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SHORT COMMUNICATION

Domestic horses (*Equus ferus caballus*) fail to intuitively reason about object properties like solidity and weight

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Abstract
From early infancy, humans reason about the external world in terms of identifiable, solid, cohesive objects persisting in space and time. This is one of the most fundamental human skills, which may be part of our innate conception of object properties. Although object permanence has been extensively studied across a variety of taxa, little is known about how non-human animals reason about other object properties. In this study, we therefore tested how domestic horses (*Equus ferus caballus*) intuitively reason about object properties like solidity and height, to locate hidden food. Horses were allowed to look for a food reward behind two opaque screens, only one of which had either the proper height or inclination to hide food rewards. Our results suggest that horses could not intuitively reason about physical object properties, but rather learned to select the screen with the proper height or inclination from the second set of 5 trials.

Keywords Object properties · Animal cognition · Object permanence · Solidity · Core knowledge

Introduction

The ability to reason about the external world in terms of identifiable, solid, cohesive objects, which continuously persist in space and time (i.e., object permanence), is one of the most important human skills (Rakoczy 2015). From 2.5 months, infants show the first rudiments of object permanence (e.g., Aguiar and Baillargeon 1999; Spelke et al. 1992; Wilcox et al. 1996). From 3.5 months, they also understand object properties like height, looking longer when a tall object moves behind a small screen and remains unexpectedly invisible (e.g., Baillargeon and DeVos 1991). Moreover, 5-month-olds understand object properties like solidity, looking longer when solid objects move through other solid objects, instead of stopping (Baillargeon et al. 1985). Similarly, 9-month-olds look longer when objects are retrieved from under a cloth lying flat on the table, rather than under a cloth with a marked protuberance, and even expect larger objects to be hidden under clothes with larger protuberances (Baillargeon 1995). These and other studies suggest that complex understanding of object physical properties is present from early infancy and may even be part of our innate core knowledge (e.g., Aguiar and Baillargeon 2002; Baillargeon 1987; Baillargeon et al. 1985; Cacchione and Call 2010; Hespos and Baillargeon 2006; Kellman and Spelke 1983; Spelke 1990; Spelke et al. 1992; Wilcox et al. 1996).

Studies on animals would also support the idea of an innate ability to reason about object properties, beyond mere object permanence. Newborn chicks (*Gallus gallus*) reared with a small imprinting object, for instance, saw it disappear, and were then faced with two screens of different inclination, height or width, which could or could not be compatible with the presence of the hidden imprinting object (Chiandetti and Vallortigara 2011). Chicks reliably searched for the imprinting object, behind the screen with the inclination/height/width compatible with the presence of the

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object, despite having had very little chance to previously learn about object properties. Likely, newborn chicks have intuitive object permanence (i.e., looking for the disappeared object) and also understand physical properties of objects, intuitively realizing that the inclination and size (i.e., height and width) of an occluder determine whether it can hide an object. As solid objects occupy space, for instance, an occluder lying flat on the ground is not compatible with the presence of an object.

Call (2007) used a similar paradigm to test whether great apes inferred the location of hidden food, when confronted with two screens, only one of which was inclined. In the first 4 trials, apes reliably selected the food under the screen with the inclination compatible with food presence. When tested with the same setup, pigs (*Sus scrofa domestica*) also reliably selected food under the inclined screen, but only if they had had previous everyday experience with solid objects in their enclosure (Albiach-Serrano et al. 2012). Using different setups, rhesus macaques (*Macaca mulatta*; Santos and Hauser 2002) and dogs (*Canis familiaris*; Kundey et al. 2010; Pattison et al. 2010) also appeared to rely on solidity to locate hidden objects.

Although object permanence has been extensively investigated in numerous animal taxa (see Cacchione and Rakoczy 2017), little is yet known about how other species understand other object properties, and whether they intuitively do so. Here, we tested how domestic horses (*Equus ferus caballus*) reason about object properties like solidity and height. Horses show object permanence (McLean 2004; Baragli et al. 2011;) and long-term categorical and conceptual memory (Hanggi and Ingersoll 2009). Moreover, horses learn to select the larger of two two- and three-dimensional stimuli, suggesting that they discriminate objects based on their relative size (Hanggi 2003). However, very little is known about their physical understanding of other object properties. In this study, we therefore adapted the procedure used by Chiandetti and Vallortigara (2011) to test whether horses look for a reward behind the one of two opaque screens which has either the proper height or inclination to hide a human with food rewards. The ability to rely on object properties to locate them when they move out of view may be adaptive for a variety of species, like horses, not only to keep track of food, but also of social partners, including humans and predators. Therefore, we expected that horses could reliably locate a human with food by using their understanding of object properties. If horses, like domestic chicks, had intuitive physical reasoning, they should look for hidden food rewards behind the screen compatible with the presence of the hidden reward, from the first trials.

Methods

Subjects

We tested 16 volunteered horses from two different stables, whose owners were associated with the University of Bern, Switzerland (6 females, 10 males; mean age ± SD = 15.44 ± 5.44 years).

Methods and procedure

Horses were isolated in a room with music (to reduce inadvertent acoustic cues during testing) and no food, except for a bucket with highly valuable food (i.e., carrots, apples, horse pellets), used as a reward. All trials were video-recorded. To allow reliable interspecific comparisons, we largely followed the procedure used by Chiandetti and Vallortigara (2011). However, chicks and horses differ in crucial ways, including the fact that the former are smaller and more manageable and can be imprinted on the testing stimuli. Therefore, we introduced the following minor procedural differences: Subjects were tested using humans with food rewards as stimuli, instead of imprinting objects, and no imprinting phase was implemented; chicks were prevented from seeing the stimuli being hidden by confining them in a box and covering the stimuli with an opaque partition, while horses were held by Exp1, who covered their eyes.

Given that horses participated on a completely voluntary basis, and no invasive procedures were used, no ethical approval was required according to the Swiss law. During the task, moreover, individuals were never food-deprived, and motivation to participate was exclusively ensured by the use of highly preferred food, so that the experiments provided a form of enrichment for the subjects and did not pose any risks or adverse effects. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Each subject went through only one of two Training phases, and one Testing phase with four different conditions. The Training phase could be of two different types (i.e., Height Training Phase and Inclined Training Phase) and consisted of 2 Warm-up trials and up to three blocks of 5 Training trials. Warm-up trials aimed to habituate horses and make them associate one of the two experimenters (Exp2) with food. In the Warm-up trials of the Height Training Phase, two white opaque screens (180 × 110 cm) were positioned 5 m from each other (Fig. 1a); horses could freely explore the room and the screens, and when they seemed comfortable with the setup, Exp2 fed them, while Exp1 brought them in the Starting position (10 m

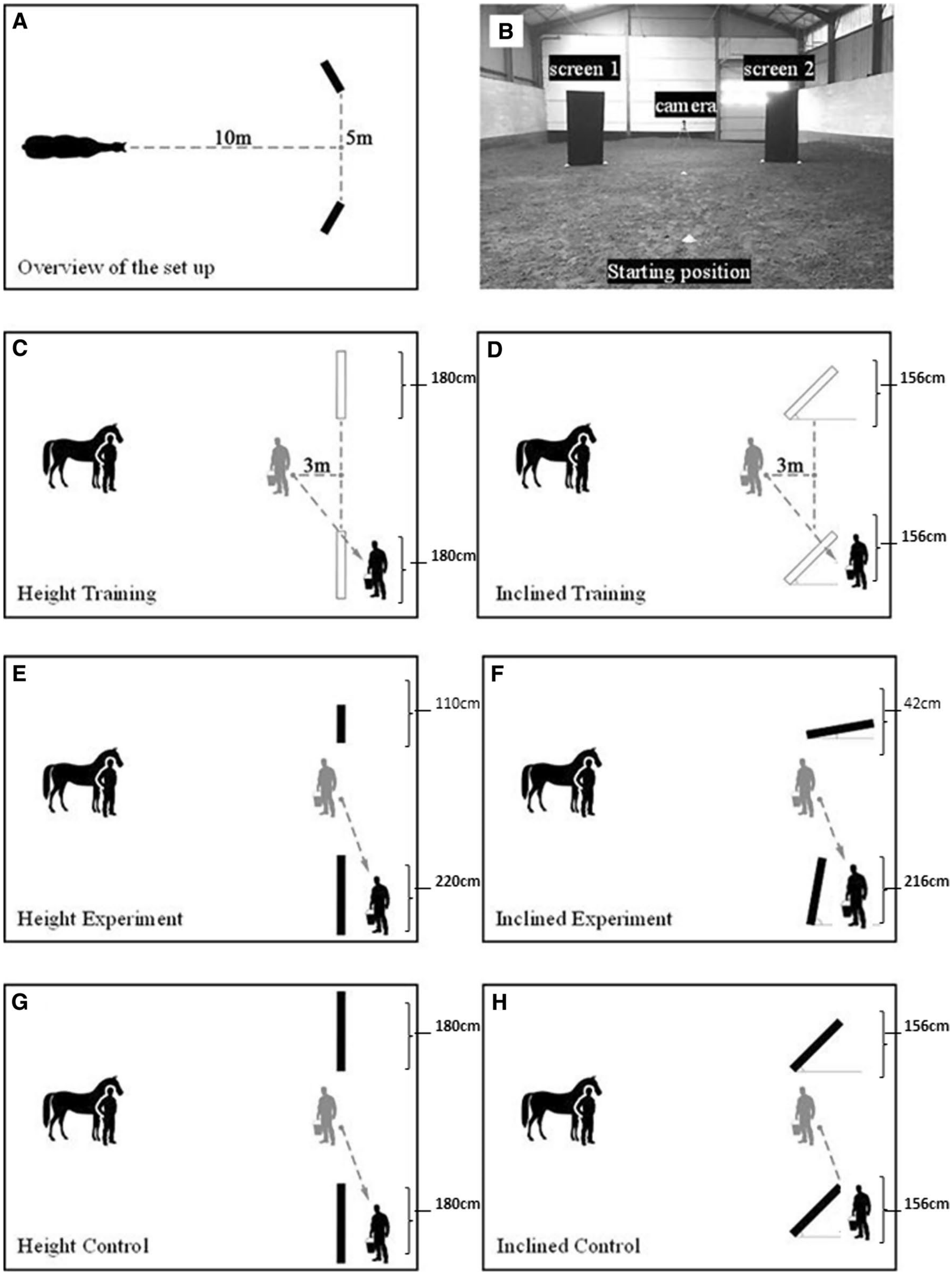

Fig. 1 Experimental setup for Training and Testing phases. Close to each screen, we noted the height of the screens as perceived by a horse in the Starting position

from the screens; Fig. 1a, b). In full view of the subject (i.e., when the horse's head was directed toward Exp2), Exp2 moved away from the horse and stood positioned between the screens. Exp2 then called the horse showing it the food, while Exp1 released the horse. When the horse approached, Exp2 praised and rewarded the horse with food. In the Training trials of the Height Training Phase, Exp1 brought the horse in the Starting position, and Exp2 moved in front of the screens, 3 m from the screen baseline (Fig. 1c). In full view of the subject, Exp2 hid behind one of the screens, and then Exp1 let the subject go. If the horse moved within 1 m from Exp2, Exp2 praised and rewarded the horse. If not, Exp2 called the horse from behind the screen, eventually moving from behind the screen and repeating the procedure for up to three 5-trial blocks, until the horse approached Exp2 in at least 4/5 trials. The Inclined Training Phase was identical, but screens were 220 × 110 cm and inclined at 45° in all trials (Fig. 1d).

The Testing phase consisted of 2 Motivational trials (i.e., Exp1 brought the horse in the Starting position, and Exp2 called and fed it in front of one of the two screens), followed by 10 trials for each testing condition (counterbalanced and pseudo-randomized across subjects): Height Experimental (hereafter, Height Exp), Height Control (Height Ctrl), Inclined Experimental (Inclined Exp) and Inclined Control (Inclined Ctrl). In Height Exp, two black screens (220 × 110 cm, 110 × 110 cm) were positioned on the same line, so that only the first one could hide a standing person. Their position was counterbalanced and pseudo-randomized across trials, with the reward never being in the same position for more than two trials in a row (see Osthaus et al. 2013, on significant spatial perseveration; Fig. 1e). Exp1 brought the horse to the Starting position, Exp2 moved between the screens, calling the horse and shaking the bucket, and Exp2 quickly hid behind the higher screen, while Exp1 covered the horse's eyes with two cloths. Exp1 uncovered the horse's eyes and let the horse go, coding a correct choice when the horse moved within 1 m from the screen (but repeating the trial if the horse moved between the screens and was thus able to see Exp2 before making its choice). In Height Ctrl, we followed exactly the same procedure, but both screens (180 × 110 cm) could hide a standing person (Fig. 1g). In Inclined Exp, one 220 × 110 cm screen was inclined at 80° and the other 220 × 110 cm screen was inclined at 10°, so that only the first one could hide a person (Fig. 1f). In Inclined Ctrl, both screens (220 × 110 cm) were inclined at 45° and could hide a person (Fig. 1h). For more details, see the Electronic Supplementary Material.

Statistical analyses

For each subject and testing condition, we computed the mean percentage of correct choices across all 10 trials, across the first trial, the first 5 and the last 5 trials (to explore learning effects). We ran nonparametric two-tailed statistics in R 3.2.3 (R Core Team 2016) to analyze whether our dependent variable varied (i) across conditions and from chance level (Wilcoxon exact tests) and (ii) depending on subjects' sex and breed in the two Experimental conditions (Kruskal–Wallis tests). For each individual and condition, we also ran exact binomial tests to assess whether performance across all 10 trials was above chance. Alpha level was set at 0.05. Inter-observer reliability was based on 20% of all trials (Cohen's $\kappa = 0.94$, $p < 0.001$). Complete statistical results are reported in Electronic Supplementary Material.

Results

Sex and breed had no effect on performance in the two Experimental conditions, for no group of trials ($p \geq 0.084$). Across the 10 trials, horses performed better on average in Inclined Exp than in Inclined Ctr ($p = 0.060$) and when compared to chance ($p = 0.059$; Fig. 2), although these differences were not statistically significant. Performance in Height Exp did not differ from Height Ctrl and chance ($p \geq 0.071$).

In the first trial, only 50% horses made the correct choice in Height Exp and Inclined Ctrl, 56% in Height Ctrl, and

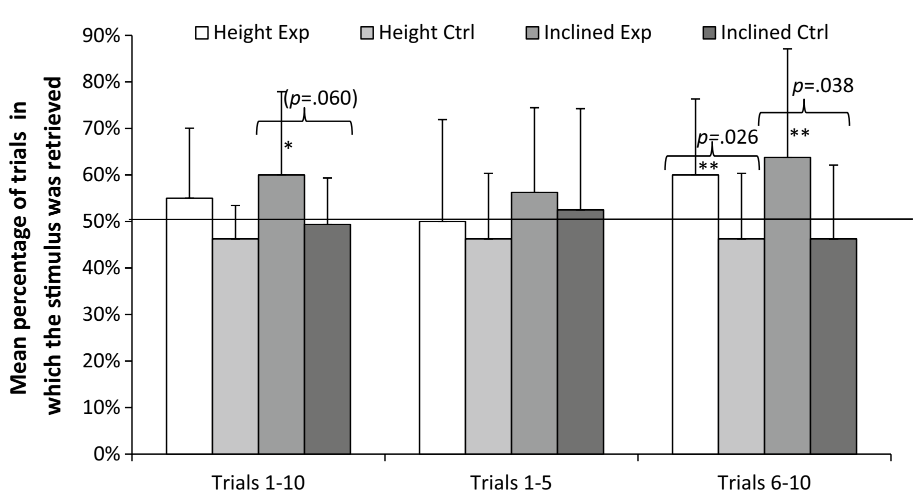

Fig. 2 Mean percentage of trials in which the hidden stimulus was retrieved (+SE) in the four testing conditions, across all 10 trials, in the first and in the last 5-trial block. *P*-values are noted for significant and (in parentheses) for tendentially significant differences across conditions. For each condition, performance above chance is noted with two asterisks (**), and performance tendentially above chance with one (*)

69% in Inclined Exp. In the first 5 trials, performance did not differ across conditions and from chance ($p \geq 0.176$; Fig. 2).

In the last 5 trials, horses in Inclined Exp performed significantly better than in Inclined Ctrl ($p = 0.038$) and chance ($p = 0.034$; Fig. 2). Also in Height Exp, horses performed better than in Height Ctrl ($p = 0.026$) and chance ($p = 0.042$).

At the individual level, only one subject performed significantly above chance in Inclined Exp ($p = 0.011$). Three further individuals performed tendentially above chance in Inclined Exp, and one in Height Exp ($p = 0.055$). No individual performed above chance in Inclined Ctrl and Height Ctrl ($p \geq 0.172$).

Discussion

Overall, horses failed to reliably rely on height to locate an experimenter with food, and only tendentially relied on inclination. In the first 5 experimental trials of both conditions (Height and Inclined), horses' performance was not significantly better than expected by chance. This was also true for control trials. Only in the last 5 trials did horses reliably select the screen with the height or inclination compatible with the presence of a hidden human with food. No statistically significant differences in performance were detected between sexes or across breed.

These results suggest that horses may not intuitively reason about physical object properties. Despite being naïve to these experimental procedures, these horses had already had the chance to learn about object properties during their lives, in contrast to the newborn chicks tested by Chiandetti and Vallortigara (2011). Nonetheless, only specific experience with the setup (i.e., more trials) allowed horses to learn to reliably select the taller or less inclined screen, compatible with the presence of a hidden reward. Like chicks, horses are precocial and may especially benefit from intuitive physical understanding of objects to survive in their environment (Chiandetti and Vallortigara 2011). However, our results suggest that horses may lack innate core knowledge and rather rely on direct experience to learn about object properties. Also in humans, understanding of object properties may not be completely part of our innate core knowledge, and thus partly acquired through experience: Only from 3.5 months, for instance, do infants expect taller objects to be visible behind smaller screens (Baillargeon and DeVos 1991).

Unfortunately, our data cannot clarify whether horses learn to understand the physical properties of objects, or whether they simply learn to associate a specific screen to food. However, it is remarkable that at least some of the horses showed a very quick learning effect, significantly improving their performance after few trials. This may come as no surprise, if we consider that horses are very good at observing and learning about subtle cues to obtain food rewards, retaining and generalizing learned information and possibly also learning from conspecifics (Brubaker and Udell 2016; Murphy and Arkins 2007).

Finally, horses seemed to perform slightly better with inclination rather than height cues, at least when considering performance across all trials. Also at the individual level, more subjects performed significantly above chance in Inclined Exp than in Height Exp. Possibly, the Inclined Exp condition was slightly easier than the Height Exp one: In the former, the difference between the screen sizes on the visual field was more pronounced (42 cm vs 216 cm), while in the latter, there was still a minimal possibility that a crouching human could hide behind the smaller barrier (110 vs 220 cm). These results, however, contrast with what we know about humans, who appear to have clear expectations about both height and solidity, from early on (Aguiar and Baillargeon 1999; Baillargeon and DeVos 1991; Baillargeon et al. 1985; Spelke et al. 1992). Also in newborn chicks, performance is highly successful both with height and inclination cues (Chiandetti and Vallortigara 2011). However, our limited sample size and the lack of direct comparisons across more species and conditions make it hard to draw further conclusions.

Our study only relied on a small sample size, so our results need to be taken with caution. Future studies should include more individuals, and better control for previous experience (see e.g., Rochais et al. 2016), to investigate which object properties are used by horses to locate food. This is especially relevant if considering that individuals may importantly differ in their ability to understand object properties and/or learn, as suggested by our results. Ideally, different setups should be used to test their abilities, allowing interspecific comparisons but also using more socio-ecologically relevant stimuli (e.g., social partners and trees, rather than food and screens). Moreover, it would be interesting to investigate whether horses learn to understand the physical properties of objects by generalizing their experience to new contexts, or simply learn to associate specific objects to food. Finally, future studies should compare more species to better understand the distribution of physical cognitive skills across taxa, and ultimately gain a better understanding of the evolution of human physical reasoning.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

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