in the Appendix).

The model included 357 trials across 17 subjects and 19 sows.

Given that in study 2 the probability of pushing from the other side was analyzed for three instead of just two conditions, pairwise post-hoc comparisons were performed using the functions emmeans and pairs in the R package "emmeans" (Lenth, 2022).

Frequency of inspecting the back of the apparatus

The frequency of inspecting the back of the apparatus was compared across the A, UUS and KUS condition. 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 apparatus". The frequency was subsequently summarized for each subject and trial to be compared across conditions intra-individually. This was done using 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). Again, a full-null model comparison was performed. The model was not overdispersed (dispersion parameter = 0.720) and the fixed effects were not found to be collinear (all variable inflation factors < 1.357). The correlations between random slopes and random intercepts were equal or very close to 1 or -1, which is why we removed these correlations. Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat for study 1. One out of 26 models did not converge, hence the stability assessment is based on 25 models. As can be seen in Figure 22 (see Appendix), 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 starting estimate of the intercept was extreme (around -6).

370 trials across 17 subjects and nine sows were included in the analysis.

As for the probability of pushing from the other side, a post-hoc comparison was performed.

Latency to push from the other side after stepping off

A Cox Mixed Effects Model for the latency to push from the other side after stepping off the mat with the front legs was fitted with the same fixed and random effects as in study 1. The correlations between random intercepts and random slopes were not close to 1 or -1 and hence did not have to be excluded. The fixed effects were not found to be collinear (all variable inflation factors < 1.327). Model stability was assessed as for the latency to push from the other side after stepping off the mat for study 1. Stability for all fixed and random effects was very good (see Figure 23 in the Appendix).

The analysis included 357 trials across 17 subjects and nine sows.

As for the probability of pushing from the other side, pairwise post-hoc comparisons were performed.

Foot discomfort: Latency to step off

The new FDC condition gave us the opportunity to precisely analyze the influence of foot discomfort by comparing the latency to step off the mat with the front legs between the FD (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 test, 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 in section 3.1.7 were used. No collinearity among fixed effects was detected (all variable inflation factors <

1.002). The correlations between random intercepts and random slopes were not close to 1 or -1 and hence did not have to be excluded.

The model was based on 268 trials across 17 subjects and nine sows.

Between-batch comparisons

To investigate potential effects of the subtle differences in the procedure and set-up between study 1 and 2, 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 (study 1 or 2), 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. This full model was compared with a null model lacking the fixed effect of batch. The correlations between random slopes and random intercepts were close to 1 or -1 and were therefore excluded. The model was not overdispersed (dispersion parameter = 0.643) and 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 study 1. Out of 39 models, seven failed to converge, hence the results of the stability assessment ought to be interpreted with caution. Based on the 32 models that converged successfully, stability seems to be good or very good for all fixed and random effects as well as the intercept (see Figure 24 in the Appendix).

192 trials across 27 subjects and 14 sows were included in the analysis.

Second, the blue blocks for the KUS condition in study 2 were designed to be more obvious and 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 apparatus was compared between the KUS condition of study 2 and the US condition of study 1. For this purpose, a GLMM with a Poisson distribution with fixed and random effects identical to those just described for the probability of succeeding in the attached condition was fitted and compared with the null model. The correlations between random slopes and random intercepts were close to 1 or -1 and were therefore excluded. The model was not overdispersed (dispersion parameter = 0.890) and no collinearity among fixed effects was detected (all variable inflation factors < 1.136). Model stability was assessed as described for the probability of pushing from the other side after stepping off the mat for study 1. Out of 41 models, one failed to converge. As can be seen in Figure 25 (see Appendix), 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 sample for this model included 201 trials across 27 subjects and 14 sows.

4.2 Results

4.2.1 Descriptive statistics

As in study 1, pigs always succeeded when they attempted to push the panel in the unattached condition (122 valid unattached trials). Their success with the attached condition, however, was only at 52% (63 out of 121 trials, 16 out of 17 subjects succeeded at least once), even though pigs stepped off with the front legs in 94% (114 out of 121 trials) of the attached trials.

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.

4.2.2 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: $\chi^2 = 0.1816$, $p = 0.9805$).

4.2.3 Probability of pushing from the other side after stepping off

The probability of pushing from the other side after stepping off was significantly (full-null model comparison: $\chi^2 = 9.4606$, $p = 0.009$) influenced by the test condition. Based on Figure 12, pigs were visibly less likely to push from the other side in the KUS condition, whereas no clear difference can be seen between A and UUS. The pairwise post-hoc comparisons revealed that the pairs KUS – UUS ($p = 0.003$) and A – KUS ($p = 0.046$) but not A – UUS ($p = 0.661$) reached statistical significance.

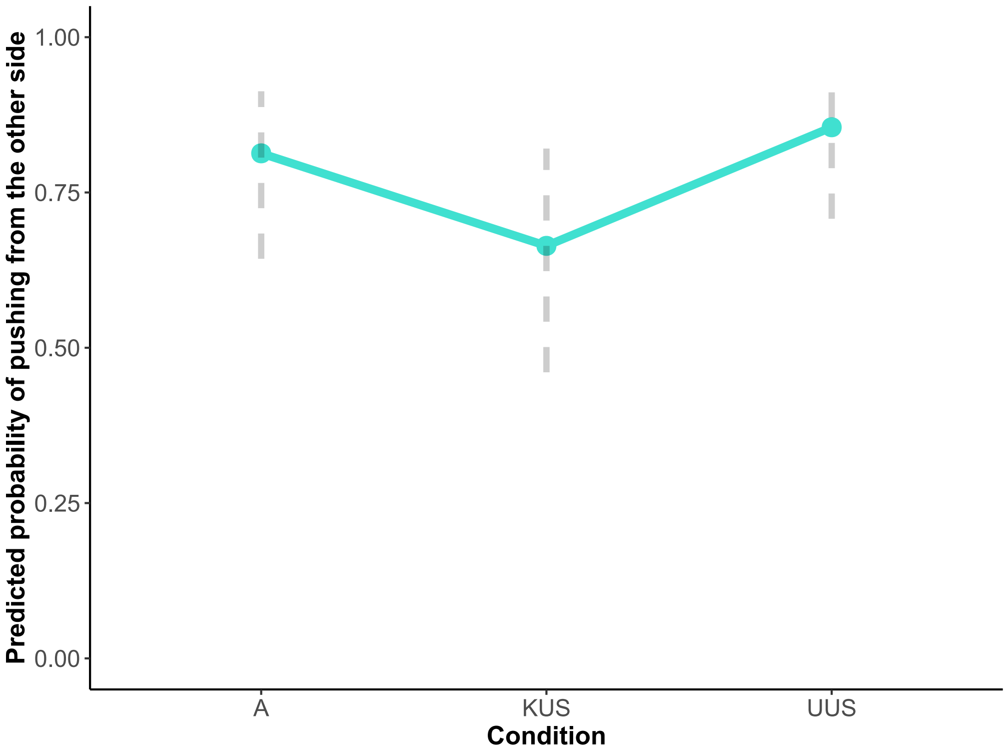

Figure 12: Predicted probabilities of pushing the panel from the other side after stepping off across conditions (A, UUS, KUS). Dashed lines indicate the 95% confidence intervals.

4.2.4 Frequency of inspecting the back of the apparatus

The frequency of inspecting the back of the apparatus varied significantly across conditions (full-null model comparison: $\chi^2 = 20.75$, $p < 0.001$). As can be seen from the plot (Figure 13), subjects looked behind the panel more often in the KUS condition than in all other conditions. This was confirmed by the post-hoc pairwise comparisons that revealed that both the pair A–KUS ($p < 0.001$) and UUS–KUS ($p < 0.001$) differed significantly.

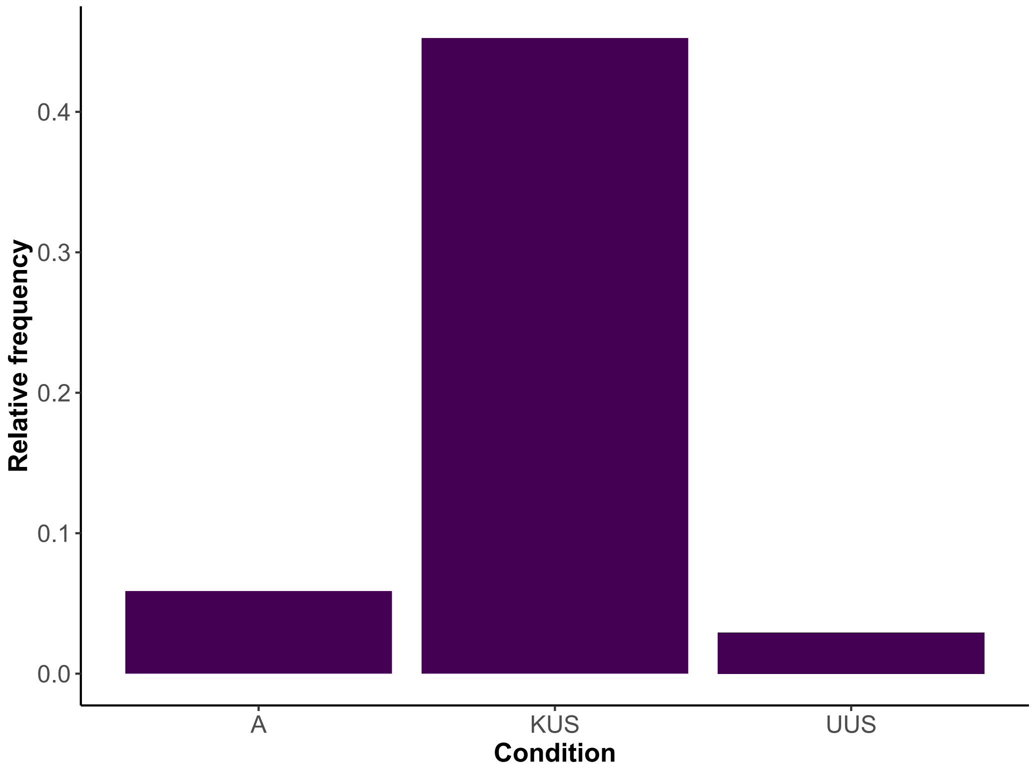

Figure 13: Relative frequency (i.e., the number of occurrences per trial divided by the latency to push from the other side from the start of the trial) of "inspecting the back of the apparatus" across conditions.

4.2.5 Latency to push from the other side after stepping off

As in study 1, pigs were again significantly (full-null model comparison: $\chi^2 = 20.661$, $p < 0.001$) slower to push from the other side after stepping off with the front legs if the task was visibly unsolvable (KUS condition). However, no difference between the A and UUS condition is evident from the plot (see Figure 14). The post-hoc pairwise comparisons confirmed this impression: Both the comparisons between A – KUS ($p < 0.001$) and KUS – UUS ($p < 0.001$) were highly significant, whereas no difference between the A and UUS condition was detectable.

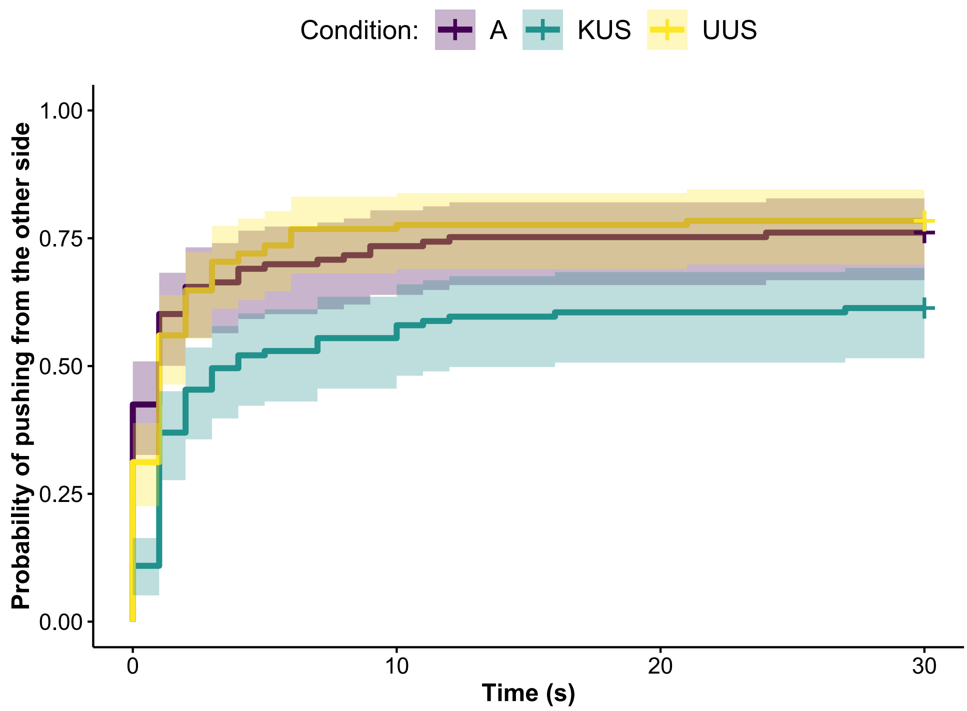

Figure 14: Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time. Crosses indicate trials in which pigs did not push from the other side until the end of the trial.

4.2.6 Latency to step off from the start of the test in the FD and FDC condition

When comparing the FD and 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: . $\chi^2 = 0.165$, $p = 0.198$), see Figure 15.

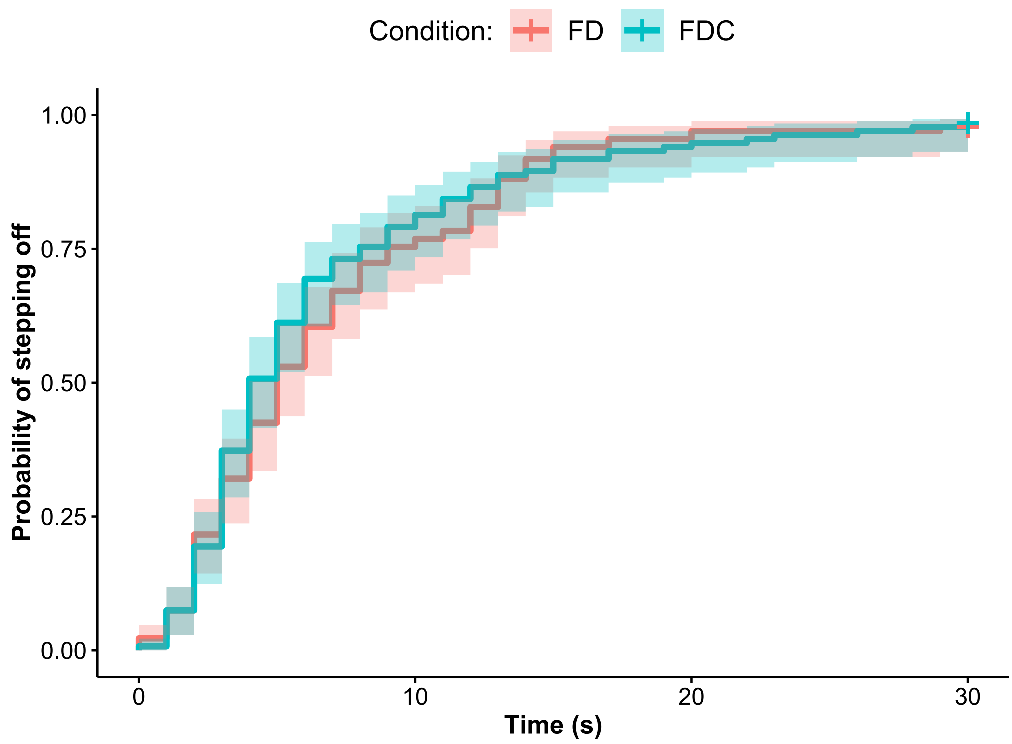

Figure 15: Cumulative incidence plot depicting the probability of stepping off from the start of the test in the foot discomfort conditions across time. Crosses indicate trials in which pigs did not step off within 30 s.

4.2.7 Between-batch comparisons

Success in the attached condition

Even though pigs were considerably more successful (see Figure 16) in the attached trials of study 1 (76%) compared with study 2 (52%), this difference did not reach statistical significance (full-null model comparison: $\chi^2 = 1.482$, $p = 0.223$).

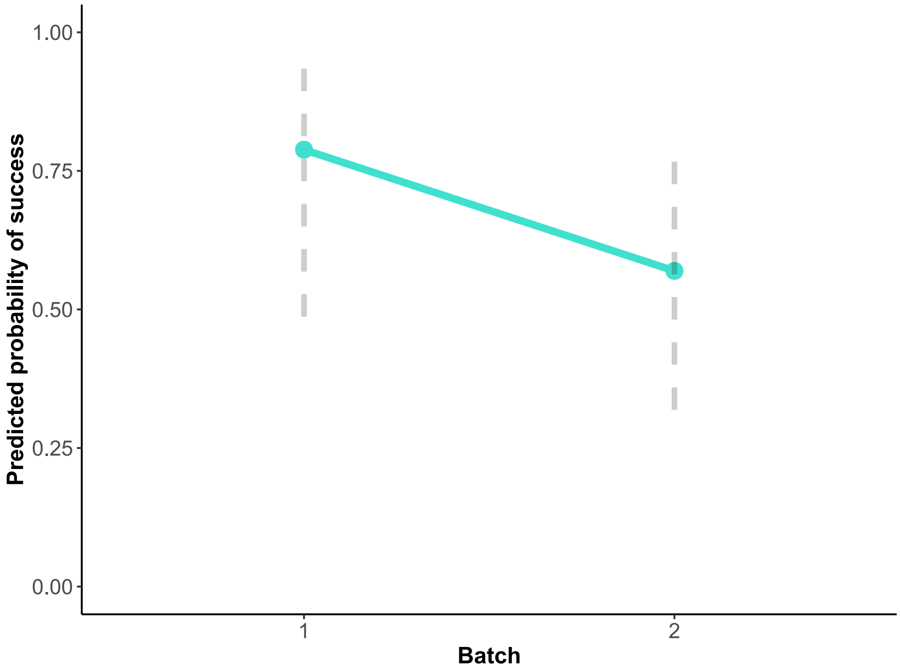

Figure 16: Predicted probabilities of succeeding in the A condition between batches of pigs (studies). Dashed lines indicate the 95% confidence intervals.

Inspecting the back of the apparatus

Comparing the US condition of study 1 and the KUS condition of study 2, a visibly higher frequency of inspections of the back of the apparatus in study 2 becomes evident (see Figure 17). The full-null model comparison revealed a significant difference between the studies ($\chi^2 = 9.227$, $p = 0.002$).

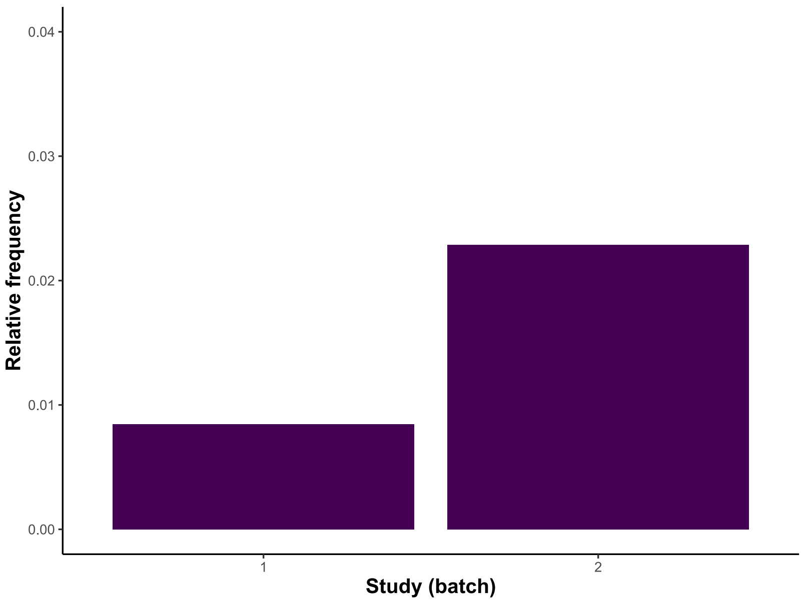

Figure 17: Frequency of inspecting the back of the apparatus relative to the latency to push from the other side and the number of trials per study between batches (in study 1 and 2).

5. Discussion

The aim of the present study was to assess body awareness in domestic pigs by subjecting them to a body-as-an-obstacle task. This task required subjects to push a sliding panel from one of two positions – on or off a mat. In the main test condition, this sliding panel was attached to the mat pigs were positioned on. Hence, pigs' body became an obstacle to the successful completion of the task. We predicted that, if pigs are body-aware, they should be able to recognize their body as a physical obstacle in the task and act accordingly by a) being more likely and b) quicker to push from the other side after stepping off when the mat was attached compared with a control condition unsolvable from both sides, and c) being more likely to inspect the back of the panel in search of an external obstacle blocking it in the unsolvable condition(s). Even though pigs solved the body-as-an-obstacle task, our results do not support the hypothesis that their actions were driven by body awareness.

Pigs' excellence in the unattached trials (all attempts to push the panel were successful in both studies) indirectly demonstrates the feasibility and success of the training procedure applied in this study. In only a week of training with the test apparatus, subjects were able to master the new task. This achievement does not only illustrate pigs' immense learning speed and trainability but is also in line with their previously demonstrated ability to horizontally push a lid to uncover a food reward (Nestelberger, 2019).

What is hence more surprising than the number of successful unattached trials, is our subjects' performance in the attached trials. The fact that subjects successfully solved the body-as-an-obstacle task in about half (study 2: 52%) or more than half (study 1: 76%) of the attached trials is demonstrative of pigs' remarkable behavioral flexibility. Subjects were able to spontaneously change a learned response, i.e., pushing from the indicated side, to adapt to altered circumstances. The flexibility demonstrated in the attached trials is especially noteworthy given how persistent pigs can be. For example, Pérez Fraga et al. (2021) found that pigs show higher manipulative persistence and independence than dogs in an unsolvable task. On the other hand, our results are in line with findings suggesting a considerable degree of behavioral flexibility in pigs. For instance, pigs are able to find innovative solutions when confronted with novel foraging challenges (Nestelberger, 2019; Sommer et al., 2016). Apart from pigs' flexible behavioral response to the body-as-an-obstacle task, the mechanisms underpinning their success, i.e., their motivation for stepping off and pushing from the other side are worth investigating.

In virtue of our control for foot discomfort, we could show that pigs did not step off the mat in the attached condition solely because they disliked the mat's movement underneath their feet. The latency for pigs to step off the mat from the start of the test was not significantly shorter if the experimenter pulled at the mat (FD condition) than when she did not (FDC condition). Therefore, foot discomfort is highly unlikely to explain the pigs' significantly greater propensity (study 2) and significantly shorter latency (both studies) to push from the non-mat side in the attached compared with the (K)US condition. However, unlike in the other conditions, the experimenter could not hide behind the cover of the apparatus in the foot discomfort conditions and was visible to the pigs. Therefore, experimenter cues could not be ruled out as rigorously as for the other conditions. Given that such cues can influence subjects' behavior (Rosenthal, 2005), this shortcoming needs to be acknowledged when interpreting the results of the foot discomfort conditions.

Despite the exclusion of foot discomfort as a causal factor, we cannot yet conclude that pigs' success in the attached condition constitutes a recognition of their body as an obstacle (and, hence, body awareness). As suggested by Lenkei et al. (2021), subjects' behavior in the body-as-an-obstacle task (attached condition) ought to be compared with a condition in which the task is unsolvable (for reasons other than the subject's body) and stepping off is therefore pointless.

By comparing the attached and unsolvable conditions, in the present study, we found that the pigs differentiated between the condition in which their body was an obstacle and that in which a visible external obstacle made the task unsolvable. This differentiation manifested in their reduced probability of pushing from the other side, which was statistically significant only for study 2, and an increased latency to do so in the (known) unsolvable condition. Moreover, subjects were significantly more likely to inspect the back of the apparatus, where they could assume the presence of an external obstacle, in the known unsolvable condition of study 2 which was made more saliently unsolvable by the use of larger blocks than in study 1. Pigs' tendency to inspect the back of the apparatus more frequently when an external obstacle was present behind the panel hints at a basic causal understanding of the mechanisms behind the perceived obstruction. Taken together, pigs' reaction differed between a visibly unsolvable condition and the attached condition in that they were more likely and quicker to push from the other side in the attached condition and by more frequently looking behind the panel in the known unsolvable condition.

It is, however, possible that the difference in the frequency of inspecting the back of the apparatus between the known unsolvable and the attached condition (i.e., an external and a bodily obstacle) does not reflect any causal understanding of the obstruction, but can instead be explained by the distracting effect of the blue block(s). Although this possibility cannot entirely be ruled out, our results suggest that a potential distraction effect alone is insufficient to account for the pigs' behavior. That is, if the blue blocks had been distracting enough to keep pigs from pushing the panel from the other side, a similar distraction effect should have been observed on the mat side (given that the obstacle(s) was/were symmetrically positioned). That is, it should have also decreased the pigs' probability of pushing from the *mat* side (first) in the KUS condition. Instead, pigs were equally likely to refrain from pushing on the mat side before stepping off in all conditions. Consequently, our conclusion that pigs recognize visible external obstacles remains valid.

Despite the differentiation of conditions depending on whether an external obstacle was visible, pigs treated the attached condition as if 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; nor did they inspect the back of the apparatus more frequently when an inconspicuous cardboard box, and not their body's weight, was blocking the panel. A straightforward explanation for the pigs' failure to discriminate between the unknown unsolvable and the attached condition is that they cannot recognize their body as a physical obstacle, and, consequently, lack body awareness. In this interpretation, pigs' success in the attached condition is the result of a default strategy applied in all cases in which the task is not solvable from the mat side and no obvious reason for the obstruction can be determined. A lack of body awareness, and, hence, presumably self-awareness, in pigs would be in line with the finding that pigs are unable to use their mirror image as a point of reference for locating food reported by Gieling et al. (2014). Nevertheless, before the possibility of body awareness in pigs can be dismissed, several alternative explanations for the subjects' failure to differentiate between the UUS and A condition need to be considered.

One limitation of the comparison between the attached and the unknown unsolvable condition is that the salience of the mat's movement was potentially insufficient. In contrast to the body-as-an-obstacle tests in dogs (Lenkei et al., 2021), elephants (Dale & Plotnik, 2017) and human infants (Bullock & Lütkenhaus, 1990; Geppert & Küster, 1983; Moore et al., 2007), our set-up only provided minimal visual cues when the mat was being tugged at. Subjects therefore had to rely on tactile cues alone to identify the attached condition. However, even these tactile cues presumably were less salient compared with the previous studies. On the one hand, 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 before/under their front legs. Considering that the movement was most salient at the front end of the mat (where also a little bit of upward movement could be perceived), especially situations in which only a pig's hind legs remained on the mat must have been difficult to interpret for the subject. This also explains why the pigs were often unsuccessful in the attached condition despite having stepped off with their front legs. Especially for these cases, we uphold that, rather than a lack of body awareness, the inconspicuousness of the mat's movement underneath the hind legs is responsible for the pigs' failure to differentiate between the A and UUS condition. In conclusion, the insufficient salience of the tugging in the attached condition potentially led to the difference between the attached and unknown unsolvable condition being minimal and not easily recognizable for the pigs.

Another potential reason why we failed to observe a difference between the attached and unknown unsolvable condition could be the low success rate with the attached condition in study 2. In the second study, pigs were only successful in 52% of the valid attached trials, even though they stepped off the mat with their front legs in 94% of the cases. Such a repeated failure to succeed in the attached condition might have discouraged pigs from making an effort to solve the task in all three (seemingly) unsolvable conditions, including the attached condition. As a result, subjects might have perceived all attempts to solve any of these conditions as futile, which could have masked any existing, measurable differences between the attached and unknown unsolvable condition. Given this possible explanation, the question of how the diverging success rates between studies 1 and 2 might have come about arises.

First, a prominent difference in procedure between the two studies is the number of test conditions and, concomitantly, length of the test sessions. While only one unsolvable and one foot discomfort condition were included in study 1, in four out of the six conditions in study 2 the panel was either inaccessible (the cover was closed in the FD conditions) or blocked. Consequently, the frustration inherent in these conditions could have had a direct impact on pigs' choice (Van Rooijen & Metz, 1987; Wesley & Klopfer, 1962). Alternatively, their performance could have been indirectly affected by the reward schedule. That is, the inclusion of more unsolvable trials led to a decreased reward frequency across trials (compared with study 1). A similar combination of factors, i.e., a partial reward schedule in the absence of reinforcing secondary cues, is known to reduce learning speed in rats (Denny, 1946). As such a reduction presumably goes hand in hand with a decline in motivation, the low reward frequency could account for pigs' dwindling success in the attached condition.

This mechanism is interlinked with the second potential reason for the unequal success rates between study 1 and 2: a dichotomization of our subjects into "persistent" and "discouraged" individuals. If pigs were not successful in the early attached trials (e.g., because their hind legs were still on the mat, as discussed before), they presumably either began to perceive it as (sporadically) unsolvable (from both sides) or were persistent enough to nevertheless try again on their next attempt. Such a dichotomization can be regarded as problematic in several respects. On the one hand, the more persistent and impulsive pigs might have lacked the discriminatory abilities to take subtle cues into account. Persistent and/or impulsive pigs have been reported to perform worse in choice tasks (Nawroth et al., 2013), impatient or restless pigs were less successful in discrimination tasks (Van Rooijen & Metz, 1987; Wesley & Klopfer, 1962). Furthermore, pigs' personality ("high resistance" or "low resistance" in a back test) considerably influenced their success in a reversal learning task with high-resistance pigs demonstrating less behavioral flexibility (Bolhuis et al., 2004). A similar mechanism could have led some of our pigs to perseverate on a once successful strategy (i.e., pushing from the other side) even in the unsolvable condition(s). The easily frustrated pigs, on the other hand, either gave up on all three conditions (A, UUS and KUS), as the seemingly low probability of success was not worth the effort, or failed to identify the unknown unsolvable condition as unsolvable. In the latter case, pigs could have even perceived the (initial) likelihood of succeeding in the unknown unsolvable condition as higher than that in the attached condition because clear cues for its unsolvability were missing. As a result, the similarity between the unknown unsolvable condition and the unattached condition might have been higher than between the attached and unattached condition. Taken together, the pitfalls associated with both an impulsive/persistent and a less impulsive/persistent problem-solving style, as well as the dichotomization of the two, provide additional reasons why pigs might have failed to discriminate between the attached and unknown unsolvable condition – even if body-aware.

Even though the dogs in Lenkei et al. (2021) more clearly differentiated between the unsolvable condition and their body being an obstacle than our pigs (a comparison with elephants is not possible given that no unsolvable condition was conducted in Dale and Plotnik (2017)), one should be careful to infer that pigs' body awareness is inferior to dogs'. On the contrary, such a hasty conclusion would be flawed for a number of reasons. First, pigs did solve the body-as-an-obstacle task, i.e., the attached condition, with a success rate comparable to dogs'. The latter tried to pass the toy in 68% of the "test" trials (in which it was attached to the mat) after stepping off (27/32 dogs stepped off; Lenkei et al., 2021). Assuming that the incentives to step off and solve the task were comparable between the two set-ups, the difference between the species does not seem to lie in subjects' ability to solve a task in which their body is an obstacle. Rather, dissimilarities in the way the unsolvable condition was implemented appear to be the reason why, unlike dogs, our pigs did not differentiate between the attached and the unknown unsolvable condition.

The diverging results for the unsolvable condition for dogs (Lenkei et al., 2021) and pigs can best be accounted for by the several fundamental differences between the set-ups. First, the unsolvable condition dogs were confronted with more closely resembled our known unsolvable condition (for which pigs *did* show a difference in the probability and latency to push from the other side compared with the attached condition) rather than the unknown unsolvable condition. That is, dogs had clear visual and sensorimotor feedback (seeing and feeling the toy resist any attempts to being picked up) at their disposal to identify the condition as unsolvable. Furthermore, as discussed before, the visual and tactile cues in the mat-attached condition were more salient for the dogs, facilitating the discrimination of the two conditions. A second important difference between the two studies lies in the amount of innovativeness required to solve the body-as-an-obstacle task (attached condition). Our subjects had undergone a training phase in which pushing from on or off the mat were presented as two equivalent alternatives for action. Dogs' options, on the other hand, were less clearly defined. Hence, the strategy that led to success (pushing from the other side, in the case of the pigs, or stepping off and passing the toy with the mat, in the case of the dogs) was more straightforward and likely to be chosen by chance (trial and error) in the test in our study than in Lenkei et al. (2021).

Similarly, pushing from the other side in any other but the attached condition was not an illogical strategy in our set-up. On the contrary, given the negligible effort, i.e., "costs", of quickly trying from the other side, pushing from there in every condition that initially appears unsolvable (especially if the reasons for this are not very obvious) might even be the most successful and least costly strategy. In other words, pushing from the other side in the unsolvable conditions is not costly or disadvantageous but merely unnecessary. Such a lack of differentiation in cases in which the negative consequences of erroneous choices are negligible is 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). This effect is exacerbated by the fact that the only activity dogs could engage in until the end of the trial was the manipulation of the unliftable toy for which moving off the mat was unnecessary. Our pigs, on the other hand, had two sides of the blocked panel to switch between, providing stronger incentives to step off. In the future, dogs could be tested in an unsolvable condition that gives them more room for maneuver while holding the toy than the set-up of Lenkei et al. (2021). By doing so, dogs' tendency to step off the mat in both conditions could more accurately be compared to pigs'. In conclusion, numerous crucial differences between the set-ups – that both come with several advantages but also pitfalls – make the interpretation of the results for the unsolvable conditions for dogs and pigs too incomparable to draw inferences on species-specific differences in subjects' understanding of the body-as-an-obstacle task.

An additional advantage that dogs (Lenkei et al., 2021) and also elephants (Dale & Plotnik, 2017) had over the pigs in our study is age. While dogs were at least 1 and elephants at least 4 years old when they participated in the experiment, the pigs in the present study were only 7–8 weeks old. Testing juvenile animals on body awareness or self-awareness tests could be seen as problematic considering that self-awareness can be expected to develop gradually with age (de Waal, 2019). Self-directed or mark-directed behavior in the mirror mark test is first shown at around 24 months of age in human infants (Bard et al., 2006), between 28 months and 8 years in chimpanzees (Bard et al., 2006; Povinelli et al., 1993) and at approximately 7 months of age in dolphins (Morrison & Reiss, 2018). Therefore, it would be desirable for future studies to focus on pigs at a developmental stage more comparable to that of humans, elephants and dogs in previous self-awareness tests.

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 the comparison with other cognitive abilities and species. A study investigating social and physical cognition in pigs living in different environments (Albiach-Serrano et al., 2012), found that both pigs' ability to follow human pointing gestures and their understanding of inclined surfaces as potential hiding locations for food are dependent on individuals' previous experience and living environment. The same seems to apply to the context of self-awareness: 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 showed self- and mark-directed behaviors after sufficient exposure to a mirror. To do justice to this assumed influence of experience on animals' ability to exhibit self-awareness, future studies should ideally apply a battery of different body awareness tests to pigs to allow for sufficient experience (with body awareness-eliciting situations), while at the same time controlling for associative learning by measuring transferability.

Until alternative paradigms for testing body awareness in pigs are developed, the task applied in the present study remains a viable and ecologically valid approach – in spite of the aforementioned limitations. As species-specific constraints, such as the lack of hands or low visual acuity, considerably limit the variety of tests pigs and other (farm) animals can reasonably be subjected to, the panel-pushing task, or variations of it, can be seen as the first tool available to assess body awareness in many of these species. However, before the task is adapted to other species, one should carefully consider the shortcomings identified in the present study and, ideally, overcome them.

The insights gained from the current investigation suggest various possibilities of how our adaptation of the body-as-an-obstacle task could be improved and transformed into a more precise instrument 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. This can either be achieved by augmenting the visual (and potentially auditory) cues already present or by changing the direction of movement so that the salience of the tactile cues increases (e.g., if the mat is pulled upwards). 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 adopt alternative strategies – regardless of the type of obstacle (external or bodily). For example, three different positions to push the sliding panel, two of which are covered by a wider, continuous mat, could be offered to subjects. This way, the frequency of stepping off to either an equally unfavorable position or a position from which the task is solvable can be recorded separately and compared across different test conditions. Ultimately, it would be worthwhile to also test previously researched species, i.e., humans, elephants and dogs, on a body-as-an-obstacle task more comparable to that for pigs. Otherwise, no clear answers on potential species differences can be found. 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.

5.1 Conclusion

The present study has introduced a new variation of the body-as-an-obstacle task applicable to pigs and potentially other species. Even though pigs demonstrated remarkable behavioral flexibility and solved a condition in which their body was an obstacle, body awareness could not unambiguously be shown. While subjects seemingly noticed the presence of visible external obstacles, they failed to differentiate between a less conspicuous external obstacle and their body being an obstacle. 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, it remains unclear whether pigs' understanding of their body as an obstacle is inferior to previously tested species' or whether these earlier set-ups are not sufficiently similar to ours. Therefore, designing body-as-an-obstacle tasks that are comparable across species and convincingly control for subjects' reactions to non-bodily obstacles (unsolvable conditions) is the next step towards elucidating the mechanisms and the evolution of body awareness.

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6. Appendix

6.1 R codes and model stability plots for the main analyses

Study 1:

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=AUSB1d, family=binomial, control = glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)))

null = glmer(attemptafter ~ z.Condition_Order + z.Day + (1 + z.Condition_Order + Condition.A + z.Day||Subject) + (1 + z.Condition_Order + Condition.A + z.Day||Sow), data=AUSB1d, 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 the 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
- z.Day: day, i.e., test session 1–4, z-transformed
- Subject: subject ID (identity of each individual tested in study 1)
- Sow: Litter from which the subject was taken (6 different ones)
- AUSB1d stands for attached + unsolvable batch 1 excluding one subject to enable the inclusion of certain random slopes

Model stability:

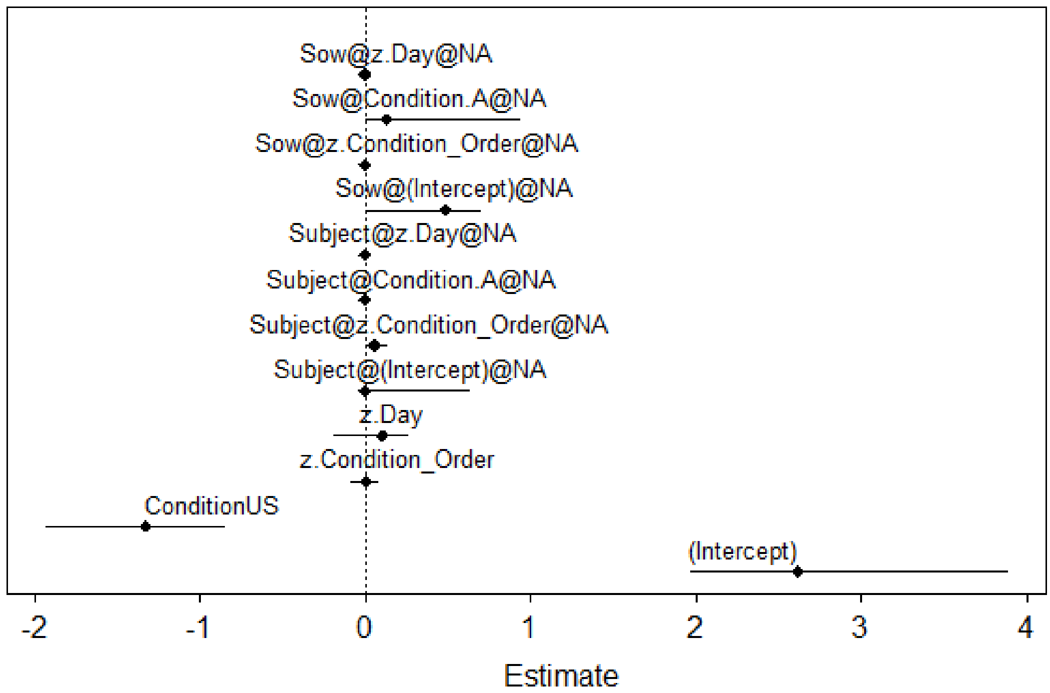

Figure 18: Model stability plot for the probability of pushing from the other side after stepping off the mat. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Random effects 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 between random slopes 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.

<u>Latency to push from the other side after stepping off the mat:</u>

full = coxme(faa ~ Condition + z.Condition_Order + z.Day + (1|Subject) + (0 + z.Day|Subject) + (1|Sow) + (0 + z.Day|Sow), data=AUSB1d)

null = coxme(faa ~ z.Condition_Order + z.Day + (1|Subject) + (0 + z.Day|Subject) + (1|Sow) + (0 + z.Day |Sow), data=AUSB1d)

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

Model stability:

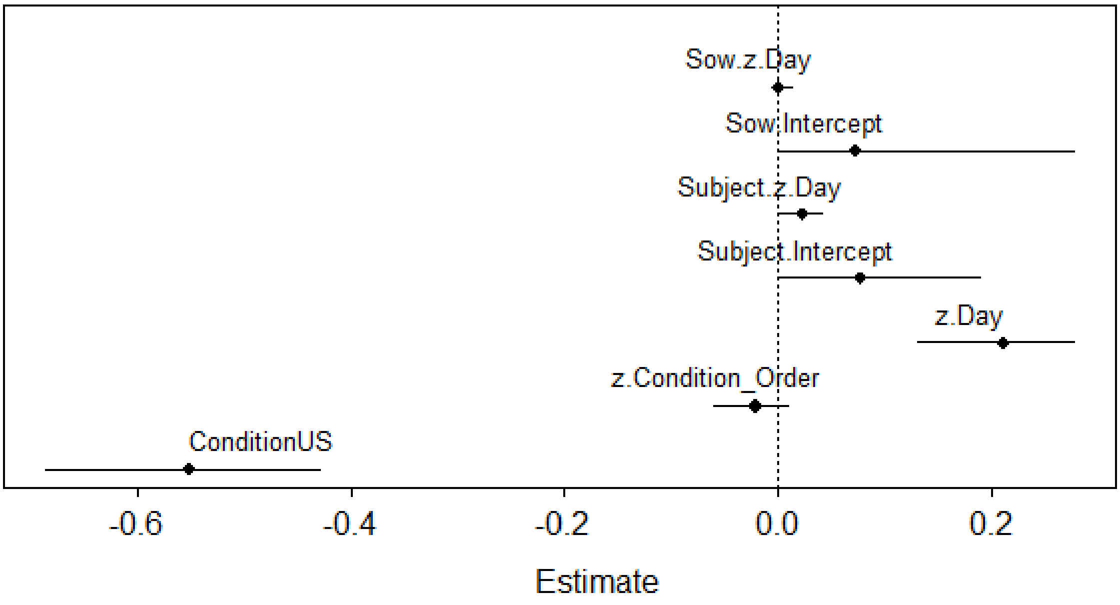

Figure 19: Model stability plot for the latency to push from the other side after stepping off. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Names starting with "Sow" or "Subject" are random effects, with the second term denoting a random slope or intercept.

Study 2:

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=B2panel, family=binomial, control = glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

null = glmer(pushed_before ~ z.Condition_Order + z.Day + (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=B2panel, 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 the 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
- B2panel stands for: batch 2 conditions in which the panel was accessible (all but FD and FDC)

Model stability:

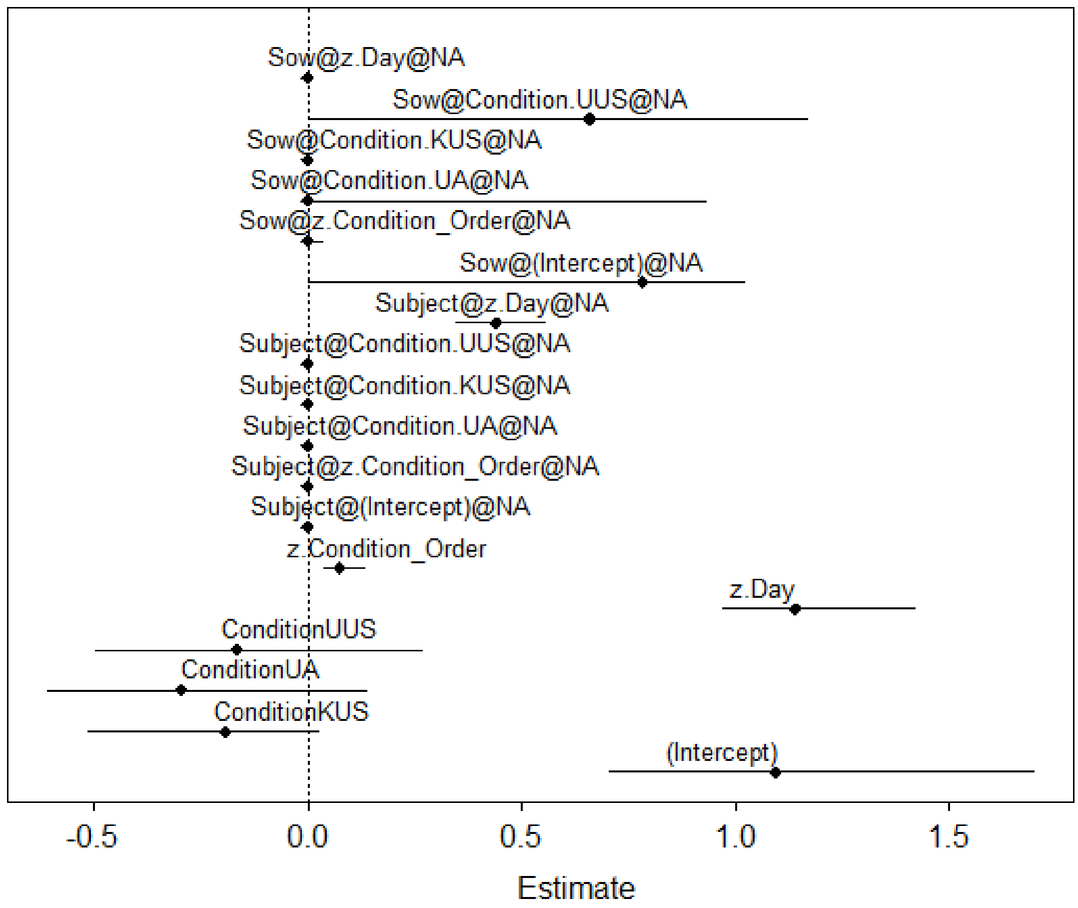

Figure 20: Model stability plot for the probability of pushing from the mat side before stepping off. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Random effects are indicated 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 between random slopes 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.

<u>Probability of pushing from the other side after stepping off:</u>

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=AUSB2, family=binomial, control = glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)))

null = glmer(attemptafter ~ z.Condition_Order + z.Day + (1 + z.Condition_Order + Condition.UUS + Condition.KUS + z.Day||Subject) + (1 + z.Condition_Order + Condition.UUS + Condition.KUS + z.Day||Sow), data=AUSB2, 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 the inclusion as a random slope
- AUSB2 stands for: attached + unsolvable conditions batch 2
- Other variables: see above

Model stability:

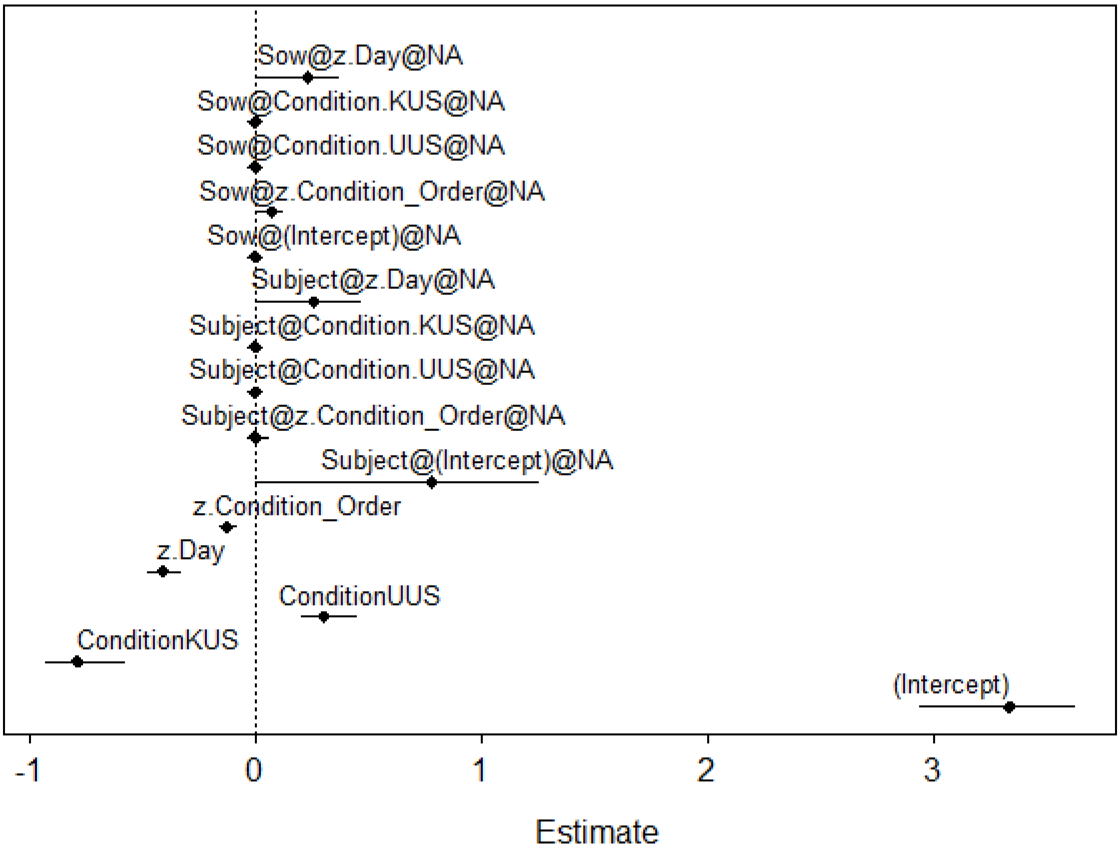

Figure 21: Model stability plot for the probability of pushing from the other side after stepping off the mat. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Random effects 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 between random slopes 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.

<u>Frequency of inspecting the back of the apparatus:</u>

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=B2panel, family=poisson, glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

null= glmer(inspect_before ~ 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=B2panel, family=poisson, glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

Variables:

- inspect_before: number of investigations of the back of the apparatus 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 apparatus were counted
- Other variables: see above

Model stability:

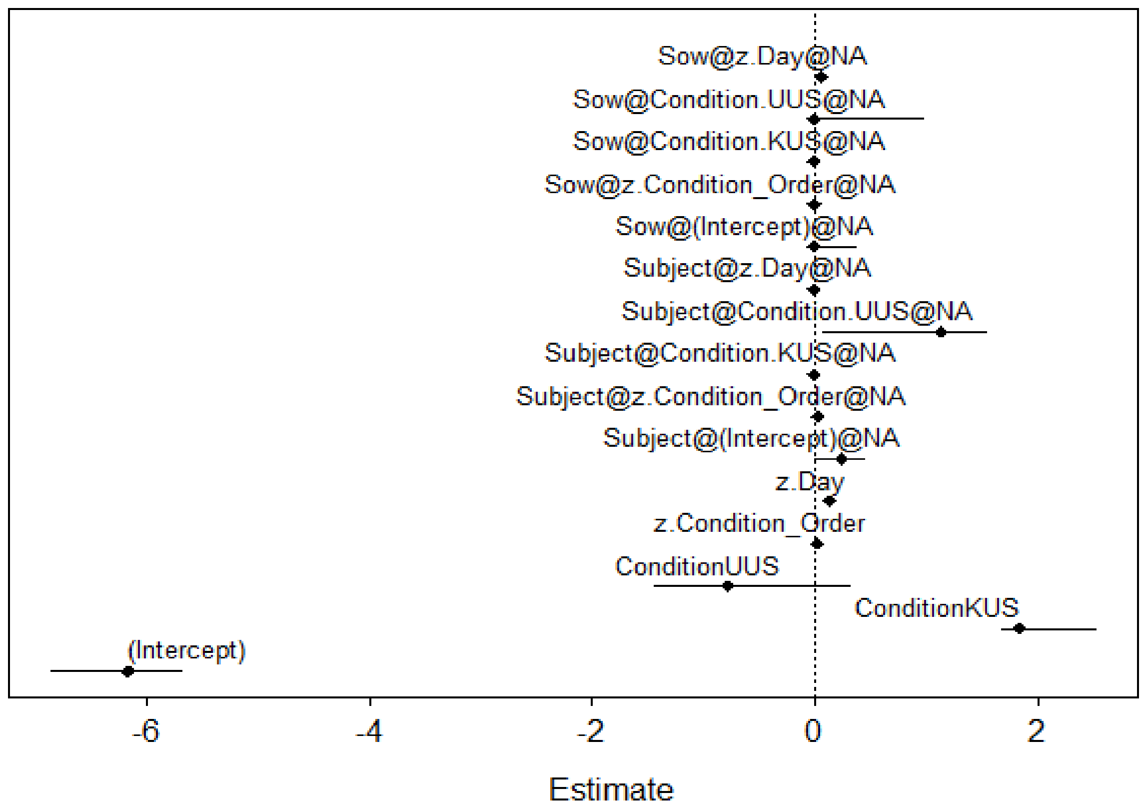

Figure 22: Model stability plot for the frequency of inspecting the back of the apparatus. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Random effects are indicated by 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 between random slopes 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 + z.Day|Subject) + (1 + z.Day | Sow), data=AUSB2)

null = coxme(faa ~ z.Condition_Order + z.Day + (1 + z.Day |Subject) + (1 + z.Day|Sow), data=AUSB2)

Variables:

- See above

Model stability:

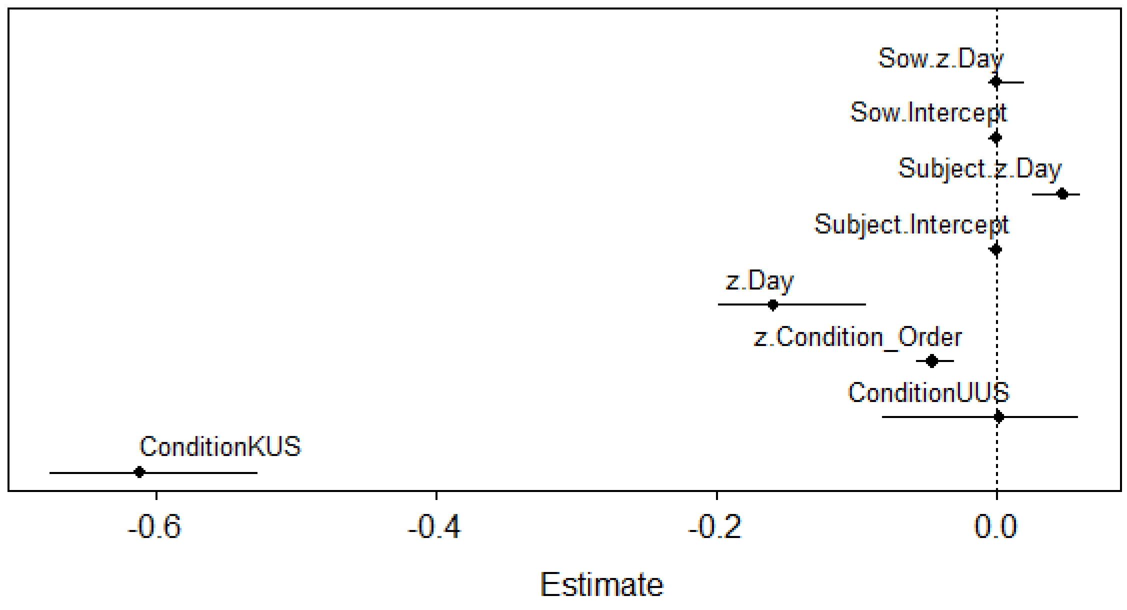

Figure 23: Model stability plot for the latency to push from the other side after stepping off. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Names starting with "Sow" or "Subject" are random effects, with the second term denoting a random slope or intercept.

<u>Latency to step off the mat with the front legs from the start of the trial (FD and FDC condition):</u>

full = coxme(sso ~ Condition + z.Condition_Order + z.Day + (1 + z.Day|Subject) + (1 + z.Day| Sow), data=FDB2)

null = coxme(sso ~ z.Condition_Order + z.Day + (1 + z.Day|Subject) + (1 + z.Day|Sow), data=FDB2)

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
- FDB2 stands for: foot discomfort batch 2
- Other variables: see above

<u>Between-batch comparisons:</u>

<u>Probability of succeeding in the attached condition between batches:</u>

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

null = glmer(succeeded ~ z.Condition_Order + z.Day + (1 + z.Condition_Order ||Subject) + (1 + z.Condition_Order + z.Day||Sow), data=ABC, 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 (study 1) or batch 2 (study 2); manually dummy-coded and centered for the inclusion as a random slope
- Subject could now take 27 different values and sow 16 different values
- ABC stands for: attached batch comparison
- Other variables: see above

Model stability:

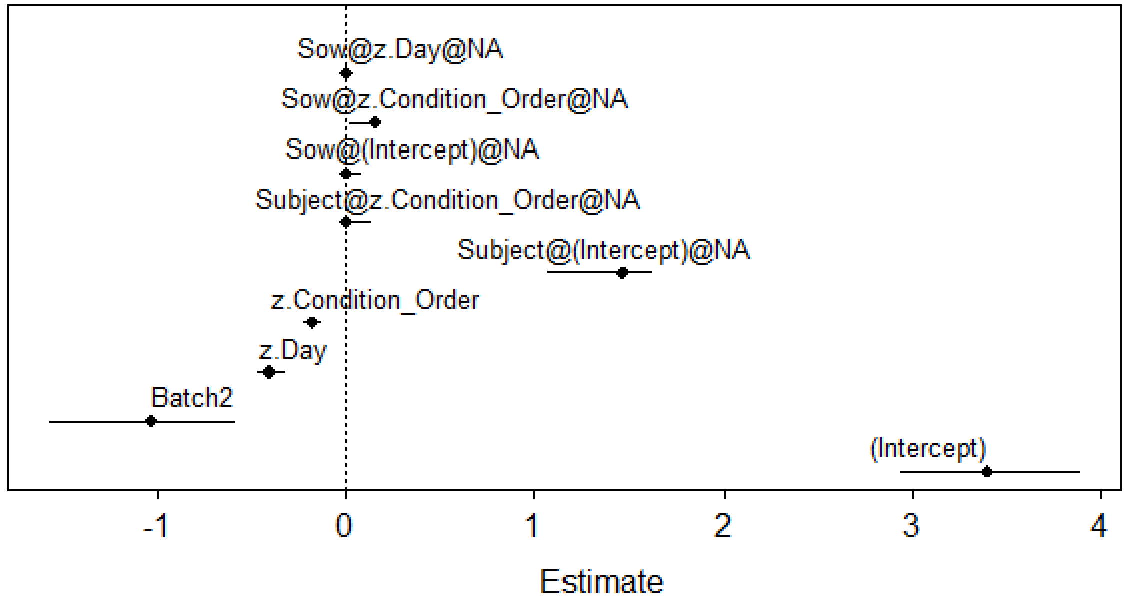

Figure 24: Model stability plot for the probability of succeeding. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Random effects are indicated by an at sign (@), with the 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 between random slopes 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.

<u>Frequency of inspecting the back of the apparatus in the (known) unsolvable condition between batches:</u>

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=BCUS, family=poisson, glmerControl(optimizer="bobyqa", optCtrl = list(maxfun = 10000)))

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

Variables:

- BCUS stands for: batch comparison unsolvable
- Other variables: see above

Model stability:

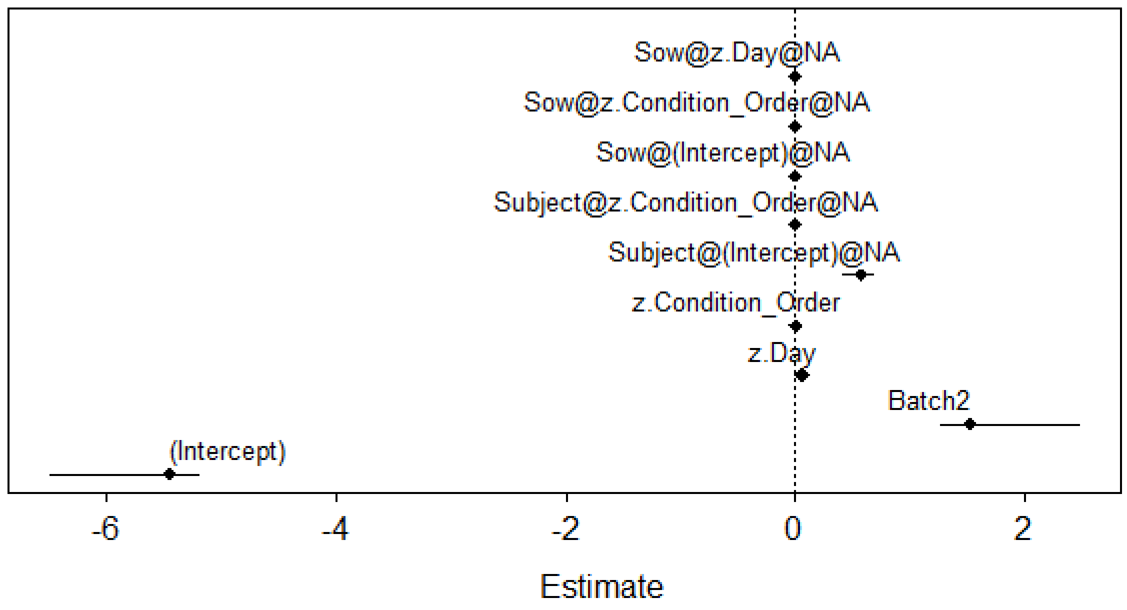

Figure 25: Model stability plot for the frequency of inspecting the back of the apparatus. Each horizontal line represents the range of model estimates for one term in the model. For each model the estimates were based on, one level of the random effects was excluded. Random effects are indicated by 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 between random slopes 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.

6.2 Analysis of the first trials

To investigate the influence of potential learning effects across trials and sessions (days), we performed the analyses described in sections 3.1.7 and 4.1.7 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 study 1 and most models in study 2 (for details see below). Considering that only focusing on the first trials substantially reduced the sample size, the results listed below ought to be interpreted with caution and serve mainly a descriptive purpose.

6.2.1 Probability of pushing from the other side after stepping off – study 1

The model included 18 observations across nine subjects and five sows, it was underdispersed (dispersion parameter = 0.35) 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 ($\chi^2 = 5.551$, $p = 0.0185$). That is, pigs were more likely to push from the other side in the attached than in the unsolvable condition (see Figure 26).

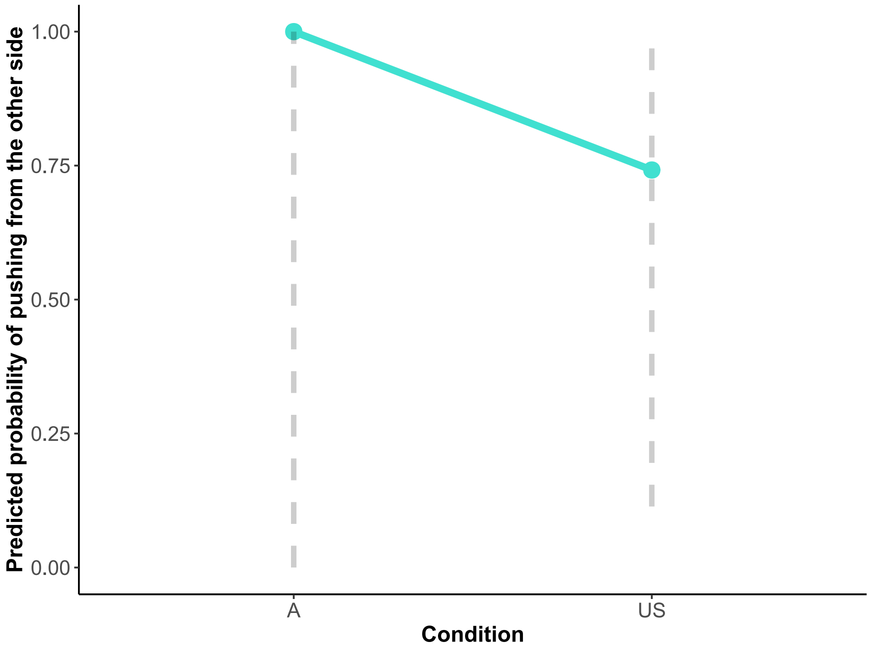

Figure 26: Predicted probabilities of pushing from the other side after stepping off across conditions (US and A) in the first trials of study 1. Dashed lines indicate 95% confidence intervals.

6.2.2 Latency to push from the other side after stepping off – study 1

17 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 and unsolvable condition did not reach statistical significance ($\chi^2 = 1.5186$, p = 0.2178). Nevertheless, Figure 27 illustrates that pigs already tended to be quicker to push from the other side after stepping off in the first attached trials of study 1 than in the unsolvable trials.

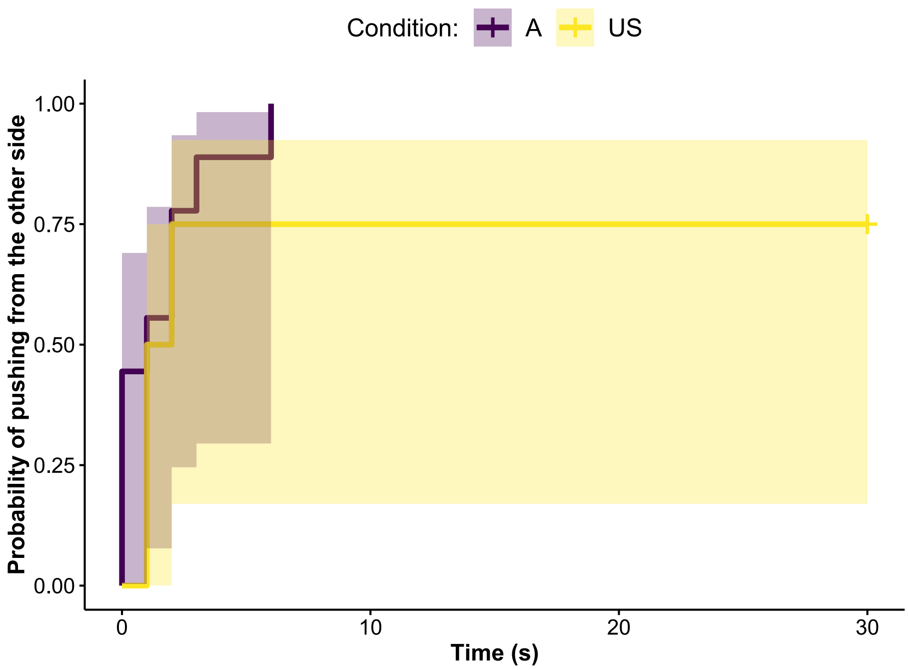

Figure 27: Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time in the first trials of study 1. Crosses indicate trials in which pigs did not push from the other side until the end of the trial.

6.2.3 Probability of pushing from the mat side before stepping off – study 2

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 model was not overdispersed (dispersion parameter = 0.755) and the fixed effects were not found to 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 = 1.532, p = 0.675; see Figure 28).

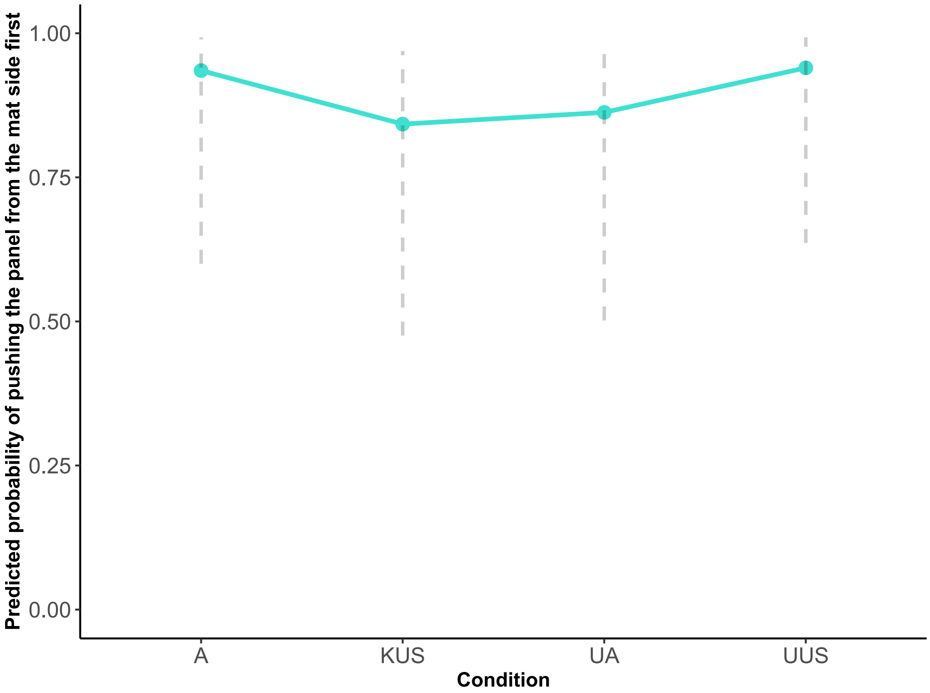

Figure 28: Predicted probabilities of pushing from the mat side before stepping off across conditions in the first trials of study 2. Dashed lines indicate 95% confidence intervals.

6.2.4 Probability of pushing from the other side after stepping off – study 2

The sample for this model consisted of 38 observations across 16 subjects and nine sows. The model was not overdispersed (dispersion parameter = 0.9) and 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 29), the difference did not reach statistical significance (χ^2 = 3.618, p = 0.164).

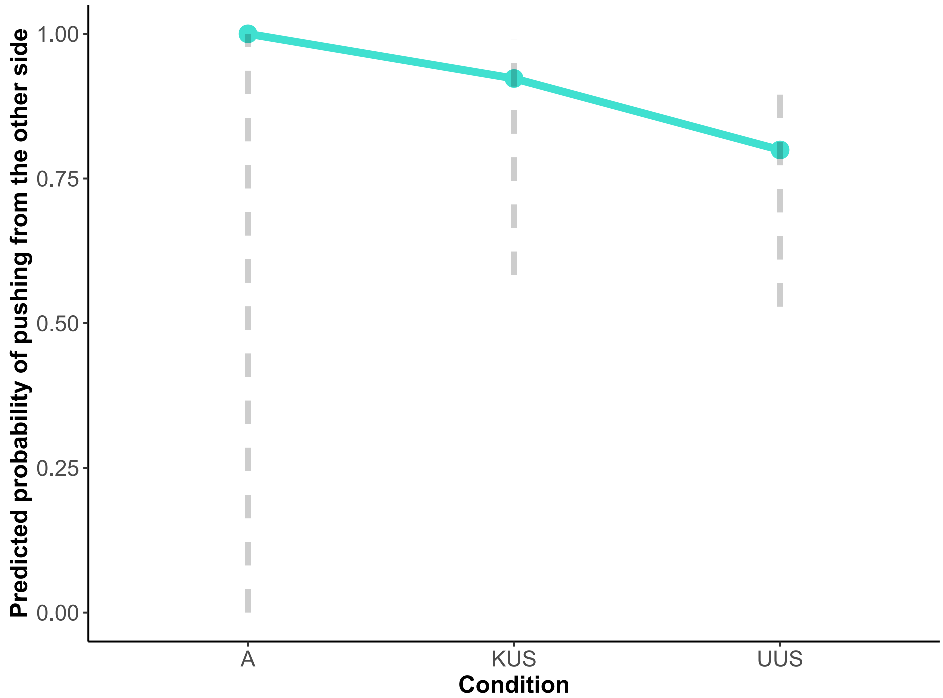

Figure 29: Predicted probabilities of pushing from the other side after stepping off across conditions (UUS, KUS and A) in the first trials of study 2. Dashed lines indicate 95% confidence intervals.

6.2.5 Frequency of inspecting the back of the apparatus – study 2

The model was underdispersed (dispersion parameter = 0.3) and the fixed effects were not found to 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 apparatus) only happened three times, always in the KUS condition. Therefore, a significant difference across conditions was detected (χ^2 = 7.775, p = 0.02).

6.2.6 Latency to push from the other side after stepping off – study 2

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 30 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 (χ^2 = 2.295, p = 0.317).

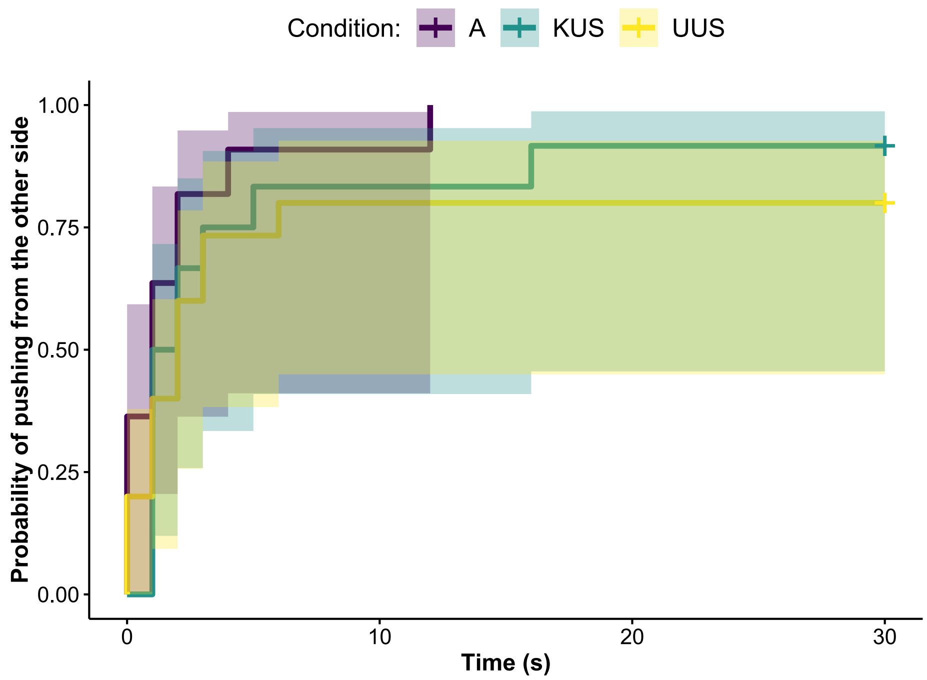

Figure 30: Cumulative incidence plot depicting the probability of pushing from the other side (after stepping off with the front legs) across time in the first trials of study 2. Crosses indicate trials in which pigs did not push from the other side until the end of the trial.

6.2.7 Latency to step off from the start of the test in the FD and FDC condition – study 2

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 test between the FD and FDC condition was found (χ^2 = 1.638, p = 0.2; see Figure 31).

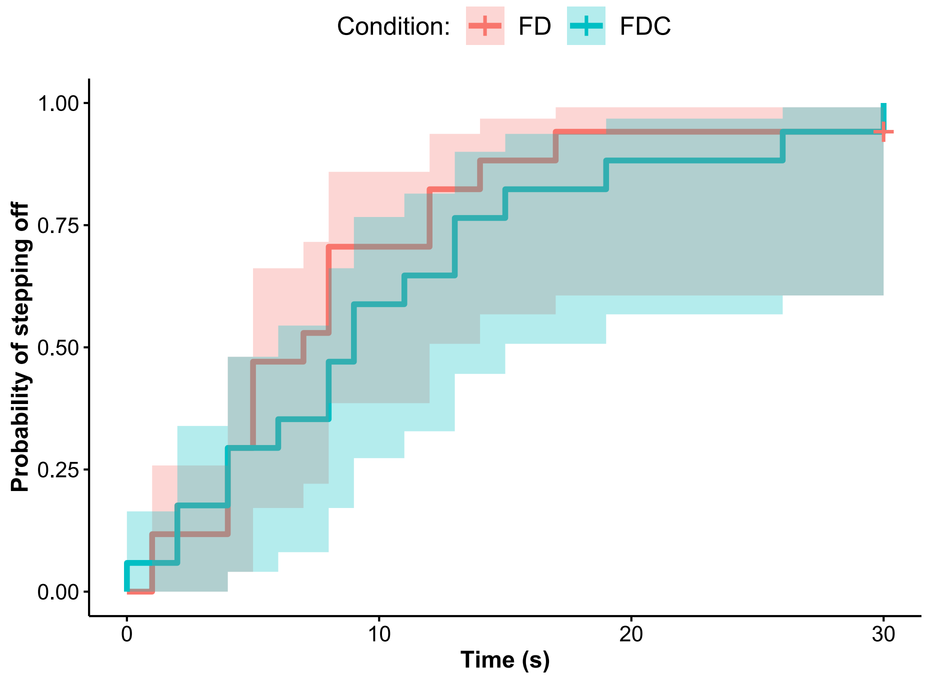

Figure 31: Cumulative incidence plot depicting the probability of stepping off with the front legs across time in the first FD and FDC trials of study 2. Crosses indicate trials in which pigs did not step off until the end of the trial.

6.2.8 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. The model was underdispersed (dispersion parameter = 0.64) and no collinearity between the fixed effects was detected (all variable inflation factors < 1.08). Subjects in study 1 were more successful in their first trial (all nine subjects were successful) than the subjects in study 2 (see Figure 32). Nevertheless, the difference between batches (studies) was not statistically significant ($\chi^2 \sim 0$, $p \sim 1$).

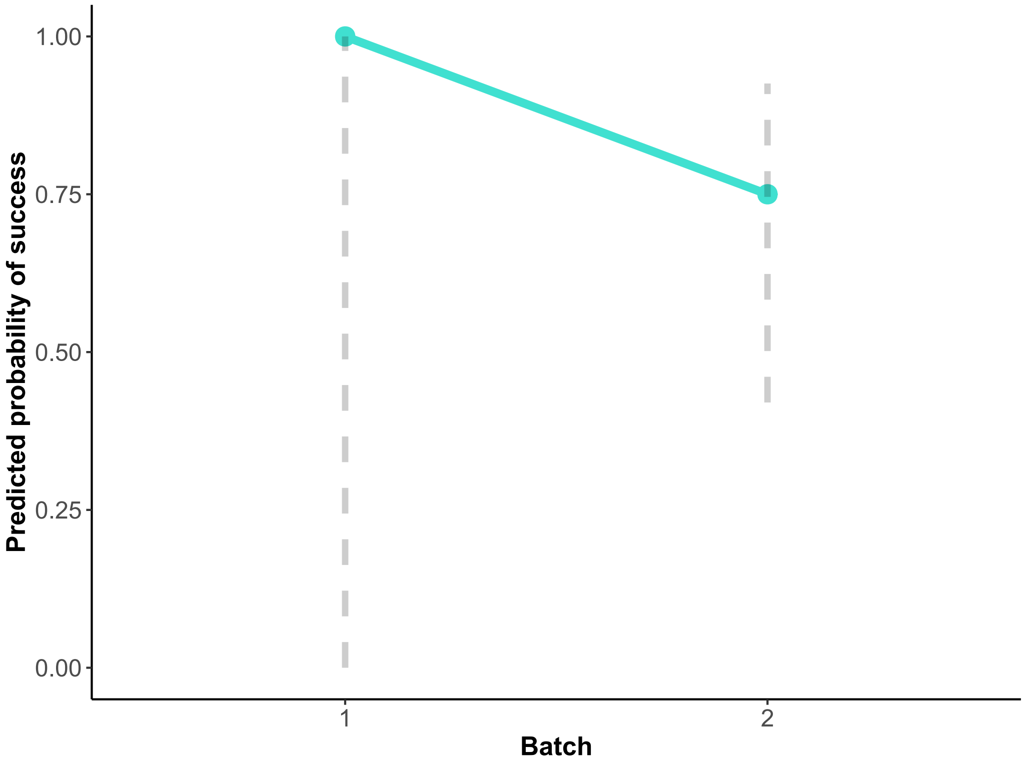

Figure 32: Predicted probabilities of succeeding in the first trial of the A condition between batches of pigs (studies). Dashed lines indicate the 95% confidence intervals.

6.2.9 Frequency of inspecting the back of the apparatus 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 not found to be collinear (highest variable inflation factor = 1.237). Unlike in the comparison for the full sample, no significant difference emerged between the two batches/studies ($\chi^2 = 0.934$, $p = 0.334$; see Figure 33).

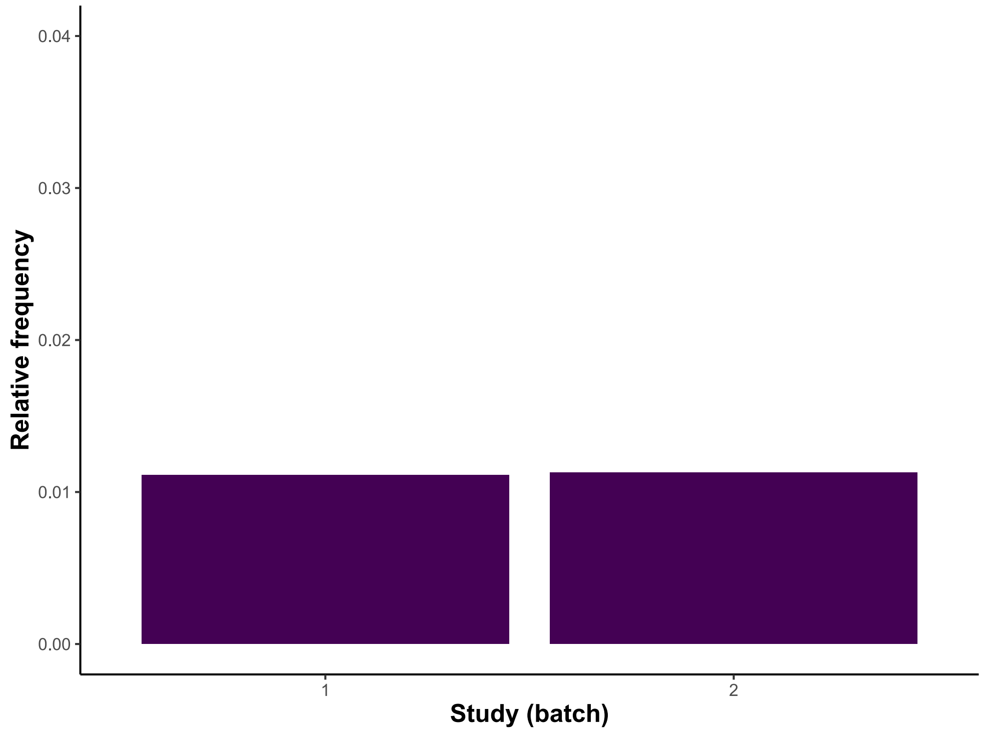

Figure 33: Frequency of inspecting the back of the apparatus in the first (K)US trials – relative to the latency to push from the other side and the number of trials per study – between batches (in study 1 and 2).